

# Solid wastes generation in India and their recycling potential in building materials

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## Abstract

Presently in India, about 960 million tonnes of solid waste is being generated annually as by-products during industrial, mining, municipal, agricultural and other processes. Of this ~350 million tonnes are organic wastes from agricultural sources; ~290 million tonnes are inorganic waste of industrial and mining sectors and ~4.5 million tonnes are hazardous in nature. Advances in solid waste management resulted in alternative construction materials as a substitute to traditional materials like bricks, blocks, tiles, aggregates, ceramics, cement, lime, soil, timber and paint. To safeguard the environment, efforts are being made for recycling different wastes and utilise them in value added applications. In this paper, present status on generation and utilization of both non-hazardous and hazardous solid wastes in India, their recycling potentials and environmental implication are reported and discussed in details.

*Keywords:* Hazardous and non-hazardous waste; Recycling; Construction materials; Environmental pollution; Resources conservation; Greener environment

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## 1. Introduction

Traditionally materials like clay, sand, stone, gravels, cement, brick, block, tiles, distemper, paint, timber and steel are being used as major building components in construction sector. All these materials have been produced from the existing natural resources and will have intrinsic distinctiveness for damaging the environment due to their continuous exploitation. Nevertheless, during the process of manufacturing various building materials, especially decomposition of calcium carbonate, lime and cement manufacturing, high concentration of carbon monoxide, oxides of sulphur, oxides of nitrogen and suspended particulate matter are invariably emitted to the atmosphere. Exposure to such toxic gases escaping into the environment does lead to major contamination of air, water, soil, flora, fauna, aquatic life and finally influences human health and their living conditions. The cost of

construction materials is increasing incrementally. In India, the cost of cement during 1995 was Rs. 1.25/kg and in 2005 the price increased ~three times. In case of bricks the price was Rs. 0.66 per brick in 1995 and the present rate is Rs. 1.9 per brick. Similarly, over a period of 10 years from the year 1995 the price of sand has increased four times. Also due to high transportation costs of these raw materials, demand, environmental restrictions, it is essential to find functional substitutes for conventional building materials in the construction industry. In view of the importance of saving of energy and conservation of resources, efficient recycling of all these solid wastes is now a global concern requiring extensive R&D work towards exploring newer applications and maximizing use of existing technologies for a sustainable and environmentally sound management. As a result, in India, the informal sector and secondary industries recycle 15–20% of solid wastes in various building components [1–3]. More details on the availability of solid wastes of all kinds from different sources, their present utilization and recycling potentials for safe, sound and substantial development are summarised and discussed in this paper.

## 2. Solid wastes generation and their environmental importance

Growth of population, increasing urbanisation, rising standards of living due to technological innovations have contributed to an increase both in the quantity and variety of solid wastes generated by industrial, mining, domestic and agricultural activities. Globally the estimated quantity of wastes generation was 12 billion tonnes in the year 2002 of which 11 billion tonnes were industrial wastes and 1.6 billion tonnes were municipal solid wastes (MSW). About 19 billion tonnes of solid wastes are expected to be generated annually by the year 2025 [4]. Annually, Asia alone generates  $\sim 4.4$  billion tonnes of solid wastes and MSW comprise 790 million tones (MT) of which about 48 ( $\sim 6\%$ ) MT are generated in India [4,5]. By the year 2047, MSW generation in India, is expected to reach 300 MT and land requirement for disposal of this waste would be  $169.6 \text{ km}^2$  as against which only  $20.2 \text{ km}^2$  were occupied in 1997 for management of 48 MT [5]. Fig. 1 shows the details on current status of solid waste (non-hazardous and hazardous waste) generation from different sources in India [2,6]. As can be seen from Fig. 1 that apart from municipal wastes, the organic wastes from agricultural sources alone contribute more than 350 MT per year. However, it is reported that about 600 MT of wastes have been generated in India from agricultural sources alone [7]. The major quantity of wastes generated from agricultural sources are sugarcane baggase, paddy and wheat straw and husk, wastes of vegetables, food products, tea, oil production, jute fibre, groundnut shell, wooden mill waste, coconut husk, cotton stalk etc., [2,6,8]. The major industrial non-hazardous inorganic solid wastes are coal combustion residues, bauxite red mud, tailings from aluminum, iron, copper and zinc primary extraction processes. Generation of all these inorganic industrial

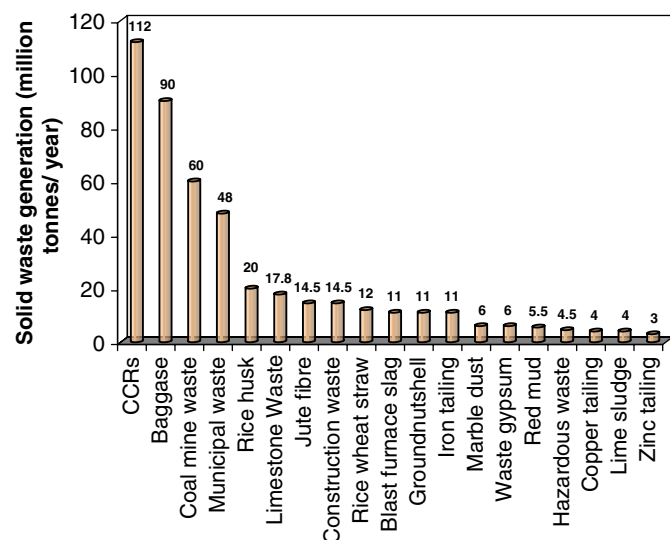


Fig. 1. Current status of solid waste generation in India. (Million tonnes/year).

