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Eco-Engineered Building Materials using Construction and Demolition waste: A Review

Hariprasad N. V.
Research scholar
Dept. of Environmental Engineering
Vidyavardhaka college of Engineering,
Mysore, Karnataka, India

Dayananda H. S.
Professor,
Dept. of Environmental Engineering,
Vidyavardhaka college of Engineering,
Mysore, Karnataka, India

***Abstract* - This review paper collates and compiles the available published literature on reuse and recycle of construction and demolition waste materials. Construction and demolition waste is generated whenever any construction/demolition activity takes place such as residential buildings, roads, bridges, flyover, subway, remodeling etc. The production of construction materials involves utilization of natural resources. Added to this, various toxic substances are emitted into the atmosphere during the manufacturing process of construction materials. Rapid industrialization and urbanization has led to generation of these wastes, and are being dumped in open and low-lying areas. These activities pose serious problems to human beings and the environment. Recycling construction and demolition materials can be a best alternative to open dumping and also in conservation of the natural resources.**

Keywords: C & D waste, Construction materials, Reuse and recycle, Environment friendly Recycled concrete

I. INTRODUCTION

Construction and demolition (C&D) waste is generated whenever any construction/demolition activity takes place such as building roads, bridges, flyover, construction of new apartments, malls and by the demolition of old buildings, widening of roads, remodeling etc., C & D waste consists mostly of inert and non-biodegradable material such as concrete, plaster, metal, timber, plastics etc. These wastes are heavy, bulky and occupy considerable space in huge piles on the road sides. Often it finds its way into surface drains choking them. It constitutes 10 - 20% of the municipal solid waste. It is estimated that the construction industry in India generates about 10-12 million tons of wastes annually [1]. It is more often dumped in open and low-lying areas; however, recent recognition of the potential for diversion of waste components from landfills has led C&D waste becoming a topic of interest for recycling [2].

The traditional construction materials like concrete, bricks, tiles, solid and hollow blocks are being produced from the existing natural resources. The environment is being damaged due to continuous exploration and depletion of natural resources. Various toxic substances such as high concentration of carbon monoxide, oxides of sulfur, nitrogen and suspended particulate matters are emitted to the atmosphere during manufacturing process of construction materials. These toxic substances contaminate air, water, soil, flora, fauna and aquatic life, and in turn human health and their living standards. Therefore, the issues related to environmental conservation have gained great importance in the society in recent years [3]. Construction and demolition waste has caused serious environmental problems in many large cities [4].

Recycling of concrete wastes in construction has been investigated extensively in the past decades due to environmental pollution and exhaustion of natural resources. In some countries, many technologies for recycling concrete waste have been developed and some recycling specifications have been established [7, 8, 9]. Construction and demolition wastes might be considered as harmless materials that do not cause any trouble at all. However, these wastes represent huge masses that are often deposited without any consideration, causing lot of trouble and inviting illegal deposit of other kinds of waste and garbage. As a result, the building and construction industry is a significant player in waste generation [12].

The world is becoming increasingly conscious about environmental implications not only for production processes, but also for products discarded after use [10]. Construction and demolition are the two activities usually receiving the most attention. Several studies have indicated that renovation has become the dominating activity related to the built environment; measured either in terms of economic investments or in floor area [11].

II. SOURCES OF CONSTRUCTION AND DEMOLITION WASTE

Amongst the most developing countries, India has more scope for construction activities, and it is second largest activity in employment generation. The volume of construction waste is increasing due to unnecessary material wastage at building sites. Demolition waste is a mixture of materials used in the building and the composition is highly variable. A typical building waste is a mixture of ceramic or concrete blocks, mortar, reinforced concrete, steel, plastic, asbestos cement and timber. The use of gypsum as plaster board or plaster is on the rise and is expected to become a significant part of the waste in a few years time [17]. Table 1 illustrates the various factors responsible for generation of construction waste.

Table 1: Factors responsible for generation of Construction waste

Activity	Reason
Work execution	Lack of construction equipment
Materials	Material handling and onsite storage, delivery of materials that are not in accordance to schedule
Manpower	Unskilled labourers
Design and documentation	Design changes
External factors	Weather, site condition and damages caused by third parties
Professional management	Poor planning, co-ordination and information distribution

(Source: Nazech E. M et. al., 2008)

Construction and demolition waste content varies considerably because it comes from many different sources. A road crew rebuilding a highway, a construction firm erecting a new apartment complex, a demolition contractor tearing down a old office building; or a house owner renovating a living room will produce construction and demolition waste [13].

