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October 7 World Habitat Day 2019

Frontier Technologies as an innovative tool to transform Waste to Wealth




निर्माण सामग्री एवं प्रौद्योगिकी संवर्द्धन परिषद्
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BUILDING MATERIALS & TECHNOLOGY PROMOTION COUNCIL
Ministry of Housing & Urban Affairs, Government of India

"Creating Enabling Environment for Affordable Housing for All"

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From the Desk of Executive Director

World Habitat Day under the patronage of UN-habitat is celebrated World over on the first Monday of October every year to comprehend the need of bringing transformative change in the Urban living on chosen theme. This year's theme of ***Frontier Technologies as an innovative tool to transform waste to wealth*** has been quite apposite when the entire world is struggling to cope with Green-house gas emissions, resource-efficient technologies and climate change. At the time of writing this editorial for BMTPC's quarterly newsletter Nirman Sarika, the UN climate meet is taking place in New York and it has been vociferously promulgated by all world leaders that time is running out and we must put our act together to tackle climate change before it becomes too late. *Waste to wealth* is one such motto which has potential and can really assist the World community to achieve Sustainable Development Goals so as to have better quality of living conserving our resources and preserving our eco-system. Therefore, the theme of this year needs to be followed religiously in letter & spirit. If we can eliminate the waste & continue to use it as resource, we enter into a closed system called circularity. This circularity employ reuse, sharing, repair, refurbishment, remanufacturing and recycling, thereby minimizing the use of resource input and the creation of waste, pollution and emissions. The *degenerative approach* of taking, making, using & then disposing by polluting ought to be changed into *regenerative approach* of making, using, reusing, remaking & recycling.

Government of India has been making sincere efforts towards waste utilization and has distinct waste management rules defining roles, responsibilities, technologies and implementation strategies. There are many flagship missions run by our Ministry of Housing & Urban Affairs (MoHUA) namely Swachh Bharat Mission - Urban, Smart Cities Mission & Pradhan Mantri Awas Yojana - Urban where waste management is one of the core issues to achieve transformative & sustainable development. Waste to energy, waste to value-added building materials & products and waste to resource are some of the key indicators in these missions and are being promoted by us across states while sanctioning & implementing the projects.

The construction sector is one of the largest contributors to the waste generation and at BMTPC, we have identified more than 30 inorganic industrial waste & agricultural waste which have potential and can be converted into useful building materials & components. These cutting-edge technologies are to be pushed hard by bringing researchers & industry together for acceleration & market support.

Since its inception in 1990, BMTPC has been publishing Nirman Sarika with articles on the chosen theme by Researchers, Practioners & Industry. I commend the editorial team of BMTPC for their unflinching support especially Sharad Kr. Gupta & Dalip Kumar and also acknowledge contributors without whom, this publication would not have been possible.

Let us make 6Rs: ***Reduce, Reuse, Recycle, Recover, Redesign, Remanufacture*** *our daily chores.*

(Dr. Shailesh Kr. Agrawal)

सत्यमेव जयते

HARDEEP S PURI
Minister of State (I/C),
Housing and Urban Affairs and Civil Aviation
Minister of State, Commerce & Industry
Government of India

MESSAGE

I am glad to know that the United Nations has adopted **"Frontier Technologies as an Innovative tool to Transform Waste to Wealth"** as the theme for World Habitat Day, 2019, to be celebrated globally on 7 October. The theme resonates with Prime Minister Modi's vision of Swachh Bharat, or Clean India, and also his mission to eradicate single-use plastic from the country.

Waste to wealth has assumed salience in India, and is part of the government's larger climate action and healthcare agenda. To this end, several innovative technologies have been successfully developed and tested to convert waste to wealth. The next step in this effort is to scale the operations of the technology available and disseminate best practices with relevant stakeholders.

To achieve this objective and to commemorate the 150th birth anniversary of Mahatma Gandhi, the Government of India has launched Waste to Wealth Mission Project under the Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC). This mission will promote the implementation of sustainable, scientific and technological solutions for waste management, through validation and deployment of available technologies for transformation of waste to wealth. This initiative will assist and augment the Swachh Bharat Mission and Smart Cities Mission by creating circular economic models that are financially viable for waste management. The Ministry of Housing and Urban Affairs is taking various steps to create awareness about the Mission, particularly at the level of Urban Local Bodies.

I am happy that BMTPC is bringing out this special issue of their Newsletter 'Nirman Sarika' on the occasion of World Habitat Day. BMTPC plays a significant role in helping the Government achieve its target of 'Housing for All', particularly through the development and promotion of innovative alternate building materials and technologies.

I congratulate BMTPC and wish it success in its endeavours.

(Hardeep S Puri)

20 September 2019
New Delhi

DURGA SHANKER MISHRA
Secretary
Ministry of Housing & Urban Affairs
Government of India

MESSAGE

The Ministry of Housing and Urban Affairs celebrates World Habitat Day on first Monday of October each year on the theme chosen by the United Nations. This year's theme is "Frontier Technologies as an Innovative tool to Transform Waste to Wealth".

Efficient handling of waste is an important factor in the developmental progress of any nation and the health of its people. Effective management of waste is now a national priority as seen through the Swachh Bharat Mission and Smart Cities Mission being implemented by the Ministry of Housing & Urban Affairs throughout the country. It seeks to sensitize every citizen and make them a partner in creating a Clean and Green India. Generation of less waste, reuse of consumables, recycling of waste and recovery of valuable resources from waste are considered as good practices. They help conserve valuable natural resources & energy and also lower environmental damages caused by socio-economic development. Thus, the Sustainable Development Goals (SDGs) cannot be met unless waste management is addressed in an integrated manner as a priority.

In India, we have various kinds of waste generation from industries as well as agriculture such as fly ash, phosphogypsum, mine tailings, metallurgical slags, jute fibre, coir fibre and other agro-industrial residues. Lot of efforts have been made for effective utilization of fly ash and we can see the results also with quantum jump in its utilization in last few years. Similarly, extensive efforts are required to reuse other wastes to convert them into energy-efficient and environment-friendly building materials and products. Construction & Demolition waste is also one of the refuse which till now is being used as landfills only. With the ambitious schemes in the housing sector launched by Govt. of India, where it is envisaged to construct 11.2 million of houses by 2022 in urban sector, the amount of C&D waste generated will be several thousand metric tonnes. Therefore, it calls for a concerted effort to efficiently utilize the C&D waste with the know-how already available and make it a viable preposition for the construction sector.

I congratulate BMTPC for bringing out the Special Issue of their Newsletter "Nirman Sarika" on the occasion of the World Habitat Day with a focus on this year's theme.

I wish BMTPC all the best in its efforts.

(Durga Shanker Mishra)

New Delhi
23 September, 2019

सत्यमेव जयते

SHIV DAS MEENA
Additional Secretary (Housing)
Ministry of Housing & Urban Affairs
Government of India

MESSAGE

Global observance of World Habitat Day this year with the theme "Frontier Technologies as an Innovative tool to Transform Waste to Wealth" highlights the issue of waste, wishing to change the discourse into a positive one, where waste is presented as an opportunity to bring about wealth and change in the communities and cities. Across the world, cities produce 7 to 10 billion tonnes of solid, liquid, domestic, industrial and commercial waste every year. Managing waste properly is essential for building sustainable and liveable cities, but it remains a challenge for many countries like India.

We know that the sustainable waste management presents opportunities. From innovating waste management through the 5Rs (rethinking, refusing, reducing, reusing and recycling), cities can face this challenge, besides creating employment, promoting economic growth and improving health and ecosystems – thus leading to happier, greener and healthier cities. The Ministry of Housing and Urban Affairs, Government of India, through its flagship Mission Swachh Bharat Mission (SBM)-Urban, has taken several initiatives to address this issue. SBM has made several strides in effective solid waste management in cities and towns of the country, especially by bringing behavioural changes. The National Urban Housing and Habitat Policy, 2007 with multi-pronged approach promotes sustainable development of habitat in the country having equitable supply of land, shelter and services at affordable prices to all section of society. The Policy also lays emphasis on developing cities/towns in a manner which promotes a healthy environment, encouraging use of renewable energy resources and ensuring effective solid waste management in collaboration with persons involved in recycling activities.

BMTPC has been playing an important role in promotion and adoption of energy-efficient and environment-friendly housing technologies including promotion of building material and technologies from agro-industrial and construction & demolition waste. The Council should also look for cutting edge technology options now available across the world to bring further improvement in housing construction.

I am happy that BMTPC is bringing out a special issue of its Newsletter "NIRMAN SARIKA" on the occasion of the World Habitat Day. I extend my best wishes to the Council for the efforts and also wish the publication all success.

(Shiv Das Meena)

सत्यमेव जयते

AMRIT ABHIJAT
Joint Secretary & Mission Director (Housing for All)
Ministry of Housing & Urban Affairs
Government of India

MESSAGE

In pursuance of the resolutions of the General Assembly of the United Nations, the first Monday of October is celebrated every year as the 'World Habitat Day' world over. The theme of this year's World Habitat Day is "Frontier Technologies as an innovative tool to transform waste to wealth".

The environmental problem arising from unscientific and indiscriminate disposal of waste is a menace for the society. The provision of land filling for waste management is not a primary solution, the science and technology has to play a major role in successful implementation of waste management. The Sustainable Development Goal-12 targets among other things including environmentally sound management of all waste through prevention, reduction, recycling, reuse and reduction of food waste is the paradigm to work on as we move ahead.

The Government of India through Ministry of Housing &Urban Affairs, has been implementing several flagship programs in this regard such as Pradhan Mantri Awas Yojana (Urban) - Housing for All Mission (PMAY-U), Swachh Bharat Mission (Urban), Smart Cities Mission, Atal Mission For Rejuvenation And Urban Transformation (AMRUT) and Heritage City Development and Augmentation Yojana (HRIDAY). These flag-ship programs are addressing the gigantic problem of creating livable and sustainable urban cities which also includes management of waste in an efficient manner.

Under PMAY-U Mission, against a validated demand of 1.12 cr houses, so far more than 90 lakhs houses have been sanctioned in all over the country. Under PMAY-U, a Technology Sub-Mission (TSM) has been set up to facilitate adoption of green, disaster resistant & environment-friendly technologies by States/UTs while undertaking construction of social housing. TSM is also coordinating with other agencies working in green and energy efficient technologies, climate change etc.

One of the recent initiatives undertaken under this Mission was the Global Housing Technology Challenge - India (GHTC-India), under which proven innovative and alternate construction technologies along with future potential sustainable technologies were identified. The proven technologies are being showcased through execution of Light House Projects (LHPs) across six States. These LHPs will act as live laboratories to establish clean and green construction practices across India and will help in sustainable construction. GHTC-India is also planning to incubate and accelerate identified potential future technologies through Affordable Sustainable Housing Accelerator (ASHA) - India.

Recently, 'ANGIKAAR' campaign has also been launched to create awareness on the best practices of water & energy conservation, waste management, health & hygiene, tree plantation and environment protection. This will also converge with missions and programs of various Ministries to create an enabled environment for PMAY-U beneficiaries through their schemes/services.

I appreciate the efforts of BMTPC in bringing out the Special Issue of the Newsletter "Nirman Sarika" on the theme of the World Habitat Day.

I take this opportunity to wish BMTPC every success in its efforts

(Amrit Abhijat)

Technologies Transforming Waste to Wealth for Construction Sector: An Overview


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Dr. Ashok Kumar[3]

1. Introduction

Waste is a natural by-product of the life cycle and growth of societies. Living things take in raw materials and excrete wastes that are recycled by other living organisms. However, humans produce an additional flow of material residues that overload the capacity of natural recycling processes, so these wastes are to be managed in order to reduce their effect on our health, or the environment [1]. Industrialization is inevitable for the development of any nation. This escalates production of waste in variety of forms, many of which cause serious environmental pollution and degradation. In the absence of proper mechanisms for disposal and management, waste is often viewed as a menace. It not just spoils the aesthetics of living spaces, but becomes a source of pollution and poses a major hazard to health and life of all organisms [2]. Efficient handling of waste is an important factor in the developmental progress of any nation and the health of its people. Effective management of waste has been identified as under the 'Swachch Bharat Mission' [2]. Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC) has identified nine different technology missions and one of the missions is 'Waste to Wealth' [3]. The objective of the mission is to identify, develop and deploy technologies to treat waste to generate energy, recycle materials, and extract resources of value. The goal of the mission is to identify and support the development of new technologies that promise to create a clean and green environment. The mission will assist and augment the 'Swachh Bharat' and 'Smart Cities' projects by leveraging science, technology and innovation to create circular economic models that are financially viable for waste management to streamline waste handling in the country [3]. Under Swachh Bharat Mission (SBM) the target is set to achieve 100% municipal solid waste processing and disposal by 2019. The 11 kg per capita per annum plastic use in India in 2014-15 likely to touch 20 kg by 2022.

At present in India, 3.8 million tonnes of waste per year is left uncollected, out of the 9.4 million tonnes per year; plastic waste is generated during 2017-18. Government of India has set to ban on plastic bags, cups, plates, small bottles, straws and certain types of sachets. Still multi-pronged strategy is required for collection, safe disposal and recycling etc. This paper given an overview of the technologies transforming waste to wealth for construction sector.

2. Solid Waste, Its Generation and Utilization for Construction Sector

The waste generated through various sources are characterised as Municipal Solid Waste (MSW), Construction & Demolition (C & D) waste, plastic waste, bio-medical waste, agro waste, mining mineral waste, E-waste, Industrialised waste. According to Report of Task Force on Waste to Energy, an estimated 62 Million tonnes of MSW waste is generated annually by 377 Million people in India's urban areas, of which 80% is disposed of indiscriminately at dump yards in an unhygienic and unscientific manner by the municipal authori-

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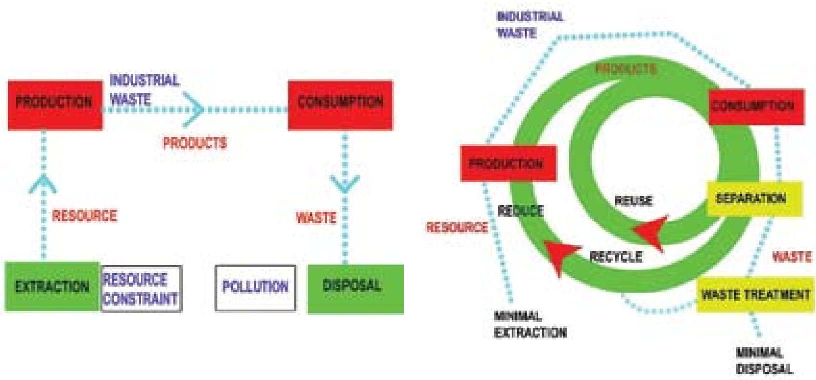
Fig. 1 Concept of 5R



(a) (b)

Fig. 2 (a) Linear loop economy, and (b) Circular loop economy

ties leading to problems of health and environmental degradation [4]. The best way to deal with the management of these solid wastes is by recycling and safely integrating these materials into new products. To manage this waste, focus should be on 5R concept, which is refuse, reduce, reuse, recycle and recover as shown in Fig 1. Also, there is a need to focus on circular economy, which builds economic activity and rebuild overall system health. A circular economy aims at redefining growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system as shown in Fig. 2. This will lead to waste generated to value added products. The solid waste and their utilization in construction is summarised in Table 1.

3. Technologies from waste to wealth for construction sector

(i) Construction and Demolition (C&D) waste

C&D waste is nothing but a waste material consists of the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges. Construction activity leads to generation of solid wastes, which include sand, gravel, concrete, stone, bricks, wood, metal, glass, plastic, paper etc. The management of construction and demolition waste is a major concern for town planners due to the increasing quantum of demolition's rubble, continuing shortage of dumping sites, increase in transportation and disposal cost and above all growing concern about pollution and environmental deterioration. It is a challenging task to handle C&D waste because it is bulky, heavy and inert and also mixture of various materials of different characteristics [5]. Building Materials & Technology Promotion Council (BMTPC) has come up with, strategy for Promoting Processing of Construction and Demolition (C&D) Waste and Utilisation of Recycled Products. CSIR-Central Building Research Institute (CBRI), has carried out extensive work on the treatment of the aggregates from construction debris and developed building products, concrete, paver block, bricks, tiles [6].

(ii) Industrial waste

Industrial solid waste means solid waste generated by manufacturing or industrial processes that is not a hazardous waste regulated under Subtitle C of RCRA. Such waste may include, but is not limited to, waste resulting from the following manufacturing processes: electric power generation; fertilizer/agricultural chemicals; food and related products/by-products; inorganic chemicals; iron and steel manufacturing; leather and leather products; nonferrous metals manufacturing/foundries; organic chemicals; plastics and resins manufacturing; pulp and paper industry; rubber and transportation equipment; and water treatment [7]. Cement industry is responsible for 5-7% of worldwide emission of CO_2, (which means 1.6 billion tons of carbon dioxide into the atmosphere), in prepar-

Table 1. Waste utilization for construction Industry

S. No	Type of Waste	Source	Utilization of waste in construction Sector
1	Construction and Demolition (C & D) Waste	Construction site debris, demolition of old structures	Bricks, Paver blocks, concrete, Geopolymer concrete, Self-compacting concrete, asphalt production. CSIR-CBRI has developed products using C & D waste.
2	Industrial wastes (Inorganic)	Coal combustion residues as fly ash, steel slag, copper slag, bauxite red mud, foundry sand, tires, cement dust, glass waste	Fine aggregate, Lime-Gypsum bricks, Cement, bricks, blocks, tiles, paint, aggregate, concrete, wood substitute products, ceramic products, light weight concrete blocks, geopolymer concrete, road development, stabilization of soil, rubber modified bitumen, glass-fibre reinforcement, stabilization of base, pavements, prefabricated units, claddings. CSIR has developed products using many industrial wastes.
3	Agro- Industrial waste (Organic nature)	Baggage, rice and wheat straw and husk, bamboo leaf, cotton stalk, saw mill waste, ground nut shell, paper sludge, banana stalk and jute, sisal, pine needle, oil palm residues, vegetable residues, lignocellulosic wastes	cement-bonded construction materials, Particle boards, insulation boards, wall panels, corrugating medium roofing sheets, fibrous building panels, bricks, acid proof cement, fiber reinforced composite, polymer composites, cement boards. CSIR has developed products using agro-industrial waste.
4	Mining mineral waste	Coal washeries waste, mining overburden waste tailing from iron, copper, zinc, gold, aluminium industries	Bricks, tiles, lightweight aggregates. CSIR has developed products using mining waste.
5	Non-hazardous waste	Gypsum, lime sludge, lime stone waste, marble processing residues, broken glass and ceramic, kiln dust.	Gypsum plaster, fibrous gypsum boards, bricks, blocks, cement clinker, super sulphate cement, hydraulic binder, tiles. CSIR has developed products using non-hazardous waste.
6	Hazardous waste	Metallurgical residues, galvanizing waste, Tannery waste	Cement, bricks, tiles, ceramics and board. CSIR has developed products using hazardous waste.
7	Plastic waste	Pet bottles	Bottle bricks, Hot bituminous mixes. CSIR-CBRI demonstrated a wall of pet bottles.

ing concrete, the cement dosage can be reduced by using mineral additions, strategy that also can contribute to environment protection by preserving the energy and consume the huge quantities of wastes[8]. The industrial waste fly ash typically is used at a replacement rate of 20–40% of Ordinary Portland Cement. Silica fume typically is used at a replacement rate of 5–10% of ordinary Portland cement. Ground granulated blast furnace slag (GGBFS) typically is used at a replacement rate of 30–70% of ordinary Portland cement. These Pozzolanic materials are siliceous or aluminous materials, which possess by themselves little or no cementitious properties, but in finely divided form react with calcium hydroxide in the presence of moisture at ordinary temperatures to form compounds possessing cementitious properties, which enhance the performance characteristics of concrete in hot weather conditions than ordinary Portland cement with respect to strength and pore structure. The production of 1 ton of paper generates about 30 kg of primary sludge. India produces 10.11 million tons paper per annum which is 2.6% of world's overall production quantity of paper [9]. Wastepaper sludge ash contains considerable amounts of alumino-siliceous material, most of which appear to be combined with calcium can facilitate the hydration of latently hydraulic materials as well as undergo its own hydration [10]. Mineral wastes are resulted from the industry processes where the natural resources are transformed in products. In construction industry a lot of natural raw materials are used in natural state [8]. CSIR-CBRI, Roorkee is pioneer R&D organisation working in utilizing industrial waste for the development of building products.

(iii) Agro-Industrial waste

Agricultural-based industries produced the vast amount of residue every year. If these residues are released to the environment without proper disposal procedure that may cause to environmental pollution and harmful effect on human and animal health [11]. The sludge or the ashes obtained by burning the sludge can be used for obtaining ceramic products such as tile, brick block, pavement, etc. Several works have been carried out in this field [12]. CSIR-CBRI, development process technologies for the manufacture of cementitious products from agro-industrial wastes such as rice husk, straw ash, hemp etc.

(iv) Hazardous waste

The information provided by the Central Pollution Control Board (CPCB), there are about 41,523 industries in the country generating about 7.90 million tonnes of hazardous waste annually, out of which landfillable waste is about 3.32 million tonnes (42.02%), incinerable waste is about 0.60 million tonnes (7.60%) and recyclable hazardous waste is about 3.98 million tonnes (50.38%) [13].

(v) Non-hazardous waste

As per the Indian Bureau of Mines (IBM) around 5 million tons of waste gypsum such as phosphogypsum, fluorogypsum etc., are being generated annually. CSIR-CBRI, developed Fibrous Gypsum Plaster Boards, Water–resistant Gypsum Binder, Gypsum Blocks, Multiphase Plaster, Anhydrite cement, Gypsum Tiles, Hollow core panels [6]. The ceramic industry is known to generate large amounts of calcined-clay wastes each year. Ceramic wastes can be used safely in concrete with no need for dramatic change in production and application process [14]. Plastic consumption is observed to be consumed more all over the world in the recent years, which leads to huge quantities of plastic-related waste. Recycling of plastic waste to produce new materials like concrete or mortar, aggregate appears as one of the best solutions for disposing of plastic waste, due to its economic and ecological advantages [15].

4. Smart Waste Collection, Disposal and Recovery

Looking into the gravity of the problem of waste collection, its disposal and recovery, as defined in the previous sections, information technology can act a frontier technology tool, wherein a waste management system may be developed for household, cluster / block, community, and neighbourhood levels. The waste collected at these levels may be collected through the information systems using GPS, and taken to disposal sites once the alert message is displayed on the mobile for that location.

The disposal sites as well as treatment sites can also be linked through the database using Network system (GPS) for smart disposal and treatment. A small demo of the App for Roorkee town (Uttarakhand) is shown below. This needs to be updated and may act as a model for similar towns of 2.5 lakh population. Similar models can be developed for large and mega cities of India. And, this may also be useful for smart cities identified by Government of India.

5. Conclusions and the Way Forward

The huge quantity of waste generated can be safely collected, disposed, and recycled in India. There are several technologies available on this to convert waste to wealth. However, there are hardly very few smart technologies that are being used for smart waste collection for the source, and taken to disposal sites or for recycling. Hence, there is a need to develop a smart waste management system for all the towns and major urban centres to stop contaminations of environment, soil, and groundwater due to land filling. An attempt made in this regard is just a conceptual model that needs to be tested in a small location and the finalized foe effective implementation.

Once the different kinds of

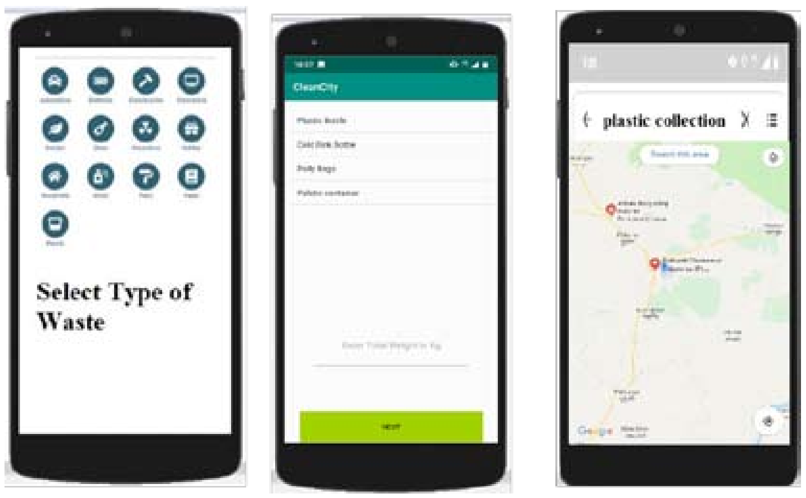


Fig. 3 Screenshot's of Android App (Demo)

wastes are identified and segregated at the household / community level, these can also be converted into a wealth in the form of technologies / products that can be used for construction sector. Therefore, the government should formulate stringent policies and guidelines that could include penalties at different scale linked to the kind of waste generated like hazardous or non – hazardous etc.

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Circular Economy from Urban Waste in India

KK Pandey[1]

Introduction

This paper flags the issues pertaining to hidden wealth in the waste and its conversion into a circular economy. It is noted that circular economy from waste is also essential for sustainable development and preserving scarce resources for future generations. The circular economy is directly linked with income, employment and environment .Circular economy is particularly important for India which is fifth largest producer and third largest importer of scrap in the world. Accordingly, have to tap the vast potential of material recovery from urban waste. Finally, the paper suggest a roadmap for wider discussion and elaboration by concerned stakeholders.

The Need

Hon'ble Prime Minister quite often refer to our age-old tradition to keep used items for exchange of goods (old cloths, plastic, utensils, wooden items etc.) with vendors who recycle household goods. This practice leads to a value chain in the economy. However, the age-old practice is not duly recognised in case of waste management in our cities and towns. Only 56 percent urban waste is processed which is not entirely done scientifically leading to health, environment and low productivity issues.[1] The output does not qualify minimum standards to be used as input for further processing.

Content Rich Urban Waste

UN sustainable development goals place emphases on efficient use of scarce resources without compromising the ability of future generations to meet their own needs. In this context, the Urban waste contains valuable and scarce resources (biotic and abiotic material)[2]. In addition, using natural resources more efficiently, we can live healthier lives, save money, create jobs, boost our economy and respect the limits of the planet[3]. Urban waste in this sense conform special significance to meet the objectives of resource efficiency.

Scope for Resource Efficiency in India

With the objective to make India a US$ 5 trillion economy by 2024, the resource consumption will undergo a significant jump. It is estimated that the material consumption in India during 2015 to 2030 will witness a three time increase if moderate growth (7-8%) is maintained[4]. Resource consumption in India in past following the liberalisation of economy and upward shift in the pace of economic growth reported 2.30 times increase in 2010 as compared to 1990 whereas resources productivity (output per unit of resource input) has increased around 1.5 time. Thus, there is a need to enhance resource efficiency or there is substantial scope to improve resource use in India. In this regard, urban waste which is rich in material has vast potential for recycling

1 As on June 2019 as per website of Ministry of Housing and Urban Affairs GoI.

2 Biotic material- Wood, Straw (dry stalk of plants without grain & chaff), manure, bark (stense/roots of plants), cotton etc and Abiotic material- : Aluminium, Iron, Steel, Stainless steel, Gold, Silver, Copper, Magnesium Marble, granite, sandstone, porphyry, , other ornamental or building stone ; Chalk and ; Limestone ,Salt; Clays and kaolin; Sand and excavated earthen materials.

3 http://ec.europa.eu/environment/green-growth/resource-efficiency/index_en.htm

4 Strategy on Resource Efficiency, NITI Aayog, Government of India ,2017

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to develop circular economy in the larger context of productivity and equity. (Box 1)

Annual Urban Waste Generation and Recovery in India

Municipal solid waste generation in India is estimated to be 145441 Tones per day (TPD) or 52.92 million ton (mt) per annum out of which only 56 percent is stated to be processed[5].it is also noted that sizeable waste is not processed scientifically and leads to environment and health related issues. In addition to the municipal waste, India also annually generates 7 to 8 mt of c&d (Construction and Demolition) waste, 1.8 mt. of e-waste per annum and 8.7 million ELVs (End of Life Vehicles) which are predominantly produced in urban areas.

ELVs have vast potential of 75% for recovery of recyclable metals and 25% for plastic. Delhi alone has 4 million vehicles out of 8.7 million under the category of >15 years which do not comply norms to operate. Around 20 million ELVs would be available by 2025 for dismantling, recycling, reuse and recovery. India is fifth largest generator of e-waste (around 5 million tonnes per annum) with huge potential to recover material gold, silver, copper and other valuable material. In this regard, end of use disposal norms of Govt. of India along with Extended Producer Responsibility (EPR) need to be applied widely. Around 15% of c&d waste, 2% of e-waste and 10% of ELVs are recovered. Therefore, urban waste in India, as elsewhere, has vast potential for gainful processing. (Table 1).

The recycling of urban waste has a multiplier effect on environment, productivity and quality of life. (Box 1) It is by and large processed by a range of segregators, dismantlers and recyclers (mainly from informal sector) for value chain only and not certified for health and safety standards. This leaves wider scope for scientific recovery and productivity.

Box 1

Recovery from Waste: The Multiplier effect

Recovery from urban waste has dual advantage (i) availability of material for further use and (ii) promotion of the environment friendly management of waste. Recovery of material also has vast potential to save material extraction and preserve natural resources for future use. One ton of steel recovered saves 1.2-ton iron ore, 0.7 ton Coal, 0.5 ton Limestone, 285 litre fuel and 2.3 cubic metre land. Similarly, one ton of recycled paper saves 17 Trees, 2.5-barrel oil,4100 Kwh electricity, 4 cubic meter of landfill, 31780 litre of water. (a) All these items are integral part of environment, productivity and quality of life. Further recycling generate 6 to 8 times more jobs than landfill. (b)

It is also noted that inadequate handling of waste also affects the air quality (PM2.10) C&D waste is one of the important attributes to increase PM 2.10 in the air quality index.

Government of India has launched its flagship programme namely National Clean Air Programme (NCAP) in January, 2019 which aims to reduce PM2.10 in top 102 cities by 2024 taking 2017 as base year. The programme is implemented through Central Pollution Control Board (CPCB) and aims to rationalise street cleaning, c&d waste, water treatment etc. to promote safe environment along with enhancement of productivity. (c)

Source:
(a) The Hindu Business Line, 28th August, 2018
(b) Indiatoday.in, Air Quality, November, 2018
(c) India Today App Magazine, 11th January, 2019

Table 1

Urban waste in India

Items	Annual Quantity	Recycling Processing (%)
Municipal Solid Waste	68 mt/year	56
C&D waste	10-15 mt/year	15
E waste	1.8 mt/year	2
End-of-Life Vehicles	8.7 million	Less than 10%

Source: MoHUA Website;
http://www.seas.columbia.edu/earth/wtert/sofos/Sustainable%20Solid%20Waste%20Management%20in%20India_Final.pdf;
http://www.cseindia.org/userfiles/Construction-and%20-demolition-waste.pdf;
http://www.assocham.org/newsdetail.php?id=5725;
http://cpcb.nic.in/openpdffile.php?id=TGF0ZXN0RmlsZS9MYXRlc3RfMTE0X0FuYWx5c2lzT2ZFTFZzSW5JbmRpYTFfLnBkZg

The Issue

The urban waste is by and large processed by a range of segregators, dismantlers and recyclers (mainly from informal sector) for value chain only and not certified for health and safety standards. These workers do not have a safety net in terms of health, insurance, technical skills and marketing facilities.

Urban waste in India as elsewhere is fairly rich in content.

5 Opcit 2 .

There is a vast untapped potential to convert waste into wealth. This needs to be harnessed in a systematic manner to develop circular economy to conserve resources, promote safe environment, employment, productivity in a larger context of sustainable development.

It is, therefore, evident that -material extraction from urban waste scientifically- is the need of hour. There are five main areas of attention (i) wet waste (primarily, kitchen waste), dry waste, C&D waste, electronic waste and hazardous waste.

Ibidrequirements of scrap. India is third largest importer of scrap. This also reflects our inability to produce scrap as per acceptable standards.

Innovations are emerging to recover material from waste at different places. These need to be adopted and adapted in a wider context of waste management.

Emerging Innovations on Circular Economy

Inter-governmental agencies and other stakeholders are taking several initiatives to recover material and wealth from the waste. Some important points to be noted on this practice are:

a. Decentralised composting applied at several places is successfully converting municipal waste as input for new products. The Bengaluru is widely using segregation at source with 40% of households adopting the practice in the city[6].

b. Bengaluru has also initiated separate collection from hazardous waste from households containing unused and outdated medicines, sanitary napkins,

c. BBMP (Bruhat Bengaluru Mahanagar Palike) has a city-wide network of dry waste collection centres for all the 198 wards to segregate and sell the paper, plastic, metal etc. to vendors mainly belonging to informal sector. This practice is creating employment and income[7]. The collection centres are operating with the helps of CSR (Corporate Social Responsibility) funds from ITC (Indian Tobacco Company).

d. Further, nearly 40% households process kitchen waste within the premises (Koramangla/Yelahanka) or neighbourhood (Dollor Colony) level. This is a result of joint effort from civil society activists, municipal officials, vendors and other stakeholders.

e. City also has a practice of a Composting Santhe (fair) organised weekly on every Sunday at ward level on rotation, wherein the stakeholders interact and showcase models on decentralised processing for adaptation.

f. Ahmedabad Municipal Corporation used to sell sewage to Arvind Mills for treatment for use in the manufacturing of cloths. The water after treatment was cheaper than buying municipal water.

g. A first of its kind concession agreement has been signed for Hybrid Annuity based PPP mode STP in Mathura between Namami Gange Mission and Indian Oil to reuse of 20 MLD treated water, bear O&M cost

6 Pandey, KK, Turning waste into circular economy benefits, Financial express,7 November, 2018

7 Ibid

Box-2

Best Practices on Circular Economy

(i) Germany has the best recycling rate in the world, followed by Austria, South Korea and Wales. Germany has urban mining to use existing building material for use in the housing and other sectors of production.

(ii) One of the most innovative approaches to waste management was the Garbage Clinical Insurance in Indonesia. It is health micro-insurance program which uses garbage as financial resources. Community pay clinic service using garbage. This way the community mobilizes their own resources to improve health access and breakdown barrier between health facilities and community.

(iii) The main portion of non-combustible waste for Singapore stemmed from construction waste, industrial sludge that had been stabilised and copper slag from margin industries. But over the years, much of this has been diverted. For instance, by 2005, the country was recycling almost 94 per cent of construction and demolition waste.

(iv) Using material from demolished homes (tiles, commodes, bricks etc.) an Architect from Bengaluru has saved fifty percent cost on building his house.