wastes in India is estimated to be  $\sim 290$  MT per annum [6,9]. In India,  $\sim 4.5$  MT of hazardous wastes are being generated annually during different industrial process like electroplating, various metal extraction processes, galvanizing, refinery, petrochemical industries, pharmaceutical and pesticide industries [7,10]. However, it is envisaged that the total solid wastes from municipal, agricultural, non-hazardous and hazardous wastes generated from different industrial processes in India seem to be even higher than the reported data. Already accumulated solid wastes and their increasing annual production are a major source of pollution. Due to environmental degradation, energy consumption and financial constraints, various organizations in India and abroad, apart from the regulatory framework of United States Environmental Protection Agency (USEPA), have recommended various qualitative guidelines for generation, treatment, transport, handling, disposal and recycling of non-hazardous and hazardous wastes [10–14]. Safe management of hazardous wastes is of paramount importance. It is now a global concern, to find a socio, techno-economic, environmental friendly solution to sustain a cleaner and greener environment.

The heterogeneous characteristics of the huge quantity of wastes generated lead to complexity in recycling and utilisation. The comparative physico-chemical characteristics of solid wastes generated from hazardous and non-hazardous sources over clay and cement are shown in Tables 1 and 2, respectively [3,7,15–18]. The physico-chemical properties of solid wastes depend on the properties of feed raw materials, mineralogical origin, operating process and their efficiency. It is evident from the characteristics of these wastes, generated from different processes, that they have good potentials for recycling and utilization in developing various value-added building components.

Use of industrial wastes and by-products as an aggregate or raw material is of great practical significance for developing building material components as substitutes for the traditional materials and providing an alternative or supplementary materials to the housing industry in a cost effective manner. In order to effectively utilise all these solid wastes, effort have been made and mathematical models were also established universally and as a consequence considerable quantity of wastes is now being recycled and used to achieve environmentally sound management [19]. As against the Not In My Back Yard (NIMBY) Syndrome view on the inherent imbalance in the project's cost in terms of human health and environment due to improper management of all these wastes, now, the Yes In My Back Yard (YIMBY) concept is gaining ground in most of the countries due to the benefits of newer technologies on waste recycling.

### 2.1. Organic solid wastes generation, recycling and utilization

Solid waste generation from organic sources includes municipal and urban wastes, animal wastes, farming

Table 1  
Comparative physical characteristic of solid wastes generated from hazardous and non-hazardous sources over sand and clay soil

Sl. No.	Characteristics	CCRs	Jarosite	Copper slag	Red mud	Marble dust	Sand	Clay (Kaolinite)
1	Particle size ( $\mu\text{m}$ ) ( $D_{80}$ )	130–260	14–23	<150	<2.0	43.9–103.1	300–600	<15
1	Bulk density (g/cc)	0.96–1.25	0.97–1.0	1.44–1.62	1.36–1.6	1.87	1.59	1.48
2	Specific gravity	2.08–2.3	2.92–3.0	2.8–3.8	2.6–3.4	2.51–2.76	2.64	2.37–2.56
3	Porosity (%)	37.45–37.5	66.5–67.7	—	49.26–54.66	39.65–49.0	68.41	36.31
4	pH	6.98–7.03	6.7–6.85	<5.70	11–12.5	8.36–9.5	8.18	7.64
5	EC ( $\mu\text{mhos/cm}$ )	491.65–504.24	13260–14090	500.56	495–766.48	276.94–500.	246.11	6506.67

Table 2  
Comparative chemical characteristic of solid wastes generated from hazardous and non-hazardous sources over cement and clay soil

S No.	Constituents in %	CCRs	Jarosite	Red Mud	Marble waste	Copper Slag	Phosphogypsum	Cement OPC	Clay (Kaolinite)
1.	SiO <sub>2</sub>	55.9–57.6	2.91–4.0	5–13.5	1.69–8.5	28.0–32.0	2.41	19.7–22.62	42.09–61.54
2.	Al <sub>2</sub> O <sub>3</sub>	16.0–24.0	0.70–4.4	10–23	1.3–6.1	2.4–6.8	<0.5	4.93–6.6	28.65–32.9
3.	Fe <sub>2</sub> O <sub>3</sub>	5.38–6.34	51.28	28–56	0.25–3.66	44–47.70	<0.5	3.19–3.5	11.77–12.88
4.	CaO	0.25–6.5	0.98–12.0	8–17	29.5–55.4	1.65–6.60	32–41	63.0–64.0	0.13–2.22
5.	MgO	1.01–1.34	1.81–1.94	0.35	4.04–20.6	0.75–2.54	0.10	0.7–2.38	2.04–2.63
6.	K <sub>2</sub> O	1.62–2.13	0.71–0.75	0.39–0.50	0.01–1.9	0.61	<0.22	0.55–0.6	0.74–3.51
7.	ZnO	1–2.6	13.29	<0.5	NA	0.005–1.30	NA	NA	NA
8.	PbO	< 0.1	1.8–2.04	<0.2	NA	0.002–0.28	4–5.11	NA	NA
9.	CuO	< 0.1%	0.46–1.65	<0.2	NA	0.46–3.76	3.42–17.6	NA	NA
10	LOI	1.53–	>12.6	6–14	40.6–43.46	<1	19.20	0.3–1.75	<12.55