One of the major causes for demolition waste is due to natural disaster like Tsunami and earthquake. After the disaster, huge quantities of debris get mixed with soil and water, and moves with high speed causing casualties and this debris destroy transport sector. During rainy season, debris flow often damage the railway and roads especially the road beds and buried building components, causing traffic disruption [14].

III. ENVIRONMENTAL PROBLEMS

Aggregate generated from quarries, produce number of environmental problems like noise and dust pollutions [31]. Generally, quarries are located on the city outskirts. As cities grow, these quarries have to be relocated further away from the urban centers. The cost involved in transporting the aggregate, increases tremendously due to increase in distance between urban centers and relocated quarry. Every year, tons of concrete are being used in various construction activities [32].

The problem arises while disposing the demolished concrete once its design life is over. The availability of landfill sites for disposal of waste has been drastically decreased over the past 15 years due to strong environmental lobby [33]. With the limited landfill sites and great demand for waste disposal, the cost of dumping waste has been increased in recent times [30]. Huge quantity of construction and demolition waste is produced during the construction and development works. As the construction industry grows, it generates more and more waste, which creates a major portion of solid waste [24].

Waste is defined as any material by-product of human and industrial activity that has no residual value [18]. As per the statistics of Department of Environmental Protection, about 38% of total waste is generated from construction and demolition activities, which is about 6408 tons of waste per annum [19]. During construction phase, a range of activities on construction sites has the potential to pollute surface water. These include earthwork excavation that results in erosion and sedimentation [21]. This erosion may result in a significant increase of sediment loads to receiving waters [20]. Sediment chokes urban waterways, exacerbating flooding and often necessitating expensive river de-silting and training works.

The constituents derived from demolition activities and other sources can accumulate on the ground surface. Rainfall washes these materials from site, debris, and runoff transports the substances into surface waters [22]. Changes in sediment and pollutants from storm water runoff can be detrimental to aquatic life, wildlife, habitat and human health.

Other demolition waste constituents like concrete waste, paints, sanitary fixtures, timber, paper materials and metals discharged to waterways can lead to unsightly and pollute them. However, the amount of construction and demolition waste generated has a potential impact when it is not properly stored, collected and disposed of to an appropriate location [23]. The amount and type of construction and demolition waste depend on many factors such as the stage of construction, type of construction work, and nature of construction practice on site. Most of the construction and demolition waste debris are generally disposed of in landfills or openly dumped into uncontrolled waste pits and open areas [25]. Therefore, the continuous industrial development would pose a serious disposal problem of construction and demolition waste [26].

The most effective way to reduce the waste problem is in implementing best management practices viz., reuse, recycle and reduce the use of excessive resource. These '3R' has the positive influence on Economy, Ecology and Energy. Application of recycled materials in the building industry is important for sustainable development and preserving the primary natural sources of every country. Recycling and reuse of building rubble presents interesting possibilities for economizing on waste disposal sites and conserving natural resources [27].

IV. RECYCLING OF CONSTRUCTION MATERIAL

When recycled concrete aggregate is used in buildings, etc., the quantity required is generally the equivalent to natural aggregate such as gravel and sand. However, in the case of manufacturing such aggregate, the manufacturing cost and amount of CO_2 emissions is likely to rise sharply, consequently limiting the extent to which recycled aggregate concrete is used [29].