Source: Times of India 22 September 2019 and https://www.news18.com/news/india/as-modi-calls-for-cutting-down-plastic-use-here-are-the-best-waste-management-practices-from-across-the-globe-2284093.html for 15 years and pay Rs. 8.75 kl towards partial capital cost.

h. Ahmedabad and Delhi are one of the initial efforts in the country to process C&D waste as input (for producing bricks, slabs etc.) which is associated with a buy back facility from respective city government.

i. C&D waste also has potential for urban mining under renewal and reconstruction projects to use 35 to 40 percent material on the plot itself[8] .A household in Bengaluru has saved fifty percent cost by using second hand material (Box 2)

j. Some initiatives (Mahindra Cero-Greater Noida, Chennai and Mumbai) are emerging to handle ELV waste which need to be integrated with the informal value chain already existing in the market.

The Road Ahead

There is a need to integrate informal sector in a formal value chain and provide suitable technology options, safety measures, finance, raw-material (c&d waste etc.), incentives (buy back facility) and concessions. It will also enable us to reduce import of scrap and save valuable foreign exchange. Some important points for attention are:

- Govt. of India should recognise potential of circular economy and plan suitable incentives and concessions and technology transfer accordingly.
- Include recycling in the national urban missions namely Swachh Bharat Mission, Deeen Dayal Antyodaya Yojana-National Urban Livelihood Mission (DAY-NULM), Smart City Mission and Atal Mission on Rejuvenation of Urban Areas etc.
- Efforts should be taken to establish circular economy at different levels such as Urban Mining for building and housing sector, Two-way processing of garbage (kitchen and dry waste), scientific processing of automobile sector scrap, e-waste and plastic waste and a separate treatment of hazardous waste.
- At the same time the role of social activists, community, judicial activism, and media needs to be involved in a larger context of safe environment, productivity and sustainability.
- Indian scrap should lead to import substitution and also export promotion.
- Formalise the informal sector involved in the process of recycling. Provide training to ragpickers/Kabadiwala and integrate them with insurance, minimum wage, credit and marketing facilities.
- Initiate annual stakeholder meet on circular economy.
- Promote peer learning and adaptation of best practices through a network of capacity building institutions.

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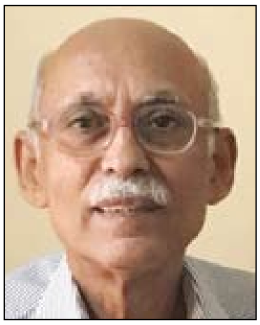
8 Times of India, 22 September, 2019

Building Materials from 47 wastes



Pramod Adlakha[1]

Preamble

Rapid population growth, urbanisation, industrialisation and economic development have resulted in mass solid waste especially in the rapid growing cities. The issue of minimising construction waste is becoming a great concern. 28.34% of waste comes from industrial and construction waste. Renovating and demolishing buildings comprises 10-30% of the waste received.

The development of cities and increasing high demand have resulted in high mass production of construction waste and the clients are not the least aware of the negative impact to the environment and to the community. The vital promotion of the appropriate technology for the environmental management of waste and the mission of sustainable development as an important tool to push the construction players to protect the environment and minimise waste have exerted the pressure demanding for the adoption of waste.

The sustainable attributes of building products, consideration must be given to how the product is manufactured, used and disposed of and how the disposed waste is utilized and recycled as building material element which relates to sustainability.

1. AAC waste

The test results of AAC waste shows that it is suitable for concrete aggregate without any addition of conventional aggregate with particle size of 16mm. Maximum compressive strength is possible with the selected cement dosage.

It can be used as load bearing walls for low rise buildings and non load bearing in a multi-level buildings. The masonry mortar, necessary for walling, can also be manufactured from the AAC waste (with fractions under grain size of 1mm).

The test results confirm the suitability only for indoor application. If used as panels, their low apparent density generates savings in the costs of the mounting equipments, and generates less load on the structures compared to the commonly used bricks. Low thermal conductivity and moisture absorption capacity makes it ideal to maintain comfortable indoor air condition.

2. Aluminium anodizing sludge

Aluminium anodizing sludge cake is used in brick manufacturing. The sludge contains huge toxic components such as aluminium, calcium oxide, silica, nickel, sulphur and other dangerous components. From the results, it shows all brick are in standard range of usual brick, usable and have no limit in water absorption. In all, the optimum proportion of sludge in brick is 10% with 24% optimum moisture content, prepared mixture fired between 8800C and 9600C to produce a good quality brick.

3. Brick aggregate waste

That strength of brick aggregate concrete is less than that of stone aggregate concrete for same aggregate size. However, permeability of brick aggregate pervious concrete is to drain off rainfall runoff quickly, therefore, permeability is of important characteristics. Brick aggregate performs better in this regard.

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Thus brick aggregate can be used in pervious concrete in places where load is comparatively less and more permeability is required.

4. Brick waste

In any structure during construction, a substantial quantity of bricks is broken and treated as waste. Even at the brick kiln, lot of wastage occur in the form of under burnt, over burnt and the broken bricks cannot be used as half or quarter three quarter bricks / in the wall masonry. This waste can be judiciously utilised in the form of precast blocks.

5. Ceramic Waste

The ceramics industry is comprised of the following subsectors : wall and floor tiles, sanitary ware, bricks and roof tiles, refractory materials, technical ceramics and ceramic materials for domestic and ornamental use.

Use of such waste offers a series of advantages such as a reduction in the use of other raw materials, contributing to an economy of natural resources. Moreover, re-use also offers benefits in terms of energy, primarily when the waste is from kiln industries (the ceramics industry) where highly endothermic decomposition reactions have already taken place, thus recovering the energy previously incorporated during production.

Ceramic waste is used for manufacturing concrete, mortar and prefabricated blocks, followed by use in road construction. In the case of industrial use, the processes involved in ceramics production, or in transport, involves embodied energy. When a defective construction material is discarded, or a building demolished, a huge quantity of embodied energy is wasted. One of the best ways to take advantage of this waste is to include it in mortar and concrete manufacturing processes.

The Green Concrete Blocks proposed by mixing ceramic waste have lower self weight (10% to 15%), better insulating properties (30% to 50% reduction in thermal conductivity), improved strength (5% to 10% improvement) and better durability (lower water absorption) characteristics and have also higher abrasive resistance. Blocks can be used for load bearing construction.

6. CLC Rubble

Light weight broken CLC blocks are also called as CLC Rubble. CLC broken blocks are best alternative to Broken bricks, Brick Jelly, Light Weight Cinder, Coal lumps, Burnt Tar lumps, and other filling materials. Being normally cured cement based product, it continues to gain strength with time so long as some moisture is available in the environment, requiring little maintenance. This is unlike other filling materials like coal which deteriorate with time.

7. Coconut Shells Waste

The coconut shells are considered as one of the most common agricultural waste. Coconut shells are hard and have important characteristics which are suitable for replacement of the coarse aggregate in the masonry blocks.

By using crushed coconut shell in masonry blocks, a lightweight masonry block can be made due to low density of coconut shell compared to the coarse aggregate.

The maximum compressive strength of Coconut shell based cement sand block is achieved at 25% replacement level of coarse aggregates. The water absorption capacity is below 12%. Blocks are light weight, implying that they can be used for the partition walls of buildings.

8. Construction & Demolition waste

The use of crushed construction & demolition waste as a recycled aggregate in the production of new concrete has been successfully demonstrated by researchers as well as by practitioners in the field.

There is a potential market for RAC (recycled aggregate concrete) produced in various grades including non structural and even structural application. The Recycled aggregate in concrete is both economically viable and technically feasible.

Recycled Aggregate can be used for non structural concrete applications with upto 30% replacement like curb stones, gutter, valley gutter, side walks, barriers, driveways, temporary pavements, ramps shoulders, internal chambers, manholes, signages, landscape elements, masonry blocks, plain cement concrete, flooring.

The recycled concrete aggregates can be effectively used in mass concrete in foundation and flooring with great economy.

Construction and demolition waste sand can be applied as a partial substitute for fine aggregate in concrete paving block & building blocks production. Therefore, this will help in reducing the usage of depleting resources by reducing the use of natural sand.

The compressive strength of

the concrete blocks manufactured with recycled aggregates depends on : The percentage of recycled aggregates, cement addition, water addition and the use of superplasticizer

We can use up to 50% recycled aggregates without affecting blocks compressive strength as long as a small cement quantity is added.

9. Crumbled Rubber waste

Waste rubber obtained from used and abandoned tyres can be collected. These tyres are crumbled in machine. The rubber that passes through 2.36 mm sieve is used, mixing with cement, sand for blocks.

10. Dry grass waste

Dry grass obtained from yard waste is being collected. It is made ground into fine matter. It should pass through 2.36mm sieve. It is mixed with cement and sand to produce concrete block.

The compressive strength of Dry grass brick with 40% replacement of fine aggregate with dry grass is about 12 to 13 N/mm2.

11. Egg shells waste

Egg shells are collected from various sources such as domestic and commercial sources. These are neatly washed and air dried for two days. They are ground into fine powder in a mixer. The egg shell is passed through 80 micron sieve. It is mixed with cement & sand to produce blocks.

The compressive strength of Egg Shell brick with 20% replacement of cement with eggshell powder is about 11.00 N/mm2. It is a recommendable value for use.

12. EPS waste

Styrofoam or the Expanded Polystyrene (EPS) are highly popular plastic packaging material which finds wide application in packaging of goods. EPS has low specific weight, therefore, with its use in concrete mix design, different kinds of light weight concretes having different specific weight and different mechanical properties are made, for both structural and non-structural use as blocks. EPS waste can also be used as filtration mats and as light weight mortars.

13. Fibrous Coir waste

Kerela state in India Produces 60% of the total world supply of white coir fiber. This industry produces fibrous wastes during the processing. Even though coir waste is biodegradable, the rate of degradation is very slow due to high lignin content. Accumulations of these waste materials are causing serious environmental issues. Utilization of fibrous coir wastes is possible in the production of stabilized Earth Blocks. Coconut coir fiber cement board (CFB) is also manufactured from coir fibrous materials.

14. Foundry sand waste

Foundry sand is high quality uniform silica sand that is used to make moulds and cores for ferrous and non-ferrous metal casings. Foundry sand consists primarily of silica sand, coated with a thin film of burnt carbon, residue and dust. Foundry Sand can be used as a partial replacement of cement or as a partial replacement of fine aggregates or total replacement of fine aggregate and as a supplementary addition to achieve different properties of concrete. Foundry sand can be used in concrete to improve its strength and other durability factors.

15. Glass waste

Glass makes up a large component of household and Industrial waste due to its weight and density. The glass component in municipal waste is usually made up of bottles, broken glassware, light bulbs and other items. Glass can be recycled indefinitely with no loss in quality or purity. Making new glass from old glass, saves energy because recycled glass is processed at a lower temperature than glass made from raw materials.

Concrete made with recycled glass aggregates have shown better long term strength and better thermal insulation due to its better thermal properties of the glass aggregates.

It is one of the most durable materials known because it has basically zero water absorption. The excellent hardness of glass may give the concrete improved abrasion resistance that can be reached only with few natural stone aggregates.

Density of concrete decreases with increase in waste glass content thus making concrete light weight in nature. Workability of concrete mix increases as well as durability of concrete also increases in waste glass content. Compressive strength increases with glass parentage from 15% to 30%.

Incorporating 20% waste glass in placed of sand in concrete paving block gives acceptable mechanical properties. These blocks can be used for heavy duty industrial roads.

16. Granite Sludge Waste

Granite sludge powder is generated in processing activities of granite stone such as cutting polishing and finishing process. The Granite sludge powder is non-biodegradable waste. Masonry blocks paver block can be made using 20 % 20% granite sludge powder with sand 70 to 20%, line 8% and gypsum 2%. However more than 20% granite slurry increase the water absorption.

17. Gypsum Plaster waste

Gypsum plaster waste is an environmental and economic problem, and that this material has its destination often inadequate.

Blocks can be developed that incorporate the industrial gypsum plaster waste through reverse logistics.

One of the advantages of gypsum plaster waste is that it can be recycled several times; on the other hand, there are some properties that distinguish it from commercial gypsum plaster (CGP), which often present challenges in its applicability. The results show that, since the first cycle of recycling, the pastes with recycled gypsum plaster offer a substantial reduction of the workability in comparison with a CGP, using the same water/gypsum ratio (W/G).

The recycling in this comprised steps typical of a conventional gypsum plaster manufacturing process, namely : comminution, calcinations and storage. The production stage of the blocks, which especially includes the mixing, hardening, and drying process of gypsum plaster, also occurred in an industry, and consisted of the mixing of the RGP to water, dumping of the paste in the mold, manual vibration and work piece finishing.

The paste with 100% recycled gypsum plaster (RGB) waste prove to be feasible for block manufacturing, although its application time is short. The RGB, from a physical and mechanical point of view, meet the requirements stipulated by the gypsum block standard for civil construction-NBR 16494. Other tests such as fire resistance, watertightness and acoustics reinforce the technical feasibility of using this material in internal.

18. Human Sludge waste

One of the most common wastes which can be incorporated in building materials is sludge. Generally sludge from residential areas is in organic condition. Human waste cause less harmful and impact to the environment compared to industrial waste. The dried sludge (cake) can be used in production of fired clay bricks.

19. Marble Slurry waste

Ultra fine calcium carbonate dust recovered from marble sawing and processing slurry, have interesting application of economically feasible industrial uses.

In concrete production, replacing of sand up to 20% by marble waste powder gives almost similar strength as of concrete mixes with 100% sand.

Broadly speaking, marble slurry, due to the high percentage of limestone (calcite, dolomite, serpentine) in it can be used as a substitute for lime stone in most of its industrial and other applications. It can be used in the treatment of Sewage sludge to quell obnoxious fumes. As curing material Marble slurry helps in effective curing and saving a Loss of Lot of Water, by spray of Marble slurry fine particles. Due to fine particles of Marble Slurry and bulking, the voids of concrete are filled up and the water trapped inside the concrete is available for curing for long time.

Fineness modulus of Marble Slurry is 0.91 which allows it to be used for white washing making fine layer and white color repels heat resulting passive cooling of building. Marble slurry can be utilized as an ingredient to prepare cement mortar replacing fine aggregate. Utilization of Marble slurry replacing 30% sand shows equal strength.

20. Marble / Granite stone waste

Stones are cut into smaller blocks in order to give them the desired shape and size. During the process of cutting, the original stone mass is lost by 30%. The waste is dumped in nearby pits and vacant spaces. This leads to serious environmental pollution and occupy vast area of land.

The production of concrete of normal strength is feasible and viable by replacing the natural aggregates by the waste marble stone aggregates without compromising the strength characteristics. Marble Waste materials can potentially be used as aggregates in light to medium trafficked asphalt pavement binder layers.

Recycled aggregate of Marble and Granite waste comprise of crushed, graded inorganic particles processed from the materials that have been considered as a waste material. 20% to 30% waste marble / granite aggregates in concrete have shown increase in compressive strength, tensile strength, flexural strength from 6 to 12%

Big size rock fragments named

Khandas are used in building works in foundations, columns and under flooring as a hard sub base. The medium size stone is used in sub base of footing, foundation concreting and under pathways as hard base.

21. Kota Stone Waste

The waste generated from kota stone industry during the quarrying operations is mainly in the form of rock fragments are dumped in empty pits creating huge amount of waste.

17% replacement of kota stone waste in concrete gives same compressive strength as like 0% of the waste kota used. But in 100% waste kota used there is the more water absorption and less tensile strength. Optimum results are obtained at 51% replacement of aggregate with kota stone waste aggregate. After Crushing of kota stone concrete paving block using fly ash as replacement of fine aggregate along with kota stone industry waste would further reduce the cost of paving block.

22. Mineral waste

Increasingly, manufacturers of landscaping products crush, this material into recycled concrete aggregate (RCA) at the manufacturing site and recycle into new production as a partial replacement for primary aggregates.

23. Old concrete cubes and hollow concrete block waste

Concrete landscaping products are factory produced products which include block paver, slabs, kerbs etc. Concrete block pavers are one of the major manufactured concrete landscaping products.

Crushed old concrete cubes and cut / waste hollow concrete blocks can be reused for fresh concrete blocks. The results of study shows that crushed old concrete cubes possess less contamination and can be safely used in the production of high grade concrete with little adjustment in w/c ratio.

24. Organic Waste

Organic waste from cities and the countryside can provide the industry with lower cost, lower CO2 building materials such as bricks, insulation and partition boards.

- **Peanuts**: shells can be used to produce low-cost materials, such as partition boards that are resistant to moisture and flame retardant.
- **Rice**: rice husk ash can be mixed with cement to reduce the need for fillers. Rice husk can also be used as a raw material for the production of boards.
- **Banana**: banana fruit and leaves are being used to make rugged textiles. Bananas contain high strength fibre and have good acoustic absorption and durability.
- **Potato**: the peel from potatoes can be cleaned, pressed and dried to create a low-weight, fire resistant, water repellent, insulating material and acoustic absorber.

25. Palm Leaves waste

An environmentally friendly artificial wood for structural application is manufactured, by recycling mixed plastic waste and date palm leaves waste. Several pretreated wood plastic composites mixtures, using palm leaves and plastic waste, namely, polycarbonate (PC mix), polystyrene (PS mix), and polyvinyl chloride (PVC mix) have been developed.

Wood plastic composites (WPC) are a new group of materials generating interest in different parts of the world because they can divert recyclable wood and plastics from the landfill into durable building applications; additional environmental benefits oculd be obtained if the composites themselves are recycled at the end of their useful life.

The developed wood plastic composites exhibited less water absorption, linear burning and hardness, higher density than that of natural and MDF wood, and can be used in outdoor structures.

26. Paper waste

Paper is a natural polymer which consists of wood cellulose. Cellulose is made of units of monomer glucose. Although containing several hydroxyl groups, cellulose is water insoluble. The reason is the stiffness of the chain and hydrogen bonding between two OH groups on adjacent chains. The chains also pack regularly in places to form hard, stable crystalline region that gives the bundle chains even more stability and strength.

Different type of papers like newspaper, magazines, old invitation cards, paper tickets etc. can be used for making papercrete.

The Paper Crete bricks can be prepared from paper waste, which are relatively low cost, light weight and more flexible and they are most suitable for earthquakeprone areas. This brick does not expand or contract. However, uncoated bricks are not suitable for water logging and external walls; they can be used in inner partition walls, for sound absorption, fire resistance.

It is an important building material that is light weight, insulate and low cost concrete. It is cost effective, relies on locally available materials, it is insect free, fire resistant, durable and has great potential as a low carbon building material. Papercrete, is also known by alternative names such as fibrous concrete, padobe and fidobe, low carbon construction material.

Visvesvaraya NIT have developed a way to create paper bricks from recycling waste. Made from 90% recycled paper mill waste and 10% cement, the mixture is mechanically mixed and pressed into molds and then cured in the sun.

From tests it has been observed that fibrous bricks can sufficiently hold the nail. Also screws work well and can holds a considerable weight.

27. Pet Bottles Waste

Plastic bottles are increasingly becoming a menace to the environment due to the chemicals used in the manufacture, improper use and disposal. As noted by Plastics Industry reusing plastic bottles may seem safe, but a chemical found in reusable plastic bottles, known as Biphenyl A, is suspected of posing a health risk to human beings.

In the past, the glass was common in packing some foods. They could be returned to the factory for using again for the same purpose. But now by changing the human's disposal culture, glass bottles have been replaced by plastic bottles, as they have increasingly become one of the substances of destruction of the landfills because they decompose in a long time. Two alternative solutions against the plastic bottle disposal are : recycling and reusing process. Recycling needs additional energy to treat the materials for producing something usable. Moreover, the recycling process produces waste water and air pollutants. So the best solution is reusing for which no additional energy is required and does not contribute to pollution. Indeed, when we reuse junk, we are helping to save the obtained energy which would otherwise be wasted.

If it is used in walls with cement it can play as sustainable material. Fill the bottle with sand, fly-ash, wood-husk, combination and even soil also. Compact material in bottle well with proper tamping. After filling bottle with proper compaction cap, if start using in place of bricks it will help people to make their shelter at affordable low cost.

Fig.1 Wall with Pet Bottle Waste

28. Petroleum sludge

Petroleum sludge is hazardous sludge containing high amount of hydrocarbons. The petroleum sludge contains oil, water and inorganic material. The major constituents of the sludge are SiO2, CaO, Al2O3 and Fe2O3. The test result shows that, the quality of brick sludge is better than the standard bricks due to color and less fuel for firing.

The utilization of different types of Petroleum sludge waste into fired clay brick always obtain various advantages in terms of physical and mechanical properties such as low density, lightweight bricks, better strength and even reducing energy consumption during firing even though some drawbacks are also demonstrated. Most of the chemical compositions as well as the heavy metals are emitted during firing or solidification during curing. The end product comply with the standards.

29. Phosphate Fertilizers waste : Phosphogypsum

Growing demands for phosphate fertilizers have yielded enormous amounts of phosphogypsum for years worldwide. Despite being essentially CaSO4.2H2O, such material has currently little economic value due to environmental issues notably regarding radon – 222 (222Rn) exhalation

Phosphogypsum gets simply piled up nearby phosphate fertilizers industrial units, requiring considerable open air space. For inactive phosphogypsum stacks research has been conducted to overcome difficulties related to the disposal and handling of this waste. Feasible solutions have suggested its exploitation as soil amendment in agriculture, mine recovery, road base, and embankment filling.

Phosphogypsum (pure or blended to building materials) can be used as construction elements such as pre-fabricated blocks or panels for cost effective dwellings.

30. Poo-Cow dung waste

Cow's digestion produces impurities and can be used as a fuel called biogas, can also be used as fertilizer because of high cellulose. In some areas dry cow dung is also used as fuel. cow-dung reacts with kaolinite and fine quartz to produce insoluble silicate amine, which glues the isolated soil particles together. Moreover, the significant presence of fibres in cow-dung prevents the propagation of cracks in the adobes and thus reinforces the material.

The above phenomena make the adobe microstructure homogeneous with an apparent reduction of the porosity. The major effect of cow-dung additions is a significant improvement in the water resistance of adobe, thus adobes stabilized by cow-dung are suitable as building materials in wet climates.

Fig.2 Treating Poo Cow Dung Waste

31. PUF Polyurethane Foam Waste (PFW)

Polyurethane Foam (PUF) is one of the larger polymer product groups within the plastics family. Each year, plastic industries generate huge volumes of PUF wastes during the fabrication and conditioning. The re-use of these materials promotes sustainable development and environmental management. In India, the total PUF waste is estimated to be about more than 2 million tons, approximately half of which is not suitable for collection and subsequent reuse, because of small volumes and wide distribution. The incorporation of such materials into the lightweight mortar and concrete is an interesting alternative for the valorisation of Polyurethane Foam Wastes (PFW).

It has comparatively moderate compressive strength : PFW is a compressible material that has high porosity, which means greater water absorption in its pores and a lesser need for the cement – polyurethane paste mixture, which in turn results in a reduction of compressive strength. This loss of strength is compensated in part by diminishing the w/c ratios due to the plasticity effect. On the other hand, mortar using Polyurethane waste has a certain flexibility that gives the mixture good resistance to fissures which, in turn, makes it capable of absorbing small structural movements without breaking up, maintaining its adhesion to the supporting structure.

As the entrapped air acts as thermal insulator, the thermal conductivity of the mortar thus reduces. Due to this it also has acoustic insulation properties, which could be of great use.

It has less thermal conductivity hence it acts as an insulator. Thus, using this mix as mortar in the walls makes them passive. Thus it provides a promising building material for sustainable development of Green Passive Homes.

32. Quarry Dust waste

Quarry rock dust can be defined as residue, tailing or other non-valuable waste material after the extraction and processing of rocks to form fine particles less than 4.75mm. Quarry dust can be used for non-structural concrete, sand fill, non load bearing blocks, road applications.

33. Recycled Plastic bags & packaging materials

Recycled bags or plastic packaging can be used for wall blocks. The waste bags etc. are placed in a heat mold, and forced together to form the blocks. They are too lightweight to act as load bearing walls, but can be used to divide up rooms or outdoor areas.

34. Red Mud & GGBS Blocks

Red mud is the solid waste residue of the digestion of bauxite ores with caustic soda for alumina production and is usually disposed in mud lakes in the form of slurry impoundment or stack in ponds. Due to the characteristics of fine particles, high alkalinity (pH 10-12.5) and trace metal content, the disposal of large quantities of red mud has caused serious environmental problems including soil contamination, ground water pollution and fine particles suspension. Moreover storage of the same in lakes or ponds leads to dust pollution which is a serious health problem.

The GGBS (Ground Granulated Blast Slag) is a waste product from the iron manufacturing industry. This has been used as a partial replacement of cement in concrete due to inherent cementitious properties.

It is observed that, red mud & GGBS blocks possess lesser compressive strength when compared to that of conventional blocks and hence are not suitable for the construction of load bearing walls but can be used for the construction of partition walls.

Red Mud blocks can be manufactured composing of 50-60% clay, 10-30% GGBS & 10-30% red mud.

35. Rice Husk Waste as (RHA)

RHA, produced after burning of Rice husks (RH) has high reactivity and pozzolanic property. IS 456-2000, recommends use of RHA in concrete but does not specify quantities. Chemical compositions of RHA are affected due to burning process and temperature. Silica content in the ash increases with higher the burning temperature.

Use of RHA with cement improves workability and stability, reduces heat evolution, thermal cracking and plastic shrinkage. This increases strength development, impermeability and durability by strengthening transition zone, modifying the pore-structure, blocking the large voids in the hydrated cement paste through pozzolanic reaction.

RHA replacing 10% Portland cement resists chloride penetration, improves capillary suction and accelerated chloride diffusivity.

36. Rubber Tyre waste

The disposal of waste rubber tyre has been a critical environmental concern. Tyres are designed to have a very good resistance to weather and waste tyres do not degrade in landfill. Owing to the hardness and elasticity properties of waste tyre rubber, several studies have indicated the potential of using waste tyre rubber in concrete production as sound/crash barriers, retaining structures and pavement structures.

The compressive strength of crumbled rubber brick with 40% replacement of the fine aggregate with crumbled rubber is about 14 to 15 N/mm2. It is almost equal to the strength of conventional cement brick.

37. Sewage Sludge

It has been demonstrated that the appropriate percentage of ash sludge to produced good quality bricks is in the range of 20% to 40% by weight with a 13% to 15% optimum moisture content prepared in the moulded mixture. Firing is conducted at 10000C for 6 hours. Utilization of 10% sludge ash exhibited even higher compressive strength than normal brick.

The brick process uses less energy and produced a smaller amount of air pollution compared to standard brick. Biofly brick also saves energy upto 44%, produces 20% to 24% lighter brick and 10% to 30% stronger compared to the conventional bricks.

38. Steel balls waste as aggregates

In cycle marts and motorbike, repairing garages & factories, steel bearings are used in wheels of cycles and motorbikes. The purpose of ball bearing is to reduce rotational friction and support radial and axial loads. Once ball bearings lose their lubrication, it becomes useless material. Such steel bearings are wasted in large quantity in cycle marts, garages and factories.

These waste steel rounded bearings can be used in manufacturing concrete paver blocks as coarse aggregates in some amount. Steel has higher specific gravity and density as compared to coarse aggregate. Hence adding steel bearings in paver blocks is beneficial as it helps to increase the compressive strength, abrasion resistant capacity, impact value of paver blocks.

39. Sugarcane Bagasse Waste

The bricks prepared in commercial plants using Sugarcane Bagasse Ash quarry dust and lime meet all the requirement as described in the Indian standard. The bricks with 20% addition of lime to SBA and quarry dust exhibit a compressive strength of 6 to 7MPa, which required, is more than minimum strength of (3.5MPa).

40. Textile cloth waste

Textile cutting waste from the industries and tailoring shops are disposed as waste product in heaps thus causing disposal problem and environmental pollution. Studies have indicated that many forms of fibers recovered from various waste streams and suitable for concrete to act as reinforcement. It has been reported that polymer concretes can also be reinforced with fibers of both synthetic and natural. The textile waste cuttings when mixed with thermosetting polymer as binder produces a unique kind of composite material that can be used for low cost light weight construction. Improved chemical resistance and mechanical strengths are achieved. It is reported that waste cloth incorporated polymer concrete display brittle characteristics that have limited its usefulness to non-load bearing walls only.

Waste cloths in the concrete reduces compressive strengths. Due to loss of cohesion however.

Inclusion of waste cloths increases the tensile properties of concrete due to reinforcing effect of cloth fibers in concrete. This special concrete provide thermal and sound insulation and therefore it can be used as ceiling and wall panels, floor tiles. Carpets are made of T-shirts, second-hand clothing or scrap, which are cut into strips and woven by hand form carpets for homes and offices.

Textile fabric bed spreads can be cut with patterns and form that will be joined with the help of a sewing machine to construct canvases based on pieces.

41. Textile sludge waste

Textile effluent treatment plant waste sludge can be reused in production of clay bricks. Textile sludge can be added upto 15% as it gives compressive strength above 3.5MPa and the water absorption ratio is also less than 20%. The sludge composition vary from 3% to 30% and the firing temperature is about 2000C to 8000C. Strength achieved is between3.5 to 4MPa which satisfies the (BIS).

42. Unsorted plastic waste

The grains of plastic produced from unsorted plastic waste is called Plasphalt, which replaces the sand and gravel traditionally used in asphalt production. In testing, it has been found that plasphalt roads are far less vulnerable to wear and tear than traditional asphalt, because the asphalt emulsion bonded better with the plastic than with gravel or sand.

43. Waste blood

Animal blood counts as a waste product. This, we realise, is a potentially offensive idea-but while carnivores are still munching away, they are still wasting loads of animal blood, especially in societies without industrialised food production systems. And, as it turns out, blood is one of the strongest bio-adhesives out there, as it contains high levels of protein.

Using freeze dried blood (which comes as a powder), mixed with sand to form a paste; this can then be cast as bricks. This could be especially useful in remote communities, where blood from animal slaughter is plentiful, but strong construction materials are not available.

44. Waste bottle corks

Wall or floor tiles are made by combining recycled granulated cork with whole wine corks, which is visible in oblong shapes in the figure. This is a pretty useful idea, considering consumption of large number of bottles of wine a year.

Fig. 3 Corksheet Made From Bottle Corks Waste

45. Waste Heineken beer bottles

Lots of companies now make bottles in cuboid or other tesselative shapes, to make them easier to transport. When used in walls, these bottles provide firm base due to shape.

To create construction materials actually started with beer company Heineken.

The company landed on a new, brick-shaped designed for the bottle, shown in the image (fig.). The bottleneck slots into the base of the next bottle, forming an interlocking line. These bottles can be filled with soil / flyash mix, compacted and then laid as a walling

Fig. 4 Heineken Beer Bottles Waste

material laid with cement mortar.

46. Waste Plastics

The waste plastics can be used in the cement concrete mix. This modified cement concrete mix is applicable in the construction of rigid pavements. The compressive strengths of modified cement concrete are as equal as plain cement concrete. The optimum modifier content of waste plastics is found to be 4% for paver blocks and 2% for solid blocks.

Mixing waste plastic with heated bitumen and coating the mixture over stone has provided positive results for Road construction. Recycled PET fibres have also been considered as reinforcement for concrete as a means for improving its performance.

PET aggregate concrete have less compression strength, flexural rigidity and tensile strength which can be attributed to the decreased bonding tendency of PET with cement matrix. But as the density of PET fiber is lower than the conventional aggregate, it is very useful in producing light weight construction entities. The blocks have higher toughness. PET fibres are ductile.

47. Wood waste

Mortar and cement concretes often contain chemical or mineral additives. The purpose and dosage of these additives are to modify one or more properties of the mixture, improving its performance either in their fresh or hardened state.

As an additive, wood has interesting properties from a seismic point of view. It performs well when bent and compressed and it also has low thermal, acoustic and electrical conductivity. There is high volumes of wood waste in factories and sawmills that can be potentially used for construction products (blocks).

The compressive strength of ordinary blocks is greater than that of blocks with wood additives. However, concretes with upto 15% wood additives still comply with structural use.

The ductility of traditional concrete blocks is significantly lower than that of concrete with saw dust or wood shavings. A concrete with 15% wood shaving addition practically doubles the ductility of ordinary concrete, which considerably improves the seismic resistant behaviour of the block.

Additionally, the volumetric expansion that these types of concrete experience when adding wood based materials reduce concrete quantity. This may result in substantial economic savings in large scale construction works. Depending on the amount of wood aggregate that the mixtures has, the expansion of these concretes can save upto 10-15 % of the material.

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Sustainable Degradation of Municipal Solid Waste




Prof. D. N. Singh[1] *Dr. B.S. Patil*[2] *Goli Venkata Siva Naga Sai*[3] *Arif Mohammad*[3]

1. Introduction

Over the past few decades, enhancement in living standards, increase in per-capita income, growth in population and a lackadaisical attitude of the populace are becoming primary drivers for the uncontrolled generation of millions of tons of municipal solid waste (MSW) in the modern-day cities. Disposal of this huge amount of MSW has led to unscientifically created landfills and dump yards, UCLD, which are not only a nuisance to the geoenvironment but also pose a severe safety and health hazard to the flora and fauna, both in the short- and long-run. This is mainly due to emission of toxic gases, ingression of leachate into the ground, fire and prolonged 'natural degradation' process. In addition, these dumpsites/landfills occupy huge land in the outskirts or within municipal boundaries and are responsible for creation of the manmade hills in and around the modern-day cities.

Under these circumstances, a bioreactor landfill, BLF, wherein leachate recirculation is practiced to accelerate decomposition of MSW and generation of methane gas appears to be a promising solution (Patil et al., 2017, Chembukavu et al., 2019). A BLF has numerous advantages over the conventional landfill such as (i) less requirement of space due to compaction of MSW (ii) shorter time period for stabilization (≈5–10 years) of waste as compared to the conventional landfill (≈decades), (iii) reuse of space for several times in a short time span, (iv) utilization of mined residues and (v) environmental safety due to the confinement. In addition, the methane gas, which is ≈45–60% of the total landfill gas, generated and collected from the BLF, could be utilized for generation of electricity.

Realizing these facts, research and development activities are being pursued, vehemently, by the researchers at Environmental Geotechnology Laboratory, Department of Civil Engineering, IIT Bombay on various aspects of the BLF. A BLF was successfully commissioned at IIT Bombay campus (Patil et al., 2017) and subsequently even a US patent has been obtained (Patent number: US 10,071,403 B2). A brief discussion on various aspects of the BLF is presented in the subsequent sections.