NA—not analysed.

wastes, horticulture wastes, domestic refuses and other agro industrial wastes. A number of wide ranging agro industries have come up in India due to availability of agricultural resources, manpower and technological innovations. The main objective of waste management system is to maximise economic benefits and at the same time protection of the environment. The urban waste mainly consists of organic matter (~46%), paper (~6%), glass (0.7%), rags (~3.2%), plastic (1%) and the rest is moisture [8]. Animal wastes are primarily composed of organics and moisture. Decomposition of both the animal and urban organic wastes can be done in an aerobic or anaerobic digestion. Since, huge quantity of both these organic wastes are produced annually in India, there is great potential for production of CH<sub>4</sub> and also which will help to reduce the green house gases thereby contribute to reduction of global warming. India is one of the richest countries in agricultural resources. Agricultural wastes are the by-products of various agricultural activities such as crop production, crop harvest, saw milling, agro-industrial processing and others. In India sugar industry alone produces about 90 MT of baggase per year and being used in manufacturing of insulation boards, wall panels, printing paper and corrugating medium. [2,20]. There is a growing concern for agricultural wastes, which are mostly being burnt thereby contributing considerably to global warming. Use of organic wastes such as peanut husk, mahau and linseed residues, coconut coir dust, rubber

seedpod, spent cashew nut shell etc., were explored and used for different applications as shown in Table 3 [2,6,20].

## 2.2. Inorganic solid wastes generation, recycling and utilisation

Inorganic solid wastes are of both non-hazardous and hazardous in nature. Inorganic non-hazardous solid wastes are primarily from mining sector and these wastes are the primary process rejects which constitute overburden wastes. However, the inorganic hazardous wastes are mainly from the secondary process of non-ferrous metal extraction like lead, zinc, and copper. The details of both non-hazardous and hazardous inorganic wastes generation, recycling potentials and their environmental concerns are reported and discussed in the following section.

### 2.2.1. Solid waste generation from mining operations and their utilisation

In India, more than 200 MT of non-hazardous inorganic solid wastes are being generated every year [15,21], out of which ~80 MT are mine tailings/ores of iron, copper and zinc mines etc., [6,16]. India has considerable economically useful minerals and they constitute one-quarter of the world's known mineral resources. In India, Rajasthan, Chhattisgarh, Bihar, Madhya Pradesh, Orissa, Andhra Pradesh are rich in minerals, especially non-ferrous and

Table 3  
Types and nature of solid wastes and their recycling and utilisation potentials

Sl. No.	Types of solid wastes	Source details	Recycling and utilisation in building application
1	Agro waste (organic nature)	Baggage, Rice and wheat straw and husk, Cotton stalk, Saw mill waste, ground nut shell, banana stalk and jute, sisal and vegetable residues.	Particle boards, insulation boards, wall panels, printing paper and corrugating medium, roofing sheets, fuel, binder, fibrous building panels, bricks, acid proof cement, coir fibre, reinforced composite, polymer composites, cement board.
2	Industrial wastes (inorganic)	Coal combustion residues, steel slag, bauxite red mud, Construction debris	Cement, bricks, blocks, tiles, paint, aggregate, concrete, wood substitute products, ceramic products
3	Mining/Mineral waste	Coal washeries waste, mining overburden waste Tailing from iron, copper, zinc, gold, aluminium industries	Bricks, tiles, lightweight aggregates, fuel
4	Non hazardous other process waste	Waste gypsum, lime sludge, lime stone waste, marble processing residues, broken glass and ceramics, kiln dust	Gypsum plaster, fibrous gypsum boards, bricks, blocks, cement clinker, super sulfate cement, Hydraulic binder
5	Hazardous Waste	Metallurgical residues, galvanising waste, Tannery waste	Cement, bricks, tiles, ceramics and board

ferrous metals/minerals. India has considerable mining deposits of iron ore, bauxite ore, tin ore, dolomite, chromite, manganese, limestone, diamonds, gold, lignite, bituminous and sub-bituminous coal etc. After the ore is extracted from the mine, the first step in beneficiation is generally crushing and grinding. The crushed ores are then concentrated to separate the valuable mineral and metal particles from the less valuable rock. Beneficiation processes include physical/chemical separation techniques such as gravity concentration, magnetic separation, electrostatic separation, flotation, solvent extraction, electro-winning, leaching, precipitation, and amalgamation. The beneficiation processes generate tailings, which generally leave the mill as slurry consisting of 40–70% liquid and 30–60% solids. Most mine tailings are disposed of in on-site impoundments/ponds.

Mining operations are the primary activity in any industrial process and major sources of pollutants include overburden waste disposal, tailings, dump leaches, mine water seepage and other process wastes disposed near-by the industries. Management of mining wastes is likely to be of some significance in many developing countries where recycling/extraction and processing of minerals have important economic values. In coal washery operations about 50% of the material is separated as colliery shale or hard rock. Most of this spoil is used as filler in road embankments. Some spoils, be considered for use in producing lightweight aggregate. Presently most of these wastes are being recycled and used for manufacture of various building materials and details are shown in Table 4 [2,6,15,20]. Studies on potential use of different mining tailings in bricks have revealed that this waste alongwith clay can be effectively utilized for making better quality fired bricks and use of copper tailing (60%) has resulted in achieving strength of 190 kg/cm<sup>2</sup> under firing temperature of 950 °C [22].

