Applications of Recycled and Waste Materials in Infrastructure Projects

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Abstract. More production equals to large quantities of wastes which are being generated worldwide from sources such as household, domestic, industrial, commercial and construction demolition activities, and these wastes often lead to environmental concerns of toxic threat. But, as it is said that the waste of plenty is the resource of scarcity, utilization of these wastes as building construction materials can be an economically viable solution to this problem. When these waste products are used in place of other conventional materials, energy and natural resources are preserved, air and water pollutants are reduced, greenhouse gases are lowered and harmful waste disposal is avoided which in turn minimizes the heavy burden on the nation's landfills. The construction industry can start being aware of and take advantage of the benefits of using recycled and waste materials. The use of fly ash, bottom ash, quarry dust, wood ash, foundry sand, tyre shreds, silica fume, animal fat, cement kiln dust, roofing shingles, swine manure, steel slag, blast furnace slag, copper slag, crushed glass, plastic waste, electronic waste, paper waste, carpet, textile waste reclaimed asphalt pavement, spent fire bricks, recycled aggregates, rice husk ash, coconut shell, olive husk and bagasse ash amongst the endless list in construction is becoming increasingly popular due to the shortage and increasing cost of raw materials. This paper presents an overview of the possible applications of recycled and waste materials after reviewing the results of laboratory tests and important research findings, and the potential of using these wastes in building construction materials with a focus on sustainable development. Furthermore, it reviews some best waste-based materials that can be used as a small-scale alternative to the conventional materials, and also, the implementation of recycled and waste materials in construction applications and in real life projects.

Keywords: Construction materials · Infrastructure development
Recycled and waste materials · Sustainable development

1 Introduction

Solid waste management is gaining significant importance due to continuous increase in industrial globalization and generation of waste and has become one of the major global environmental issues. Solid wastes such as plastic, metal, paper, glass and textile

H. Singh et al. (Eds.): ICSWMD 2018, LNCE 21, pp. 569–585, 2019.
https://doi.org/10.1007/978-3-030-02707-0_65

represent a major part of the municipal solid wastes that originate from household, schools, hospitals and business activities. Whereas, thermal power plants producing coal ash, the integrated Iron and Steel mills producing blast furnace slag and steel melting slag, cement industry producing cement kiln dust, silica fume, etc., are the major generators of industrial solid wastes. Waste concrete and wood waste are other types of waste common in the environment nowadays due to construction and demolition wastes.

Population growth, rise in living standard and urbanization are the main parameters in generating large amount of wastes around the globe in both developed and developing countries from various human activities. The disposal of waste is becoming an increasing concern because of the increasing volume of waste by-product generated by many industries, increasing costs of operating landfills in combination with the scarcity of landfill sites. The legislation bans the disposal of wastes in landfills. Also, due to the rapid industrialization and uncontrolled urbanization, the use of cement and other construction materials such as coarse and fine aggregates is increasing exponentially. Due to the consumption of these materials for the infrastructural development of the nation, the demand increases and as a matter of fact the price is increased and these naturally available materials may not be available in the future, leading the scarcity of raw materials for construction.

The prime concern and objectives of the engineers and researchers is to use raw materials that would enhance the strength properties and at the same time is durable in long run and under adverse environmental conditions. The need of an hour is to minimize the use of natural resources as construction materials such as limestone, shale, clay, natural river sand, natural rocks and also to reduce the emission of greenhouse gases. This is possible only if waste materials are utilized by replacing conventional materials to a possible extent. This will not only lead to preserving natural resources and the environment, but will eliminate the crucial concern of disposing these waste and thus will prevent environmental destruction and will lead to sustainable development. Thus, to explore the potential materials for the same, this paper reviews the results of laboratory tests and important research findings, and the potential of using these wastes in building construction materials with a focus on sustainable development.

2 Potential Recycled and Waste Materials

As emphasized above, with increased environmental awareness concerning potential hazardous effects, utilization of recycled and waste materials has become a fetching alternative to disposal. The use of recycled and waste materials having inherent or latent cementitious properties can possibly be used in constructional materials for the production of concrete and for the construction materials of any other civil engineering work. An exhaustive review of recent researches has shown that there is an endless list of potential waste materials that can be incorporated by replacing the conventional materials as discussed below:

2.1 Fly Ash

Fly ash, obtained as a by-product during the operation of coal-fired power plants is a widely researched material. It is well known that, cement production units emit around 0.88 Ton of CO_2 per Ton of clinker produced. Therefore, fly ash replacement in cement production proves to be quite sustainable as it reduces carbon dioxide emission to a great extent [2]. Apart from being sustainable, technical benefits of fly ash includes, Higher ultimate strength, Increased durability, Improved workability, Reduced bleeding, Increased resistance to sulphate attack, Increased resistance to alkali-silica reactivity, Reduced shrinkage, Decreased permeability, Reduced efflorescence, Reduced heat of hydration, Improved finishing, Reduced slump loss. Currently in the concrete industry, the percentage of fly ash as part of the total cementing materials in concrete normally range from 15 to 25%, although it can go up to 30–35% in some application [28, 60]. Also, High-lime fly ash has permitted normal replacements of 25–40% and up to 75% of cement in concrete materials for parking lots, driveways and roads [7].