2. The Sustainable Engineered Bioreactor Landfill (SEBL)

The SEBL (refer to Fig. 1) was developed to (a) demonstrate the effectiveness of instrumentation (viz., FDR probe and thermocouples) for monitoring the moisture content and temperature, (b) maintain favorable conditions for bacterial activity to harp and multiply, (c) ascertain the collection of landfill gases, (d) sampling and analysis of the leachate characteristics and (e) develop a post-closure monitoring system to assess contamination of the geoenvironment (viz., soil, groundwater and atmosphere) due to the ingression of leachate and release of biogas emanating from the SEBL.

2.1 Components of the SEBL

The major components of SEBL are: (i) bottom and top liners, (ii) leachate collection and recirculation system, (iii) landfill gas collection system, as discussed in the following sections. The liners

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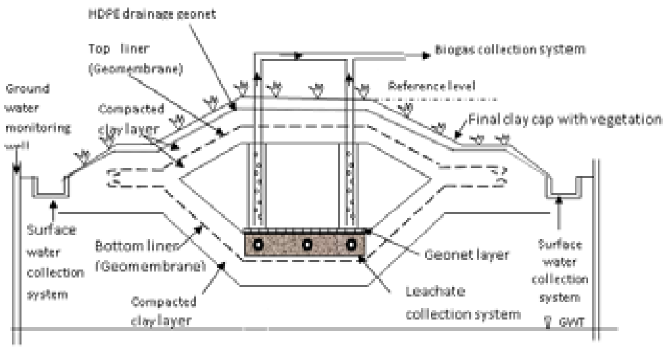


Figure 1: Schematic diagram of the SEBL

were provided with an intention to safeguard the surrounding geoenvironment from the buried MSW. The thickness of the subgrade layer, compacted clay layer and the protective soil layer on the geomembrane are provided as per the guidelines listed in MSW Rule (2000).

The bed of the landfill is designed typically to collect the leachate by gravity with the use of perforated HDPE pipes. These pipes are then connected to a collection sump outside the bioreactor landfill, as depicted in Fig. 2, from where the leachate can be recirculated in the BLF, as per the requirements, by employing a submersible pump. The leachate collection system was constructed with a drainage layer of coarse-sand and gravel as recommended by MSW Rule (2000). Size of the sump well is decided based on the estimated quantity of the leachate generation as well as the recirculation requirements.

Landfill gas collection system consists of a series of perforated pipes embedded in the bioreactor, surrounded with bentonite plug and solid casing at the top, and 20 cm thick gravel packing in the remaining portion as depicted in Fig. 3. The gas collected from the bioreactor can be stored in a separate gas holding tank.

2.2 Instrumentation in the SEBL

Monitoring of the ambient temperature and humidity was conducted by employing a commercially available temperature and humidity meter. Further, multilevel thermocouple (refer to Plate 1) and Frequency Domain Reflectometry (FDR) probe (refer to Plate 2) were employed for monitoring of temperature, θ, and moisture content, *w*, of the MSW (Reinhart et al. 2003; Haydar and Khire, 2006, Rao and Singh, 2011). The thermocouple was connected to a data logger (Measurement computing USB-TC, Norton, MA 02766) for recording the temperature over the prolonged periods.

The FDR probe, which is employed to determine volumetric moisture content, employs a split cylindrical electrode probe (Dean et al., 1987) that can be moved in a PVC access tube (refer to Plate 2), embedded in the MSW matrix.

Five access tubes were installed for insertion of the FDR probe (access tubes A, B, C and D) for monitoring the *w,* and multilevel thermocouple for measuring θ (access tube E) at three different depths (viz., 0.3, 0.5 and 0.7 m) of the MSW, as depicted in Fig. 4. After the measurement, both the FDR probe and the thermocouple were removed and stored in a controlled environment and the access tubes were closed with top caps, to prevent loss of landfill gas or infiltration of water into the landfill.

Apart from this, for monitoring leachate migration into the subsoil and surrounding soil, HDPE perforated pipes have been installed in the ground, at a known distance from the edge of BLF; one at the upstream and another at downstream of the SEBL. The water collected from these pipes was analyzed to assess the extent of leachate migration in the subsurface, which in turn indicates the groundwater contamination level.

2.3 Loading and Operation of the SEBL for treatment of MSW

MSW was collected from various sources (viz., academic area, residential areas like staff quarters, hostels, canteens and restaurants, a shopping area in IIT Bombay) in the form of the mixed waste,

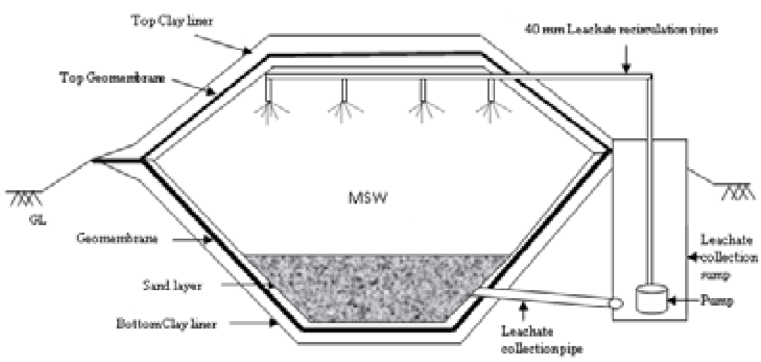


Figure 2: Schematic diagram of the leachate collection and recirculation systems

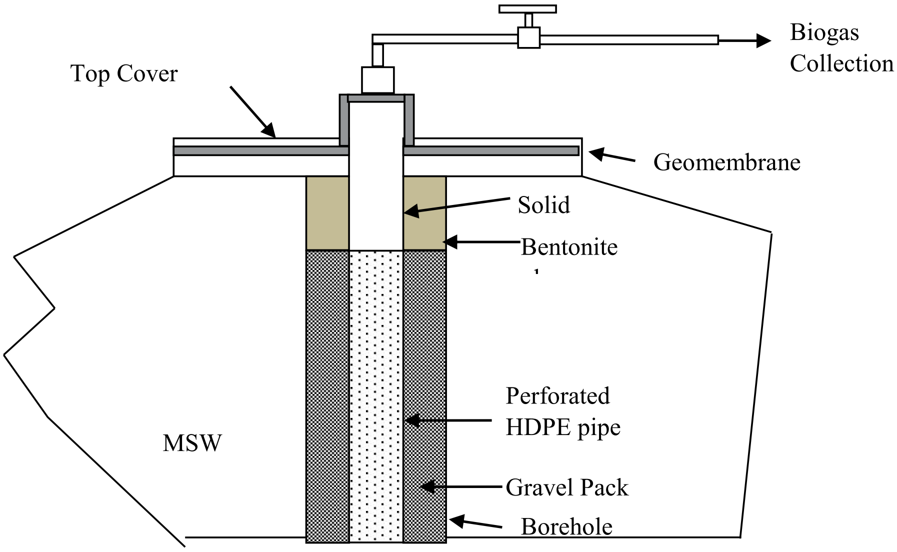
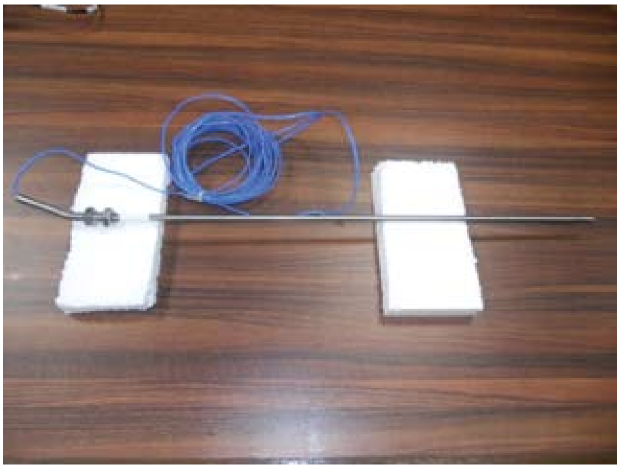


Figure 3: Schematic diagram of the biogas collection system



(a)

(b)

Plate 1: (a) The thermocouple and (b) its installation in the MSW

(a)

(b)

Plate 2: (a) Components of the FDR probe and (b) its installation in the bioreactor landfill

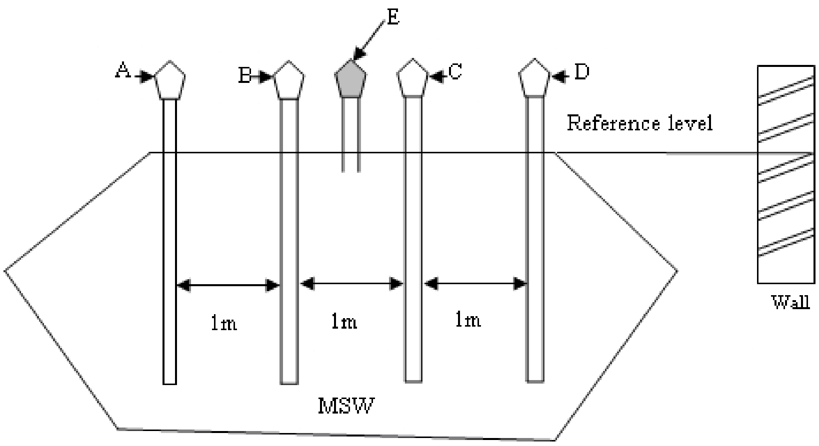


Figure 4: Schematic diagram of the access tubes for the FDR probe (A, B, C, D) and thermocouple (E) installed in SEBL

as segregation of the waste is a cumbersome exercise and not commonly practiced in developing countries. As the percentage of organic waste is considerably high in the MSW, methane gas that gets generated could be captured and utilized for energy generation. From the collected MSW, segregation of the glass and metals has been done and the remaining MSW has been shredded before feeding it into the SEBL. The bioreactor has been loaded to achieve 0.2 m height of compacted MSW and an intermediate cover of 0.1 m thick partially decomposed biomass in five similar layers. Landfill gas collection and leachate recirculation pipes, access tubes were installed during MSW dumping activity. Subsequently, final top cover, as depicted in Fig. 1, was laid and the waste was left to decompose over a certain duration, under the favourable anaerobic conditions to enhance the bacterial activity at θ ≈25°C to 40°C and *w*≈40 to 65%, thereby achieving maximum decomposition within a short time. In order to achieve this, the leachate was circulated. During the decomposition process, the presence of methane has been confirmed by flaring the landfill gas. For the sake of brevity, the flow chart of BLF is depicted in Fig. 5.

3. Summary and path ahead

This study is a proof of concept or the philosophy; '*decentralized municipal solid waste management*' for small communities (viz., smart cities, institutions/campuses etc.) without depending on the external MSW processing plants or facilities. Furthermore, the non-biodegradable fractions (viz., plastics, synthetic textiles, glass, e-waste, C&D waste) that are left over as the 'residues' can be utilized as manure and/or for infrastructure development (viz., construction of roads, manufacturing tiles, blocks etc.). However, installing SEBLs at various places in India, where different climatic and socio-economic conditions prevail, to check the efficacy of this *engineering philosophy* and its potential to manage the MSW is the dire need of the hour. In this context, it would be prudent to create a 'business model' that would encapsulate the novel and scientific engineering approaches for facilitating the sustainable management of the MSW.

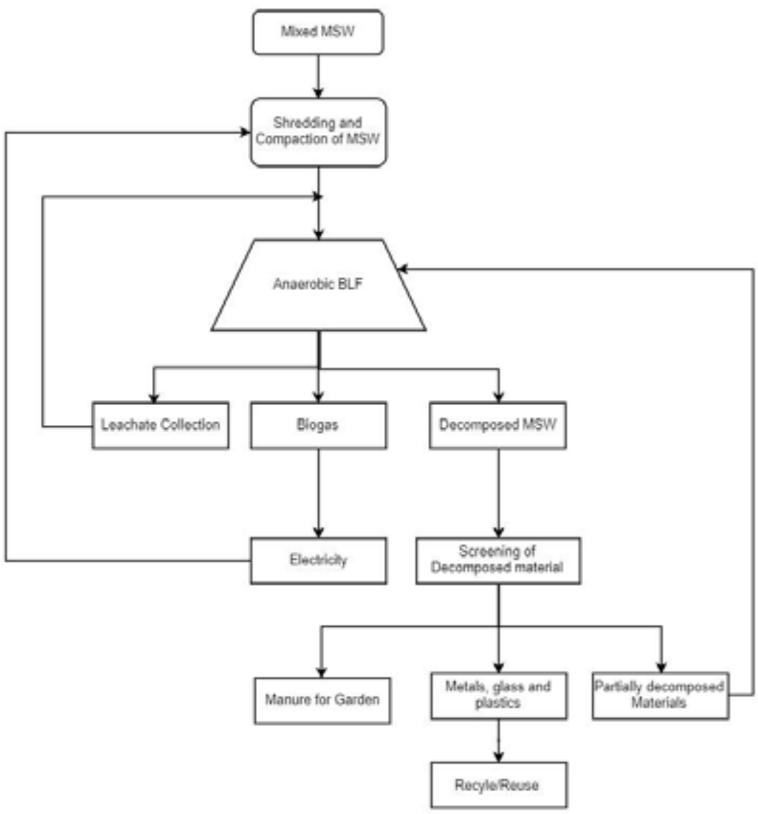


Figure 5: The flowchart for the SEBL

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Release of digital version of Third Edition of Vulnerability Atlas of India

BMTPC has finalised and published digital version of third edition of Vulnerability Atlas of India. Hon'ble Prime Minister, Shri Narendra Modi, released the digital version of Third Edition of Vulnerability Atlas of India on the occasion of Global Housing Technology Challenge - India (GHTC-India), Construction Technology India 2019 Expo-cum-Conference on 2nd March, 2019 at New Delhi. The third edition of Vulnerability Atlas of India is collation of the existing hazard scenario for the entire country and presents the digitized State/UT-wise Hazard Maps with respect to Earthquakes, Winds & Floods for district-wise identification of vulnerable areas. This edition contains additional digitized maps for Thunderstorms, Cyclones and Landslides. The Atlas also presents the district-wise Housing Vulnerability Risk Tables based on wall types and roof types as per 2011 Census Housing data. The Atlas is a useful tool not only for public but also for urban managers, State & National Authorities dealing with disaster mitigation and management.

Perforated Plastic Cement Bags as Retrofit Material for Masonry Buildings


Dr.Ajay Chourasia[1] *Shubham Singhal*[2]

Abstract

This paper provides an insight to the research program, where Plastic Cement Bag Mesh (PCBM) is explored for the retrofitting of masonry. PCBM was obtained using ordinary empty cement bags (made up of plastic), which were modified into the mesh for the purpose of retrofitting. The PCBM was evaluated on the basis of compressive strength, shear strength and retrofitting cost performed on masonry prisms and wallets. The PCBM retrofitting technique was then implemented on the previously tested damaged confined masonry building. Retrofitted confined masonry building (CM_RET) and its original counterpart (CM) were compared to evaluate the effectiveness of retrofitting technique. It is expected that experimental investigation on retrofitting of masonry and its effectiveness will be useful to practicing engineers to choose suitable material for a seismic resistant and cost-effective effective retrofitting technique.

1. Introduction

Masonry construction has been adopted since ages, known for its satisfactory performance, easy to construct technology, thermal insulation and cost effectiveness. However, it has been perceived that masonry buildings have shown poor performance during seismic events as seen in the case of Bhuj earthquake (Jagadish et al. 2001) and Kashmir earthquake (Rossetto and Peiris, 2009) among many others. Unsatisfactory performance of masonry buildings is attributed to lower tensile and shear strength along with lack of integral action.

Reconstruction of damaged buildings is never encouraged as it imposes a huge demand on the national economy. Retrofitting and strengthening is a better solution to improve the seismic performance and damage control in deteriorated masonry buildings. Many retrofitting techniques such as post tensioning, ferro-cement overlay, shotcrete, reinforced concrete jacketing etc. are available and adopted around the globe. However, these retrofitting techniques are costly and often require special techniques and skills to implement on the structure.

Plastic cement bag is an unutilized waste, which is very commonly found at construction sites. Disposing the waste of plastic cement bags is a major problem, which often creates environmental issues. Plastic cement bags as waste may be converted into wealth by utilizing them for the retrofit of masonry buildings. Plastic Cement Bag Mesh (PCBM) was implemented on masonry prism and wallet to determine compressive and shear strength. PCBM was then implemented on a full-scale damaged Confined Masonry (CM) building and tested under reverse cyclic quasi-static lateral loading. The effectiveness of retrofitting was assessed by comparing failure pattern and seismic performance of Retrofitted Confined Masonry Building (CM_RET) with its original counterpart (CM). CM_RET building performed significantly well

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by demonstrating remarkable increase in lateral strength, displacement capacity, stiffness, ductility and drift along with the minimum structural damage among all the tested masonry building systems.

2. Evaluation of Plastic Cement Bag as Retrofit Material

In order to assess the performance of plastic cement bag as a retrofitting material, an experimental program was carried out on masonry prisms and wallets to evaluate their compressive and diagonal shear strength. The masonry prisms were 410 mm x 220 mm x 110 mm, while masonry wallets were 670 mm x 670 mm x 230 mm built with solid burnt clay brick units in 10 mm thick cement-sand mortar (1:4). The surface of masonry was cleaned with a brush and PCBM was wrapped on both the sides of prisms and wallets with the help of epoxy and nails. In addition, unretrofitted masonry prism and wallet was also constructed as plastered control specimen (PCS). Curing of masonry was done by spraying water after 24 hours of construction which were then covered with jute bags for 28 days. The specimens were tested in a close loop fashion, following the ASTM C1314 and ASTM E519 standard protocol with the help of 1000 kN capacity hydraulic jack. Figure 1 demonstrates test set-up for masonry prisms and wallets, while Figure 2 demonstrates damage pattern of masonry prisms and wallets respectively. The results showed PCBM as an effective retrofit strategy by demonstrating high compressive and shear strength i.e. 6.09 N/mm^2 and 0.51 N/mm^2 respectively. Cost analysis indicates that retrofitting with PCMB amounts to Rs. 60/m^2, which is quite reasonable as compared to other prevalent retrofitting strategies. PCBM has advantages of cost-effective, high flexibility, minimum thickness, non-corrodible nature, adequate grip and reuse of waste material, which makes it a potential material for retrofit.

(a) (b)

Figure 1. Experimental set-up for (a) masonry prism, and (b) masonry wallet

(a) (b)

Figure 2. Damage Pattern of Masonry Prisms under (a) Compression and (b) Shear

3. Retrofit Technique for Confined Masonry Building

PCBM was used for the retrofitting of extensively damaged CM building previously tested by Chourasia et al. (2016). Grouting in damaged CM building was carried out as per ASTM C 1107 standards. Grouting material consisted of standard epoxy resin, thoroughly mixed with 10 litres of water with 6 to 7 kg of cement and 100 gm of grouting powder. Retrofitting process initiated with the cleaning of surface of damaged masonry wall. Subsequently, cracks were sealed with the mortar and grouting holes were drilled into the cracks at a distance of 500 mm, which were then injected with the grouting material through the injection nozzle. The PCBM was prepared by forming 25 mm wide strips and 50 x 50 mm square holes in empty plastic cement bags. PCBM was fixed to both the sides of masonry walls with the help of epoxy and nailing. The application of cement slurry was done over the entire wall surface before applying 15 mm thick, 1:4 cement: sand mortar paste to achieve adequate bond between plaster and masonry. Finally, the

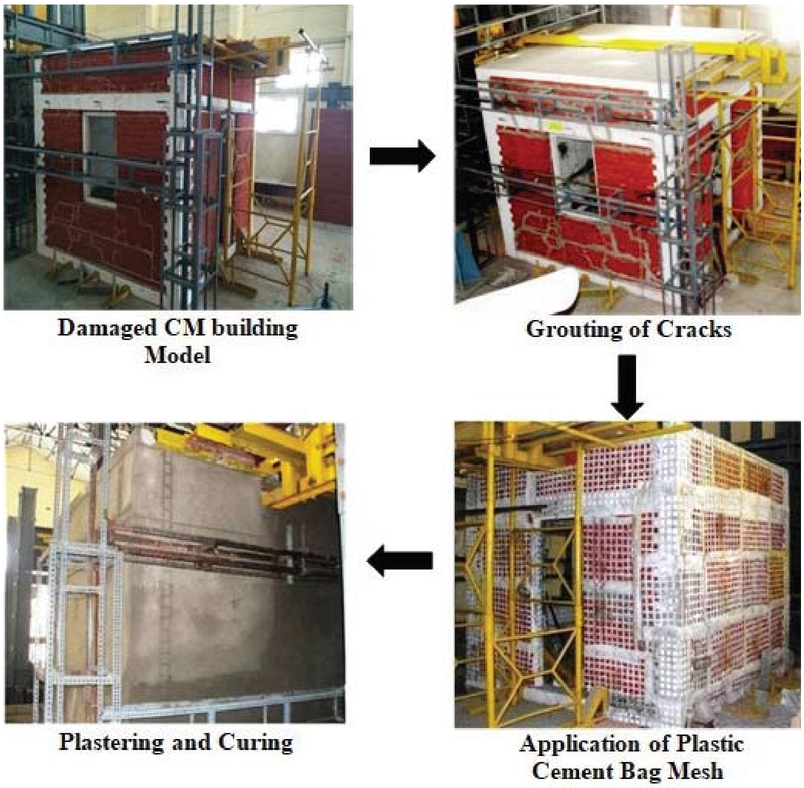


Figure 3. Retrofitting of CM Building

masonry walls were cured for 7 days. Figure 3 describes the retrofitting process of CM building.

4. Experimental Set-up

The confined masonry model (CM) was constructed on a reinforced concrete beam anchored to the strong floor of the laboratory. Table 1 presents material and structural specifications of CM and CM_RET buildings. The test buildings were subjected to the displacement controlled reverse cyclic lateral loading at the top level through a two-way servo-hydraulic programmable actuator, having 500 kN lateral load capacity actuator with ±75 mm stroke length. The displacement time-history was drawn as per protocol of ASTM-E-2126. Accordingly, the model was subjected to reverse cyclic lateral displacements with increasing amplitudes, in which each set of amplitude peak was repeated three times. The lateral load was distributed over eight points at roof level through roller type ball bearings attached to grillage mechanism which created restrained boundary condition, simulating rigid diaphragm action in the building. Lateral deformation occurred in the building during the test was recorded at a sampling frequency of 200 Hz through ten Linearly Variable Displacement Transducers (LVDT) having 0.01 mm sensitivity, placed at critical locations and connected to the data acquisition system. LVDTs were mounted on an independent steel frames fabricated using perforated steel angles, which were fixed to the strong floor. Figure 4 shows the retrofitted confined masonry building with the experimental set-up. The test was terminated when the load dropped to 85% of the peak load, although the building could bear more lateral load and deformation.

Figure 4. Experimental Set-up of CM_RET Building

5. Results and Discussion

The seismic behaviour of CM_RET building was studied with respect to crack pattern, lateral load carrying capacity, stiffness and deformation characteristics and compared with the seismic performance of previously tested CM building.

Table 1. Material and structural features of tested masonry buildings

Building designation	Building typology	Material specification	Structural features
CM	Confined Masonry	Burnt solid clay brick units, cement: sand (1:6) mortar, M20 grade tie columns at corners and beams at lintel level. M20 grade RC slab.	220 mm thick brick masonry walls with openings for door and window, 100 mm thick slab. 220 x 220 mm RC tie columns, 220 x 200 mm RC tie beams, 40 mm groove between masonry and tie column.
CM_RET	Retrofitted Confined Masonry	CM + cementitious grouting in the cracks and mesh of plastic cement bags.	CM + 25 mm wide PCBM strip fixed on both faces of masonry wall with epoxy and embedded in 10 mm thick cement: sand (1:4) mortar plaster.

5.1. Crack Pattern

As compared to CM building, intensity of cracks was relatively low in CM_RET building, thus performing relatively better due to the effect of resilience provided by the retrofitting with the mesh of plastic cement bag. Crack pattern of all the walls of CM_RET in shown in Figure 5. In-plane walls of CM building experienced first flexural horizontal hairline crack (at lower course) at a displacement of 7 mm (Chourasia et al. 2016), whereas CM_RET experienced its first flexural hairline crack at a displacement of 10 mm. Diagonal shear cracks appeared at higher displacement cycles. Cracks were observed in the plaster, while no cracks were observed in the masonry till the displacement cycle of 70 mm, owing to the effect of retrofitting with the mesh of plastic cement bags. However, at 72.5 mm displacement, crushing of mortar occurred near the bottom of the building in the out-of-plane wall. In CM building, crushing of masonry units occurred in the compression zone along with concrete spalling and kinking of reinforcement in tie-column at higher displacement cycles (Chourasia et al. 2016). Thus, CM_RET resulted in lower damage owing to the presence of plastic cement bag mesh which prevented spreading of cracks deep into the masonry.

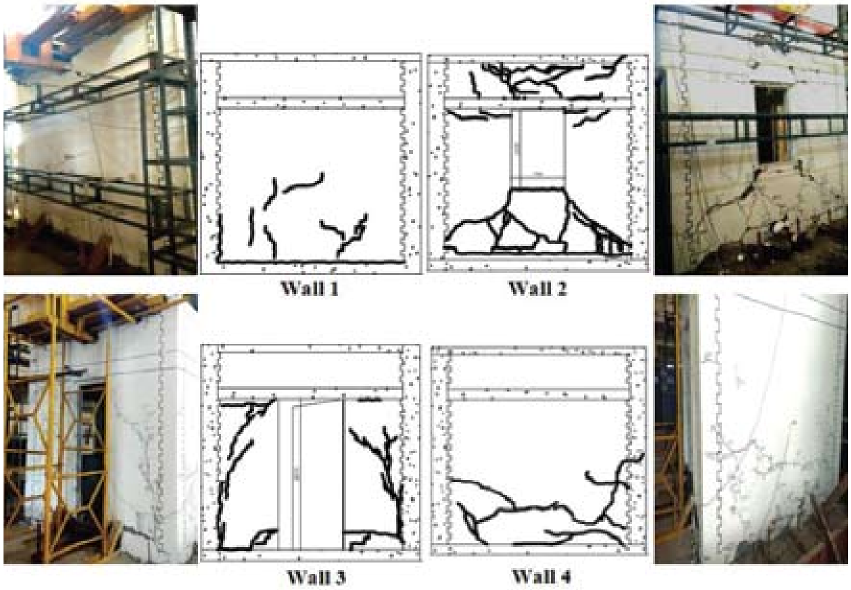
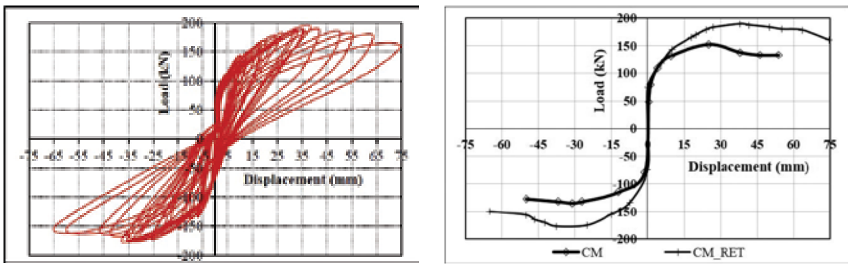


Figure 5. Final crack pattern of CM_RET building



(a) (b)

Figure 6: (a) Hysteretic curve for CM_RET; and
(b) Lateral load-displacement envelope curves for CM and CM_RET

5.2. Lateral Load Carrying Capacity and Stiffness

Figure 6(a) demonstrates lateral load-displacement hysteresis curve for CM_RET building. Figure 6(b) demonstrates the comparative envelop curve for lateral load v/s displacement for CM and CM_RET buildings. It indicates that CM_RET building attained maximum lateral strength i.e., 189.07 kN and ultimate displacement of 74.5 mm before the collapse stage. Retrofitting with the mesh of plastic cement bags proved to be an effective retrofitting technique as 24.18% increase in lateral load reistance was observed in CM_RET building as compared to CM building with the CM building sustaining lateral load up to 152.25 kN, while CM_RET up to 189.07 kN. Maximum initial stiffness was obtained for CM_RET building as 63.33 kN/mm, while CM building achieved initial stiffness of 56.74 kN/mm. Lateral load and stiffness data for both the buildings is summarized in Table 2.

5.3. Deformation Characteristics

Drift of any building is calculated as the ratio of top displacement and height of the building. Maximum drift in CM_RET building reached up to 2.48% at the limit state of safety before reaching the condition of collapse. Drift at damageability and serviceability were obtained as 0.35% and 1.28% respectively. Ductility of any material is its ability to undergo deformation beyond the elatic limit without the significant loss in its strength. In general, material ductility is expressed as the ratio of ultimate strain to the yield strain. Response reduction factor (R) indicates the capacity of a structure to dissipate energy through inelastic behaviour (Patel et al. 2010). Response reduction factor determines design base shear by normalizing the elastic seismic force in idealized linear elastic structure. The response reduction factor can be expressed in terms of lateral load as:

$$R = \frac{H_{le,max}}{H_{u,d}} \qquad (1)$$

where, $H_{le,max}$ = maximum earthquake load developed in a completely elastic structure; and $H_{u,d}$ = ultimate designed earthquake load. In terms of ductility (μ), response reduction factor can be expressed as:

$$R = \sqrt{2\mu - 1} \qquad (2)$$

Table 2. Seismic Characteristics for Tested Masonry Buildings

Seismic Characteristics		Building Typology	
		CM	CM_RET
Lateral deformation	d_{cr} (mm)	9.89	12.00
	$d_{H',max}$ (mm)	25.15	38.48
	$d_{d,max}$ (mm)	54.01	74.50
Lateral Load	H_{cr} (kN)	131.04	149.00
	$H_{H,max}$ (kN)	152.25	189.07
	$H_{d,max}$ (kN)	132.90	157.00
Stiffness	K_{in} (kN/mm)	56.74	63.33
	K_{cr} (kN/mm)	13.95	12.42
	$K_{H,max}$ (kN/mm)	6.05	4.91
	$K_{d,max}$ (kN/mm)	2.46	2.11
Maximum drift (%)		1.800	2.483
Ductility		5.755	6.208
Response reduction factor	Eq. (1)	3.242	3.444
	Eq. (2)	3.344	3.379

6. Conclusion

PCBM was wrapped on severly damaged CM building as a retrofit material on both the faces of the wall. The retrofit CM model was subjected to cyclic lateral displacement loading at the roof level. The seismic performance of CM_RET building was studied in terms of strength, stiffness, ductility and behaviour factor and compared with its CM building. The key conclusions derived based on the comparative experimental investigations are summarized as:

PCBM as a retrofit material demonstrated adequate compressive, shear strength along with cost effectiveness, adequate bonding, grip with masonry, high flexibility, non-corrodible and minimum thickness. PCBM reuses waste material, thus minimizing the negative impact on the environment. These merits of plastic cement bag can be utilised as retrofit material in the form of PCBM to enhance the seismic performance of masonry.

The cracks pattern of CM_RET building was observed to be similar to CM building with significantly lesser magnitude. The failure mode of CM building was sliding and shear failure combined with toe crushing at higher displacement level while CM_RET building failed in flexure at significantly higher displacement level. The PCBM mesh wrap prevented shear and crushing of masonry.

Retrofitting of building with the PCBM proved to be the most propitious retrofitting technique as CM_RET building exhibited superior seismic behaviour as compared to CM building in terms of increase in lateral strength ( ), initial stiffness ( ), ductility, drift, behaviour factor.

It is evident from the present study that retrofitting with PCBM is an effective technique and hence can be implemented for retrofitting of distress/vulnerable low to medium rise masonry buildings, serving the dual purpose i.e. making seismic resilient construction at lower cost using waste material.

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Potential of Clay Tile Waste as Supplementary Cementitious Material in Sustainable Construction

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Abstract

Production of cement is highly resource intensive and causes severe environmental impacts. This paper illustrates the potential of clay tile waste as supplementary cementaceous material in masonry mortar. A successful replacement of 15% was found feasible with respect to sustainability characteristics in mortar. Improved long term strength, better performance on exposure to aggressive environments were also observed as the positive features. Suitability of clay tile waste mortar in sustainable construction was also verified.

Key words :- clay tile waste, masonry mortar, pozzolana, sustainable construction

1. Introduction

Cement plays a significant role in all construction activities. But its production is highly resource intensive and causes environment pollution. It is reported that the production of 1 ton of cement supposes the consumption of 1.4 tons of quarry material, consumes 5.6 GJ/ton of energy and causes the emission of nearly 0.9 ton of CO_2, representing 5% of total anthropogenic CO_2 emission [1].Utilization of supplementary cementitious materials in construction can reduce the consumption of cement, mitigate the above said issues and contribute to sustainable construction initiatives.

Large quantities of clay tile wastes are available in Kerala as the remains of demolished buildings and as the discarded remains from tile industries. A survey conducted by Terracotta Consortium of Kerala reveals that the total quantity of clay consumed by terracotta tile industries in the state is 1,87,500 MT. Out of which 10% is discarded as damaged during manufacturing process and results in disposal issues [2]. Data reported from previous literatures has established the potential of clay tile waste as supplementary cementitious material [3, 4]. This paper investigates the feasibility of clay tile wastes as a cement replacement material in masonry mortar suitable for sustainable construction.

2. Materials and Methods

Experimental program consists of material characterization, tests on pozzolanicity, tests on mortar and building blocks. Materials used for this research were cement, river sand, and clay tile waste.

2.1 Cement

Cement used was 53 grade Ordinary Portland Cement with commercial name Coromandel conforming to IS: 12269:1986 [5].

2.2 Fine Aggregate

River sand were used as fine aggregate for this study. Tests on aggregates (IS:2386-1963) [6] were conducted and the results (IS:383-1970) [7] are presented in Table 1.

Table 1. Physical properties of fine aggregate

Sl. No.	Properties	River sand
1	Grading	Zone II
2	Fineness modulus	2.48
4	Specific gravity	2.6
5	Bulking	33.3%

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2.3 Clay tile powder wastes (Roof tile waste-RTP)

Clay tile wastes from the premises of a tile manufacturing unit at Muringoor, Trichur district of Kerala was used for this study. It was then crushed using a ball mill for a duration of 30 minutes and sieved through 90 μ IS sieve. Fig.1 shows the picture of broken roof tile and roof tile powder (RTP). Physical properties are tabulated in Table 2.

Table 2 Physical properties of roof tile powder

Physical Properties	
Colour	Orange red
Specific gravity	3.49
Surface area	341 m^2/kg

Fig.1 Broken roof tile and roof tile powder

2.4 Particle size distribution

Particle size distributions of OPC and RTP were measured using a Malvern mastersizer laser diffracometer. The raw materials were mixed in iso-propanol instead of water to avoid the hydration of cementitious material during measurements. Both materials have similar particle size distributions and plotted as shown in Fig.2.