### 2.2.2. Construction debris, Marble processing waste and their recycling potentials

In India, about 14.5 MT of solid wastes are generated annually from construction industries, which include wasted sand, gravel, bitumen, bricks, and masonry, concrete. However, some quantity of such waste is being recycled and utilised in building materials and share of recycled materials varies from 25% in old buildings to as high as 75% in new buildings [23,24]. In India, about 6 MT of waste from marble industries are being released from marble cutting, polishing, processing, and grinding. Rajasthan alone accounts for almost 95% of the total marble produced in the country and can be considered as the world largest marble deposits. There are about 4000 marble mines in Rajasthan and about 70% of the processing wastes is being disposed locally [6,15,25]. The marble dust is usually dumped on the riverbeds and this possesses a major environmental concern. In dry season, the marble powder/dust dangles in the air, flies and deposits on vegetation and crop. All these significantly affect the environment and local ecosystems. The marble dust disposed in the riverbed and around the production facilities causes reduction in porosity and permeability of the topsoil and results in water logging. Further, fine particles result in poor fertility of the soil due to increase in alkalinity.

Attempts are being made to utilise marble wastes in different applications like road construction, concrete and asphalt aggregates, cement, and other building materials. [25]. Earlier work carried out on polymer composites substituting wood products indicates that about 40% of marble slurry waste can be utilized. Importantly, these artificial wood products have showed better quality compared with teak wood, medium density and particle boards [15]. It is evident from such studies that there is a great potential for recycling of wastes released from different industrial processes. Work carried out by earlier

Table 4  
Recyclable hazardous wastes and their sources

S.No.	Industrial processes	Resultant waste types
1	Production or use of zinc, zinc oxide	Zinc ashes, dross, filter cake, jarosite
2	Production and use of copper oxide, Electro-refining & winning operations in copper smelter	Exhaust dust, residues, sledges.
3	Production of crude iron and steel	Dust, slag, sludge
4	Production of aluminium (primary or secondary production)	Filtered material, cathode residues
5	Production of asbestos or asbestos-containing materials and or products	Asbestos-containing residue
6	Metal surface treatment, such as leaching, staining, polishing, cleaning, degreasing and hot dip galvanising	Acidic and alkali residues, sludge,
7	Production or use of coatings paints, dyes, dye-intermediates and pigments Removal of coatings from ships.	Blasting material contaminated with coating residues ,sludge from waste water purification in production processes
8	Production or materials made with silicones	Silicone-containing residues
9	Waste treatment processes, e.g. incineration, distillation and separation and concentration techniques	Sludge, ashes, flue gas cleaning residue
10	Tanning of leather/ tannary and leather production process waste	Chromium bearing residue, Chromium bearing sludge, leather forming waste
11	Spent solvent from refinery	Solvent residues

researchers has shown that marble process residues could be used in road construction since they help to reduce permeability and improve settlement and consolidation properties [26,27]. Waste of marble slurry showed great potential in improving quality of jarosite bricks and also to immobilise the hazardous substances leaching from jarosite [6]. Nevertheless, detailed studies are required for effective recycling of marble wastes.

### 2.3. Recycling and utilization of other non-hazardous inorganic wastes

#### 2.3.1. Coal combustion residues from thermal power plants

Coal Combustion Residues (CCRs) is a collective term referring to the residues such as fly ash, bottom ash, boiler slag, and other solid particles produced from coal combustion finally disposed to ash pond. Because of economic viability, thermal power plants mostly dispose the ashes collected by bag filter or electrostatic precipitator, as well as unburned carbon and residues settled at the bottom of the boiler together as slurry to the pond in which these are stored for a longer period. In India, thermal power plants release ~112 MT of CCRs as solid waste per annum and being utilised in cement, concrete, bricks, in back fill/road embankments, adhesives, wallboard, agriculture/soil amelioration, wasteland development, wood substitutes, paint and various environmental applications [28]. In India, about 211 billion tonnes of coal reserves exist as the largest resource of energy. Though nuclear power programme is envisaged for generation of 20,000 Mega Watt (MW) energy by the year 2020, India mainly depends on the fossil fuel from coal sources. However, to achieve a sustainable development, India need to generate ~260,000 MW of power by the year 2020 and as a consequence ~270 MT of CCRs is expected to be released. In India, presently, ~35% of the CCRs is being utilized and utilization of remaining almost 65% of CCRs is a

major challenge. Keeping in view of alarming situation for safe management of CCRs to achieve Environmental Sound Management, it is crucial time for maximising the use of CCRs in newer area of applications, confidence building and increase in acceptability of CCRs-based existing products among the user agencies. In order to overcome the difficulties connected with the problem, a detailed long-term environmental and economic analysis including Life Cycle Assessment studies are to be carried out on the CCRs-based technologies with an objective to maximize the use of CCRs.