2.2 Bottom Ash

Coal ash is residue resulting from combustion of pulverized coal or lignite in thermal power plant. The combustion of coal produces smoke which goes into air and is captured as fly ash. The burnt coal so obtained at the bottom of the burning chamber is cooled and is known as bottom ash. Bottom ash forms up to 25%–90% of total ash generated while the remaining is fly ash. The type of coal and the temperature it is subjected to, decides the percentage of bottom ash [16]. From the review of the past researches, it is evident that coal bottom ash is economical substitute which is suitable to be used in the construction industry. It is found to be suitable as partial replacement of aggregate in the production of concrete. From various researches, it has been seen that up to 30% replacement of coal bottom ash as sand replacement in the concrete production can be done [47].

2.3 Tyre Shreds/Crumb Rubber

Rubber tyres are also amongst other materials which researchers are showing interest in. They can be used in many civil and non-civil engineering applications in different shapes and sizes like in the production of rubber composites, as a fuel in cement kilns, by incineration for the production of electricity, as an aggregate or additive in cement products, in road construction, as lightweight fill for embankments or as backfill material for retaining walls. In recent years, the use of crumb rubber and tyre granules in Portland cement concrete has been the subject of research in many projects. It has been observed from the past researches that concrete modified with tyre rubber can be used in applications where mechanical properties are not of prime importance [55]. Though, the high strength concrete with crumb rubber shows better resistance to abrasion than the conventional mix. Thus, it also finds applications in pavements, floors and concrete highways, hydraulic structures such as tunnels and dam spillways, particularly where the abrasive forces are applied by moving objects during service [38].

2.4 Blast Furnace Slag (BFS), Ground Granulated Blast Furnace Slag (GGBFS)

Blast furnace slag is a by-product from blast furnaces in the iron industry. It has been used extensively as a successful replacement material for Portland cement in concrete materials to improve durability, produce high strength and high performance concrete [59]. Depending on the method which is used to cool the molten slag, different forms of slag product are obtained namely Air-Cooled Blast Furnace Slag (ACBFS), Expanded Blast Furnace Slag, Pelletized Blast Furnace Slag. Ground Granulated Blast furnace Slag (GGBFS) is another by-product from the blast furnaces which is pulverized to reduce the particle size to cement fineness, fine powder and cement like material. It is a non-crystalline material varying in size depending on its chemical composition and method of production; its own production as well as that of its iron source [2]. It has been observed from the past researches that the compressive strength of concrete improves with increase in GBFS percentage up to a certain percentage. The most optimum percentage of GBFS considering both strength and economy factor is from 40% to 50% under normal conditions and 50% to 60% for marine conditions [52].

2.5 Steel Slag

Steel slag is obtained as a by-product from steel industry. It produced as a residue during the steel production [2]. Electric arc furnace slag (EAFS) and ladle furnace slag (LFS) are both produced at different stages of steelmaking process, respectively, in electric arc furnaces and refining ladle furnaces [32]. Successively, it is recycled as an aggregate for the construction of roads, soil stabilization, and base and for the surfacing of flexible pavement. Steel slag has considerable potential and can be used in subgrade or embankments. Especially countries like Europe, Canada, Australia and USA have not treated it as an industrial waste but a potential construction material. Steel slag has been successfully used as an aggregate in surfacing and base of flexible pavements. Use of steel slag aggregate in asphalt surface mixtures provide pavement surfaces with good skid resistance [19]. Apart from this, use of steel slag pose no environmental risks for use as aggregates in road work applications and thus proves to be a sustainable alternative. The material proves to be ideal for usage as a construction material in road work applications such as pavement base and engineering fills as far as the engineering properties of LFS aggregates is concerned, particularly its high CBR values [32].