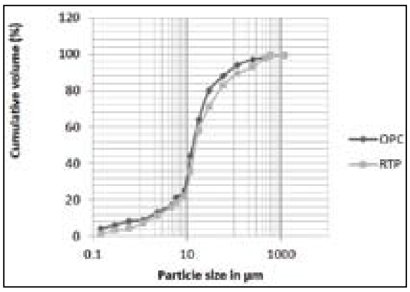

Fig. 2 Particle size distribution curve of OPC and RTP

3. Tests on Pozzolanicity

Chemical analysis and lime reactivity tests were conducted to analyze the pozzolanic property of RTP.

3.1 Chemical Analysis

RTP samples were subjected to chemical analysis as per IS: 1727-1967 [8] and ASTM C 311-00 [9]. Table 3 gives the chemical composition of these materials.

Table 3 Chemical composition of RTP

Chemical Oxide composition (%wt)	RTP	ASTM C 114 [157]
SiO_2 + Al_2O_3 +Fe_2O_3	80.4	>70
Soluble silica	71.5	-
SO_3	2.7	Max 3
MgO	1.7	Max 6
Loss on ignition	2	Max 6
Soluble silica	73.05	-

3.2 Lime Reactivity Test

Lime reactivity test was conducted as per IS 3812:2003 [10]. Cube specimens of size (70 mm x 70mm x 70 mm) were prepared (Fig.3) and tested. The specimens were cured at 90 to 100% relative humidity at 50°C and tested. The 28th day compressive strength (6.3 N/mm^2) of RTP was much above the specified limits (4.5 N/mm^2) and thus justifying the pozzolanic property.

Fig. 3 Lime-pozzolana-sand mortar cube specimens

Presence of amorphous silica (71.05%) and chemical composition (SiO_2 +Al_2O_3+Fe_2O_3) of RTP (80.4%) indicate the pozzolanic property of RTP. This was further confirmed by the lime reactivity test.

4. Application in Masonry Mortar

4.1 Mix Optimization and Tests

Powdered clay tile waste were interground with OPC in the specific proportion for a duration of 30 minutes immediately before the mixing and used as binder. Mortar cubes of size 7.01x7.01x7.01 cm were prepared with 1:5 mix according to IS 2250:1981 [11] using cement and RTP as binders with varying proportions of replacements (0%, 5%, 10%,15%, 20% corresponds to designations MM_0, MM_5, MM_{10}, MM_{15},MM_{20}).Trial mixes were initially prepared with a water-binder ratio of 0.45. As the workability of mixes were found reducing for higher replacement levels (above 15%), water-binder ratio was further increased to 0.5 and 0.55. 28th day compressive strength was taken as the basis for optimization.

4.2 Water absorption test

The cured specimens after 28 days were taken out, wiped off and subjected to oven dry for 24 hours and water absorption test was conducted as per IS 1237 [12].

4.3 Sorptivity test

Sorptivity can be determined by the measurement of capillary rise absorption rate on reasonably homogeneous material and is considered as a measure of the pore structure of the specimen. The test was conducted as per ASTM C 1585 [13]. Fig.4 shows the picture of the specimens submerged in water with water level not more than 5 mm above the base of specimen. Flow from the peripheral surface was prevented by sealing it properly with a non-absorbent coating.

Fig. 4 Sorptivity test on mortar

4.4 Thermal Conductivity

The Lee's disc experiment (ASTM D7340 -07) [14] determines an approximate value for the thermal conductivity K of poor conductors. The procedure is to place a disc of radius r and thickness x, between a steam chamber and two good conductivity metal discs (of the same metal) Allow the setup to come to equilibrium after passing steam. The upper disc temperature T2 and the lower disc temperature T1 are recorded. The mortar disc is removed and the lower metal disc is allowed to heat up to the upper disc temperature T2. Finally, the steam chamber and upper disc are removed and replaced by a disc made of a good insulator. The metal disc is then allowed to cool through T1 < T2 and towards room temperature T0. The temperature of the metal disc is recorded as it cools so a cooling curve can be plotted. Then the slope s1 =ΔT/Δt of the cooling curve is measured graphically where the curve passes through temperature T1.

4.5 Exposure to elevated temperatures

Samples prepared as per ASTM E 119-01[15], cured for 90 days were used for this test and kept in a muffle furnace. The rate of temperature increase was set at 5°C/min. The exposure temperatures were set at 100°C, 200°C, 400°C, 600°C, and 800°C. After reaching the desired temperature, an exposure period of 2 hours was maintained. Samples were taken out and tested for compressive strength after cooling to the room temperature.

4.6 Tests on aggressive environments

Specimens were immersed in chemical solutions to test their performance in aggressive environment for different durations of 56, 90, 120 & 150 days (Fig. 5 and Fig. 6). HCl and H_2SO_4 (0.05 molarity and 98% purity) were selected as the acidic solutions. 10% solution of Sodium sulphate (Na_2SO_4) and Sodium chloride (NaCl) were also used to assess the performance of the samples in sulphate and chloride mediums. Changes in compressive strength and weight of samples were investigated after specified periods.

5. Discussions on Sustainability Characteristics

Sustainable construction employs the application of the principles of sustainable development to meet the needs of the present without compromising the ability of future generations to meet their own needs in construction industry. This concept is associated with four pillars of sustainability such as socio-cultural sustainability, eco-

Fig. 5 Samples immersed in NaCl and Na_2SO_4

Fig .6 Samples immersed HCl and H_2SO_4 solutions nomic sustainability, technological sustainability and environmental sustainability [16, 17]. A comparison of the proposed mortar against control mortar with respect to these aspects is presented below.

5.1 Socio-cultural sustainability

Acceptability and awareness on a technology are considered as the basic features of socio cultural sustainability. Better performance of RTP mortar in high temperature exposures and aggressive environments can definitely add the acceptance of this mortar over conventional mortar. Results are discussed below.

• Performance on exposure to elevated temperatures

A comparison on the performance of RTP mortar (MM_{15}) and conventional mortar (MM_{15}) on exposure to elevated temperature are represented in terms of residual compressive strength and shown in Fig. 7.

Residual compressive strength of the modified mortar samples exposed at 800 ^{O} C showed better results (65%) compared to control mortar samples (58%). Cracks were observed in the control samples at 800 ^{O}C. As observed by Rahel *et al.,* [18], these cracks can be due to the weakening of the porous matrix resulted from the built-up vapor pressure. Whereas the modified samples survived the high temperature exposure without surface cracks owing to the dense matrix. Better performance of MM_{15}can also be due to the presence of clay fractions rich in alumino silicate ($Al_2O_3.SiO_2.H_2O$) which support the delay in the dehydration of cementitious compounds.

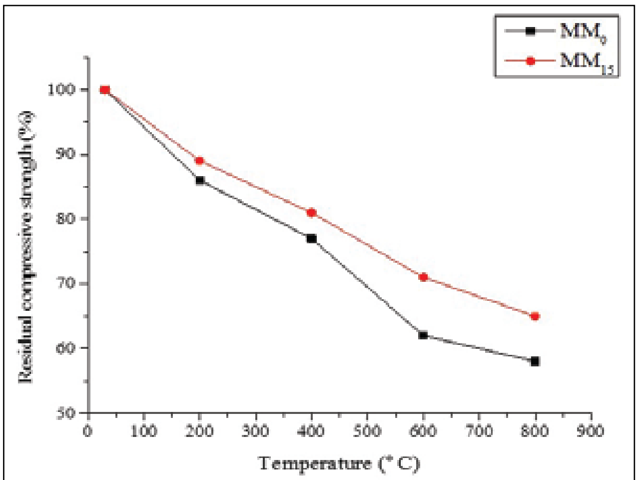

Fig. 7 Residual Compressive strength at high temperature exposures temperatures

• Performance on exposure to chemical environments

Behaviour of the samples with respect to visual appearance, residual weight and strength after immersion in chemical solutions are discussed below.

• Samples immersed in NaCl & Na_2SO_4

Visually no significant changes were observed in the external appearance of both the samples immersed in Na_2SO_4 and NaCl up to 56 days. But a weight gain and improvement in compressive strength was reported during this period. This can be due to the hygroscopic nature of NaCl and Na_2SO_4which attracts more water to it and thus accelerates the hydration of C_3S[19]. Efflorescence was noticed later in samples and reduction in compressive strength and weight loss were observed for longer durations owing to the deterioration of the samples due to the chemical reactions. Fig. 8 to Fig. 11 shows the variation in residual compressive strength and weight for different durations of immersion. Better performance of MM_{15} over MM_0 was observed due to the reduced permeability of the dense matrix of blended mortar in line with the results of sorptivity test.

• Samples immersed in HCl and H_2SO_4

Specimens immersed in acidic solutions started eroding after two weeks of exposure and recorded considerable weight loss and reduction in compressive strength. Modified mortar samples showed better behaviour in acidic environment owing to its dense matrix and reduced permeability.

A Continuous decrease in compressive strengths was observed in the case of both the samples on immersing in HCl and H_2SO_4. But the rate of decrease in strength was found more prominent for control mortar. Even though both the samples showed deterioration in long term exposure in acidic environment, modified samples showed better performance in terms of residual weight and residual compressive strength as seen in figure (Fig 12 to Fig 15).The reduction in strength of control mortar can be due to the deterioration of the matrix resulted from the loss in binder properties, influenced by the formation of pore pressure. Modified specimens with denser matrix showed significantly improved performance. This could be explained by the reduction in pore size and the decreasing diffusion of chemical substances into mortar specimens [20].

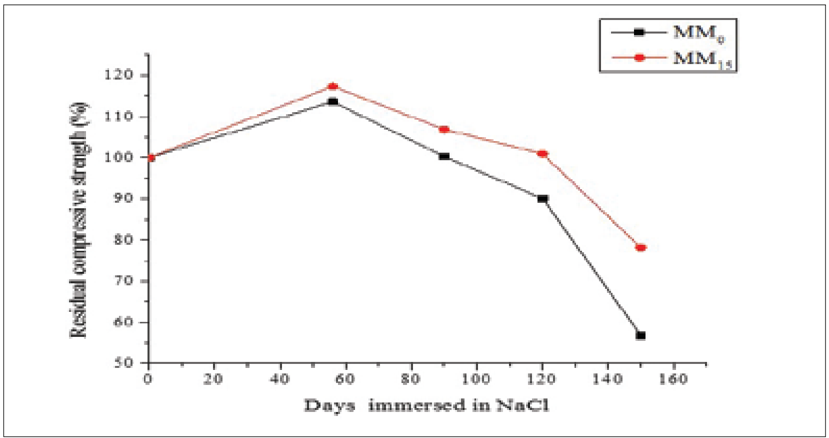

Fig. 8 Effect of NaCl on compressive strength of mortar samples

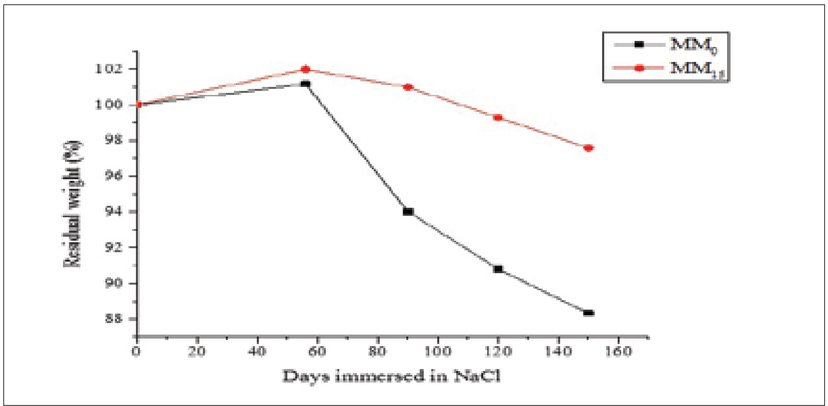

Fig. 9 Effect of NaCl on weight of mortar samples

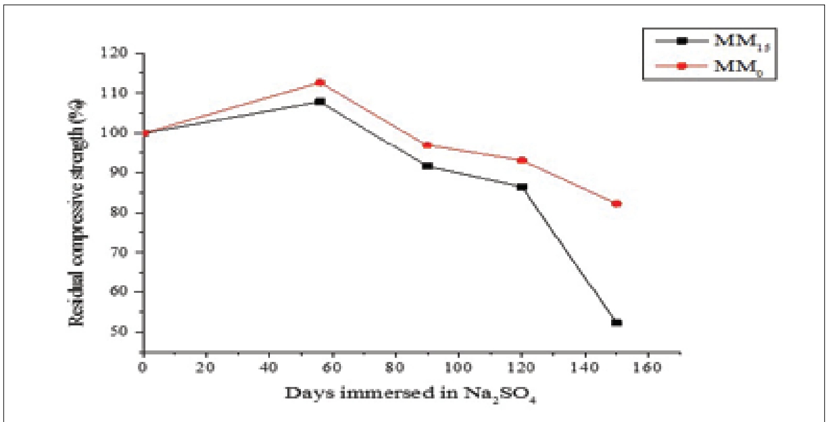

Fig. 10 Effect of Na_2SO_4 on compressive strength of mortar samples

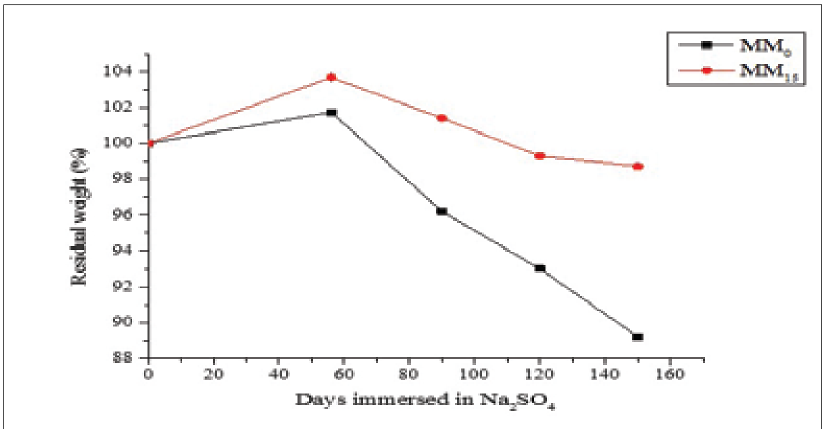

Fig. 11 Effect of Na_2SO_4 on weight of mortar samples

5.2 Economic sustainability

Economic sustainability of a material / technology refers to its affordability to the users throughout its lifecycle. MM_{15}, can assure a reduction in cost compared to control mortar as it replaces 15% of the cement. Even after considering the additional expenses of the processing charges, proposed mortar can be more economical over conventional mortar on ensuring the local availability of the waste.

5.3 Technological sustainability

Technological sustainability depends up on the strength and durability characteristics of the material / technological alternative

- **Strength characteristics of mortar**

Fig. 16(a) & 16 (b) shows the 28th day and 90 day compressive strength for 1:5 mixes for different replacement levels.

A reduction in compressive strength was observed with a water-binder ratio of 0.45 on increasing the replacement level. This is due to the higher water requirement of RTP owing to the higher specific surface area. Maximum compressive strength was observed at 5% replacement level with a water-binder ratio of 0.5. Further, reduction in strength was noticed for 0.45 and 0.55 water-binder ratios at higher replacement levels. This can be due to the deficiency in the free lime released during the hydration process of cement. MM_{15} with 0.55 water-binder ratio (41.6 N/mm^2) was selected as the optimized sample against MM_{15} with water-binder ratio 0.5 (42.9 N/mm^2) of 1:5 mix for further studies owing to the easiness in workability with respect

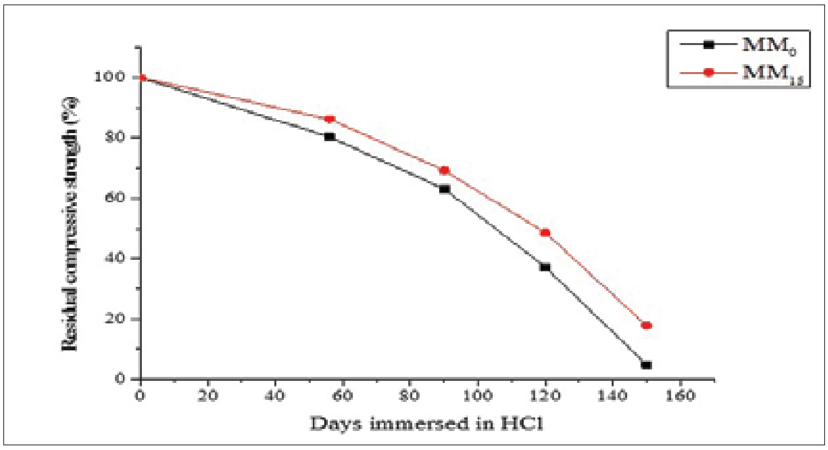

Fig. 12 Effect of HCl on compressive strength of mortar samples

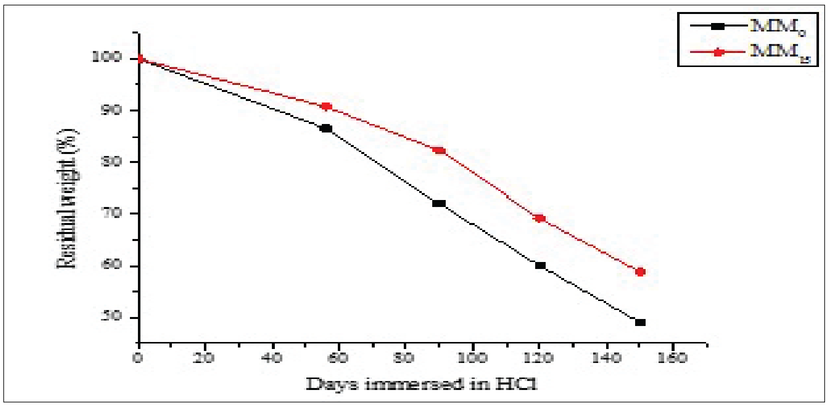

Fig. 13 Effect of HCl on weight of mortar samples

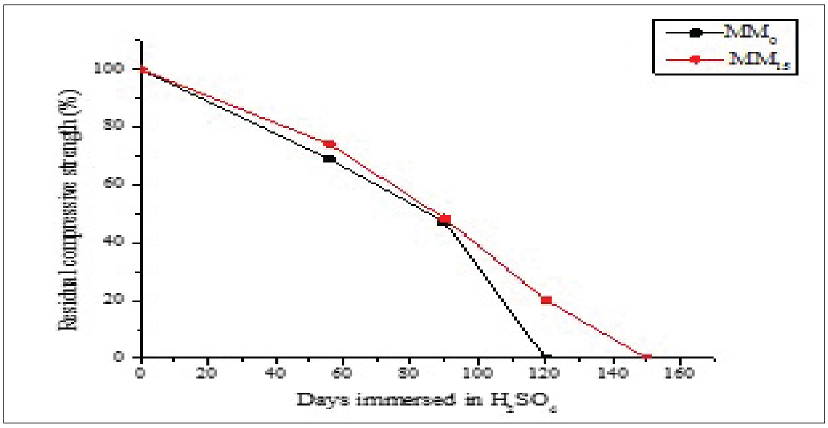

Fig. 14 Effect of H_2SO_4 on compressive strength of mortar samples

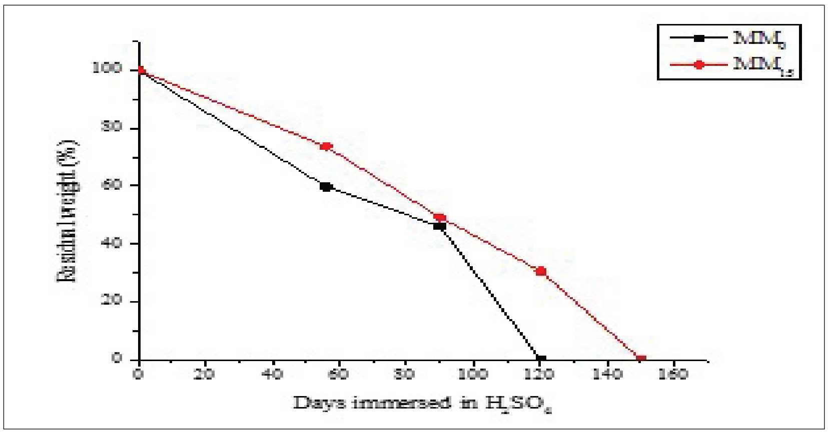

Fig. 15 Effect of H_2SO_4 on weight of mortar samples

to practical considerations. Similar trends were observed in long term strength of the samples [Fig. Fig. 16 (b)].

• Durability Characteristics

Results of water absorption (Fig 17) and sorptivity tests (Fig 18) were taken as the basis for durability characteristics. Even though the value of water absorption was found increasing at higher replacements, it was much lower than the limit as specified by ASTM C1403-15 (10%).

Fig. 18 indicates the variation in sorptivity values for 1:5 mortar samples. A drastic reduction in the sorptivity was observed for 1:5 mix up to 15% replacement level. Further, the variation was found negligible. These results justify the compressive strength results by confirming the compactness of mortar samples up to 15% owing to pozzolanic effect and filler effect. Comparison of the both the mortars verifies the technological sustainability of the proposed mortar against conventional mortar.

5.4 Environmental sustainability

Discussion on environmental sustainability of the proposed mortar is presented based on resource efficiency and environmental impact caused by the material during its life cycle.

• Resource efficiency

Resource efficiency of a material can be assessed in terms of the quantity of resources used for its production. It includes both raw materials and energy. Utilization of clay tile waste in the proposed mortar add to its resource efficiency as it utilizes a waste which would otherwise be disposed off as landfill. Comparison of the energy

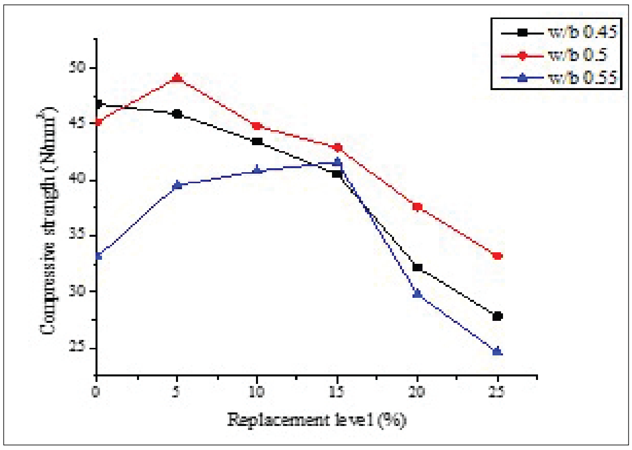

Fig. 16 (a) Compressive strength of 1:5 mix at 28 days

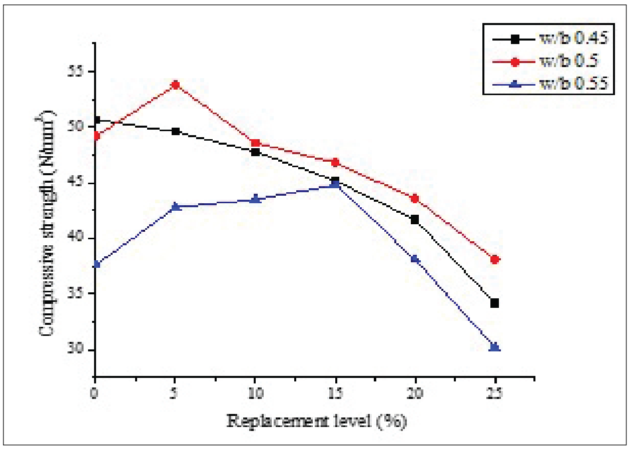

Fig.16 (b) Compressive strength of 1:5 mix at 90 days

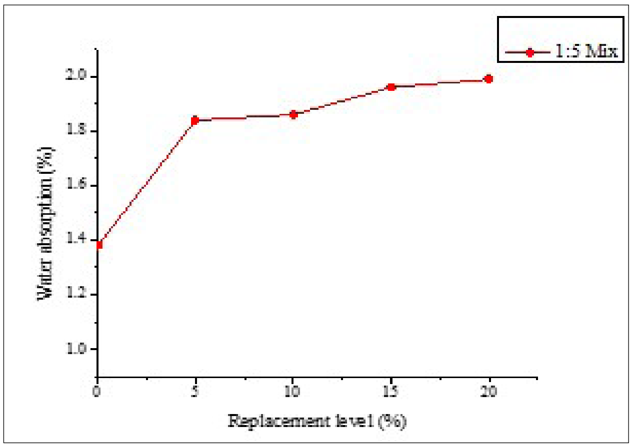

Fig. 17 Water absorption of 1:5 mortars

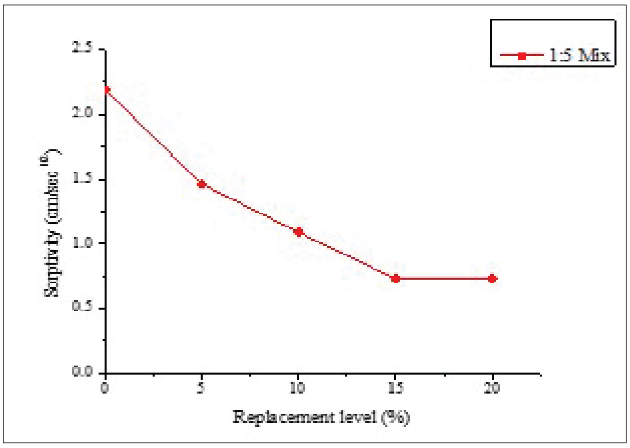

Fig. 18 Variation in Sorptivity for 1:5 mortars

requirement in terms of embodied energy of both the mortars (1:5)for 1m^3 of brick masonry is presented in Table 5 as an example. Data for the calculations are collected from Indian construction materials database of embodied energy and global warming potential [21].

A reduction in embodied energy of 13.13% was observed for the proposed mortar against the control mortar.

- **Environmental impacts due to pollution**

Production of cement is highly environmentally polluting and contributes to global warming. 15% replacement of cement in the proposed mortar can assure the corresponding reduction in environmental impacts. Table

Table 5 Embodied energy calculation for 1:5 cement mortar for 1 m^3 brick work

Material (kg)	MM_0	MM_{15}	Embodied energy (MJ/kg)	Energy requirement (MJ)	
				MM_0	MM_{15}
Cement	73.57	62.54	6.4	470.84	400.256
Fine aggregate	370.43	370.43	0.11	40.74	40.74
RTP	0	11.03	0.31	0	3.41
Total embodied energy (MJ)				511.58	444.40

Table 6 CO_2 emission for 1:5 cement mortar for 1 m^3 brick work

Material (kg)	MM_0	MM_{15}	CO_2 emission/ kg production (kg)	Total CO_2 emission (kg)	
				MM_0	MM_{15}
Cement	73.57	62.54	0.91	66.94	56.91
Fine aggregate	370.43	370.43	0.009	3.33	3.33
RTP	0	11.03	0	0	0
Total emission of CO_2 (Kg)				70.27	60.24

6 shows the comparison of CO_2 emission for cement mortar (1:5) for $1m^3$ of brick work. The values of CO_2 emission/kg production used in this work are taken from Indian construction materials database of embodied energy and global warming potential [21].

A reduction in CO_2 emission of 14.27% was observed from the calculations. Above discussion verifies the environmental sustainability of modified mortar over control mortar.

6. CONCLUSIONS

The experimental investigations and discussions with respect to sustainability characteristics confirm the potential of clay tile waste as supplementary cementitious material in masonry mortar and justify its suitability in sustainable construction.

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प्रधानमंत्री आवास योजना (शहरी) के अंतर्गत उभरती प्रौद्योगिकियों के उपयोग से प्रदर्शन आवास परियोजनाएं

परिषद देश के विभिन्न क्षेत्रों में पहचान, मूल्यांकन, मानकीकरण, प्रमाणन, क्षमता निर्माण एवं प्रशिक्षण तथा जमीनी स्तर के उपयोग के माध्यम से प्रमाणित एवं उभरती भवन निर्माण सामग्रियों एवं प्रौद्योगिकियों को बढ़ावा दे रही है। पिछले कुछ वर्षों में परिषद् ने देश के विभिन्न हिस्सों में कई प्रदर्शन आवासों का निर्माण किया है। परिषद् के इन प्रयासों ने सार्वजनिक एवं निजी निर्माण एजेंसियों, पेशेवरों आदि में प्रमाणित एवं उभरते प्रौद्योगिकियों के प्रति विश्वास को बढाने और स्वीकार्यता में सहायता की है।

बीएमटीपीसी प्रधानमंत्री आवास योजना (शहरी)–सबके लिए आवास मिशन के अंतर्गत राज्यों में नई प्रौद्योगिकियों के बारे में जागरूकता फैलाने के उद्‌देश्य एवं विशेष तकनीकी प्रयोग संबंधी जानकारी के प्रसार के साथ उभरती प्रौद्योगिकियों के उपयोग से भारत के विभिन्न हिस्सों में प्रदर्शन आवास परियोजनाओं का निर्माण कर रही है। परिषद ने पहले वर्ष 2016 में नैल्लोर में जीएफआरजी तथा वैकल्पिक प्रौद्योगिकी का प्रयोग करते हुए 36 (जी+1) प्रदर्शन आवासों एवं एक सामुदायिक भवन का निर्माण पूरा किया था और वर्ष 2017 में भुवनेश्वर में एक्सपेंडड पोलियेस्टरेन कोर पैनल प्रणाली प्रौद्योगिकी का प्रयोग करते हुए 32 (जी+3) आवासों का निर्माण भी पूरा किया था। अन्य तीन स्थानों में परियोजनाओं की स्थिति नीचे दी गई है:

(क) बिहारशरीफ, बिहार में प्रदर्शन आवास परियोजना

बिहार सरकार ने प्रदर्शन परियोजना के लिए नोडल ऐजेंसी के रूप में बिहारशरीफ नगर निगम को विनिर्दिष्ट किया था। बिहारशरीफ में प्रदर्शन परियोजना के लिए 1350 वर्ग मीटर की भूमि आबंटित की थी। बिहारशरीफ नगर निगम के साथ परस्पर बातचीत और परामर्श के आधार पर आवास प्रौद्योगिकी को विचिंहित एवं भवन के आरेख को अंतिम रूप दिया गया।

इस प्रदर्शन आवास में 36 आवास इकाइयां (जी+2) का निर्माण उभरती प्रौद्योगिकी मोनोलीथिक ढांचा यथास्थाने सीआर स्टील विशिष्ट डिजाइनकृत फार्मवर्क प्रणाली (कॉफर) का उपयोग किया गया। यह परियोजना पूर्ण हो चुकी है।

प्रधानमंत्री आवास योजना (शहरी) के साथ–साथ परियोजना के लिए अन्य भागीदार एवं निधि दायी ऐजेंसियां डिपार्टमेंट फार इंटरनेशनल डेवलपमेंट (डीएफआईडी) तथा राष्ट्रीय आवास बैंक (एनएचबी) हैं।

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- आवास इकाईयों की संख्या : 36 (जी+2)
- प्रत्येक इकाई का कार्पेट क्षेत्रफल: 29.67 वर्ग मी.
- साझे उपयोग की जगह सहित प्रत्येक इकाई का निर्मित क्षेत्रफल: 45.54 वर्ग मी.
- प्रत्येक आवास इकाई में एक बहुउद्‌देश्यीय कक्ष, एक शयन कक्ष, रसोईघर, अलग स्नानघर तथा शौचालय समाहित है।
- भूकंप रोधी विशिष्टताएं भी समाहित हैं।
- बाहरी विकास
  - सेप्टिक टैंक
  - ट्यूब वैल
  - जल–मल निष्पादन
  - बरसाती पानी के लिए नालियां
  - बाहरी विद्युतीकरण एलईडी लाइट के साथ
  - चाहरदीवारी
  - जलापूर्ति

bLreky dh xbZ çkS|ksfxfd;k¡

uhao@vk/kkj
- आरसीसी फ्रेमकृत कालम फाउंडेशन

nhokjsa] LySc ,oa Nr

- ढांचागत यथा–स्थाने (स्टे इन प्लेस) सीआर स्टील फोर्मवर्क (कॉफर) प्रणाली
- आरसीसी स्लैब

njokt; dh pk[kV;

- लकड़ी के स्थान पर संपीडित स्टील दरवाजा चौखटें
- लकडी के विकल्प के रूप में फ्लश दरवाजा शटर
- शौचालय में पीवीसी के फ्रेम और शटर

f[kM+dh dh pk[kV;

- गार्ड रेल एवं ग्लैज्ड शटर के साथ एमएस सेक्शन विंडों चौखट

Q'kZ

- कमरों में सेरेमिक टाईल का फर्श
- शौचालय एवं स्नानघर में सेरेमिक टाइल का फर्श
- निकास/पैसेज में कोटा पत्थर

fdpu dkmUVj @jlksbZ iVy

- ऊपर(टाप पर) संगमरमर के साथ आर सीसी का काउंटर

lh<+h;k¡

- कोटा पत्थर के फर्श के साथ आरसीसी की सीढ़ियां

nhokj lTtk@fQfuf'kx

- अंदर की सभी दीवारों पर एक्रिलिक डिस्टेम्पर
- बाहरी दीवारों के तल पर मौसम प्रतिरोधी पेंट

vU;

- आन्तरिक सड़क पर कंक्रीट पेवर्स

(ख) औरंगाबाद जागीर, लखनऊ में प्रदर्शन आवास परियोजना

राज्य शहरी विकास प्राधिकरण (एसयूडीए), लखनऊ में प्रदर्शन आवास परियोजना के लिए औरंगाबाद जागीर, तहसील सरोजनी नगर, लखनऊ में 0.385 हेक्टेयर भूमि का आबंटित की थी। राज्य शहरी विकास प्राधिकरण (एसयूडीए) से चर्चा के आधार पर प्रदर्शन आवास परियोजना की योजना, सेक्शन एवं लेआउट योजना को अंतिम रूप दिया गया। इस परियोजना में उभरती प्रौद्योगिकी स्टे–इन–प्लेस ईपीएस आधारित दोहरी दीवार पैनल सिस्टम (सिस्मो) का उपयोग कर निर्माण पूर्ण कर लिया गया है।

प्रधानमंत्री आवास योजना (शहरी) के साथ–साथ परियोजना के लिए अन्य भागीदार एवं निधि दायी एजेंसियां डिपार्टमेंट फार इंटरनेशनल डेवलपमेंट (डीएफआईडी) तथा राष्ट्रीय आवास बैंक (एनएचबी) हैं।