#### 2.3.2. Bauxite red mud and waste gypsum generation, recycling and utilisation

Bauxite red mud is a by-product, released in Bayer process of aluminium extraction from bauxite ore. In this process, bauxite is reacted with caustic soda under heat and pressure. The major solid components of the red mud includes iron minerals goethite, hematite and magnetite [29] and about 60% of them are released as by products/wastes. In India, current status of total quantity of bauxite consumption is about 8.375 MT and annually releases ~5.5 MT of red mud. The quantity of red mud generated during the aluminum extraction process varies significantly on the properties of bauxite, operating conditions of the Bayer process, the process temperature and pressure [17,30,31]. Red mud released from aluminium production, during processing of bauxite, are highly alkaline in nature, which need special attention to avoid contamination of soil, surface and ground water.

Red mud has been used as a substitute for ordinary clay for producing bricks [32]. Below 900 °C red mud can be considered an inert component in mixtures with carbonate rich clays so that the mechanical strength decreases as the red mud concentration increases [32]. Several attempts have been made to recycle red mud not only to avoid environmental pollution, but also to use it in developing

polymer composites, wood substitute products, bricks, ceramic glazes such as porcelain, sanitary ware glazes, electroporcelain glazes, tiles and extraction of metals [17,32,33]. For production of glazes up to 37% of red mud was used in achieving good quality of surface finish, strength and abrasion resistance [17]. During high temperature firing at 1050 °C, addition of red mud increases the density and flexural strength and formation of glassy phase. One of the studies carried out in Spain showed that red mud could be used as adsorbent for wastewater treatment especially for adsorption of  $\text{Cu}^{2+}$ ,  $\text{Zn}^{2+}$ ,  $\text{Ni}^{2+}$  and  $\text{Cd}^{2+}$  [34]. Lightweight aggregate is produced from red mud by adding gas-producing materials such as carbonaceous materials, sodium carbonate and talc [34].

In India, about 6 MT of waste gypsum such as phosphogypsum, flurogypsum etc., are being generated annually [18] and plaster developed from these waste gypsum has showed improved engineering properties without any harmful effect. Phosphogypsum and lime sludge were recycled for manufacture of portland cement, masonry cement, sand lime bricks, partition walls, flooring tiles, blocks, gypsum plaster, fibrous gypsum boards, and super-sulphate cement [6,18,20]. Phosphogypsum could also be used as a soil conditioner for calcium and sulphur deficient-soils and it also has fertilizer value due to the presence of ammonium sulphate [3].

#### 2.4. Hazardous wastes recycling and utilization potentials

India generates ~4.5 MT of hazardous wastes annually. Out of these ~1.7 MT waste are recyclable; 1.89 MT are incinerable and ~2.5 MT are disposable in secured landfills [7,10]. Among these, major quantities of recyclable hazardous wastes are from metallurgical activities and the other non-recyclable hazardous wastes include chemical sludge, spent catalyst, chromium sludge, oily sludge. In the process of extraction of various metals, while smelting, refining and other metallurgical activities, such as copper, zinc, lead, cobalt, gold, silver and platinum considerable quantity of solid wastes are being released as residues, slag, dust, dross, sludge. These wastes are hazardous in nature due to high concentration of toxic elements; this leads to contamination of surface and ground water through the leachate accumulation from the disposal/dump-sites. This results in a major risk to the total environment including human health, flora, fauna and other living organisms. Most of the metallurgical industries are taking care of safe disposal of pollutants generated in the form of solids, liquids or gaseous wastes, but more attention is still required for effective action to achieve the objectives and comply with the policy of environmentally sound management imposed by Basel Convention.

##### 2.4.1. Non-ferrous metal wastes

It is estimated that annually about 11 MT of blast furnace slag is being released from steel plants [2,20]. There are three types of slags namely, blast furnace

slag, converter slag and electric furnace slag. The first two are produced by pig iron industries and the third is generated by the steel industry. The blast furnace slag, is categorized as group I waste and has been used in the manufacture of blended cement improving its soundness, strength, morphology, and abrasion resistance. However, group II materials, i.e. ferro-alloy industrial waste, have not been used extensively, but have great potential for recycling. All these solid wastes have been used in production of portland blast furnace slag cement, super sulphate cement, as an aggregate in high strength concrete and light weight concrete [6,21]. The group III materials include the tailings of iron, zinc, copper and gold ore beneficiation and have been used as fine aggregate or concrete filler material in the construction industries [3].

##### 2.4.2. Solid waste from lead, zinc and copper industries

In India, the major two organizations, namely, Hindustan Zinc Ltd. (HZL) and Indian Lead Ltd. are producing lead metal. The production capacity of HZL is 65,000 t and that of Indian Lead Limited is 24,000 t/year. Worldwide, about 60% of lead production is from secondary sources. [16,35]. Lead-acid battery is the dominant source of secondary lead, but the metal also comes from a variety of sources such as scrap, sheets and pipes, cable sheathing and solder as well as dust and drosses. The zinc lead smelter annually releases ~1,42,000 t of slag as solid waste (HZL—15,000 t/year; Tundoo lead smelter—18,000 t/year; HZL Chanderia—1,16,000 t/year; Indian Lead Ltd., Thane—3000 t/year). Some of these wastes are presently recycled for silver, lead, copper recovery and the rest is stored/disposed at the secured landfills [16].