There is a wide range of applications for recycled materials in civil engineering structures and it is necessary to seek the other possibilities for reusing those building materials whose lifespan has exhausted. As a recycled material, one can consider not only the construction and demolition waste. But, also the waste coming from the industrial production and extraction of primary materials [27]. The restrictions in improvement of recycling principles require certain criteria as indicated in Figure. 1 [28]

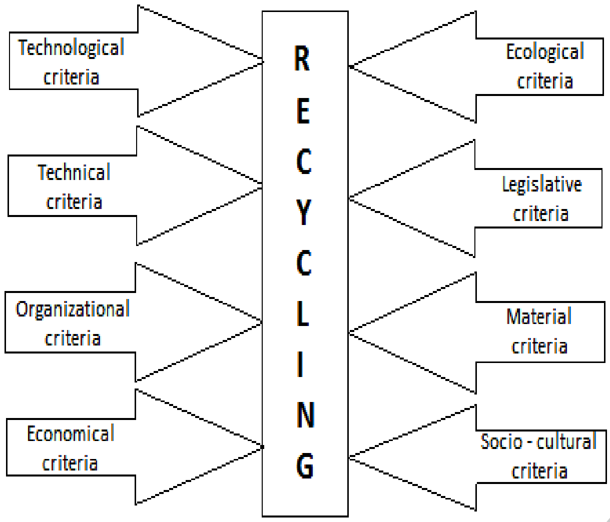

Figure. 1 Criteria in recycling process

A substantial amount of construction and demolition waste is wood; clean demolition wood, and wood pallets can be chipped and used in the manufacturing of new building products, such as particle-board. Some wood, may not be fit for recycling due to use of preservative to treat wood (lead or mercury based paints), and require special disposal. Old concrete and rubble makes good fill material. If large amount of clean concrete waste are to be disposed from bridge reconstruction, repair or large building demolition; it might be economical to reprocess it for aggregate. Three different grades; fines, medium and coarse are commonly made from old concrete. In concrete processing plants, magnets remove any metal, such as rebar, that often contaminates concrete waste.

Used bricks from demolition sites can often be reused for construction. Those in un salvageable condition can be used as fill or ground up and used as a landscaping material. Metal exists in wiring, plumbing fixtures, siding, roofing, and structural steel. Aluminum, brass and copper are especially valuable metals. These can be re-melted and reused in the manufacturing of new products. Other metals, such as steel and iron, can be sold to scrap metal dealers. Structural steel such as I beams and columns, may be reused in other construction projects or sold as scrap.

Plastic used in wiring and water distribution can be chipped and shredded, and can be sold. Glass can be recycled into fiberglass insulation or used to make new windows. Doors, windows, special molding, plumbing fixtures and other materials from demolition sites can often be sold for reuse [13].

A. Properties of recycled material

Usually coarse aggregates are partially replaced from 10% to 30% for making new concrete. It was observed that 100% recycled coarse aggregate produces acceptable quality concrete. Use of recycled fines; new mix requires close examination. Recycled fine aggregate will be angular, with a high porosity and low specific gravity. The particles of crushed brick are generally more porous and have a lower density when compared to natural and recycled concrete aggregates. It was found that concrete made with crushed brick generally has comparable compressive and tensile strengths compared to those of conventional concrete. However, the modulus of elasticity, shrinkage, creep, initial surface absorption and chloride diffusion are inferior compared to those of natural concrete. Successful applications of crushed brick as aggregates in the production of concretes are possible.

Concrete produced with recycled aggregate has lower strength compared to natural aggregate concrete. The most marked difference in the physical properties of the recycled concrete aggregate is higher water absorption, lower bulk density, porous and rough surface texture and lower resistance to mechanical action compared to natural aggregate. Workability of recycled aggregate concrete is lower than that of similar concrete mix with natural aggregate. These facts are certified in many research studies. The fiber reinforced concrete with the recycled aggregate is beneficial in the present day applications both in the fresh and hardened state [27].

B. Recycling of solid waste in the production of construction materials

The recycling of solid wastes in civil engineering application has undergone considerable development over a very long time. The utilization of fly ash, blast furnace slag, phosphogypsum, recycled aggregates, red mud, kraft pulp production residue, etc., in construction materials has shown some examples of the success of research in this area. Similarly, the recycling of hazardous wastes for use in construction materials and the environmental impact of such practices has been studied for many years [5, 34]. The recycling and utilization potentials of different solid waste are shown in Table 2. In fact, there is a great scope for setting up secondary industries for the recycling and reuse of huge solid wastes in construction materials and its utilization potential is indicated in Table 3.