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- आवास इकाईयों की संख्या 40 (जी+1)
- प्रत्येक इकाई का कार्पेट क्षेत्रफल: 26.40 वर्ग मी.
- सामान्य साझे क्षेत्र सहित प्रत्येक इकाई का निर्मित क्षेत्रफल : 40.31 वर्ग मी.
- प्रत्येक इकाई में एक लिविंग कक्ष, एक शयन कक्ष, रसोई, स्नानधर एवं शौचालय
- भूकंप रोधी विशिष्टताओं के सहित
- बाहरी विकास
    - क्षेत्र लेंडस्केपिंग,
    - इंटरलॉकिंग टाईल से खंडजायुक्त फुटपाथ,

- चाहरदीवारी,
- सेप्टिक टैंक
- जलापूर्ति, सीवरेज,
- बाहरी विद्युतीकरण एलईडी लाइट के साथ
- जलनिकासी,
- बोर वेल

bLrseky dh xbZ çkS|ksfxfd;k

uhao@vk/kkj

- आरसीसी फ्रेमकृत कालम फाउंडेशन

nhokjsa] LySc ,oa Nr

- दीवारों/स्लैब/छतों के लिए यथा–स्थाने (स्टे इन प्लेस) ईपीएस आधारित दोहरी दीवार पैनल सिस्टम (सिस्मो)

njokts dh pkS[kV

- लकड़ी के स्थान पर संपीडित स्टील दरवाजा चौखटें
- लकडी के विकल्प के रूप में फ्लश दरवाजा शटर
- शौचालय में पीवीसी फ्रेम एवं शटर

[kM+dh dh pkS[kV

- गार्ड रेल एवं ग्लैज्ड शटर के साथ एमएस सेक्शन विंडों चौखट

Q'kZ

- कमरों में सेरेमिक टाईल का फर्श
- शौचालय एवं स्नानघर में सेरेमिक टाइल का फर्श
- निकास/पैसेज में कोटा पत्थर

fdpu dkmaVj @jlksbZ iVy

- ऊपर(टाप पर) संगमरमर के साथ आर सीसी का काउंटर

lh<+h;k

- कोटा पत्थर के फर्श के साथ आरसीसी की सीढ़ियां

nhokj dh lrg

- अंदर की सभी दीवारों पर एक्रिलिक डिस्टेम्पर
- बाहरी दीवारों के तल पर मौसम प्रतिरोधी पेंट

(ग) हैदराबाद, तेलंगाना में प्रदर्शन आवास परियोजना

तेलंगाना राज्य आवास निगम लिमिटेड (टीएसएचसीएल), हैदराबाद के द्वारा प्रदर्शन आवास परियोजना हेतु निर्मिती केंद्र, गाचीवाउली, हैदराबाद में 1085 वर्ग मीटर भूमि आबंटित की गई थी। टीएसएचसीएल के अधिकारियों के साथ हुई चर्चाओं के आधार पर प्रदर्शन आवास परियोजना योजना के प्लान, सेक्शन एवं लेआउट योजना को अंतिम रूप प्रदान किया गया।

विभिन्न उभरती प्रौद्योगिकियों के प्रदर्शित करने के क्रम में, परिषद ने, दो भिन्न प्रौद्योगिकियों अर्थात (i) संरचनात्मक स्टे–इन–प्लेस सीआर स्टील विशेषतौर पर डिजाइन किया गया फॉमवर्क सिस्टम वाली मॉनोलिथिक संरचना (16 आवास) एवं (ii) हल्के गेज वाले स्टील फ्रेम संरचना (16 आवास) के उपयोग से 32 प्रदर्शन आवासों (जी+3) हेतु दो खंडों का निर्माण किया गया।

प्रत्येक आवास इकाई का कार्पेट क्षेत्र 38.74 एवं 39.50 वर्ग मीटर है और प्रत्येक आवास इकाई का निर्मित क्षेत्र 53.18 और 53.10 वर्ग मीटर है। प्रत्येक आवास इकाई में दो शयनकक्ष, बहु–उद्देशीय कमरा, रसोईघर, दो स्नानघर एवं शौचालय/डब्लूसी हैं। इस

परियोजना का निर्माण भी पूर्ण कर लिया गया है।

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- आवास इकाइयों की सं.: 32 (जी+3)
- प्रत्येक इकाई का कार्पेट क्षेत्रः 38.74 वर्ग मी. एवं 39.50 वर्ग मी.
- प्रत्येक इकाई एवं सामान्य साझी जगह सहित निर्मित क्षेत्रफलः 53.18 वर्ग मी. एवं 53.10 वर्ग मी.
- एक बहु–उद्देशीय कमरा/बैठक, दो शयनकक्ष, रसोईघर, दो स्नानघर एवं शौचालय/डब्लूसी हैं
- भूकंप रोधी विशिष्टताएं शामिल हैं
- बाहरी विकास
  - कंक्रीट पेवर्स से आंतरिक सड़क
  - सेप्टिक टैंक
  - बाहरी विद्युतीकरण एलईडी लाइट के साथ
  - जल निकासी एवं जल–मल निष्पादन

bLrseky dh xbZ çkS|ksfxfd;k¡

uho

- आरसीसी कालम/काफर दीवार नींव

nhokjsa] LySc ,oa Nr

- दीवारों/स्लैब/छतों के लिए संरचनात्मक यथा–स्थाने (स्टे इन प्लेस) सीआर स्टील से बना एवं विशेष तौर पर डिजाइन किया गया फार्मवर्क प्रणाली
- लाइट गेज स्टील फ्रेम ढांचा (एलजीएसएफएस) आरसीसी बीम/ लाइट गेज स्टील फ्रेम ढांचा (एलजीएसएफएस) स्लैब

njokts dh pkS[kV

- लकड़ी के स्थान पर संपीडित स्टील दरवाजा चौखटें
- लकडी के विकल्प के रूप में फ्लश दरवाजा शटर
- शौचालय में पीवीसी फ्रेम एवं शटर

f[kM+dh dh pkS[kV

- गार्ड रेल एवं ग्लैज्ड शटर के साथ एमएस सेक्शन विंडों/खिड़की चौखट

Q'kZ

- कमरों में सेरेमिक टाईल का फर्श
- शौचालय एवं स्नानघर में सेरेमिक टाइल का फर्श
- निकास/पैसेज में कोटा पत्थर

fdpu dkmUVj @jlksbZ iVy

- ऊपर (टाप पर) संगमरमर के साथ आर सीसी का काउंटर

lh<+h;k¡

- कोटा पत्थर के फर्श के साथ आरसीसी की सीढ़ियां

nhokj lTtk@fQfuf'kx

- अंदर की सभी दीवारों पर एक्रिलिक डिस्टेम्पर
- बाहरी दीवारों के तल पर मौसम प्रतिरोधी पेंट

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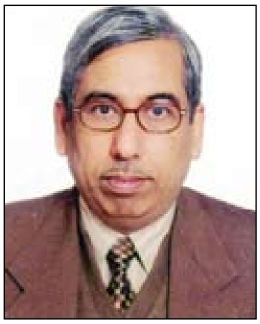
Minimizing Energy & Cost in Affordable Housing by using Alternative Building Materials

Bansal Deepak[1] *Minocha V K*[2]
Kaur Arvinder[3]

Abstract

Building industry is one of the major sectors, which are responsible for quick depletion of natural resources and for generating lots of waste in its Life Cycle. Building construction process and production of construction materials, consume significant natural resources, releases GHGs, and generates lots of bye products like Fly ash, red mud, burnt oil etc.,. Asian countries including India are witnessing a major boom in the construction industry, as a result of rapid urbanization and increased living standards. This development also creates more wastes in different phases of buildings. During building construction, lots of building waste (inorganic) is produced, during operation of buildings lots of solid wastes (organic) are produced and after life of buildings are over, construction and demolition wastes (inorganic) are produced. In all the phases, liquid wastes (sullages, sewerages and grey water) with smokes/gases are also generated. This not only increases greenhouse effect but also leads to problem of disposal of these organic and inorganic wastes.

The current practices of dealing with huge amount of waste are not yielding any results, as they are simply out of date and this need to be tackled three ways, i.e., reduce, recycle and reuse all the wastes at city level. This will not only result in conserving resources, save the environment but also in monetizing wastes. The buildings can be constructed with the product made from building wastes (Construction & Demolition wastes) and bye products, which not only results in low embodied energy construction but are cost effective also.

1 Introduction

Building construction industry is one of the major sectors, for quick depletion of natural resources and for increased primary energy uses in its building materials, construction process, operations and after use. Ignacio et al, stated that, building construction consumes about 24% of the total materials, extracted from earth globally. Worldwide buildings consume around 30-40% amount of primary energy in their construction, operation and maintenance, and are also responsible for about 40% of GHG emission.

India is second most populous country in Asia, with a population of 1.2 billion as in year 2011. There is a huge shortage of housing, especially in lower economic section or EWS/LIG. This is known as housing for weaker section or affordable housing in India. These affordable houses are having only two rooms, with kitchen toilet & bath and are naturally ventilated. They do not require much energy in operating phases, due to poor affordability of occupants. Construction & operating energy in Indian affordable housing is not significant. Hence its building materials related energy is important which is known as embodied or construction energy.

The massive construction of houses engross significant amount of embodied energy and leads to intense carbon footprint in this sec-

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tor. During construction and later during demolition of buildings, lots of construction & demolition waste is generated, which can be used in manufacturing quality building products like blocks, tiles, prefab members, etc., and can be used in new buildings, resulting in tackling the problem of disposal of building wastes and saving of natural resources. A study have been done to understand saving in embodied energy and cost of affordable housing by using these products made with building wastes in buildings construction.

2 Background

In India, with a population of 1.2 billion, despite other type of building construction, more than 2 million houses are being constructed every year in the category of 25-60 sqm of plinth area. Most of the houses are constructed with fired clay bricks, cement and steel, which are most energy intensive materials. Different substitutes of fired clay bricks are iterated in this study to see the effect of these alternative materials on embodied energy and cost of these affordable houses. The alternative materials used are hollow cement concrete blocks, solid cement concrete blocks, Flay ash bricks, FalG blocks, Aerated concrete blocks, stabilized earth blocks, stabilized flay ash blocks etc. This study aims to assess the embodied energy, of sufficient large number of affordable houses, constructed in India, and to identify energy intensive building materials has been done, so that they can be optimized for embodied energy and cost by using different types of building materials without compromising on structural/environmental parameters.

3 Methodology and Data

The houses designed, appraised and built by public service agencies of Government of India, under PMAY (Pradhan Mantri Awas Yojna), which is a pan India, affordable social housing programme, are chosen in this study . A total number of 122 affordable houses were chosen in this study. Plinth area of these houses varies between 27 sqm and 60 sqm. However, these houses have been constructed as single storeys, double storeys, triple storeys or four storeys, depending upon the load bearing capacity of the soil and housing density/floor area ratio allowed at different locations. The houses have been designed as per National Building Code of India. The bill of quantities of these houses has been calculated from its GFC drawings, and quantities of major building materials and energy of houses with different building materials from floor one to floor four of all these 122 houses were computed.

3.1 Construction materials and embodied energy

The chosen typology of the houses, in this study is most common in India. The most common construction materials are fired clay bricks, cement, steel, sand and coarse aggregates. The fired clay bricks are the most commonly used construction materials for walls & foundation construction. Since embodied energy values are quite dynamic and region specific, which may change according to the technology and transportation distances involved. In this study, basic embodied energy values (EEV) of the building materials has been taken from previously published work by BMTPC (Building Materials Technology Promotion Council, New Delhi) , Study of year 1995 . Since in India, most of the building materials are processed manually, the embodied energy of sand and coarse aggregates is assumed to be nil in this study.

4 Analysis of the chosen houses and its components

The Embodied Energy Values (EEV) of different building components of the houses have been calculated, from the bill of quantities of the building materials used in the actual construction of these components, based on the design & Construction drawings , specifications of the building/components and the EEVs of the materials. The detailed bill of quantities of the 122 houses is prepared based on detailed construction drawings. The quantities of building materials have been calculated are actual and based on real time analysis, as per the construction practices in India. Average quantities of for foundation, walling, roofing, plastering, flooring, terracing etc., per sqm of plinth area, are computed from these 122 housing design.

The calculated quantities of total building materials are calculated and average of 122 housing units are converted to per sqm of plinth area basis, for single storey to four storeys construction.

5 Results

The major building materials requirements (per sqm of plinth area) of the chosen affordable houses with different types of bricks/blocks up to 60 sqm of plinth areas and up to four storeys is presented in Table 1 to 7. The embodied energy is normalized to MJ/

Table 1: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with fired clay bricks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	Fired Clay Bricks	No	460	366	369	345
2	Cement	Bags of 50 Kg	5	4.4	4.3	4.2
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.65	0.56	0.55	0.53
5	Aggregates	Cum	0.45	0.39	0.38	0.36

Table 2: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with Hollow CC blocks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	Hollow CC Block of 400x 200x 200 mm	No	60	47	47	44
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 3: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with AAC Blocks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	AAC Block of 400x 200x 200 mm	No	60	47	47	44
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 4: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with FalG Blocks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	FalG Block of 300x 200x 150 mm	No	105	82	83	77
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 5: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with Solid CC Blocks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	Solid CC Block of 300x 200x 150 mm	No	105	82	83	77
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

sqm to neutralize the differences in plinth areas of the houses and have been averaged out, for all 122 houses. Table 8 indicates the value of embodied energy of different types of housing in different floors. The comparison of embodied energy is done in Table 9. It shows that using different types of alternative building materials embodied energy of affordable housing can be saved from 31% to 41% compared to fired clay brick based houses. Table 10 shows the cost of masonry with different building blocks/ bricks with DSR 2012/ old MR rates and it shows that Hollow cement concrete block masonry is lowest in embodied energy and cost. The energy of AAC block based houses is also comparable. However this analysis needs to be done at the place of actual construction as these materials are region specific and prices are demand sensitive. Transportation related cost and energy is not considered as this is site specific and may change the results considerably.

The products like Fly ash bricks, FalG blocks are produced from fly-ash, which is bye product of burning of coal and difficult in disposal, can be used successfully used in buildings as a quality building product resulting in less embodied energy and at competitive cost.

6. Acknowledgements

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Table 6: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with HF SEB Blocks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	HF SEB Block of 230X 220X 115 mm	No	150	117	118	110
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 7: Quantities of major construction materials in affordable houses in different storeys construction (average of 122 numbers of houses with HF Fly ash Blocks per sqm of plinth area basis)

S No	Item	Units	Single Storied	Two Storied	Three Storied	Four Storied
1	HF Fly ash Block of 230X 220X 115 mm	No	150	117	118	110
2	Cement	Bags of 50 Kg	4	3.4	3.5	3.3
3	Steel	Kg	16	15	18	18
4	Sand	Cum	0.55	0.46	0.46	0.44
5	Aggregates	Cum	0.40	0.35	0.34	0.33

Table 8: Comparison of embodied energy of affordable housing with different masonry

S No	Type of Masonry	Single Storied (MJ/sqm)	Two storied (MJ/sqm)	Three Storied (MJ/sqm)	Four Storied (MJ/sqm)
1	Fired Clay Brick	4257	3597	3677	3516
2	Hollow CC Block	2512	2153	2256	2176
3	AAC Block	2542	2177	2280	2198
4	Fal G Block	2681	2285	2390	2300
5	Soild CC Block	2944	2490	2597	2492
6	HF SEB	2767	2352	2457	2363
7	HF Flyash	2647	2258	2362	2275

Table 9: Comparative saving in Embodied energy per sqm of plinth areas in different types of housing

S No	Masonry with following	EEV(MJ) / sqm of plinth area	% Saving
1	Fired Clay Brick	4257.00	0
2	Hollow concrete Blocks	2512.00	41
3	AAC/CLC Blocks	2542.00	40
4	HF Flyash Block	2647.00	38
5	FalG Block	2681.00	37
6	HF SEB Block	2767.00	35
7	Solid Concrete Block	2944.00	31

Table 10: Comparison of cost of different masonry with different types of blocks/ bricks

Building Materials	Sizes(mm)	Wall thickness (mm)	No of Blocks/ Bricks required per sqm of wall Area	Cost/cum (INR*) DSR 2012/ MR	Cost/ Sqm (INR*)
Standard Burnt Brick (Fired Clay Bricks)	229x114x76	230	116	4000	920
Hollow cement concrete blocks	400x200x200	200	13	4000	800
AAC Block	400x200x200	200	13	5000	1000
FalG	300x200x150	200	23	5000	1000
Solid CC Block	300x200x150	200	13	5000	1000
HF SEB(soil cement blocks)	230x220x115	230	40	5000	1150
HF(fly ash blocks)	230x220x115	230	40	5000	1150

data used and critical comments during this study.

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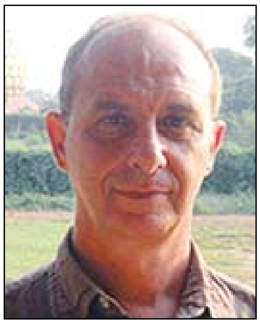
Case Studies Pushing the Mechanical Properties of Poured Earth Concrete

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ABSTRACT

Applied research in Poured Earth Concrete at the Auroville Earth Institute has aimed to maximize the percentage of soil in test samples while minimizing soil stabilization for lowest embodied energy. Testing has been carried out for wet and dry compressive strength, absorption, and shrinkage on a wide range of samples stabilized with cement and lime. Various applications have been undertaken to push specific mechanical limits of the material. This paper presents an overview of applied research, sample design, and test results. Two case studies – a PEC road, and PEC foundations and walls supporting a 15 meter span vault – demonstrate theoretical limits of mechanical strength.

Keywords: *Poured earth concrete (PEC), stabilized earth, mechanical properties*

1. Introduction

Poured Earth Concrete (PEC) is a plain concrete utilizing up to 50% of soil as the principle binder, which is stabilized for increased strength values and reduced absorption. Ongoing research in poured earth concrete at the Auroville Earth Institute (AVEI) carried out over the last eight years has aimed to maximize the percentage of soil in test samples while minimizing overall soil stabilization for lowest embodied energy and carbon (Davis, et al, 2013). Sample mix ratios have been elaborated to optimize the grain size distribution for maximum sample density, minimum water absorption, and target compressive strengths of 7 MPa dry and 4 MPa wet, which would enable the construction of multi-story loadbearing buildings. Note that this target compressive strengths of 7 MPa dry and 4 MPa wet has been obtained by the structural analysis and study of buildings built up to 4 stories by AVEI in Auroville (see appendix 1). Extensive testing has been undertaken in wet and dry compressive strength, absorption, and shrinkage on a wide range of samples stabilized with a combination of cement and lime. Larger scale applied research on foundations, loadbearing walls, and road pavements has been undertaken to push specific mechanical limits of the material. The soil type in Auroville is in general a ferralitic soil, rich in iron oxide and composed of 50-60% sand, 20-25% silt and 20-25% clay (mostly kaolinite).

This paper will first present an overview of the development and applications by AVEI of this technique, methodology of sample design, and selected test results in mechanical strength and absorption. Two case studies will be presented to demonstrate theoretical limits of this material's mechanical properties: 1. A case study of a PEC road (44m long and 4.5m to 6.5m wide) will address limits of shrinkage over large cast surface areas. 2. A case study of a 15 meter span conical vault built with Compressed Stabilized Earth Block (CSEB) over loadbearing PEC foundations and walls will address limits of loadbearing strength. As the settlement of abutments for long-span, single curved vaults can induce significant structural cracking and failure mechanisms in vaults, this case study offers an effective yet conservative example

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for strength values in walls built with poured earth concrete.

2. Overview/History of Research Development and Applications

Research on PEC at the Auroville Earth Institute, begun in 2011, had the following initial aims:

a) To maximize the percentage of earth in PEC mix ratios.

b) To stabilize PEC for target compressive strengths of 7 MPa dry and 4 MPa wet, which would allow for the construction of multi-story loadbearing buildings.

c) To minimize shrinkage, for casting greater lengths/ surface areas with minimal cracking/ control joints.

Various directions of supervised research on PEC have been carried out by research interns in civil and environmental engineering. Initial studies concentrated on minimizing shrinkage, controlling consistency and workability with slump tests, and experimenting with various stabilizers and plasticizers. Various natural and chemical products were tested (e.g. soap nut, washing powder, superplasticizers). While results indicated that such plasticizers reduce shrinkage, they also apparently reduced the mechanical resistance of PEC (le Huédé, 2011). Many tests were conducted on soil analysis, shrinkage and the compressive strength of samples. These findings have clearly demonstrated that moisture content and mix gradation were critical parameters to achieve strength, while minimizing shrinkage.

Subsequently, the research focused on mix design with the aim of achieving the maximum compactness of the designed mix. A tool was developed, based on the Dreux-Gorisse Method for concrete design (Gorisse and Dreux, 1983), to achieve an ideal grain size distribution curve of an aggregate mix with highest density (Cochet, 2011). This was used for the formulation of mix ratios for the casting of many samples (Fig. 1) for wall construction.

The results obtained from these initial trials consolidated methodologies and material target values, and were used to elaborate various mix ratios with optimized grain size distributions, for maximum mix compactness and density, minimum water absorption, and target compressive strengths. The research scope was then broadened to several directions of applied research: foundations, walls and road pavements. Research for foundations and walls maintained the initial target compressive strengths of 7 MPa dry and 4 MPa wet. Applied research for road pavements emphasized the aspect of shrinkage/ cracking minimization, ductility, and abrasion resistance.

2. Methodology of Mix Ratio Design

The principle difference between PEC and plain cement concrete (PCC) is that PEC requires a highly controlled soil/ aggregate grain size distribution and low water content/ slump levels to minimize shrinkage. Coarse aggregate sizes in PEC mix ratios are therefore much more elaborate and complicated than those of PCC. For example, the conventional PCC ratio (as per IS 456:2000) for M15 concrete is 1 cement: 2 sand: 4 aggregate; and for M20, 1 cement: 1.5 sand: 3 aggregate. There is no simple equivalent for PEC. These ratios show more complex grain size distributions and corresponding mix ratios. The following PEC ratios are the results of years of researches, based on the aims described above. They are first calculated by weight of dry materials and then converted in kilos for the stabilisers and litres for the aggregates, so as to have easy measurements for site application (see table 1).

- **Foundations** (~6.5% cement): 50 kg cement: 125 L. soil: 125 L. sand: 125 L. aggregate 15mm: 125 L. aggregate 40mm
- **Walls** (~8% cement, ~3.5% lime): 36.5 kg cement: 15.5 kg lime: 75 L. soil: 50 L. sand: 50 L. aggregate 15mm: 50 L. aggregate 25mm: 50 L. aggregate 40mm
- **Road pavement** (~5.5% cement, ~5.5% lime): 25 kg cement: 25 kg lime: 75 L. soil: 30 L. sand: 60 L. aggregate 6-8mm: 50 L. aggregate 15mm: 50 L. aggregate 25mm: 50 L. aggregate 40mm

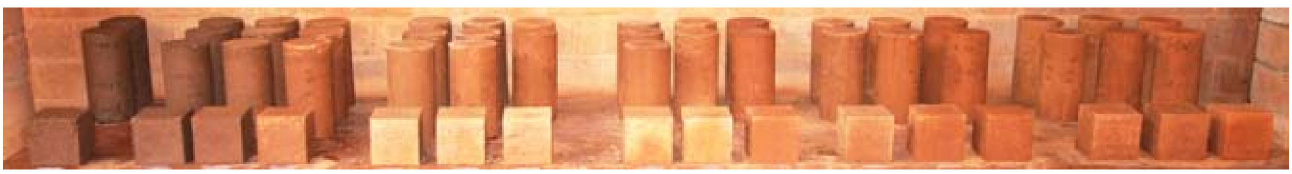

Figure 1: Test samples for PEC walls

Table 1: Mix ratio calculation tool for practical applications

POURED EARTH CONCRETE				MIX CALCULATION				PROJECT NAME	
DATA			CHOSEN QTY (MIXER)	ACTUAL % (MIXER)	QTY TO CAST (MIXER)	THEO. CALC. PER BAG	CHOSEN QTY (HAND MIX)	ACTUAL % (HAND MIX)	QTY TO CAST (HAND MIX)
Components	Bulk densities	Desired %	Weights & volume per mix (mixer)	From chosen quantities (mixer)	Exact quantities required (mixer)	Theoretical quantities per bag cement	Weights & volume per mix (hand)	From chosen quantitites (hand)	Exact quantities required (hand)
Cement	1.1910	8.0%	35 Kg	7.88%	2,374.5 Kg	50 Kg	50 Kg	7.92%	2,385.8 Kg
Lime	0.6462	3.5%	15 Kg	3.54%	1,017.6 Kg	21.4 Kg	21.4 Kg	3.55%	1,021.1 Kg
Soil (raw)	1.3800	25%	75 L	25.30%	5,088.2 L	107.1 L	107 L	25.39%	5,105.5 L
Sand (not sieved)	1.6540	20%	50 L	20.22%	3,392.1 L	71.4 L	71 L	20.19%	3,387.8 L
Chips aggregate (6-8 mm)	1.4495	0%	0 L	0.00%	0.0 L	0.0 L	0 L	0.00%	0.0 L
Aggregate 1/2" (~15 mm)	1.4350	19%	50 L	17.54%	3,392.1 L	71.4 L	71 L	17.52%	3,387.8 L
Aggregate 1" (20-30 mm)	1.5102	18%	50 L	18.46%	3,392.1 L	71.4 L	71 L	18.44%	3,387.8 L
Aggregate 1.5" (40-50 mm)	1.5120	18%	50 L	18.48%	3,392.1 L	71.4 L	71 L	18.46%	3,387.8 L
Water	1.0000	12%	60 L	13.07%	4,070.6 L	85.7 L	86 L	13.17%	4,103.5 L
Percentages & quantities aggregates only		100%	275 L	100.00%			391 L	100.00%	
Reduction ratio: 0.67	Bulking ratio: 1.49		Volume required to cast (Litres):			12,500			

Notes: Columns (Mixer) are used for mix elaboration, using a concrete mixer – Columns (Hand mix) are used for mix elaboration, by mixing manually.

Consequently, the earlier grain size distribution tool has been carried over into another calculation tool to define more rationalized and simplified mix ratios for practical applications on site (Maïni, 2015) (Table 1).

Various ratios have been developed for different applications with the principle variable parameter of grain size distribution. Certain mix designs have been adapted according to successful trial results collected over the years. Soil percentages have been tested up to 50%; however, around 25% has been found to be more optimal, as results obtained from samples with greater percentages have significantly reduced compressive strength. The remaining percentages of sand and aggregates (e.g. from chips aggregate of 6-8 mm to aggregate 40-50 mm) have been simplified to equal parts whenever corresponding differences are insignificant. Chips aggregate have been increased for road pavements, with sand reduced proportionally, for increases in abrasion resistance. Stabilization percentages vary from 6.5% to 8% cement for foundations and walls, to achieve target compressive strengths. Lime percentages are lower and variable for a balance between early strength and long term strength gain. Where greater ductility is required for reduced shrinkage cracking (e.g. roads or other large surface areas), cement percentages have been reduced and lime increased.

4. Test Results In Mechanical Strength And Water Absorption

Extensive testing has been undertaken in wet and dry compressive strength and water absorption on a wide range of samples stabilized with a combination of cement and lime. Scores of ratios have been elaborated and hundreds of samples have been tested. Initially, cube samples were cast in standard molds of 15 cm^3 and 20 cm^3. However, it became quickly evident that these samples were too small for the aggregate sizes required and representational strength values. Therefore, custom cylindrical molds were developed from a standard Indian size PVC pipe of 12" diameter (∅ 305 mm x 300 mm height).

Samples were tested in a 3,000 kN compression-testing machine 7 weeks after casting (including 4 weeks of curing, 2 weeks of drying in the shade and 1 week of drying in full sun). Dry compressive strength was tested on 'air dried' samples as the laboratory oven could not accommodate this custom size. Therefore, all data for water absorption were measured from residual moisture content after air drying. Wet compressive strength and water absorption were tested after 48 hours of immersion. Results have demonstrated that PEC has much lesser absorption rates than CSEB. PEC foundations stabilized with ~5.3% cement had an average absorption of ~2.3 %, whereas CSEB stabilized with 5% cement have an average absorption of 8 to 10% (up to a 4-fold increase). This can be explained by two factors: (1) The casting procedure increases density, and reduces porosity and water absorption; (2) PEC contains about half soil than CSEB and a lot of coarse aggregates. The wet compressive strength of PEC is on average 70 to 80% of the dry compressive strength (Table 2), amounting to a much greater relative gain in wet compressive strength than that of Class A CSEB (55 to 60%). While this is influenced by slight differences in stabilization rates, this is also due to the casting procedure which increases density, decreases porosity and water absorption (e.g. the average density of PEC is ~2,300 kg/m^3, versus 1,900 kg/m^3 for CSEB).

Certain samples, including those for road pavements, have been tested over long durations, in order to evaluate the increase of strength over time due to the stabilization with lime (Table 3). After 18 months, increases were seen of up to 208% in dry compressive strength and 166% wet.

The successful trial research has made it possible expand into larger scale applied research. The following two case studies demonstrate three different applications of the research on poured earth concrete and serve to outline both the process and mechanical properties achieved.

5. Case Study of a PEC Road of 44 meters Length

An access road for the Auroville Visitor's Center (44 m long, 4.50 m to 6.50 m wide, and 15 cm thick) was paved with PEC in 2015. Prior to the construction of this road, two small scale experiments had been undertaken at the AVEI premises. These initial road casting tests had sought to optimize PEC mixes for minimal shrinkage, adequate workability, appropriate strength and abrasion resistance. The Visitor's Center road also provided the opportunity to develop a full road cross section (i.e. with curbs, slope and embankment), as well as a method to create split joints with a continuous casting process. Other aims were: 1. To improve the casting procedure; 2. To balance workability with low moisture content and slump values, for less labor intensive work yet minimal shrinkage; 3. To observe the development of cracking on road sections varying from 39 to 53 m^2 (max. length of 9.36 m); and 4. To observe durability over time.

Three different mixes were developed for this road. The soil employed – a composition of 30% sand, 40% silt and 30% clay – was far from the ideal soil according to the tools developed for grain size optimization, and much more clayey and silty than those used in previous road experiments at the AVEI premises. It therefore tended to crack more throughout the casting process. The initial mix was slightly modified from the mix ratio used at the AVEI premises, principally with an increase of chips aggregate (50%) for greater abrasion resistance. While appropriate for grainsize distribution, this mix ratio was difficult for workability on account of the quantity of chips aggregate; the screed level pulled the aggregate, leaving a honeycomb in the cast surface. 20 m^2 were cast with the 1st mix ratio before the mix was altered (Table 4).

The 2nd mix was modified to reduce the percentage of chips for improved workability. More

Table 2: Average mechanical characteristics of samples prepared for various PEC applications

Application	Mix Ratio	Vol. Mass (kg/m^3)	Absorp. (48 hr)	Dry Comp. Strength (MPa)	Wet Comp. Strength (MPa)
Foundations 5.3% cement	50 kg cement: 150 L. soil: 150 L. sand: 150 L. aggregate 15mm: 150 L. aggregate 40mm	2,300	2.2%	5.2	4.3
Walls 8.3% cement 3.5% lime	36.5 kg cement: 15.5 kg lime: 75 L. soil: 50 L. sand: 50 L. aggregate 15mm: 50 L. aggregate 25mm: 50 L. aggregate 40mm	2,300	2.9%	8.2	6.0
Road pavement 5.4% cement 5.4% lime	25 kg cement: 25 kg lime: 75 L. soil: 30 L. sand: 60 L. aggregate 6-8mm: 50 L. aggregate 15mm: 50 L. aggregate 25mm: 50 L. aggregate 40mm	2,245	3.9%	5.0	3.8

Table 3: Increase of strength of PEC road pavement samples over time

	1 month	6 months	12 months	18 months
Dry Compressive Strength (MPa)	4.42	8.45	8.88	9.18
Increase of Dry Strength	-	191%	201%	208%
Wet Compressive Strength (MPa)	3.88	6.12	6.28	6.43
Increase of Wet Strength	-	158%	162%	166%

Figure 2: Mixing with a concrete mixer

Figure 3: Slump test, ~33 mm

Figure 4: Pouring and vibrating PEC

Figure 5: Levelling near a split joint

Figure 6: Covering the road with jute cloth

Figure 7: Scratching the pavement with a wire brush

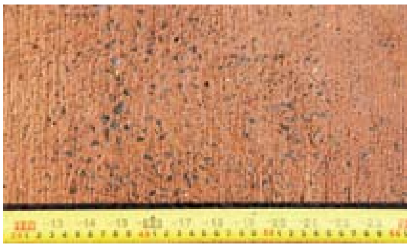

Figure 8: Texture of the pavement in 2015

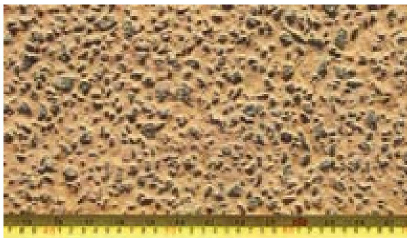

Figure 9: Texture of the pavement in 2018

25mm aggregate was added to compensate for the reduction in chips aggregate. This is consistent with a theory used to model the best compactness, in which mixes without middle-size aggregates are used to improve workability without decreasing specific density (Fontaine and Anger, 2009). This 2nd mix was used for another 20 m².

The third and final mix attempted to correct the problem of shrinkage, as the first mix started to crack due to overly direct sun exposure on the road. The ambient temperature in shade at noon was 35 °C, but the surface temperature of the ground was 50 °C. Soil was reduced (from 100 L to 75 L) and coarse sand was added to the mix. Chips aggregate were again increased (10 L more) with the aim to reduce shrinkage. This final mix was effective in balancing workability in the casting process, while addressing shrinkage over large surface areas, ductility and abrasion resistance.

The Visitor's Center road is trafficked by up to 500 vehicles a day, albeit with reduced speeds from ~10 to 30 km/h, too slow to accurately evaluate abrasion resistance for normally trafficked roads. Future testing should be undertaken for roads with normal speed traffic. Nevertheless, this pavement has behaved extremely well after 3 years. Abrasion resistance has been excellent, and the road was not damaged at all by the 100-year rain event of Tamil Nadu in 2015, with 1,590 mm of rainfall in a period of 3 weeks. Fig. 9 show the texture of the pavement after 3 years, compared to the initial stage (Fig. 8): PEC lost only a few mm of the stabiliser-soil milk on the surface, between the chips aggregate, which are still bound properly by the matrix.