Presently, ~75% of the world's zinc metal is produced hydrometallurgically through acid leaching. During the process a large quantity of jarosite residues in the form of mud are released and stored in different types of closed containers or sealed reservoirs in the premises of production units. Jarosite is universally categorized as hazardous waste due to the presence of toxic substances like Zn, Pb, Cd, S, Fe etc. In India, HZL has a multi-unit of mining and smelting with an installed capacities of 3.49 MT/per year. Zinc is manufactured from four smelters located in the states of Rajasthan, Andhra Pradesh, Bihar and Orissa. Debari Zinc Smelter plant, Rajasthan is one of the largest units having ammonium jarosite process utilizing electrolytic extraction method. During Zinc metal extraction process, Dabari zinc smelter produces ~59,000 t/annum of zinc metal and as a consequence jarosite is released as hazardous waste. The major quantities of jarosite are generated in China, USA, Spain, Holland, Canada, France, Australia, Yugoslavia, Korea, Mexico, Norway, Finland, Germany, Argentina, Belgium and Japan [36]. Efforts are being made to recover valuable elements/value added materials and to transform them into other forms less harmful to the environment [37]. Jarosite is a potential resource, which has to be recycled in a technically feasible and environmentally friendly manner and an attempt to

develop an alternative construction materials has shown encouraging results [38,39].

#### 2.4.3. Solid waste generation, disposal and recycling in copper industries

Copper melting and refining activities are often associated with generation of a large quantity of wastes as sediments from concentrator plants and scrap, slag, dust, dross and sludge. Worldwide, annually about 50,000 t of hazardous wastes, containing copper as the major compound, are imported and exported [40]. Copper based industrial waste is suitable for copper recovery and is classified on the basis of physical form, copper content, chemical nature, chemical composition and recycling potential. Certain solid wastes from the copper industries are real assets and become important secondary source to the other industries [3,16]. These secondary sources include converter slag, anode slag, effluent treatment plant sludge, anode slime etc. The metallic wastes and certain other wastes like dross, reverts etc. are best recycled by pyrometallurgical process including melting, fire refining and electro-refining. Copper slag is also being used in making tiles, mine backfill materials, granular materials [41].

### 3. Solid waste minimization and safe management options

The optimal solution for solid waste management is to minimize the quantity of waste both at generation and disposal stage followed by preventive environmental management action. Recycling of solid wastes is another major productive area in which considerable quantity can be utilised for manufacturing new products. The enforcement of the Resource Conservation and Recovery Acts (RCRA) of US is one of several interacting mechanism for controlling damages from hazardous wastes [14]. As per USEPA the hazardous wastes are defined as the wastes, which possess the characteristics of ignitability, reactivity, corrosivity, and toxicity [13,14]. As per the guidelines of Hazardous and Solid Wastes Amendment (HSWA), several wastes have been prohibited for land disposal. The work done both in India and abroad showed various environmental threats due to disposal of these wastes without minimising/detoxifying the contaminants. Very little work has been reported on the beneficial aspects of hazardous waste especially in ceramic products. Some of the wastes are indeed resources and raw materials and can be used in another industry. However, opportunities for this approach may be limited as a result of mismatches between waste stream composition and process specifications. These approaches can be justified because of savings in raw materials and energy inputs, as well as reductions in the costs of disposal.

### 4. Saving energy, economy and social benefits

Pollution abatement, saving energy and social benefits are the primary indices to measure the advantages in

Sustainable Solid Waste Management (SSWM) System. In SSWM cost benefits analysis become a widely accepted concept for economic appraisal for designing regulatory frame work/ policy options. Presently, in India, about 28% of the total energy resources are accounted for the development of various building materials. With regard to saving energy, it is reported that for production of alumina requires about 200–250 MJ/kg of energy [42]. Similarly the manufacturing of the stainless steel and copper requires 100 MJ/kg each; cement consumes 5–8 MJ/kg, clay bricks and tiles require 2–7 MJ/kg of energy. Incorporating 25% of fly ash or 40% blast furnace slag in portland-pozzolana cement saves 30% energy and results in the product of equivalent quality to that of original portland cement. Further in making burnt clay bricks, addition of 25% fly ash with clay soil could save 15% energy [42]. Cement/resin bounded board and particle-board could be used as substitute for timber. Similarly 20% of energy could be saved by introducing rice husk or groundnut for manufacturing particle board. In case of using agro-industrial wastes in various building materials as substitute for asbestos fibre, timber and mica significant amount of energy can be saved [20,42]. However, often-mining spoils are land-tipped near the mine and simply allowed to accumulate. Straw stubble is burnt in the fields, and animal manure is stored on the farm. These wastes are having good potentials for developing other products as well as for energy generation. Stringent regulatory guidelines increase the costs of waste disposal in many industrial countries. Accurate information on the amounts and types of wastes exported, their origin and destination is not widely available. Considering the characteristics of wastes and environmental danger, multidisciplinary research work is very essential in an integrated manner to assess and understand the potential applications of hazardous and non-hazardous wastes to realise their value for various applications in an environmental friendly manner. The Basel Convention provides a framework for the control and movement of hazardous wastes with a view to achieve an environmentally sound management.