Table 2: Recycling of different wastes and their utilization potential for construction materials

Sl No.	Type of solid waste	Source	Recycling and utilization potential
1	Agro-waste (organic)	Baggage, rice and wheat straw and husk, saw mill waste, ground nut shell, jute, sisal, cotton stalk, vegetable residues	Cement boards, particle boards, insulation boards, wall panels, roof sheets, binder, fibrous building panels, bricks, acid-proof cement, coir fiber, reinforced composites, polymer composites
2	Industrial waste (inorganic)	Coal combustion residues, steel slag, bauxite red mud, construction debris	Bricks, blocks, tiles, cement, paint, fine and coarse aggregates, concrete, wood substitute products, ceramic products
3	Mining/mineral waste	Coal washeries waste; mining waste tailing from iron, copper, zinc, gold and aluminium industries	Bricks, fine and coarse lightweight aggregates, tiles
4	Non hazardous waste	Waste gypsum, lime sludge, lime stone waste, broken glass and ceramics, marble processing residues, kiln dust	Blocks, bricks, cement clinker, hydraulic binder, fibrous gypsum boards, gypsum plaster, super-sulfated cement
5	Hazardous waste	Contaminated blasting materials, galvanizing waste, metallurgical residues, sludge from waste water and waste treatment plants, tannery waste	Boards, bricks, cement, ceramics, tiles

(Source: Pappu et. al., 2007)

Table 3: Solid wastes and their uses in the production of construction materials

Sl No.	Name of waste	Type of waste	Use
1	Fly ash, bottom ash, rice husk ash, palm oil fuel ash, organic fibers	Agro-industrial	Aggregate, concrete, supplementary cementing materials, blended cement, bricks, tiles, blocks, particle boards, insulation boards, cement boards, wall panels, roof sheets, reinforced polymer composites
2	Phosphogypsum, waste glass, granulated blast-furnace slag, waste steel slag, rubber tire	Industrial	Fine and coarse aggregates, blended cement, concrete, bricks, blocks, tiles, ceramic products
3	Quarry dust	Mining / mineral	Fine and coarse aggregates, concrete, bricks, tiles, blocks, surface finishing materials
4	Construction and demolition debris (concrete rubble, tiles, waste bricks, etc.)	Industrial	Fine and coarse aggregates, concrete, bricks, blocks, sub-base pavement materials

(Source: Md. Safiuddin et. al., 2010)

There are some advantages of using fly ash as a raw material for bricks, such as the firing energy can be saved because of the carbon content in fly ash. Several studies have been carried out in Germany, England and China to produce bricks from fly ash [36-39]. The authors revealed that the use of fly ash in fire bricks as a replacement of clay effectively saves land and energy, and decreases environmental pollution. [40, 41] conducted studies to produce bricks (Solid and hollow) using fly ash with lime and phosphogypsum, and found that bricks and blocks of sufficient strength can be produced from the fly ash-lime-phosphogypsum mixture. The bricks and blocks have the potential for use in place of conventional burnt clay bricks and blocks [42].

[49] conducted studies on mix composed of demolished waste concrete, grog and hydrated lime in the ratio of 40:50:10 in terms of weight percentage and other mixes with cement kiln dust as a partial replacement of hydrated lime in the ratio from zero to complete replacement. The results of this study showed that the mix of waste concrete, grog, hydrated lime and burnt cement dust can be used instead of the cement constituent in mortars, and in concrete brick making. Compressive strength of all the mixes increased with hydration age and decreased with burned dust giving more than 20 kg/cm^2, which is enough for safe handling, after one day of hydration except for mix that has full replacement by dust. In spite of decrease in compressive strength values with the replacement of hydrated lime by burned dust, these values reached the compressive strength required for the brick used for the load bearing walls (70kg/cm^2) after 1, 3 or 28 days of hydration. The results of this study show that the mix of waste concrete, grog, hydrate lime and burned cement dust can be used instead of the cement constituent in mortars, and in concrete brick making. [54] conducted a study on reuse of crushed tiles as partial replacement substitute to conventional coarse aggregate in concrete making by casting cubes, cylinders and beams. These samples were

tested for compressive strength after a curing period of 7, 28, 56days. Compressive strength of ceramic concrete varied from 32.88 to 46.88Mpa and the split tensile strength varied from 5.33 to 7.82Mpa for 28days. The results indicated the effectiveness of crushed ceramic waste as partial replacement for conventional coarse aggregate up to 40%, without affecting the design strength.