Table 4: Mix ratios for road

	Cement	Lime	Crushed Soil	Coarse Sand	Chips aggreg. 6 – 8mm	Aggregate 15mm	Aggregate 25mm	Aggregate 40mm	Water
1st MIX RATIO									
Mix ratio	40 kg	15 kg	100 L.	-	75 L.	50 L.	30 L.	50 L.	55 L.
Practical %	8.63	3.42	33.06	-	23.73	16.40	10.29	16.51	11.50
2nd MIX RATIO									
Mix ratio	40 kg	15 kg	100 L.	-	50 L.	50 L.	50 L.	50 L.	55 L.
Practical %	8.72	3.46	33.41	-	15.99	16.57	17.34	16.68	11.61
3rd MIX RATIO									
Mix ratio	38 kg	15 kg	75 L.	25 L.	60 L.	50 L.	50 L.	50 L.	56 L.
Practical %	8.03	3.33	24.11	8.76	18.45	15.94	16.68	16.05	11.47

6. Case Study of A 15 meter Span Conical Vault on a PEC SuperStructure

The construction of a vaulted conference hall at the Sharanam Rural Development Center in Pondicherry provided the opportunity to apply PEC technology for loadbearing walls. Yet as the settlement of abutments for long-span, single curved vaults can induce significant structural cracking and failure mechanisms in vaults, great care has been taken in the overall design of the building and strength values of the PEC walls.

The structural system consists of a conical vault with a maximum span of 15 m and rise of 2.5 m, springing from a reinforced concrete slab 20 cm thick. This roof system rests upon loadbearing PEC foundations and walls. The load of the vault is carried principally by PEC pier walls (29 cm thick and 104 cm long), and a PEC strip foundation of 110 cm wide by 70 cm deep, with an RCC plinth beam to distribute the loads.

6.1 Elaboration of mix ratio and strength of samples

A vault of this span would only require several centimeters of asymmetrical settlement to induce a limit state and potential failure mechanism. Therefore, to be certain that there was no risk of abutment settlement, the PEC walls were over-stabilized, beyond average percentages for this technique: 8.33% cement and 3.68% lime. Trial samples of various mix ratios were tested to formulate an optimal ratio. 223 cylindrical samples were collected throughout the casting, with results even beyond the strengths achieved with the trial samples: 13.75 MPa dry (average assessed from 145 samples) and 11.88 MPa wet (average assessed from 78 samples).

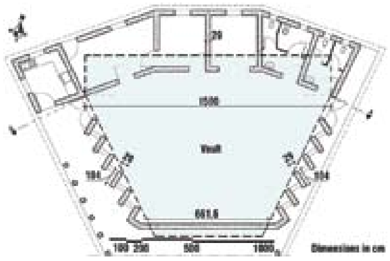

Figure 10: Plan of the conference hall

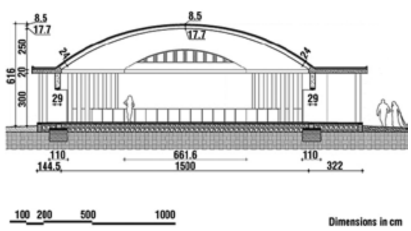

Figure 11: Section of the conference hall

Table 5: Mix ratio of PEC walls

	Cement	Lime	Soil	Sand	Aggreg. 15mm	Aggregate 25mm	Aggregate 40mm	Water
Practical mix	36.5 kg	15.5 kg	75 L.	50 L.	50 L.	50 L.	50 L.	43 L.
Practical %	7.99	3.55	27.85	16.45	17.40	18.75	19.55	9.10


Figure 12: Wall casting


Figure 13: Wall casting

6.2 Stress calculation and safety factors

The total weight of the roof system, at 179.7 tons (67.7-ton vault, 83-ton slab, 29 ton waterproofing), made it indispensable to know the exact loadbearing and stresses for all walls and piers. Safety factors were provisionally calculated considering a very conservative wet crushing strength of 4 MPa. For each case, safety factor was calculated by diving the wet crushing strength of PEC samples (4 MPa) by the loadbearing. Despite the heavy loads and low crushing strength assumed, safety factors were much beyond average, varying from 8.4 to 31.4 for the PEC walls. These high strength and low stress values make the risk of crushing statistically insignificant, therefore enabling the construction of this large span compression-only shell.

7. Conclusions

This applied research has demonstrated that poured earth concrete offers great potential for the replacement of conventional cement concrete. With stabilization of only a third to a half that of plain cement concrete (1:2:4), strength values are in general higher than required for conventional loadbearing masonry applications and well beyond the established target strengths for multi-story buildings. Greater cast surface areas have also been achieved with minimal shrinkage. One limitation of the application of PEC is the formulation of optimal mixes adapted for each soil, which makes PEC grain size distributions and corresponding mix specifications more elaborate than for standard concrete. Hence this technique is not as easily replicable as PCC, and requires further work in rationalization of mix design. While

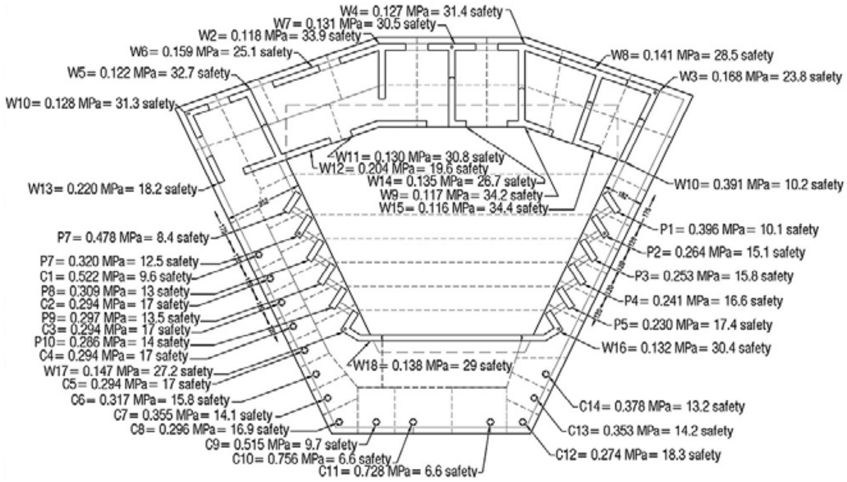

Figure 14: Stresses and safety factors

Figure 15: PEC pier walls

Figure 16: PEC walls and CSEB vault

Table 6: Load bearing and pressure calculations

Wall Ref.	Weight on wall (kg)	Wall area cm2	Load bearing kg/cm2	Load bearing Mpa	Mini req. wet strength (Mpa)	Wall Ref.	Weight on wall (kg)	Wall area cm2	Load bearing kg/cm2	Load bearing Mpa	Mini req. wet strength (Mpa)
A1	56,343.3	8,459	6.661	0.653	3.266	**A7**	58,621.0	7,214	8.126	0.797	3.984
A2	19,840.9	4,415	4.494	0.441	2.204	**A8**	45,621.5	5,687	8.022	0.787	3.933
A3	45,254.0	5,687	7.957	0.780	3.902	**A9**	32,544.0	5,654	5.756	0.564	2.822
A4	19,572.4	4,344	4.506	0.442	2.209	**A10**	56,874.5	7,025	8.096	0.794	3.970
A5	56,487.0	7,235	7.807	0.766	3.828	**A11**	27,466.5	3,654	7.517	0.737	3.686
A6	36,587.0	5,468	6.691	0.656	3.281	**A12**	29,521.3	3,625	8.144	0.799	3.993
Notes:	1 Mpa = 10.197162 kg/cm2					Safety factor from wet strength: 5					

these case studies have attempted to push certain mechanical limits, they have been quite conservative in the total percentage of soil used in designed mixes. Yet with above average wet compressive strengths, the reduction of stabilization percentages and development of raw (un-stabilized) PEC are major future axes of research to be explored.

8. Appendix 1 – Load Calculation of Realisation Apartments on 3 Stories

Minimum wet strength requirement is calculated from a safety factor of 5 (Table 6).

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Building Back Better Using Post-Disaster Debris

Kanchan Joneja[1]

Introduction and Summary

Given the increasing frequency of natural disasters in our country, there exists an enormous opportunity for the construction industry to play an environmentally and socially responsible role in building back better. Instead of adopting a linear approach of manufacturing industrial materials, which get used in construction and reconstruction post disaster, a circular approach should be incorporated in our practice wherein the debris generated is used in construction through innovative design solutions.

The areas of research in this paper cover the carbon footprint of the building construction industry, amount of construction and demolition waste generated and its use in post-disaster reconstruction scenario. We then focus on the types of disasters in the Indian context and possible design solutions that use debris for reconstruction, minimising need for manufacturing of new construction materials: random rubble masonry, gabion walls, earth bag construction and masonry block making (ordinary and interlocking)

Carbon-footprint of Building Construction Industry

The construction industry has one of the highest carbon footprints in today's time (30%), where we are experiencing the impact of climate change every day in every part of the world. The construction sector delivers infrastructure and buildings to the society by consumption of a large amount of unrenewable energy and needs to have a constant focus on developing ways of building in a sustainable manner.

Given that development and urbanisation are rapidly underway, with 60% of our country to be housing urban population by the year 2050, large-scale construction activities need to be carried out responsibly. While the production of building materials like steel and cement (8-10%) make a large contribution to global greenhouse gas emissions (embodied energy), the energy demands of the construction process and operational energy of running buildings are also immense. This includes lighting load, HVAC load and heating load, among others.

India produced 425 million tonnes of cement in the year 2017. Of the total energy consumed, around 30% goes for buildings (construction, cooling, heating, lighting combined). Figures relating to annual growth in building floor area say that by 2050, India will overtake North America and Western Europe.

C&D (Construction and Demolition) Waste

Figure 1 - Nepal Earthquake 2015; Source: SEEDS

Figure 2 - Nepal Earthquake 2015; Source: SEEDS

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Figure 3 - Leh Flash Floods 2010; Source: SEEDS

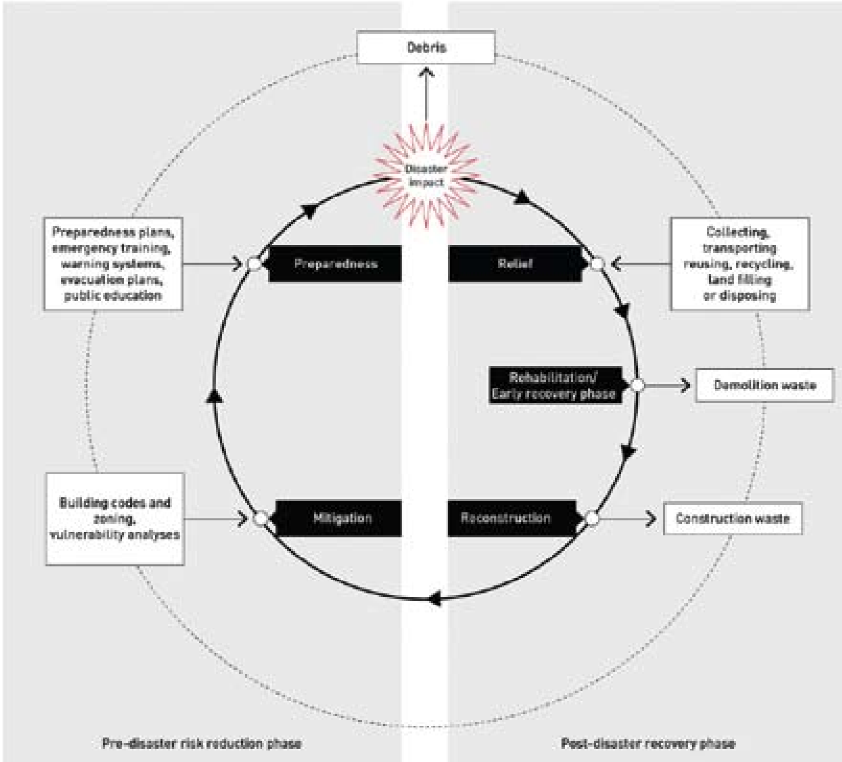

Figure 4 - Relationship of Disaster Management Cycle with Disaster Waste Management; Source: SEEDS

Apart from the high embodied and operational energy of the construction materials and buildings, there is also a large amount of waste that is generated both by intentional demolition and in the aftermath of disasters. National Buildings Construction Corporation Ltd. (NBCC) said that annually about 25% of 48 million tonnes of solid waste generated in India, is construction and demolition waste. The total quantity of waste from construction is estimated to be 12-14.7 million tonnes per annum (728 million tonnes out of this are concrete and brick waste)

Construction Waste and Debris in Post-Disaster Scenario

Recycling debris during reconstruction conserves natural resources by replacing them with recovered products that perform similar functions and reduces greenhouse gas emissions and contributes to building back better for resilience. Specifically, in the case of disasters, the third potential loss is of physical damages, which are the destruction of buildings and infrastructure creating enormous amount of **debris** and **waste**.

UNDP follows the disaster waste management guidelines developed by the Office for Coordination of Humanitarian Affairs (OCHA), the United Nations Environment Programme (UNEP) and the Swedish Civil Contingencies Agency (MSB), which define debris as "*a mixture of building waste and rubble typically arising from damaged buildings and their demolition. This waste stream can include natural materials such as clay and mud, trees, branches, bushes, etc.*"

The wider term of disaster waste refers to "*all solid and liquid waste generated from a disaster, not limited to debris: concrete, steel, wood, clay, tar elements from damaged buildings, infrastructure, household furnishings, parts from power and telephone grids such as electrical poles, wire, electronic equipment, transformers, parts from water and sewerage distribution centres, natural debris such as trees, mud and plants, chemicals, dyes and other raw materials from industries and workshops, waste from relief operations, damaged boats, cars, buses, bicycles, unexploded ordnances (UX, packaging materials, pesticides and fertilizers, paint, varnish and solvents and healthcare waste.*"

Waste and debris management as well as disposal in this case becomes crucial, keeping in mind proper environmental management and governance because disasters cause serious environmental and economic burden on normal living conditions, reconstruction as well as on general municipal waste collection. Debris management projects directly support affected citizens to rebuild their communities, reflecting their own priorities, and links their engagement to recovery. New knowledge and skills

Table 1

Sector-wise Summary of Disaster Effects (Damage and Loss) and Recovery Needs

Sector	Damage	Loss	Total Effect (D + L)		Total Recovery Needs	
	INR Crores	INR Crores	INR Crores	USD Million	INR Crores	USD Million
Social Sectors						
Housing, Land and Settlements	5,027	1,383	6,410	916	5,443	778
Health and Nutrition	499	28	527	75	600	86
Education and Child Protection	175	4	179	26	214	31
Cultural Heritage	38	37	75	11	80	11
SUB-TOTAL	**5,739**	**1,452**	**7,191**	**1,028**	**6,337**	**906**
Productive sectors						
Agriculture, Fisheries and Livestock	2,975	4,180	7,155	1,022	4,498	643
SUB-TOTAL	**2,975**	**4,180**	**7,155**	**1,022**	**4,498**	**643**
Infrastructure sectors						
Water, Sanitation and Hygiene	890	471	1,361	195	1,331	190
Transportation[a,b,c]					10,046	1,435
Power[b,c]					353	50
Irrigation[b,c]					1,483	212
Other infrastructure[b,c]					2,446	349
SUB-TOTAL	**890**	**471**	**1,361**	**195**	**15,659**	**2,236**
Cross-cutting sectors						
Environment	26	0.04	26	4	148	21
Employment and Livelihoods	881	9,477	10,358	1,480	3,896	557
Disaster Risk Reduction	17	583	599	86	110	16
Gender and Social Inclusion	0.9	0	0.9	0.13	35	5
Local Governance	28	0	28	4	32	5
SUB-TOTAL	**953**	**10,060**	**11,013**	**1,574**	**4,221**	**604**
TOTAL (A)	**10,557**	**16,163**	**26,720**	**3,819**	**30,715**	**4,389**
Integrated Water Resources Management (B)	0	0	0	0	24	3
GRAND TOTAL (A+B)					**30,739**	**4,392**
GRAND TOTAL (ROUNDED OFF)					**31,000**	**4,400**

[a] Recovery costs for roads from urban and rural infrastructure sections are included

[b] In Rapid Damage and Needs Assessment, the cost of damage and loss has not been quantified

[c] Estimates taken from the World Bank-Asian Development Bank Joint Rapid Damage and Needs Assessment (JRDNA)

Note: Figures are rounded and so column totals may not add up precisely

Figure 5 – Kerala: Post Disaster Needs Assessment, Landslides and Floods, August 2018; Executive Summary Report by Government of Kerala

TABLE 1.1: TOTAL DAMAGES AND LOSSES

Details			Number of houses	Damages and losses (NPR million)	
Damages	Collapsed houses	Low-strength masonry	474,025	199,091	258,442
		Cement based masonry	18,214	19,671	
		RC frame	6,613	39,680	
	Total		**498,852**		
	Damaged houses	Low-strength masonry	173,867	7,302	24,597
		Cement based masonry	65,859	7,113	
		RC frame	16,971	10,182	
	Total		**256,697**		
	HH goods				16,382
	Real estate sector				4,210
	Total damages				**303,631**
Losses	Demolition and debris clearance				9,941
	Transitional shelters				14,968
	Rental Loss				1,999
	Real estate				20,000
	Total loss				**46,908**
Total effects (Damages and losses)					**350,540**

Figure 6 - Nepal Earthquake 2015, Post Disaster Needs Assessment; Report by National Planning Commission, Government of Nepal

are learned that empower them to expand their opportunities and choices. Apart from quickly getting the community back on its feet, rapid recovery, including debris management projects, can make a contribution towards strengthening resilience in future.

According to EPA, planning for reuse and recycling before a disaster occurs, including creating a segregation strategy and finding recyclers who are able to accept debris, increases the likelihood that debris can be reused and recycled during a disaster-response.

Recycling debris during reconstruction conserves natural resources by replacing them with recovered products that perform similar functions and reduces greenhouse gas emissions and contributes to building back better for resilience. However, the volume of debris that may be recoverable from a specific natural disaster depends on many factors, including

- the nature of the disaster,
- types of debris generated,
- extent of contamination,
- robustness of existing recycling infrastructure,
- available capacity at recycling facilities, and
- accessible end markets.

In some cases, debris can be reused as it is, while in others they might first be resized, refinished, or reprocessed. For example, concrete can be broken up for use as aggregate in roads and bridges, bricks can be cleaned up for reuse, metals can be screened out for recycling, and organic materials, such as wood, can be reprocessed into compost or mulch.

Taking the example of the Kerala landslides and floods in August

2018, the Post-Disaster Needs Assessment (PDNA) report by the United Nations, Asian Development Bank, Government of Kerala, The World Bank and the European Union states that *"The environmental impact of the debris has to be managed by the concerned local bodies, which must not permit the dumping of this waste in an unscientific manner on hill slopes and riverbeds.* ***Much of the construction debris can be recycled to produce walling materials.*** *The local body shall design appropriate measures in consultation with expert institutions for management of debris (including a processing facility) and optimal utilisation of recycled products."*

Disasters in the Indian Context

India is a landmass with diverse geographical features which are susceptible to different kinds of disasters. The Himalayan range lies on a tectonic plate and makes the North and North-Eastern states vulnerable to earthquakes and landslides. The coastline of India, including mainland and islands, is susceptible to floods and cyclones. Within the mainland most of the rivers are prone to natural and man-made flooding due to unpredictable rainfall patterns and construction of dams.

In the last 25 years, according to Emergency Events Database (EM-DAT) a population of almost 46 lakh people have been affected in India by both natural and manmade disasters. It has been observed that poor construction in Reinforced Concrete Construction (RCC) fail during earthquakes while traditionally built houses in timber and stone (such as Kath-Khuni of Himachal Pradesh) stand unaffected. Vernacular building technologies in

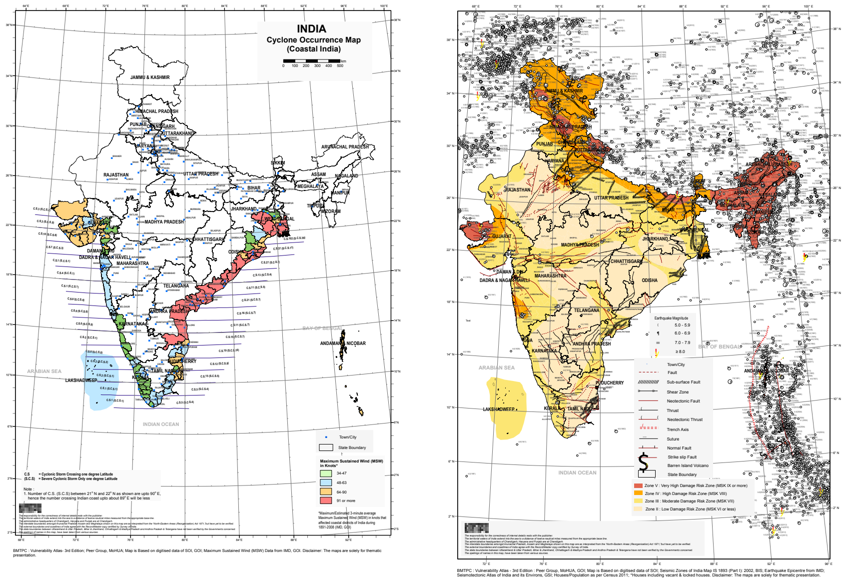

Figure 7 - Disaster Hazard Maps; Source: BMTPC

	Typical damage	Type of Reconstruction	Typical debris which can be used for reconstruction	Example where SEEDS has worked
Earthquake	Cracks around openings Collapsing of soft storey	Seismic safe Structure (RCC/timber bands) Walls Roof Floor	Concrete rubble Brick debris Stone	Nepal 2015 Sikkim 2011 Kashmir 2005 Bhuj 2001
Flood	Differential Settlement, Seepage	Water-proofing Re-plastering Painting Higher plinth	Concrete rubble Brick debris Stone	Kosi, Bihar 2008, Leh 2010, Uttarakhand 2013, Kerala 2018
Cyclone	Roof damage Structural damage	Roof Floor Walls	Roof frame (timber, steel etc.)	Gaja, Tamil Nadu 2018 Fani, Orissa 2019 Phailin, Orissa 2013

Figure 8 Matrix for Natural Disasters and Reconstruction

the various regions of India have for centuries understood nature and incorporated ways to respond to disasters but these knowledge systems have been getting lost as 'pucca' type of construction is made possible everywhere using steel and cement transported through trucks on tar-covered roads cutting through mountains.

While construction in timber allows for damaged pieces to be changed easily, RCC construction is homogeneous and can't be fixed easily without rupturing or core-cutting. Another such case was seen in Assam where annual floods of the Brahmaputra River damaged RCC houses due to the unsettling of the soil and foundation but traditionally built bamboo houses with stilts survived. At SEEDS, it is our constant effort and initiative to build back better using local building techniques, supplemented by modern technology and materials only where required.

Possible Design Solutions for Reconstruction Using Debris

The following are possible ways in which debris can be re-used for construction to build back better in the aftermath of disasters. Depending on the type of material, time, skillset available the following can be adopted for building homes, schools and health centres. The following are in the order of level of involvement of machines or materials that may not be part of debris and would have to be bought newly.

1. Random Rubble Masonry:

Stone can be used as masonry units laid with cement or mud mortar in a somewhat random manner much like random rubble masonry technique. A refined version of it is 'ashlar' in which the blocks are shaped into cuboids.

2. Earth-bag Construction:

Locally available soil coarse aggregate attained by manually crushing stone, brick or concrete debris (20-25 mm) can be filled into waste plastic sacks (such as waste cement bags) or gunny bags. This can be used to build the plinth and walls.

The disadvantage of earth-bag construction is that it is time taking and each building block/unit is at least 50 Kg if not more and requires many more people than an ordinary 2.5 Kg brick/block of some other kind.

3. Gabions:

This is a dry form of construction in which cages/boxes called 'gabions' made of GI wire are typically filled with stones and pebbles but alternatively can be filled with concrete and brick debris (or any other waste material) and stacked on top of each other in a modular way to form boundary walls, retaining walls and even infill walls of a

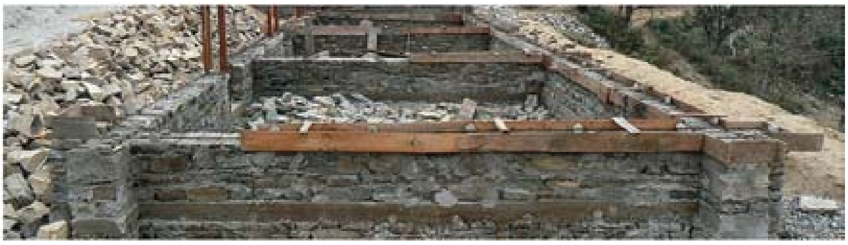

Figure 10 School building in Nepal with rubble stone masonry in cement mortar, brought to courses, and with nominal reinforcements (by courtesy of Smart Shelter Foundation).; Source: https://www.frontiersin.org/articles/10.3389/fbuil.2019.00013/full

Figure 11 Permanent shelter in Earthbag construction post 2015 Tamil Nadu Floods

Figure 12 Permanent shelter in Earthbag construction post 2015 Tamil Nadu Floods

Table 1. Building waste management strategies in global context

Place	Amount	Strategies	Remarks
Marmara earthquake, Turkey	13 million tons	• Recycling plant • 17 Dump sites	• High level of reinforcement, bars in the demolition waste causes operational problems in plant • Illegal dumping at coastal line
Kobe earthquake, Japan	15 million tons	• Minor proportion recycled • Majority disposed or land reclamation	• Separation of recycling material time consuming and costly
Beirut, Lebanon	4 million tons	• A stationary recycling plant	• Problems arising with the "cleanliness" of the demolition waste
Kosovo	10 million tons	• A mobile recycling plant • Decentralized depots collection and storage	• Spread of damage over a large rural area

Source: Baycan and Petersen (2002); de Boer and Sanders (2004).

Figure 9 - Building waste management strategies in global context; Source: Gayani Karunasena, Dilanthi Amartunga, Richard Haigh & Irene Lill (2009) Post disaster waste management strategies in developing countries: Case of Sri Lanka, International Journal of Strategic Property Management, 13:2, 171-190

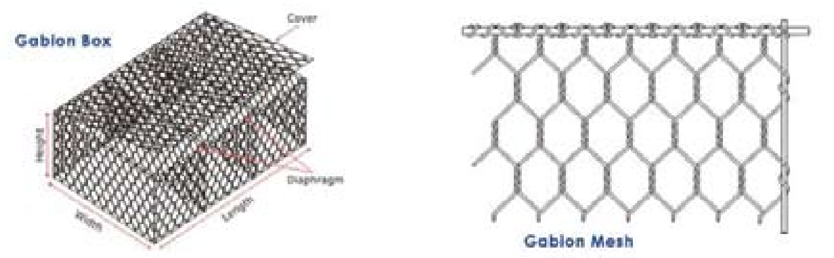

Figure 13 http://www.gabionindia.com/gabion-boxes, The wire used to manufacture the Double twisted Hexagonal wire mesh is soft annealed, low carbon content mild steel wire provided with heavy coating galvanizes as per EN 10244/ASTM A 641 to prevent corrosion.

Figure 14 Hotel Atali Ganga at Rishikesh designed by RLDA uses gabion box walls, https://www.archdaily.com/363267/atali-ganga-rlda

building with a structure in steel. In the mountains, such as in the 2010 flash floods in Uttarakhand, a lot of stones and pebbles were transported downstream and became locally available material to build with.

The pieces are stacked one by one creating a unit, or wall; each cage is attached to the other by a wire or small steel handle. In general, there are three types of gabion indicated for works with specific characteristics: box, mattress, and bag. Each varies in shape and measurement, but are made up of similar materials. In recent years, gabion walls have become widely used for a number of functions.

4. Compressed Blocks

a. Ordinary blocks:

Products such as AURA bucket crusher can be used to clear debris from reconstruction sites and crush concrete and stone with the following specifications:

- The size of the crushed particles range between 20 mm – 140 mm
- The machine can crush up to 300 tons of waste in a day's time (10 hours of machine run time)
- It can be made to order as per specifications within 15-30 days' time duration

Once crushed, blocks can be made by the following process as developed by Kongu Engineering College in Erode.

- Under this, the first step is to segregate concrete waste from the C&D debris.
- It is then crushed to produce recycled aggregates of different particle sizes.
- Sodium silicate is then added to this concrete waste, which not only helps reduce porosity but also increases durability. It plays a vital role in helping the material bind well.
- This mixture then undergoes a carbonation process. It is a process where carbon dioxide is injected into it at varying pressures in a chamber.
- Once carbonated, it is mixed with cement and water to create blocks. These blocks are then sprayed with water again and sundried for curing.
- These blocks were tested by the team for compressive strength and were found to be stronger and more durable than conventional bricks and concrete blocks.

(b) Interlocking blocks:

Interlocking cement bricks such as those by Toughie can be made from post-disaster debris and used for quick, dry construction through interlocking. Toughie blocks are made from 6mm gravel (chips) mixed with crusher dust & cement and then pressed in hydraulic press (15 T). The block is ready for use after water curing for 7 days. The block will have compressive strength of 20 T.

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Figure 15 Toughie interlocking blocks construction in Kerala by SEEDS

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Launch of E-Course on Vulnerability Atlas of India

Shri Hardeep S Puri, Hon'ble Minister of State (I/C) for Housing and Urban Affairs launched the e-Course on Vulnerability Atlas of India on August 29, 2019 at New Delhi.

The e-course on Vulnerability Atlas of India has been launched as one of the activities under "Construction Technology Year (2019-20)" which was announced by the Hon'ble Prime Minister during Construction Technology India 2019: Expo-cum-Conference under Global Housing Technology Challenge – India on 2nd March, 2019 at New Delhi.

The e-Course is being offered jointly by the School of Planning & Architecture, New Delhi (www.spa.ac.in) and Building Materials & Technology Promotion Council (BMTPC), New Delhi. It is a basic e-learning course that offers awareness and understanding about natural hazards, helps identify regions with high vulnerability with respect to various hazards (earthquakes, cyclones, landslides, floods, etc.) and specifies district-wise level of damage risks to the existing housing stock. The e-course will be a tool for effective & efficient disaster mitigation & management in the field of Architecture, Civil Engineering, Urban & Regional Planning, Housing & Infrastructure Planning, Construction Engineering & Management and Building & Materials Research.

Cultivating Our Buildings

Gaurav Dixit[1]

If we change the way we think about buildings, maybe what you build will change the world.

Late Dr P C Jain
Chairman Emeritus IGBC, AECOM, ISHRAE,FRICS

"We grow our food, we grow our clothing material, we grow our medicines, and we can also grow our buildings."

Look mindfully at a plant. It's a living creature like you and me.

It generates *Pranavaayu*, and provides nutrition to animals, birds, insects and numerous other beings. It provides shelter to birds, insects, ants, rodents etc protecting them & their young ones.

Much responsible for what our earth today is, plants have lived and died into the top soil and ocean beds making it fertile to sustain life. They have been standing devoted since million of years holding the soil from erosion, and also regulating water in the earth crust.

Life of a plant is a life of contribution, while its alive and even after its dead.

We believe that our buildings can also grow just like plants and our quest has been to find out how?

Current problem

With pressure of increased demand of built structures for humanity we have shifted gears to an approach which has led to destruction of environment. Most of the construction materials being used today are *'Mrit Dhatu'* or dead elements in form of cement, sand, gravel and steel. These materials are excavated & manufactured using enormous energy and create a lot of pollution.

Buildings account for 30% of global carbon emissions, 40% of global energy consumption and 50% of annual earth crust excavations. Also recent studies have highlighted adverse health impacts of construction materials on people involved in the process of manufacturing & in process of construction of buildings. Also there are long term adverse health impacts on occupants of the building.

Humans have always been making completely sustainable buildings from agriculture waste like straw and cow-dung. Many remarkable monuments and forts have been made using surprising materials like milk, ghee, urad dal, jaggery etc and have stood the tides of time.

Our efforts since past two years have been to bridge agriculture with construction, which can definitely help us to fulfil the promise we have made to our farmers of doubling up their income by 2022.

This unique approach will ;

- Create wealth from agriculture waste
- Provide endless supply of green

1 Cofounder of Gohemp Agroventures Pvt Ltd which is an agroindustrial startup recognised by Government of India and is working to create an Industry of growable building technology. The team recently presented the work to Shri Narendra Modi at Global Housing Technology Challenge. An alumni of School of Planning and Architecture, Gaurav is also working with Uttarakhand Hemp Association to support the development of hemp industry in the Himalayan state.Contact Info: gaurav@gohemp.in

building materials
- Provide economic benefit to farmers
- Bring skill development and employment in rural areas
- Create rural Economic development
- Support preservation of environment

Plant based building material; an ancient Indian technology

An ancient Indian technology which was used long time back in Maharashtra was discovered by group of scientists from Archaeological survey of India led by Manager Rajdeo Singh. The team found the use of cannabis plant in the inner plaster of caves of Ellora. The whole plant was crushed and mixed with lime and clay to form a plaster.

https://www.researchgate.net/publication/281226346_Characterization_of_6-11th_century_AD_decorative_lime_plasters_of_rock_cut_caves_of_Ellora

It is interesting to note that the caves of Ajanta which were built before Ellora, had interior decoration with magnificent paintings made from natural pigments. With time the natural pigments were attacked primarily by silver fish insect which ate the precious art.

Later the architects and engineers of Ellora project used the antibacterial and antifungal property of cannabis to make a plaster that has kept the paintings of Ellora safe.

Currently the same concept is being used in most parts of the world, and is called hempcrete technology. Hemp + Crete, Hemp being a variety of cannabis having no psychoactive property.

Hemp

One of the most useful plant on the planet, hemp or cannabis was also one of the first plant tamed by humans. Its each and every part has a use and gives good commercial value. No surprise that ancient Indians have been worshipping the plant just like we worship multi beneficial cow.

Leaves and Flowers

They are used in phytopharmaceutical medicines to treat diseases like cancer and epilepsy. The chemical responsible for its therapeutic value is called CBD or cannabidiol.

Seeds

The seeds of the plant are highly nutritious and are widely being used to make healthy food products. In Himalayan region there are many traditional cuisines which involve use of hemp or *'Bhaang'* seeds. The seed oil being therapeutic in nature is being used to treat problems like eczema, psoriasis and is widely being used in the cosmetic industry. Seed is also being used to make bio diesel.

Fiber

The bast fiber of hemp or cannabis is the strongest natural fiber on the planet and has been used since time immemorial to make ropes and textiles. Infact the word canvas is derived from 'cannabis'. Fiber is also used for making strong packaging material, and also in bio degradable plastics.