### 5. Challenges and potentials for recycling and utilisation of solid wastes

Tables 1 and 2 show the variation in physico-chemical properties of hazardous and non-hazardous solid waste as compared with sand, cement and clayey soil. It is known that, pure clay alone is not a good material to make bricks due to its high plasticity, which develops cracks. But reducing the plasticity by means of admixing non-plastic media will certainly improve the quality of bricks. The engineering properties (Atterberg limits) such as liquid limit, plastic limit and plasticity Index of clay soil are 31.78%, 18.94% and 12.84%, respectively. As per the Indian standard (IS 2117–1991) the plasticity index (15–25%) and the clay content indicates that the soil has a good potential for making quality bricks. However,

industrial wastes like marble processing wastes, CCRs, jarosite, metallurgical residues does not deserve Atterberg limits properties. But incorporation of these wastes as an additives with fine grained materials like clay and jarosite can reduce the shrinkage and improve the quality of several building materials [7,20]. Figs. 2–5 shows the phase constituents present in CCRs, jarosite, mable dust and clay [7]. The major mineral phases present in clay soil and pond ash are quartz, mullite, hematite and magnetite. In red mud, hematite ( $\text{Fe}_2\text{O}_3$ ), sodalite, kaolinite [ $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ] and diaspore are found to be the major mineral phases [7,29]. However, dolomite [ $\text{Ca Mg}(\text{CO}_3)_2$ ] is the dominant phase constituent present in marble dust. It is revealed from the chemical characteristics of these wastes that they can be used effectively as an enrich medium for conditioning the clay matrix and recycling for developing good quality building materials.

Apart from several physical, chemical, thermal and biological treatment processes, it is well known that the strength reduction, volume reduction and detoxification/immobilization are the common practices for solid and hazardous waste management. But, recovery of valuable materials and recycling them for making other products or applications is an interesting and essential aspect.

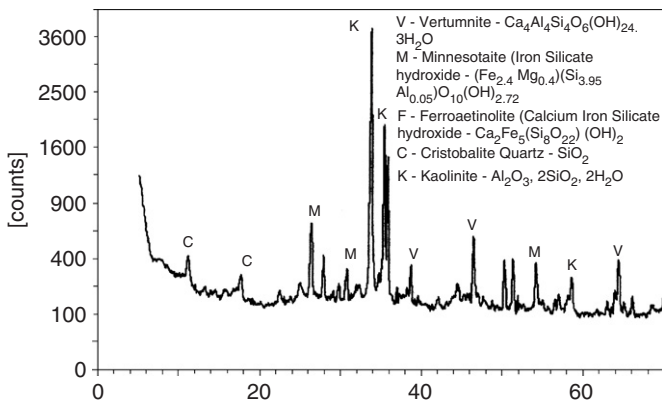


Fig. 2. X-ray diffractogram (XRD) of Clayey Soil.

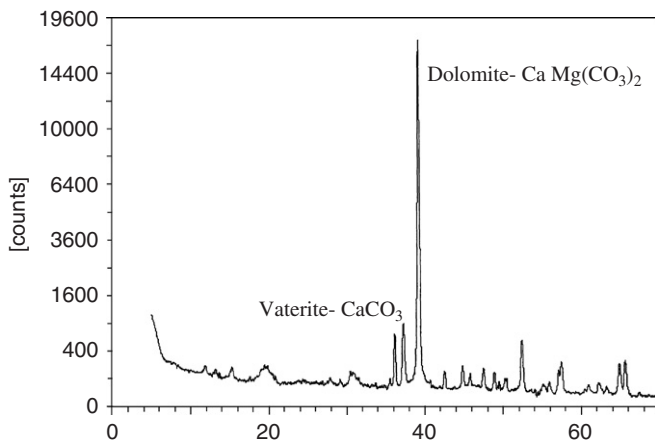


Fig. 3. X-ray diffractogram (XRD) of Marble processing waste.

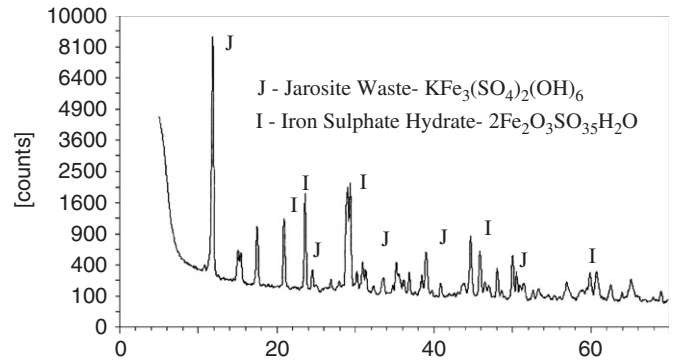


Fig. 4. X-ray diffractogram (XRD) of Jarosite.

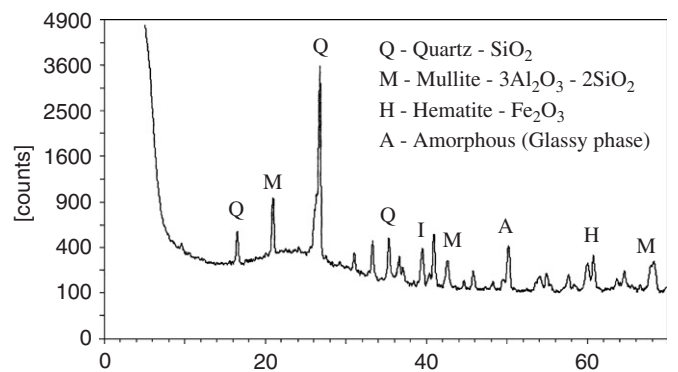


Fig. 5. X-ray diffractogram (XRD) of CCRs.