[55] used crushed C&D waste as a recycled concrete aggregate in the production of new concrete. The performance of RCA was compared with the natural coarse aggregate concrete (NAC). The study was made for M20 mix with water/cement ratio of 0.5. Compressive strength of RAC and NAC at the age of 7 and 28days were made. The results showed the compressive strength of RAC and NAC at the age of 7days were 18.2Mpa and 16.8Mpa and for 28days, 25.5Mpa and 22.18Mpa respectively. It was observed that compressive strength of RAC was 87% of NAC at the age of 28days and the slump of RAC was zero and can be improved by using saturated surface dry RAC. [50] conducted a research work to know the physical and mechanical properties of different laboratory mixed concretes, using various proportions of additional materials recovered from industrial waste and demolition rubble. The substitution of natural aggregates with ceramic and porcelain wastes produced a significant increase in compression strength, making them suitable for concrete with characteristic resistance above 40Mpa. The addition of 1% of forestry residue decreased the characteristic resistance of concrete up to 60%, compared to the reference concrete. The concrete with electrical and electronic residues showed the characteristic resistance of 18.1Mpa, which hardly reached the requirement of mass concrete. The concrete prepared with 20% of white ceramic in substitution of ordinary sand, showed the compression resistance of 55Mpa, a higher value compared with 36Mpa obtained by reference concrete. From this work, it was observed that higher the proportion of wastes, the worse the final resistance was.

[51] carried out a research work on recycled concrete aggregate (RCA) for site tested concrete specimen. The water cement ratio used in all mixes was 0.41. The workability of fresh concrete made with 100% RCA was zero, which was not satisfied. This study suggested saturating the RCA to saturated surface dry (SSD) condition before casting. From this study it was observed that 100% RAC showed higher 28day compressive strength and higher 28day split tensile strength compared to control concrete, but 28day flexural strength of 100% RAC was lower than that of natural concrete. [52] made an attempt to develop a effective technique for sustainable management of C&D waste. Forty eight standard concrete cube specimens were cast, cured and crushed. Twenty four of the cubes were cast from recycled aggregates while other twenty four were from virgin aggregates. The results showed that at higher water/cement ratio, the compressive strength of recycled concrete was lower than that of virgin concrete. Thus, at water/cement ration of 0.5 and 0.6 the compressive strength of recycled concrete at the end of 28days was 18.6Mpa and 19.6Mpa respectively. In addition, the slump and compacting factor tests revealed that the workability of virgin concrete mix was higher than that of recycled concrete.

[30] carried out a study to determine the engineering properties of the recycled aggregate and compared with conventional aggregate. Different types of building wastes viz., crushed concrete (fresh), crushed concrete (20year old), masonry stone (fresh), masonry stone (20year old), bricks and conventional aggregates were considered for the study. It was observed that, all materials had water absorption of above 2%, but the maximum permissible value of water absorption is 2% as per MORTH (Ministry of road transport and highways) specifications. According to MORTH, the upper limit for impact value is 30%. The impact values obtained for crushed concrete was observed to be within the specified limits and can be used for road works. As per MORTH the upper limit for Los Angeles abrasion value is 40%. Except brick masonry all other waste materials showed less abrasion values. From this study it was observed that the building debris can be effectively used as road material.

A clean dry glass powder is useful as a substitute for Portland cement in concrete. The finely ground glass having a particle size finer than 38 µm contain a high amount of amorphous silica, which exhibits a pozzolanic behavior [44]. Hence, the use of ground glass in concrete can be used as it has hardened properties and durability. Using waste glass as fine aggregate would produce better workability in concrete, provided its geometry is almost spherical and preferable to produce a workable mixture [45].