Hemp waste wood

Now comes the most interesting part of hemp agriculture industry. Hemp woody core is actually the waste of hemp fibre processing, where bast fiber is decorticated from stalk to yield wooden pieces as waste. It's actually cellulose and is being used to make paper, ethanol, methanol, and also sustainable buildings.

Building with hemp

Hemp or cannabis plant's wood has high silica content which binds well with lime. Pieces of wood are called shives and hemp shives in the range of 3mm-25mm, when mixed with special lime binder with mineral additives can be casted into a non-load bearing insulation material which can be use as walling as well as roof and floor insulation.

Benefits of using hempcrete

The material is light weight, thus reducing the foundation cost of structure and making it earthquake resistant. Is excellent moisture regulator and prevents any dampness and fungal development on wall finishes. Interestingly hempcrete is disliked by termites.

The material once casted doesn't need any water curing thus saving most precious resource,water. Surprisingly the lime coat on the shives resists fire for long enough providing adequate escape time to occupants in case of any fire. The material also resists spreading of fire and burns locally without smoke. It is to be noted that maximum casualties in a fire hazard happens due to suffocation of occupants in smoke and not due to the fire.

The material is very good thermal insulator, credits to the air pockets inside the moderately packed particles. It keeps the inside warm in winters and cool in summers thus reducing the electricity load of the building.

The science behind hempcrete

Hempcrete is a actually a bio crete, where stone aggregate is replaced by hemp shives and cement is replaces with lime. The lime binder used in hempcrete is in form of calcium hydroxide, which once casted starts absorbing carbon dioxide from atmosphere to convert itself into calcium carbonate which is limestone. Thus life of hempcrete structures is more than few hundred years.

The silica in the shives combines with calcium hydroxide in interior parts of the material to make calcium silicate which is equally durable as calcium carbonate. Thus this material gains strength with time at the same time sequestering carbon dioxide from atmosphere.

A sustainable approach

The results from various experiments done worldwide have proved hempcrete to be a carbon negative material, which has potential to create a sustainable, healthy built environment on earth.

Hemp or cannabis as a crop is wonderful and it grows in almost all parts of the globe, and all across India. It's a 100 day crop which require minimum pesticides and fertilisers. The annual per acre biomass production of hemp is one of the highest among all other crops giving huge amount raw material for various industries.

Scope in India

Indian government has already identified its potential and has legalised the cultivation of non psychoactive varieties of cannabis in Uttarakhand and Uttar Pradesh. The medicinal profits from the crop are sufficient to drive the industry and in turn will bring down the material cost of hempcrete in long run.

Opportunities for India

India being an agrarian country can utilise this great hemp opportunity to bridge many industries with agriculture. We have hundreds of crops like hemp, bamboo, mesta, jute, sunflower etc. which has the potential to become some of the best green building materials for coming generations.

Opportunities for housing, shelter and infrastructure :

Indian Green Building Council has projected another 5 billion sqft of green construction by 2022.

Also 70% of affordable housing needed by 2030 are yet to be constructed.

Hempcrete technology is the best suited for current times. It is highly adaptive and can be used alongside conventional building structural systems. Walls can be casted in monolithic form inside the steel, RCC, Bamboo, or wooden structure. The material can be used to make prefabricated wall panels and blocks, which can save significant construction and drying time. It is a single solution for building envelope and insulation which saves cost on material and electricity load.

The reduced self load of the building further saves cost on the structure. Plus the material is super safe for health of the occupants.

Approximately a waste from 1-1.5 hectare of hemp farm can be used to make house for an average Indian family. The costing of a hempcrete house is comparable to any other green rated home and can be brought down significantly if material is adopted by the housing sector.

Uttarakhand government is supporting research in hempcrete technology and soon India will see mass scale construction in the Himalayan state.

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Roadblocks in Recycling and Utilization of C&D Waste

Sanjay Singh[1]
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1. Introduction

Indian construction industry is growing at an annual growth rate of 10% over the last 10 years. Indian real estate operations are estimated to reach a market size of 180 million USD by 2020 and about 170 million houses are expected to be built by 2030. Such rapid urbanization puts enormous stress on the environment towards satisfying the growing demands for natural resources such as aggregates in the construction industry. Moreover, estimates of Construction and Demolition waste generation in India range between 112 to 700 million tonnes/year. C&D waste recycling, one of the sustainable solutions for managing this sector of waste is gaining popularity worldwide. The regulatory framework for C&D waste management had mandated the development of at least one C&D waste recycling facility in all cities (C&D waste management rules, 2016). The timeframe for implementation of these rules including developing and commissioning the recycling facility was set at about 18 months for cities with a population exceeding a million and 24 to 36 months for cities having lesser than a million population in the year 2016. However, very few recycling facilities are available in India presently to recycle C&D waste being generated.

Tracing the evolution of recycling in pioneer Indian cities that had established recycling facilities could help us understand the challenges being faced in developing recycling systems and thereby identify better ways of managing them in the coming years. In this paper, a historical account of C&D waste recycling and the roadblocks that hamper the development of recycling initiatives in India have been presented. Primary data including direct observation and several other data sources such as technical reports published by expert organizations, proceedings of sensitizing workshops being conducted all over the country, administrative procedures and forms from Corporation' websites, newspaper articles, and other related documents form part of our data sources.

2. Barriers in Promoting Recycling and Recycled Products

2.1 Lack of Attention on C&D Waste

The waste management operations are being handled by the urban local bodies in every Indian city, continuing the practice as it is as inherited from the British rule. British ruled India for about 200 years which ended in 1947. When they developed cities in India, they adopted the same system of solid waste management as that prevailed in the United Kingdom. The city corporations were responsible for collecting the waste from the cities and dispose in the designated dump yards developed outside the city. Bullock carts were initially used for collection and later it evolved to use powered vehicles. However, the process of dumping the waste without any processing or beneficiation continued even after the independence for the past 70 plus years.

The industrial revolution made sure the focus was on development and hence, there was no

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importance given to curb pollution including waste management. There were no governing rules to tackle the situation then. People also did not focus on the clean-up afterwards and the awareness of healthy living was not good either. While waste-to-energy (WTE) plants for handling municipal solid waste started picking up, it is mainly restricted to organic matter in the solid waste, which can be converted to fuel. However, the construction waste, the inert portion of the solid waste was left was out of the radar. It was believed that C&D waste contributes fewer pollutants to the environment as compared to other wastes and therefore least importance was given to manage it (Ramanathan and Ram 2019).

2.2 Lack of Awareness of the Value in C&D Waste and Related Initiatives

The historical practice of landfilling C&D waste had made construction stakeholders overlook the value in C&D waste. It was believed that landfilling C&D waste is the best option. Moreover, the survey by TIFAC (2000) indicated that almost 70% of surveyed participants were not aware of the recycling techniques of C&D waste. Furthermore, almost 30% were not aware of the recycling possibilities of the C&D waste stream. Several expert organizations from all over the country had worked on it. Indian Concrete Institute (ICI) was one of the professional bodies that organized many sensitizing workshops about C&D waste recycling along with Central Public Works Department (CPWD) and IIT Madras. The first of the workshop series was held in New Delhi along with the support of the Ministry of Urban Development (MoUD) and included a visit to the pilot recycling facility operating in the region. A series of workshops followed it in several cities all over the country such as Chennai, Hyderabad, Mangalore etc. Participants in those workshops included Government officials handling solid waste management in the region, construction contractors, demolition experts, equipment manufacturers, recyclers and academicians. Experts from all over the world shared their experiences on C&D waste management with the participants and brainstorming sessions were conducted to create a roadmap for the evolution of C&D waste management in the country. While the status of awareness about C&D waste recycling has improved in the present years, the activities need to be continued to improve the trust of stakeholders towards recycling.

2.3 Unavailability of Reliable Estimates

The need for a reliable estimate of C&D waste generation cannot be overstated. It is said that “one cannot control what one cannot measure”. Thus, understanding the magnitude of C&D waste generation and composition is essential in developing appropriate management systems. However, in the Indian urban areas, there are no reliable estimates available regarding the quantity of C&D waste that is getting generated. The Technology Information, Forecasting and Assessment Council (TIFAC) reported that the quantity of C&D waste getting generated in India is around 10 to 12 million tons annually (TIFAC 2001). Government reports indicate about 12 to 15 million tonnes of C&D waste generation every year (Ministry of Environment and Forests 2010). However, the estimate has been criticized for being a gross underestimation with scientific evidence (Ram and Kalidindi 2017). CSE came up with an estimate of 626 million tons of C&D waste generated in a span of eight years (2005 to 2013)(Centre for Science and Environment 2013). An independent organization named Development Alternatives projected a massive amount of 750 million tonnes of C&D waste generation annually (GIZ,2016). Using Materials flow analysis, it has been showed that the generation of C&D waste in India could range between 112 and 431 million tonnes (Jain et al. 2018). Thus, the available estimates vary to a wide extent and reliability is lacking. Since the knowledge on the quantity of C&D waste being generated helps in understanding the needs and in designing the facilities required, lack of reliable estimates was accused to be one of the reasons for the lack of proper policies to improve C&D waste management in India.

2.4 Composition and Commingled nature of Waste

C&D waste in Indian construction sites is composed of soil, brick and masonry waste to a large extent (refer Figure 1). The composition study of C&D waste in India indicated about 21% of concrete in the overall C&D waste (TIFAC 2001). This composition is in contrast with some other Asian and European countries wherein concrete waste is one of the biggest constituents. Because of this, the business model and output of recycling facilities need to be tailor-made to suit the local conditions. Washing equipment will become a primary

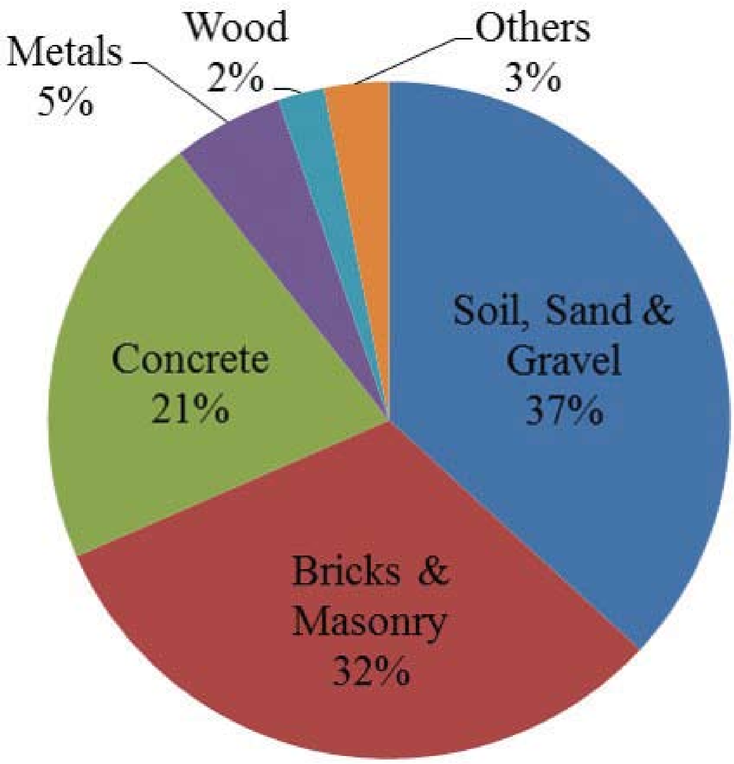

Figure 1 Composition of C&D waste in India [Source: TIFAC (2001)]

component of a recycling facility rather than crushing machinery as composition favours larger production of fine aggregates than coarse aggregates in a typical C&D waste recycling facility in India. Moreover, producing recycled fine aggregates pose significant challenges in quality control and quality assurance activities.

In addition to such challenges, absence of on-site segregation of waste as observed in Indian construction project sites affects the quality of recycled output. The waste generators cite the lack of availability of space for sorting activity as a major constraint for not segregating waste on-site. Also, segregated waste requires a larger number of trips to a recycling facility than unsorted waste and thus dis-incentivising on-site segregation. Moreover, demolition contractors seldom perform selective demolition of a building. While certain materials such as electrical wires, wooden doors & windows and steel are salvaged during demolition, a bulk of waste comprising concrete, brick, masonry, and tiles are never segregated on-site. These materials are loaded on trucks and sent for disposal (or rarely to recycling facilities). The downstream impact of commingled waste is high as the quality of recycled aggregates produced from mixed waste is low and fails to obtain attention in the market and thereby demand.

2.5 Negligible Disposal Costs and Prevalent Illegal Dumping

The waste generators do not incur any cost for the disposal of C&D waste apart from transportation costs in many Indian cities. Thus, there is no incentive for waste generators to take steps to reduce the quantity of waste generated in their project sites. The practice of disposing C&D debris in unauthorized places such as roadsides, public parks, canals and marshlands is prevalent in the Indian cities. The problem of illegal dumping is not specific to Indian cities and has been reported to be occurring in various countries worldwide. This practice affects the economic viability of recycling the debris as the costs for collection and the associated transportation from illegal dump sites to recycling facility becomes substantial. In Chennai city, there is a fine of Rs. 2000 imposed upon those truck drivers who are caught in the act of illegally dumping C&D waste. However, the fine is not adequate to deter this practice and there is a dire need for a revision in this fine structure. There is a need for more stringent action towards violations to curb this prevalent practice. The policies that have been found to be effective in other countries to minimize illegal dumping could serve as guidance while enacting one for the local scenario. Setting up various collection points as seen in New Delhi and Ahmedabad could potentially reduce illegal dumping as waste generators will be able to dispose of C&D waste in such locations at free of cost.

2.6 Quality Concerns regarding Recycled Aggregates

Any recycled product is expected to perform as its primary counterpart. Since recycled concrete aggregates are produced by crushing concrete debris, there is a layer of porous cement mortar that remains adhered to the surface of the recycled aggregates. This adhered cement mortar reduces the recycled aggregates' quality as compared to the natural aggregates owing to increased water absorption and inferior mechanical properties comparatively.

The quality gets worsened if the constituents of C&D waste were not pre-sorted. As it has been observed that practice of on-site sorting of debris is absent in Indian project sites, the quality concerns are high among the stakeholders and the acceptability of recycled aggregates is affected to a large extent.

The permission to use recycled aggregates in concrete was earlier not available in the Indian Standards. The specifications for utilizing was only incorporated in the year 2016 in IS 383. While the standards allow unlimited usage of recycled aggregates in concrete intended for non- structural applications, the usage in structural applications is limited. The use of recycled aggregates produced from sources other than concrete is only allowed in lean concrete applications and this significantly limits the applications for which recycled aggregates can be put in Indian projects. Because the quantity of sorted waste diverted for recycling is negligible as compared to mixed waste and hence, restrictions apply for a large portion of recycled output. Moreover, psychological barriers owing to the poor image associated with recycled products also plays a significant role in leading to a poor demand for recycled aggregates in the market.

2.7 Lack of Adequate Economic Incentives

Since the demand for recycled aggregates is low, there is risk and uncertainty involved in setting up recycling plants. The uncertainty lies in the quantity of waste generated in a region and the quantity that could be collected at a centralized recycling facility too. As there are very little incentives for a waste generator to sort the waste and incur transportation costs to haul C&D waste from the project sites to landfill/recycling facility, alternative options are being considered by the waste generators. A simple comparison of costs incurred with natural aggregate and recycled aggregate production facilities could help us identify the extra burden of transporting waste from sites to the recycling facility on the shoulders of recyclers. However, the output price of recycled aggregates cannot exceed its natural counterpart and thereby forming a hard constraint. Furthermore, consumers expect cost reduction with recycled aggregates owing to the poor image of recycling.

While it has been reported that gate fee (fee for accepting waste disposal in recycling facilities) is one of the primary sources of income for a recycling facility in many countries, such mechanisms are neither existent nor workable in the present regulatory framework. The municipal corporations need to play a major role in devising the much-needed incentives to nurture a recycling system. There are LEED rating and credits for recycling and use of recycled materials. However, these ratings could be obtained by consuming any recycled material and there are no incentives that are exclusively obtainable in consuming recycled aggregates. Thus, there are minimal incentives available for adopting recycling and recycled products in the market presently (Ram et al. 2019).

2.8 Lack of Appropriate Policies and Weak Enforcement

There are several risks associated with C&D waste recycling as discussed earlier. Private recyclers are not the ideal players to embrace such risks. This necessitates the role that needs to be played by the Government through appropriate policies and interventions. However, a lack of appropriate regulations and policies that enhance the economic viability of recycling is observed in the Indian market. C&D waste management is not included in the construction / demolition contract at all and hence the waste arising out of project sites are poorly handled.

There are no national policies mandating the need for recycling even in Government projects. The taxes levied for recycled aggregate and recycled aggregate-based products presently make them non-competitive in the market. Moreover, weak enforcement of existing rules and regulations serves as a big deterrent for developing recycling facilities.

3. International Best Practices

There are several best practices that have been reported to help C&D waste management systems and especially recycling. A gist of them is discussed in this section.

3.1 Landfill Ban / Landfill Tax

Polluter pays principle has been adopted by several countries worldwide in various fields including construction to create awareness and improve management of scarce resources. Under the principle, the waste generator needs to bear the costs of collection, transportation and processing of waste generated to ensure the resource does not get wasted and re-enters the supply chain. In Netherlands, the landfilling of reusable C&D waste is banned throughout their country. A similar ban on landfilling C&D waste was also noted in countries such as Belgium and Germany (Symonds Group Ltd. 1999). Although the landfilling ban might not be the only reason for higher recycling ratios in these countries, it might have contributed a major part in achieving higher recycling ratios irrespective of the kind of use to which they have been put. Wherever landfill ban is absent among the EU countries, landfill taxes are high to discourage landfilling of C&D waste.

3.2 Channelizing Waste: Permits & Waste Management Plans

The waste needs to be channelled to a recycling facility to help recycling facilities gain from economies of scale. In Spain, a deposit-refund model called Alcores model ensures that the waste being generated reaches the recycling facility (Solís-Guzmán et al. 2009). The developer gets the permit for construction only after depositing a sum of money with the urban local body and needs to dump all the waste generated from the project at the designated recycling facility to retrieve the deposit made. Thus, sufficient incentives are embedded in the system to bring about compliance. A trip ticket system has been devised in Hong Kong by which unauthorised disposal is controlled. Because of high transparency in the transportation routes and destination of C&D waste being hauled, disincentive has been made very high for non-compliance. Illegal dumping could also be controlled by interventions such as introducing Green police and vehicle impoundment (Seror et al. 2014). Apart from such permits and systems, mandating the preparation of waste management plans by contractors have also reported contributing to the improvement of C&D waste management in a region.

3.3 On-site Sorting and Selective Demolition

On-site sorting of debris and selective demolition are essential to enhance recovery of C&D waste and to produce high quality recycled aggregates that can be used in higher grade applications. Having acknowledged this, they have been made mandatory in Norway and other Scandinavian countries (Christian J Engelsen, 2013). TA specific set of guidelines for selective demolition and on-site sorting have been framed and enforced through the Norwegian Waste Handling Rules in Norway. The implementation and enforcement of this initiative help in easier processing as well as in achieving high quality recycled product in an economically viable manner. Hong Kong enacted a differential waste disposal charging scheme based on the sorted nature of waste at the point of disposal that ensures segregation of reusable/ recyclable waste before being disposed of in landfills (Lu and Tam 2013).

3.4 Pilot Facilities and Demonstration projects

Unavailability of recycling facilities has been cited to be one of the reasons for lack of development of market for recycled aggregates. It has been reported that establishing pilot recycling facilities contributes to market development and improves confidence in using recycled products among the stakeholders. Demonstration projects help reinforce the fact that the utilization of recycled aggregates is safe and boosts demand in the market.

3.5 Incentives

Subsidies for purchasing recycling machinery could boost the development of C&D waste recycling facilities. Tax exemptions and exemptions in Gross Floor Area could be instituted to incentivise contractors in using recycled aggregates. Incentives in the form of financial grants are sometimes essential as higher capital costs and longer breakeven periods tend to discourage recyclers in taking initiatives.

3.6 Developments in Recycling Technologies

Conventional crushing of C&D debris does not remove the adhered mortar from the surface of recycled aggregates. Several advanced treatment technologies have been developed in the literature such as mechanical scrubbing, thermo-mechanical treatment, acid soaking, microwave heating and ultrasonic cleaning. Other methods include usage of surface modifiers such as pozzolans, polymers, and bio-deposition of CaCo3. All these treatments have been reported to improve the aggregate-mortar interface. Several industrial bodies have also contributed to the development. CDE Asia Ltd. has been one of the pioneers to work in C&D waste recycling and have brought several technological innovations that maximise quality of recycled output and minimise waste from the process at the same time. CDE's advanced processing systems for construction, demolition and excavation waste allows recovery of high- quality sand and aggregates for use in a range of high-value construction applications including concrete and asphalt production. Several recycling plants commissioned in India have obtained their machinery and benefitted from CDE Asia Ltd.

3.7 Standards and Guidelines

Development of standards and guidelines for safe utilization of recycled aggregates is essential to ensure legitimacy for consuming recycled products. For instance, Japan Industrial Standards Committee formulated three classes of recycled aggregates: Class H, Class M and Class L. The classification were according to the material properties of the recycled aggregates and the scope of application was limited with respect to the class of the aggregates. Similarly, several other countries have developed various guidelines and incorporated provisions in their national standards for the use of recycled aggregates in concrete and other applications.

3.8 Voluntary Agreements and Strengthening Ecosystem

There is a need to create a market for recycled products by involving the construction industry and encouraging them to use recycled materials in projects. Forging voluntary agreements among the stakeholders to coordinate and collaborate in waste management activities could go a long way in tackling complex problems and nurture a healthy ecosystem. Public procurement of recycled aggregates has been reported to be one of the commonly adopted measures to serve as guarantees for recyclers about market demand and thereby limiting the risk exposure in developing recycling facilities.

4. Recommendations

The Indian construction market is highly cost-sensitive, and cost advantage is crucial while introducing alternative materials. While several measures have already been taken in the Indian urban areas to improve C&D waste recycling, further improvements are necessary to form an interlocking policy mechanism that can propel the growth of C&D waste recycling. A list of measures that could support recycling initiatives is discussed below.

- The existing practice of landfilling C&D waste undermines the recycling potential and contaminates the material often with municipal solid waste while dumping. Many countries have **banned landfilling C&D waste** to ensure reuse and recycling of C&D waste. **Awareness about the hazards of dumping** modern construction materials (adverse effects of leachates containing paints and other harmful chemicals) among corporation personnel and contractors is essential to improve C&D waste management.
- Although the C&D waste management rules (2016) embraced the **'polluters pay principle'** by allocating responsibilities on waste generators to bear costs of collection and processing, **tightening of enforcement** activities is essential to support the recycling ecosystem. Moreover, urban local bodies need to be encouraged to spell out processes clearly; thereby, compliance could be verified and monitored.
- Mandating the need for **creating a waste management plan** by all development permit applicants would lead to necessary steps towards reduction/reuse/recycling of waste.
- The distributed waste generation points add to the cost of collection and transportation (~INR 230-300 or 40%-50% of the natural aggregate cost per tonne), and in the current system, a large portion of it needs to be borne by the recycler if there is no government support. The collection of **input gate fee** as prevalent in many of the European countries could benefit recyclers.
- Innovative strategies such as vehicle impoundment from Israel and the deposit-refund model (Alcores model) of Spain could potentially **reinforce the system against unauthorized disposal** in addition to the act of levying fines from the truck drivers indulging in illegal dumping.
- **Channelizing a part of the money (cross-subsidization)** collected from issuing new construction or demolition permits to recyclers through an escrow account would reinforce the 'polluters pay principle' without putting an extra burden on the society.
- While developing recycling facilities, care must be taken to select appropriate technologies and machinery. Government tender documents must dictate a standard **technology selection process** that is essential in delivering high-quality recycled output.
- Policies mandating the adoption of practices such as **selec-**

tive demolition and on-site sorting at project sites would increase the quantum of C&D waste recovery.

- The market acceptance of recycled aggregates is still low even though IS 383 permits its usage. Hence value-added products made of recycled products are becoming common instead of selling as a raw material. The need for **incorporation of appropriate specifications and clauses in Government projects' tender documents** allowing the use of recycled aggregates will boost the acceptance of recycled products.
- The criteria for **standardization of recycled products** needs to be spelt out in Standards and guidelines. Depending on the quality of recycled output, appropriate classes must be designated that can facilitate quality control and quality assurance.
- The taxes on finished goods such as ready-mixed concrete and other precast products affects the economic viability of recycled products. It was inferred that some **tax concessions** on these products might help them in marketing the recycled products effectively and will make it possible to compete with other products available in the market.
- The tender conditions must mandate the development of waste management plans and **recycling/disposal plan in infrastructure works** such as metro rail works, bridges, and flyovers as infrastructure projects generate a large amount of waste and the works span a longer duration.

Closing Comments

The regulators have a big role to play and the international success stories can serve the local policymakers in establishing an effective system for managing C&D waste in Indian urban areas. Such regulatory enforcements can reduce the material procurement cost and enable the C&D recycling industry to offer cost-competitive alternatives that can aggressively penetrate the market. The demand for aggregates in the Indian construction sector is projected to be about 2 billion tonnes of coarse aggregates and 1.4 billion tonnes of sand (fine aggregates) by 2020. Even if we consider that about 500 million tonnes of the entire C&D waste generation in the country is recycled, it can just partially substitute the demand that exists in the sector and could lead to sustainable development.

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Reuse of Discarded Fishing Net as Raw Material for 3D Printing: A Novel Idea to Transform Waste to Wealth



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Introduction

The elements in the periodic table is increased to 118 in its 150th Anniversary. But still the demand for different materials are still on the rise as the world invents products with various material requirements. Methods and processes are needed to minimise the error and cost in the die making in order to manufacture such new products. There comes the idea to minimise the usage of materials, which is 3D printing. 3D printing is an additive manufacturing process for the fabrication of complex structures which was drawn as a CADD model and then exported to a 3D printer in .stl format. The process involves successive layers being imported onto each other. There are many processes according to the need or application, which were modified and enhanced from the layer by layer deposition. Some of them are powder bed fusion (SLS or SLM), fused deposition modelling (FDM) and direct energy deposition (DED). 3D printing has been widely applied in different industries, like aerospace, building interiors, medical and appliances manufacturing. The major advantage is less waste, freedom of design and automation. Among the other processes, powder bed fusion involves mostly thermoplastic raw material for the 3D printing. Powder bed fusion process where very fine powders are spread on a platform (bed) and they are fused together with a laser beam. Successive layers of powders are moved on top of preceding layers and they are fused together [1]. After the part is cooled, the excess powder is removed and can be reused for the next part to be manufactured. Powder size distribution and the flowablity determines the quality of the product formed for it is to be used as a prototype of real part [2]. The laser is used for powders with a low melting temperature and selective laser sintering (SLS) can be used for a variety of polymers. The laser does not fully melt the powders and increase in temperature on the external of prior layer results in fusion of the powders which is to be flown over each other by the rolling process [3]. High quality powders which are in nano form make the necessary good finish and better properties and powder bed fusion thus makes it suitable for 3D printing of intricate structures.

Polymers are the most common materials which are being used in the 3D printing process. They are used in the form of filaments, resin or powder. Recently, a Nylon 6 based nanocomposite material was studied to be used as a filament for FDM and have found that it can be used as an alternative to ABS and thus bringing the harmful ABS to rest in the 3D printing [4]. In this work, discarded fishing net filaments (polyamide nylon), which are being thrown away or improperly disposed is studied for its use as a raw material for 3D printing. The cost of the raw material is very low, considering only the minimal pre-processing cost to make the fishing net to powder form, which can be easily converted to wealth and used in SLS 3D printing.

Material Selection

The nylon fishing net are made of polyamide material. Nylon has the attributes such as high tensile and impact strength and thus made into twines for its application as fishing net [5]. But after a pro-

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(a) Single twine of fishing net (b) Complete fishing net being knotted (c) Chopped fishing net with knot

Figure 1. Microscopic images of collected fishing net

longed period of time, this fishing net is thrown without proper disposal method along the sea shores. Fishing net was collected from the sea shore and first cleaned using water in order to remove the dirt and other algae being attached to them. They are then dried in sunlight until all water molecules are removed from its surface. They are again dipped in a acetone solution to further remove any microbes attached on the fishing net, as they are mostly used in the sea and exposed to the marine atmosphere. The cleaned fishing net are dried and then segregated and subjected to ball milling process.

Experimentation

Morphology

The process of powder bed fusion involves powder form of raw material and hence the collected fishing net was subjected to the ball milling process. The feed of the milling machine requires the size of the material to be less than 10 mm and hence the collected fishing net are cut manually using fine pieces as shown in figure 1. Figure 1a shows the single fishing net twine with 800X zoom obtained with the aid of the optical microscope. The figure 1b is the whole fishing net being viewed at 40X and figure 1c is depicts the chopped fishing net under microscopic view.

Thermogravimetric Analysis

Thermogravimetric analysis was performed using a Perkin Elmer thermal analyzer to observe the thermal stability of the fiber following ASTM E1131-08 standard. The analysis was conditioned using nitrogen (purge gas), at a flow rate of 20 ml/min. The sample quantity 5±1 mg was justly distributed in an open pan of 6.4 mm diameter by 3.2 mm depth, were heated up to 800^{0}C with a heating rate of 25^{0}C/min. The crucible material used and reference material is alumina (powder) weighing nearly equal to each of the samples. Thermogravimetric analysis studies showed that 50% decomposition occurred at 460^{o}C, whereas the complete decomposition happened very close to 500^{o}C as shown in figure 2. The decomposition temperature range was maximum between 410^{o}C and 480^{o}C [6].

Differential Scanning Calorimetry

Differential Scanning Calorimeter model is DSC 60 plus and in order to calibrate the heat flow, a blank run with empty aluminium pans on both the reference side and the sample side was performed before the fishing net sample measurements. The sample mass was measured to be not more than 6 mg. The purge gas (nitrogen) was used in both the trail run and the test with the flow rate of 50ml/min. The heat flow versus time and the temperature versus time measurements were obtained from the DSC, which thus provides the glass transition temperature and melting

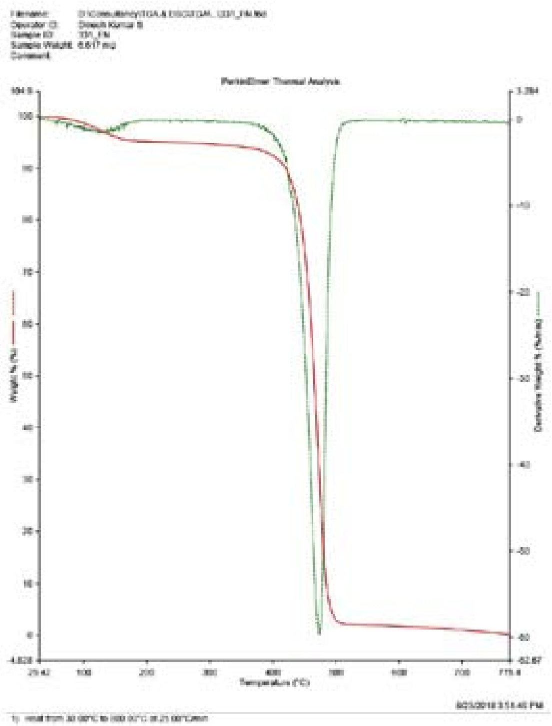

Figure 2. TGA of collected fishing net

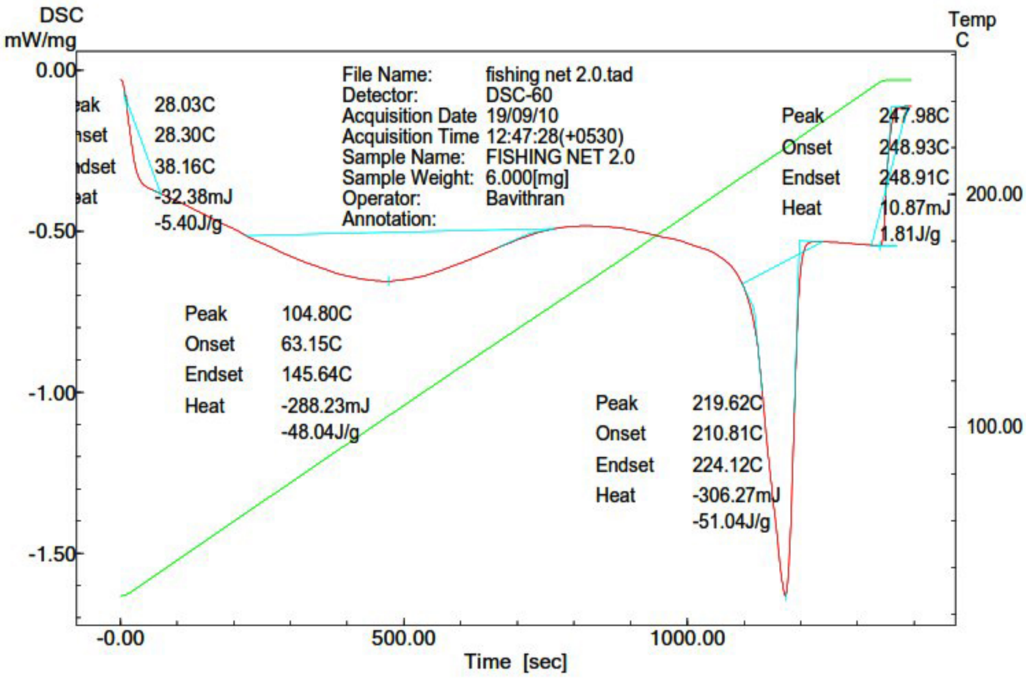

Figure 3. DSC curves of collected fishing net

point for the fishing net sample.

From the figure 3, it is clear that the glass transition temperature is around 104°C, whereas the melting point is found to be around 219 °C. Thus, it can be inferred that this polymer can be very much be used as the raw material in powder bed fusion in 3D printing.

Conclusion

The collected waste and improperly disposed off fishing net were collected cleaned and subjected to morphological studies and thermal studies. The morphology shows that the filament can be easily bind together and they are flexible for the ball milling process. It proves that the further process includes ball milling to finer level for the easy flowability of the powder, in the powder bed in SLS. The thermal properties however has given much positive hope as the used fishing net nylon melts at 219 °C and complete degradation takes place over 450 °C which is much suited for SLS. It is clear that this polyamide fishing net nylon can be efficiently used as the raw material in powder form for the powder bed fusion technology of 3D printing. Also, this paves the way to transform waste to wealth for the people of rural areas across the sea shore, where fishing is the major occupation.