Reduction of pollutants from major building material industries is directly related to the conservation of limestones, clays and other minerals. Use of some of the industrial wastes as a cementitious materials/raw materials or additives could be realised in manufacturing blended cements, concrete, bricks and aggregates. This would contribute to the control and reduction of release of undesirable gases and pollutants to the environment. Fig. 6 shows the projected recycling potentials of both organic and inorganic solid wastes in developing different building materials. However, about 20% of solid wastes are not recyclable due to their complex characteristics and are to be disposed safely. The potential of solid wastes released from hazardous sources is shown in Table 4, out of which the solid residues released from copper and steel industries are having maximum utilization potentials followed by zinc, aluminum and other non-ferrous metallurgical industries [1,3,7,10,16]. Further the leather processing residues viz foam, sludge, residues etc., can especially be used in making lightweight composites. Apart, various other wastes such as pharmaceutical, medical, hospital, radio active, municipal and animal wastes have not been included in this article. Advancement in scientific innovation through lab and pilot scale research needs to be given priority for exploring newer areas of research for utilisation of all types of wastes in achieving sustainable development.



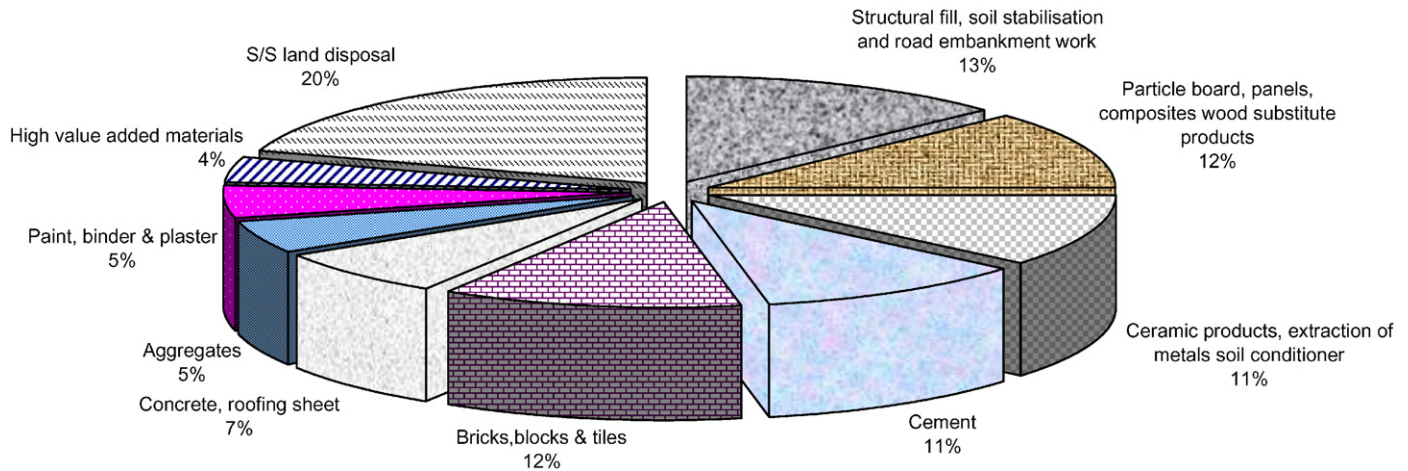


Fig. 6. Future Potentials for solid waste recycling and utilisation.

## 6. Conclusion

During different industrial, mining, agricultural and domestic activities, India produces annually about 960 MT of solid wastes as by-products, which pose major environmental and ecological problems besides occupying a large area of land for their storage/disposal. Looking to such huge quantity of wastes as minerals or resources, there is a tremendous scope for setting up secondary industries for recycling and using such solid wastes in construction materials. Though many lab processes, products and technologies have been developed based on agro-industrial wastes, non-acceptability of the alternative and newly developed products among users due to lack of awareness and confidence is to be removed. However, environment friendly, energy-efficient and cost effective alternative materials developed from solid wastes will show good market potential to cater to people's needs in rural and urban areas. To effectively utilise these wastes as a raw material, filler, binder and additive in developing alternative building materials, detailed physical-chemical, engineering, thermal, mineralogical and morphological properties of these wastes are to be evaluated and accurate data made available. In order to maximize the use of alternative building materials developed from different types of solid wastes and to increase the production capacity of lab scale processes, technology-enabling centres are needed to be set-up to facilitate entrepreneurs for effective commercialisation. Durability and performance of the newer products and dissemination of technologies emphasising costs-benefits analyses and life cycle assessment report will significantly contribute to successful commercialisation of innovative processes. Inclusion of industrial waste-based newer building materials, emphasizing their environmental significance in the curriculum at higher education level and practical applications of wastes in construction sector will give fillip to such technology promotion. The scientific advancement in recycling and using industrial and agricultural processes for utilizing

wastes will lead to a better use of world's resources. The new and alternative building construction materials developed using agro-industrial wastes have ample scope for introducing new building components that will reduce to an extent the costs of building materials. The endeavour, therefore, needs to be to encourage entrepreneurs and construction agencies to develop new products and processes using all these wastes as raw materials for setting up secondary industries and contributing to reduction of green house gases and global warming.

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