[53] investigated waste generation rates (WGRs) by conducting on-site waste sorting and weighing in four ongoing construction projects in Shenzhen city of South China. The results revealed that WGRs ranged from 3.275 to 8.791Kg/m² of miscellaneous waste, timber formwork, false work, and concrete as largest components amongst the generated waste. This work suggested waste sorting at source, employing skilful workers, uploading and storing materials has to be done properly. [56] conducted a study on utilization of sandcrete blocks from demolition waste as an alternative material to fine aggregate in concrete. A concrete with compressive strength of 30Mpa at 28days curing period was designed for normal mix and considered as reference. The fine aggregate was replaced with crushed waste sandcrete block (CWSB) in various percentages in the steps of 10 starting from 10% to a maximum of 100%, while 0% was reference. The samples were evaluated at 7, 14 and 28days curing period. Results showed that replacement for 50% of CWSB aggregate after 28days curing attained the compression strength same as that of reference sample (conventional concrete). From this study it was observed that CWSB can be used as an alternative material in concrete.

Quarry waste is obtained during the production of aggregates through the crushing process of rocks in rubble crusher units. Using quarry waste as a substitute of sand in construction materials would solve the environmental problems caused by the large-scale depletion of the natural sources of river and mining sands [47]. In addition, quarry waste can be profitable alternative to the natural sands when the overall construction cost increases due to the transportation of sands from the sources [46]. Several investigations were carried out on the use of scrap tire particles in portland cement concrete. The processed rubber tires were used to replace fine and coarse aggregates depending on the fineness of particles [48]. As concrete has become the most widely used construction material, the incorporation of rubber tire particles in concrete would be a very good and promising way to utilize the large quantities of waste rubber. The use of scrap rubber tire particles in concrete would not only make a good use of such waste materials but also help to improve some concrete properties. The rubberized concrete shows excellent flexibility, ductility and energy absorbency as compared with conventional concrete [26, 48]. [57] discussed on replacement of natural sand by by-products and recyclable materials. The study aimed to know current and future trends of research on the use of Manufactured Fine Aggregate (MFA) in Portland cement concrete. The natural sand deposits in the world over is drying up, there is an urgent need for an alternative product that matches the properties of natural sand in concrete. From the last 15 years, availability of good quality natural sand is decreasing. With a few local exceptions. Existing natural sand deposits are being emptied at the same rate as urbanization. Environmental concerns are also being raised against un-controlled extraction of natural sand. The arguments are mostly in regards to protecting riverbeds against erosion and the importance of having natural sand as a filter for ground water.

Clearly, a lot remains to be achieved in the field of demolition waste management and regulation in India. The crux of the matter lies in the fact that we have just begun to understand the magnitude and gravity of the crisis on hand. Recycling construction and demolition waste can cut disposal costs up to sixty percent on some jobs. Increasing prices and strict Regulations encourage recycling and a viable alternative to land filling. Nowadays, more contractors are becoming interested in recycling; it is likely that more recycling facilities should be available.

V. SUMMARY

Rapid industrial and urbanization has caused serious problems like depletion of natural resources and generation of huge quantity of construction and demolition waste. To forbid the problem; reuse, recycle and reducing waste has to be emphasized and encouraged. Recycling construction and demolition waste is not difficult, but requires timely planning. Effective recycle of demolition waste can reduce time, energy and can create new jobs by setting secondary industries in utilizing huge quantity of demolition waste in the production of building materials. Presently, lack of enforcement has resulted in disposing of C & D waste indiscriminately in an unscientific and non-engineered way causing social and environmental impact. Proper utilization of demolition waste through recycling will save land, resource and money.

Recycling of concrete and masonry waste is being practiced in several countries like USA, UK, France, Denmark, Germany and Japan. Literature review has shown that scanty works has been done in India on reuse and recycle of C & D waste and requires more research in developing sustainable and eco-friendly building materials. While retrievable items such as bricks, timber, metal, tiles are being recycled, the concrete and masonry waste, accounting for more than 50% of the waste from C & D activities are not being recycled much in India. Nevertheless, work on recycling of aggregates has been done at Central Building Research Institute (CBRI), Roorkee and Central Road Research Institute (CRRI), New Delhi. Added to this, in India, Strict and stringent Rules and Regulations have to be framed to promulgate the management and handling of C&D wastes.

There is enormous scope to carry out a detailed investigation and bring out a technique for reuse and recycle of C&D wastes and enable to conserve the natural resources. This provides lot of impetus in the parallel research going on elsewhere in the globe. Thus, the present research work mainly aims at carrying out feasibility studies on reuse of demolition waste with different binding materials in the production of building materials without hampering the properties of building materials.

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