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Thematic Workshop on Vulnerability Atlas of India and Disaster Resistant Design & Construction Practices

While releasing the digital version of Vulnerability Atlas during CTI 2019 – GHTC - India on 2nd March, 2019, Hon'ble Prime Minister of India emphasized the need to formulate & implement various schemes of the Central & State Governments keeping in view the vulnerability of the region & indicative risk assessment as given in Vulnerability Atlas of India. Subsequently, in order to educate about the Vulnerability Atlas of India, the Secretary, Ministry of Housing & Urban Affairs, Govt. of India addressed all Chief Secretaries of State/UTs, IITs, CPSUs and Central Ministries/Deptt. to organize state level one-day workshops. The Council has received overwhelming response for organization of Thematic Workshops. Following programmes have been organised so far:

- For State Govt.officials and students of Architecture & Civil Engineering Colleges with Town & Country Planning Department, Puducherry on September 11, 2019 at Puducherry. The programme was inaugurated by Shri V. Narayanasamy, Hon'ble Chief Minister of Puducherry and presided over by Shri Durga Shankar Mishra, Secretary, Ministry of Housing & Urban Affairs, Government of India.
- For engineers of Engineers India Ltd. on June 4, 2019 at Engineers India Ltd. Gurugram Campus. The programme was attended by more than 120 engineers, architects, town planners and designers.
- For educational institutions under Ministry of Human Resource Development and engineers of Engineering Projects (India) Ltd. May 3, 2019 at New Delhi wherein senior faculty members from 56 educational institutions and engineers from EPIL Ltd. also participated.

Sustainable Building Materials & Technologies

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Introduction

In the wake of climate change mitigation, Paris agreement, COP21, Sustainable development Goals and ongoing all-around global efforts towards making the planet clean & green, it is collective responsibility of countries to make use of sustainable practices in every walk of life. India being one of the largest and fastest growing economies in the world is witnessing massive growth leading to $5 trillion economy & construction in India is emerging as the third largest sector globally, reaching $750 billion by 2022. The construction activities are one of biggest consumer of energy, natural resources, fossil fuel and contributor to pollution, greenhouse gas emissions. As such Buildings consume 40% of energy, 25% of water & 40% of resources. Further, Buildings activities contribute 50% of air pollution, 42% of GHG emission, 50% of water pollution & 48% of solid wastes. It is happening because the construction sector is still grappling with hackneyed materials and technologies which are based on natural resources, require energy in its manufacturing & implementation and not in sync with nature. As per UNEP, GHG emissions will double by 2050 as compared to 30% as of today on a business as usual approach. Therefore, it is imperative to bring disruption in the construction sector by introducing materials & technologies which are resource-efficient, climate-responsive and ecofriendly leading to sustainable development. These sustainable materials and techniques are already available and being used in bits and pieces. These have shown their worth with the passage of time but unfortunately could not be mainstreamed as brick, cement, steel and concrete became ubiquitous. Concrete is the most widely used world over material after water on the planet despite of the fact that cement production emits CO_2 through an energy intensive process of burning clinker using fossil fuel and is extracted from limestone, a sedimentary rock available as finite natural resource. It will not be any longer sustainable to use it in its present form, if not used judiciously and would endanger our eco-system. The cement companies and researchers, world over are experimenting with various kinds of blended cements and even using successfully concrete with cement i.e. geo-polymer concrete.

The use of sustainable materials and technologies coupled with sustainable practices can bring down energy use by 30%-50%, water use by 40%, GHG emission by 35% & waste reduction by 75% reduction. *Is it not then prudent to make use of sustainable materials and technologies in the construction?* The paper enlists such materials & technologies already available in India and being promoted by Building Materials & Technology Promotion Council (BMTPC).

Conventional Building Materials

The most commonly used building materials for construction are stone, timber, aggregates, sand, brick, cement, steel, glass, plastics, ceramics, aluminum etc. The manufacturing process of all these materials i.e. extraction to use and then disposal after service life has been found to be unsustainable because of any of the following reasons or combinations thereof:

- Based on natural resource
- Use of fossil fuel

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- Energy intensive process of manufacturing/usage
- Irreversible/irreparable environmental impact
- Contributes towards waste generation & GHG emission
- Inefficient disposal
- Centralized production involving transportation

Sustainable Building Materials

Sustainable building materials are environmentally-responsible and resource-efficient materials throughout their life span involving all cradle-to-grave processes i.e. extraction of raw materials through materials processing, manufacture, distribution, construction, use, operation, repair & maintenance, renovation, demolition & disposal and recycling. The practice of sustainable buildings complements environmental, social and economic concerns. In addition, the global warming potential, air pollution, water pollution, and waste are also part of sustainable materials.

Sustainable technologies are constantly being developed to complement current practices in creating sustainable structures with the objective to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation
- Reducing environmental impact

Properties of Sustainable Building Materials

Any material or technologies qualifies to be sustainable, if it is based on the following:

- ***Renewable Source***

  The natural resources which are rapidly renewable such as bamboo, wood from certified forest.

- ***Reuse of Waste Product***

  The conversion of agricultural and industrial waste into useful building materials or any value added product is the clarion call and is the way to achieve sustainability. The use of salvaged products such as used steel, tins, old plumbing materials, door & window frames, construction & demolition frames to produce materials is also underway and add to sustainability. Recycled contents of agriculture and industrial waste to produce materials such as fly-ash bricks, Cellular light weight blocks/concrete, Autoclaved Aerated Concrete blocks rick husk boards, bagasse boards etc. are eco friendly materials.

- ***Embodied Energy***

  While using the materials, one should bear into the mind the energy required to produce that material. For example, burnt bricks require huge amount of fossil fuel. Another dimension to energy is transportation. The transportation cost to bring the building products to the construction site should not be high.

- ***Local Availability***

  Take cue from our rural technologies, they always used the local materials such as mud, stone, thatch, straw to make buildings. The materials not available locally, the transportation cost may form the significant part of embodied energy. For example, cement and steel, they are always transported from far flung places.

- ***Reduction in air, land and water pollution***

  The material should be such that its production should cause minimum pollution to air, water and land. For example, use of materials with low Volatile Organic Compounds (VOCs) emissions such as cement, paints cause little air pollution. Materials to be used in construction should also prevent leaching. Leaching is an environmental concern which contributes to groundwater contamination. To avoid land pollution, materials that reuse waste that would otherwise resulted into hazardous waste dumps and landfills such as fly ash bricks, recycled aggregates, red mud bricks etc.

- ***Durability and life span***

  Life cycle cost of materials is of paramount importance while planning building for urban future. Materials that are exceptionally durable or require low maintenance are to be preferred such as PVC/UPVC/CPVC pipers over GI pipes.

- ***Reduce Material Use***

  There is inclination towards technologies which minimise the use of conventional materials in construction. These technologies are not only energy efficient but also help in reduction of dead load of buildings such as ferro cement, mortar less masonry, fibre cement boards fixed with light gauge steel studs and light weight concrete etc.

- ***Energy Efficiency***

  There has been lot of work being done all over the world to come out with green technologies. Building materials and components which require less energy during construction e.g. compressed earth blocks and bricks, precast slabs, beams & columns; materials that help reduce the cooling loads such as aerated concrete blocks, hollow bricks; products that conserve energy like solar heating, LED; fixtures and equipments which conserve water like dual flush cisterns are the materials and technologies to look for.

- ***Biodegradability***

  Building materials, which are neither recyclable nor biodegradable like thermosetting plastics should be avoided. The building Materials which do not decompose easily are to be preferred such as wood or earthen materials.

- ***Reuse/Recycle***

  Any material which can be reused or recycled is sustainable such as use of recycled steel, aluminum is now more common than before.

Sustainable Building Materials and Construction Technologies in India

Some of the available and sustainable building Materials and technologies in India, which have proven to be successful after years of rigorous R&D, trials by scientists, engineers and architects from different parts of the country, are listed below:

Walling
- Fly ash bricks/blocks
- Fly ash lime gypsum bricks/ blocks (FaL-G)
- Cellular light weight concrete blocks (CLC)
- Autoclaved aerated blocks (AAC)
- Clay Fly ash bricks
- Compressed earth bricks/ blocks
- Interlocking type compressed earth blocks
- Ferrocement panels
- Solid Concrete blocks
- Hollow concrete blocks
- Precast stone masonry blocks
- Bamboo mat boards
- Rat trap bond in bricks
- Jute composite boards
- Coir composite boards
- Cement bonded particle boards
- Phosphogypsum based panels
- Bamboocrete
- Portland Pozzolana Cement Flyash / Calcined Clay Based / Portland Slag Cement
- Pozzolonic mortar in blended cement
- EPS composites
- Bricks/blocks/pavers from C&D waste

Roofing
- Filler slab
- Prefabricated reinforced brick panels and joist
- Precast RCC plank and joist system
- Ferrocement channels
- Micro concrete tiles
- Bamboo mat corrugated roofing sheet
- Bamboo mat ridge cap
- Jute-Bamboo composite roofing sheet
- Cuddapah slabs over RCC rafters
- L-panel sloping roofing
- Funicular shell roofing
- Brick funicular shell roofing
- Precast blocks over inverted T-beams
- Insulation Tiles from mining waste

Joinery and Miscellaneous
- RCC Door and Window Frames
- Ferro cement door shutters
- RCC Jallies
- Precast thin lintels
- Precast sunshades
- Ferro cement sun shades-cum lintel
- Brick on edge lintels
- Corbelling for lintels
- Brick arch for lintels
- Precast RCC shelves units
- Ferrocement staircases
- Plantation timber such as poplar, rubber, eucalyptus
- Geo-textiles

These building materials and technologies can help in reducing the GHGs emissions. There may be more such technologies, since India is a country of diversity and rich cultural and architectural heritage. These building materials and construction technologies do not compromise with the quality, safety and security of the buildings and mostly follow the prevailing building codes.

Suggestions for Sustainable Eco Friendly & Energy Efficient Building Materials

Any planning for urban future entails large scale adoption of environmentally sustainable construction in the peri-urban areas so as to arrest the adverse environmental impact of massive construction and infrastructural growth. The most common materials used for construction of a building are cement, steel, bricks, blocks, sand, aggregates, sanitary & drainage, plumbing pipes, wooden window, door frame and shutters, paints, water proofing compound etc. Here are a few suggestions as regards efficient building materials which are to be considered before using any conventional material. This would provide a meaningful differentiation and edge over the conventional thinking as regards impact on environment is considered.

Base material for construction: Reinforced Cement Concrete

Replace Ordinary Portland cement with Blended Portland Cement (BPC)

In order to reuse/ recycle waste product, it is strongly recommended that maximum percentage of pozzolana materials may be used as technically feasible by properly blending with portland cement. Use of blended cements conforming to IS 455, IS 1489 should be encouraged with necessary awareness and guidance for their use.

Wherever feasible supplementary cementitious materials like flyash, granulated blast furnace slag, metakaoline, rice husk ash may be used in concrete. Provisions given in IS 456 may be utilised for this purpose.

Replace natural sand and aggregates with manufactured ones

The constituent part of concrete is aggregates i.e. sand and coarse aggregates. There has been dearth of natural resources of aggregates due to environmental degradation and therefore, use of sand and aggregates from pulverized debris and/or sintered flyash is better viable option for sustainable development. The Indian standard IS3833 dwells upon equivalent to coarse and fine aggregates from natural sources.

Recycled Steel

Every tonne of recycled steel saves 1134 kg of iron ore, 635 kg of coal and 55 kg of limestone. Therefore, recycled steel may be utilised provided the end product meet the requirements of the relevant standard. IS 432, IS 1785 and IS 1786 give requirements for mild steel and medium tensile steel, hard drawn steel ores and high strength deformed bars respectively.

Indian standards are being referred here just to stress a point that use of these materials do not violate the code requirements and the structures are as good as conventional ones using these materials in RCC.

Alternative Structural Systems

The traditional structural systems are mainly comprising either of load bearing walls made up of bricks, blocks or RCC column-beam framed structure with brick or blocks walls as infill. These systems are being replaced by alternate systems in order to achieve economy, speed and quality. A future would be of precast factory-made building components for walls, roofs, columns, beams, staircases, lofts, balconies, and slabs. Some options for precast components being practiced successfully in the field are precast RC lintels, precast RC staircase components, RC plank and joist systems, waffle units, ribbed slabs and RC channel units, brick panel & cored units for roofs, RC L-panels to replace tiles and sheets for pitched roofs. Ferro cement, light weight concrete, fibre cement boards fixed with light gauge steel studs, load bearing panels from Phospho-Gypsum and other waste stiffened with steel stiffeners and filled with concrete are a few emerging and must technologies for sustainability. The cement used for these technologies must be blended Portland cement or ordinary Portland cement blended with raw pozzolana materials and reinforcement steel should be recycled steel.

Use of ready mix concrete and resinous curing agent instead of water is to be encouraged for mega projects. The basic intent is to use lesser quantities of material and to reduce site wastages, thus reducing the amount of resource extraction.

Masonry

To proscribe topsoil denudation and minimise use of fossil fuels as a result of burnt clay bricks, it is must to use bricks/blocks made from the following materials individually or in combination:

- Flyash + sand + lime bricks/ blocks (IS 4139)
- Pulverized debris + Cement bricks/blocks
- Red mud, Industrial waste based bricks/blocks
- Auto claved Aerated Lightweight blended Portland cement based concrete blocks (IS 2185)(P-III)
- Phospho-gypsum based blocks (IS 12679)
- Laterite + Cement blocks (IS 12440)
- Solid or hollow concrete blocks using artificial lightweight aggregates
- Cellular Light Weight Concrete Blocks (IS 2185)(P-IV)

Mortar

The mortar comprises of cement and sand. Both are dependent upon natural resources and energy intensive materials. In order to obviate dredging of water bodies for sand, depletion of natural resources and precious sources for energy for making cement and to reuse waste materials, Replace cement with blended Cement and further use of pozzolana material up to 30-50% by direct addition of raw pozzolana material such as Calcined clay or flyash. Replace sand with sand from pulverized debris and / or sintered flyash.

Plastering

The alternative plasters which are recommended for eco-friendly construction are calcium silicate plaster, fibre reinforced clay plaster, Phospho-gypsum plaster, non-erodable mud plaster. Use of resinous curing agent instead of water is further suggested.

Roofing & Ceiling

Use of energy efficient building materials and materials from renewable sources for roofing and ceiling is the future. Replace AC sheet, CGI sheets with micro-concrete roofing tiles or bamboo mat corrugated sheets. The conventional roofing of PVC, Foam PVC, Polycarbonates, Acrylics ought to be replaced with Fibre Reinforced Polymers (FRP) which is eco-friendly material.

Flooring, Paving and Road Work

To reuse/recycle waste products as building materials and to use energy efficient building materials, here are options:

- Flyash/industrial waste/pulverised debris blocks in Blended Portland Cement and/or lime-pozzolana concrete paving blocks (IS10359) for all outdoor paving (IS7245)
- Bedding sand for pavement and outdoor hard surfaces has to be from pulverised debris
- Terrazzo floor for terraces and semi covered areas (IS2114)
- Use ceramic tiles non-vitrified (IS13712)/ Mosaic tiles/ Terrazzo flooring (IS2114)/ Cement tiles (IS1237, 3801)/ Phospho-Gypsum tiles (IS12679)/ Bamboo board flooring, individually or in combination for interior spaces

Windows, Doors and openings

To use lesser quantities of material and to reduce site wastages, thus reducing the amount of resource extraction, the proposed alternatives are:

- Ferro cement and Precast R.C.C. lintel (IS9893), chajja and jalis instead of RCC
- Masonry bond combinations for jali work (achievable in rat trap bond)

Timber and Aluminum / Steel frames

To use lesser quantities of material, to reduce site wastages and to recycle waste products and prevent landfills, the timber and metal frames are to be replaced by

- Ferrocement and Precast R.C.C. frames (IS6523)/ frameless doors (IS15345) and/or Bamboo Reinforced Concrete Frames
- Hollow recycled steel channels (IS1038,7452) and recycled Aluminium Channels (IS1948) and Components

Timber if used for Shutter and Panels must be renewable timber from plantations with species having not more than 10 year cycle or timber from a government certified forest/ plantation or timber from salvaged wood.

Shutters and Panels

The shutters and panels made up of timber, plywood, glass, and aluminum, the use of following alternatives so as to protect rain-forest from excessive logging, and to reuse waste as building products is suggested.

- Use of MDF Board (IS12406)
- Use any of the following individually or in combination - Red Mud based composite door shutters, Laminated Hollow Composite Shutters, Fibre Reinforced Polymer Board, Coir Composite Board (Medium Density IS 15491), Bamboo Mat Board (IS13958), Bamboo mat Veneer Composite (IS 14588), Bagasse Board, Finger Jointed Plantation Board, Recycled Laminated Tube Board and Aluminium Foil+Paper+Plastic Composite Board
- Use PVC/ FRP Doors (IS14856)/ poly carbonate and/or recycled aluminum components in wet areas.

Electrical

To use energy efficient products and products having higher recycling properties (un- plasticised PVC) and to use recycled products of non-biodegradable components, the few suggestions for eco friendly electrical fittings are

- Use un plasticised PVC or HDPE products instead of aluminum, brass, PVC, G.I.,
- Use products with recycled aluminum and brass components

Water supply, sanitary and plumbing system

To prevent lead and asbestos contamination of water, to use energy efficient products and products having higher recycling properties (un-plasticised PVC) and to use recycled products of non-biodegradable components, replace the conventional systems with the following:

- Use R.C.C., un-plasticised PVC (IS15328)/CPVC, G.I., C.I. pipes instead of lead, A.C. pipes.
- Where applicable use products with recycled aluminum and brass components for fittings, fixtures and accessories
- Use Polymer Plastic (Random) (ISO EN 15874) hot/ cold water system instead of G.I.
- Manholes and covers - use pre-cast cement concrete and high strength un- plasticised PVC instead of C.I. (IS12592)

Wood Work

Timber used must be renewable timber from plantations with species having not more than 10 year cycle or timber from a government certified forest/ plantation or timber from salvaged wood. If Plywood is used, it should be phenol bonded and not urea bonded. The basic intent is to protect rainforest from excessive logging, to use renewable resources and wood substitutes made from waste products and to use chemicals with low VOC emissions. Instead of plywood and natural timber, use the following alternatives

- Use of MDF Board (IS12406)
- Use any of the following individually or in combination - Bamboo Ply/ Mat Board (IS 13958), Fibre Reinforced Polymer Board, Bagasse Board, Coir Composite Board (Medium Density IS 15491), Bamboo mat Veneer Composite (IS 14588), Finger Jointed Plantation Timber Board, Recycled Laminated Tube Board and Aluminium-Foil+Paper+Plastic Composite Board
- Use of Mica Laminates and Veneer on composite boards instead of natural timber

Water proofing chemicals, additives, sealants and adhesives

The use of water based chemicals instead of solvent based and use Epoxy resins instead of tar felt/ pitch is recommended.

Painting, polishing, priming and similar surface finishing

The use of Cement Paint (IS5410)/ Epoxy Resin Paint for external surfaces and use of Water based paints, enamels, primers and polishes is advised with the intent to use efficient building materials and chemical with low VOC emissions.

Emerging Construction Systems

The conventional construction systems are primarily cast in-situ slow pace construction systems and can not meet the present requirement of housing shortage. Therefore, it is judicious to adopt new construction systems which are fast track and deliver quality construction without compromis¬ing functional and structural requirements.

These new systems are precast concrete construction, hot and cold form steel construction, large formwork systems, sandwich panel construction, factory made prefabricated systems etc. These systems are being practiced world over and some of the developing countries have successfully met the huge housing demand using them. It is time that construction fraternity in India take a para¬digm shift from slow track system to these fast track emerg¬ing systems. BMTPC has identified, evaluated and certificated following emerging construction systems:

Engineered Formwork System

1 Monolithic Concrete Construction System
2. Modular Tunnel Form

Stay-In-Place Formwork System

3. Insulating Concrete Forms
4. Monolithic Insulated Concrete System
5. Structural Stay-in-place formwork system
6. Lost-in-place formwork system-Plaswall Panel system
7. Lost-in-place formwork system-Plasmolite Wall Panels
8. Sismo Building Technology
9. Glass Fibre Reinforced Gypsum Panel System
10. Stay-In-Place PVC Wall Forms

Prefabricated Sandwich Panel System

11. Advanced Building System – Emmedue
12. Rapid Panels
13. Reinforced EPS Core Panel System
14. QuickBuild 3D Panels
15. Concrewall Panel System
16. Prefabricated Fibre Reinforced Sandwich Panels
17. Rising EPS (Beads) Cement Panels
18. Flyash EPS (Beads) Cement Sandwich Panels
19. PIR Dry Wall Pre-Fab Panel System
20. Baupanel System
21. K-Wall Panels
22. V-Infill Wall (Light Weight EPS Wall)
23. Nano Living System Technology

Light Gauge Steel Structural System

24. Light Gauge Steel Framed Structure (LGSF)

25. Light Gauge Steel Framed Structure with Infill Concrete Panel Technology

Prefabricated Steel Structural System

26. Factory Made Fast Track Modular Building System
27. Speed Floor System
28. Continuous Sandwich (PUF) Panels With Steel Structure

Precast Concrete Construction System

29. SRPL Building System (Waffle-Crete)
30. Precast Large Concrete Panel System
31. Industrialized 3-S system using RCC precast with or without shear walls, columns, beams, Cellular Light Weight Concrete Slabs/Semi-Precast Solid Slab
32. Walltec Hollowcore Concrete Panel
33. Robomatic Hollowcore Concrete Wall Panels
34. Urbanaac Precast Construction Technology

Closure

It is high time to use materials, technologies and practices which conserve natural resources, optimize energy efficiency, use less water, generate less waste, minimize air & land pollution and provide improved indoor environment for occupants, as compared to a conventional cast-in-place conventional construction. These systems fall under green construction and can be considered future of Indian construction industry in light of climate change mitigation.

Let us not deprive posterity from their share of resources, mother earth has bequeathed….

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Sensitization Programmes on Emerging Technologies for Housing

BMTPC organizes capacity building programmes on regular basis in various States to enhance the capacity of engineers & architects in the area of quality control and good construction practices and also to introduce them with the emerging technologies in housing sector for construction of houses under PMAY (Urban) and other schemes of the state/central Government.

Seminar on Emerging Technologies for Affordable Housing on 30 October, 2018 at Amity University, NOIDA Campus

Seminar on New Trends in Building Material & Sustainable Technology on 14-15 March, 2019 with Department of Architecture & Planning, Gautam Buddha University, Greater Noida

Sensitization Programme on “Use of New Technologies in Mass housing” under PMAY (Urban) on 17 June 2019 at Lucknow

BMTPC's Role in Implementation of the Pradhan Mantri Awas Yojana (Urban)

Site Scrutiny along with DPR Desk Scrutiny of projects under BLC vertical of PMAY

BMTPC has been designated appraisal and monitoring agency under Pradhan Mantri Awas Yojana - Housing for All (Urban) Mission for projects in various states/UTs falling in Earthquake Zone IV and Zone V. The following project has been scrutinized & visited during 2018-19:

1. DPR for beneficiary led Construction Dhemaji MB (1569 New Construction Houses) projects in Assam
2. DPR for construction of Dibrugarh DA (1033 New Construction houses) project in Assam
3. DPR for construction of 291 New Houses under BLC vertical for Bokolia Town Committee
4. DPR for construction Enhancement (121 DUs) under BLC (Enhancement) at Jammu Town J&K
5. Site Scrutiny along with DPR Desk Scrutiny of project of Srinagar (2566) projects under BLC (New) vertical
6. DPR for construction of 2203 New Houses under BLC vertical for Lilong (Thoubal) Municipal Council, Manipur
7. DPR for Construction of 1 BLC (New Construction) project of Imphal Municipal Corporation for Construction of 13,715 nos. of Dwelling Units (DUs) in respect of 1 ULB in Manipur
8. DPR for 129 DUs under BLC at Mairang, Meghalaya
9. DPR for 765 New DUs at Nongstoin Town, Meghalaya under vertical BLC
10. DPR for 402 DUs New Construction & 167 under Enhancement in Tura Town, Meghalaya under BLC vertical
11. DPR for construction of Tuli (577 New Construction houses) projects in Nagaland
12. DPR for construction of Tseminyu (95 Enhancement houses) projects in Nagaland
13. DPR for construction of 759 New DUs under BLC at Chumukedima Town, Nagaland
14. DPR for construction of 359 Enhancement DUs under BLC at Chumukedima Town, Nagaland
15. DPR Desk Scrutiny of project of 219 DU's BLC New Construction & Enhancement in Municipal Council Bilaspur H.P.

Participation in Global Housing Technology Challenge - India

BMTPC has provided technical support for Launch of GHTC-India on 14 January, 2019 and main event of Global Housing Technology Challenge – India organized from 2-3 March, 2019 at New Delhi. The GHTC-India is an initiative of the Ministry of Housing & Urban Affairs, Government of India which seeks to identify cost-effective and speedy construction technologies. The identified technologies with the capability to provide maximum number of houses in minimum time and cost would be mainstreamed into the Indian construction industry and piloted across different climatic conditions of the country. As part of Technical Evaluation Committee (TEC), coordinated the finalization of recommendation of TEC regarding basket of proven technologies for Light House Projects (LHPs). The recommendations regarding Indian Support Partner, Selection of States for LHPs and Potential technologies for Accelerator & Incubation Support, were also formulated by TEC.

The proven technologies are being showcased through execution of Light House Projects (LHPs) across six States. These LHPs will be live laboratories to establish clean and green construction practices across India and will help in sustainable construction. BMTPC is actively involved in the implemenation of Light House Projects.

Performance Appraisal Certification Scheme (PACS)

Introduction

Performance Appraisal Certification Scheme (PACS) is a third party operated voluntary scheme for providing Performance Appraisal Certificate (PAC) to a manufacturer/supplier/installer of a product/ system which includes building materials, elements of construction, assemblies, technologies etc. after due assessment. The process encompasses:

- Establishing criteria of performance
- Verifying that the product/ system conforms to the requirements for satisfactory performance, durability and safety
- Operation of a Quality Assurance Scheme by the manufacturer/supplier/installer
- Issue of PAC providing, amongst other things, necessary data to designers and users.

The Govt. of India, the then Ministry of Urban Development and Poverty Alleviation authorized BMTPC through Gazette Notification dated 4th December, 1999 to operate PACS.

PACS operation is fully transparent and in order to ensure transparency and objectivity, it is administered by a tier of committees of experts, the structure consists of:

1) BMTPC Board of Agreement (BMBA) with a senior technical expert as its President and nominees from Professional Bodies, major Govt. bodies like CSIR, Central & State PWDs, BIS, DGS&D, Industry Associations, eminent individuals etc.

2) Technical Assessment Committee (TAC) with a senior technical expert as its Chairman and members from R & D Institution, BIS, user departments and other concerned agencies/ experts.

The Committee is assisted in the assessment of products/ systems by individual experts in the related fields and well established laboratories.

Need for PACS

As a part of its mandate, BMTPC has lent its support in the development of a number of non-traditional building materials/ components and systems and machinery for their manufacture. These newly developed products are user friendly and eco-friendly. In the absence of data regarding design and use of these products, these have not become popular/ are not being used as widely as they should have been. National standards do not exist for some of these products or existing standards do not specifically cover the special aspects for these products. Therefore, a need was felt for a system which provides the necessary information to remove the inhibitions and doubts in the minds of designers and users.

PAC helps in formulating National Standards and Schedule of Rates

- PACS is designed to create necessary data and documents which are required for formulation of a standard
- While processing for PAC, criteria are fixed for performance of a product/ system
- Where test methods are not available, these are developed for specific product/system
- Laboratory, factory and field test verify performance
- The Certificate contains details required for framing Specifications and Code of Practice
- Certificates are forwarded to BIS and CPWD for formulation/review of relevant Indian Standard and Schedule of Rates (SoR) respectively.

PACs Approved and Issued Till Date

Within the framework of Power and Functions of Technical Assessment Committee (TAC), Applications for appraisal of new building materials and construction technologies were received by BMTPC. Performance Criteria, based on National & International practices were framed in consultation with other members.

So far 15 meetings of TAC have been held and 61 PACs have been issued till now.

Progress Report of Performance Appraisal Certification Scheme (PACS)

The details of activities carried out under Performance Appraisal Certification Scheme (PACS) during 2019 are highlighted below:

Approval of PACs

PAC for the following 4 systems/products approved in the TAC's 15th meeting held on 29th March, 2019 were approved and issued to the respective manufacturers:

1. Stay-in place PVC Wall Forms
2. K-Wall Panel
3. Precast Construction Technology
4. V-Infill Walls

Brief about these technologies are given hereunder:

1. Stay-in place PVC Wall Forms

System consists of rigid polyvinyl chloride (PVC) based polymer components that serve as a permanent stay-in-place durable finished form-work for concrete walls. The extruded components slide and interlock together to create continuous formwork with the two faces of the wall connected together by continuous web members forming hollow rectangular components. The hollow components are erected and filled with concrete, in situ, to provide a monolithic concrete wall with enhanced curing capacity. The polymer encasement provides crack control vertically and horizontally for the concrete, and provides vertical tension reinforcement thus increasing the structural strength of the wall. The resulting system is unique and provides substantial advantages in terms of structural strength, durability enhancement, weather resistance, and seismic resistance,

2. K-Wall Panel

Wall panels are factory produced hollow core using light weight concrete made of ordinary Portland cement, fly ash, perlite, foam, fevicol DDL, fiber-glass mesh, river sand and water. Panels have cylindrical hollow cores. The corresponding nominal weight shall be 35 kg/m^2, 61 kg/m^2 and 102 kg/m^2 for 65mm, 80mm, and and100mm thick panels respectively. Hollow cores are incorporated in panels to reduce weight, facilitate mechanical, electrical and plumbing services through hollow core, thereby increasing sound and thermal insulation properties. The sides of the panels are tongued and grooved to facilitate jointing.

K-Wall Panels

Stay-in place PVC Wall Forms

3. Precast Construction Technology

This is a system of casting concrete in a reusable mould or "form" which is then treated in a controlled environment, conveyed to the construction site and lifted to the place. Precast Construction Technology consists of various

Precast Construction Technology

precast elements such as walls, beams, slabs, columns, staircase, landing and some customized elements that are standardized and designed for stability, durability and structural integrity of the building. This technology is suitable for construction of high rise buildings resisting seismic and wind induced lateral loads along with gravity loads.

4. V-Infill Walls

V-Infill Wall is construction technology using factory made 8/10mm fibre cement boards (Vboard) on either side of GI studs and erected to produce straight to finish walls which are filled with light weight concrete made of EPS, cement, sand and additive. The system may be integrated with conventional column and beam for pre-engineered buildings. The walls may be used as partition walls for external and internal applications. The GI studs are "C" cross-section with built in notch, slots, service holes etc. fixed with floor and ceiling channels using anchor fasteners. Electrical and plumbing

V-Infill Walls

pipes/conduits shall be provided in the service holes of studs before concreting is done.

5. Nano Living System Technology

Nano Living System Technology comprise of an inner and outer skin of magnesium oxide board, with an injected core of closed cell, polyurethane foam, free of Chlorofluorocarbon (CFC) blowing agent. Cold formed metal studs are incorporated within the foam and between the magnesium oxide board skins at nominal 600mm centres.

Nano Composite Wall Panels

Receipt of Applications for PACs

Applications for the following new products/systems have been received from the manufacturers for processing further for issue of PACs:

1. PVC Wall forms
2. Conecc Precast Wall Panels
3. Bamboo Flooring
4. Exterior Drywall System
5. Integrated Hybrid Solution: ONE
6. Insulated Sandwich Panel (Glamet)
7. Insulated Sandwich Panel (Monowall)
8. Insulated Sandwich Panel (Super Wall)
9. Insulated Sandwich Panel (Hipertec Roof)
10. Insulated Sandwich Panel (Hipertec Wall))
11. Strand Woven Bamboo Wood Floor Tiles & Wall panels
12. Hybrid Building Bodyguard (Ready to use)
13. Rapicon Wall Panels & Prefabricated Steel Structures
14. LGSF Building Components & Erection
15. Bamboo Flooring and Wall Cladding
16. Magic XP- Elastomeric Paintable Plaster

Receipt of Applications for Renewal of PACs

PACs for the following systems/ products have been received for renewal.

1. Sound Proof Drainage Piping System
2. Rising EPS (Beads) Cement Panels
3. Underground Water Storage Tank ((Sump)
4. PVC Profile Door.
5. PIR Dry Wall Prefab Panel System
6. Continuous Sandwich (PUF) Panel with Steel Structure.
7. Prefabricated Fibre Reinforced Sandwich Panels

The above applications are being processed on the basis of data furnished by the firms, information available on their web sites, inspection of manufacturing plants at site of works and testing of samples of the products/systems etc. before preparation of Performance Appraisal Certificates (PACs).

Inspection of Works

Inspection of Works of the following new systems and renewal of PACs has been carried out BMTPC and TAC members:

- PVC Wall Forms, Vijayawada
- Strand Woven Bamboo Wood Floor Tiles & Wall panels, Assam
- Bamboo Flooring, Mumbai
- Exterior Drywall System, Mumbai .

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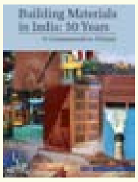

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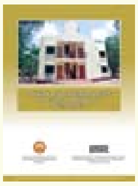

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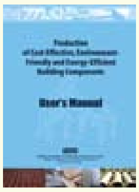

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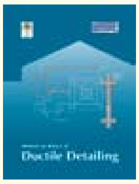

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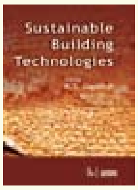

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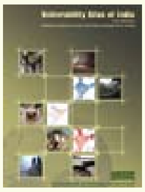

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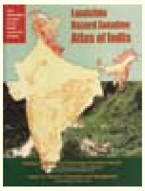

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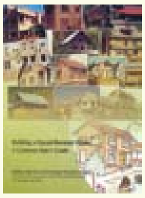

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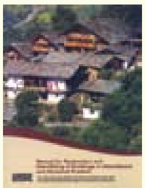

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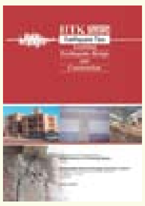

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October 7
World Habitat Day 2019

Building Materials & Technology Promotion Council (BMTPC) under the Ministry of Housing & Urban Affairs strives to bridge the gap between laboratory research and field level application in the area of building materials and construction technologies including disaster resistant construction practices.

Vision

"BMTPC to be world class knowledge and demonstration hub for providing solutions to all with special focus on common man in the area of sustainable building materials, appropriate construction technologies & systems including disaster resistant construction."

Mission

"To work towards a comprehensive and integrated approach for promotion and transfer of potential, cost-effective, environment-friendly, disaster resistant building materials and technologies including locally available materials from lab to land for sustainable development of housing."

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