2.6 Cement Kiln Dust

Cement Kiln Dust (CKD), a by-pass dust, is generated in large quantities during the production of Portland cement. It is fine grained, solid, highly alkaline particulate material primarily composed of oxidized, anhydrous, micron-sized particles collected from electrostatic precipitators during the production of cement clinker. Mortars and concrete mixtures containing 5–10% of CKD can achieve almost similar compressive strength, flexural or tensile strength, toughness and durability as that of the control mixture. The replacement of OPC with up to 20% nano-CKD resulted in an increase in the compressive strength of cement mortar by about 15 to 30%. It can thus be potentially utilized in partial cement replacements leading to the reduction of cement demand, and hence proves to be sustainable due to reduces energy demands and reduced carbon dioxide emission [4, 25].

2.7 Silica Fume

Silica Fume is a by-product extracted from the exhaust gases of ferrosilicon, silicon, and other metal alloy smelting furnaces. Condensed silica fumes have a potential to be used in the cement and concrete industry and are of high quality. It is found in many studies that minute pore spaces decreases when silica fume mixes with concrete. Silica fume posses pozzolanic behaviour, as it is reactive, like volcanic ash and its effects are associated with engineering properties such as mechanical, physical and chemical properties [42]. The optimum percentage of partial replacement of cement with silica fume is found to be 12% from literature which leads to increase in compressive strength, and the flexural strength of concrete and high performance concrete is obtained [29].

2.8 Foundry Sand

Waste foundry sand (WFS) is high quality silica sand and is obtained as by-product from the production of both ferrous and nonferrous metal castings [51]. It is seen that compressive and flexural strength is boosted, and is maximum at 50% replacement of natural fine aggregate with used foundry sand [48]. It has been observed from the literature that foundry sand could be successfully used in making concrete as partial replacement of fine aggregate as compressive strength and modulus of elasticity of concrete mix containing foundry sand was higher than the control mix in all ages [51].

2.9 Wood Ash

Wood ash, which is the inorganic and organic remnant left after the combustion of wood and wood products such as chips, bark, sawdust, etc. is another potential waste that can be used in construction materials. On the average, 70% (approx) of the wood ash is being landfilled, 20% and 10% is used as soil supplement and in other miscellaneous applications [51]. The results of 28-day compressive strengths, obtained for SDA/OPC concrete appear encouraging in the future use of SDA in concrete works [15]. XRD data from the referred literature shows that that WA contains amorphous silica, thus, making it fit as cement replacement material due to its high pozzolanic activity [8].

2.10 Spent Fire Bricks

It is a waste material from foundry bed and walls; and lining of chimney which is adopted in many industries. Due to subjection to sustained high temperature (i.e., 1000–1200 °C) for a period of 10 to 15 days, SFB lose some of the physical and mechanical properties and are replaced by fresh fire bricks. Then, instead of disposing off they are used as a substitute of sand in making a good concrete [56]. The compressive strength increases 2.57% while 20% replacing of fine aggregates by crushed SFB and further it is decreased [12]. The optimum percentage for fine aggregate replaced with crushed fire bricks achieved at 20% [54].

2.11 Construction and Demolition Waste (Malva)

C&D waste is the waste material that results from the construction, renovation, or demolition of any structure, including buildings, roads, and bridges. Examples of these waste components include Portland cement concrete, asphalt concrete, wood, drywall, asphalt shingles, metal, cardboard, plastic, and soil [40]. Recycled sand and aggregate from C&D waste is said to be used in non-structural applications like flooring and filling and has just (10–15%) less strength than normal concrete. It's a major environmental challenge to minimize the waste which generates and can be done by the reuse and recycling [60]. 50% CWSB content is adopted as the optimum for design characteristic strength of 30 N/mm^2 [48].

2.12 Quarry Dust

Quarry dust is a by-product of the crushing process which is a concentrated material to use as aggregates for concreting purpose, especially as fine aggregates. Construction industry manoeuvre quarry dust in a variety of projects. From the recent researches, it has been determined that the maximum strength result is achieved at 40% replacement of sand by quarry dust compared to conventional concrete and then further decreases from 50% [44]. Sometimes, 55% to 75% is the recommended percentage of the replacement of sand with the quarry dust in case of compressive strength. Moreover, by addition of fly ash along with quarry dust 100% replacement of sand can be achieved [48].

2.13 Copper Slag

Copper slag is a by-product of copper extraction by smelting. Copper slag can be used as a sand replacement material for horizontal surfaces such as plastering of flooring and for vertical surfaces such as, brick/block walls up to 50% and 25% respectively by mass of the total fine aggregate [31]. The mechanical properties of concrete improve with replacement of copper slag in the mix. Thus, waste copper slag can be utilized as coarse and fine aggregate to make more sustainable products [13].

2.14 Crushed Glass

Glass powder with particles size finer than 38 μm posses pozzolanic behaviour which made it suitable for substituting Portland cement, 20% replacement by weight of fine aggregate with fine glass has a potential to be used in the production of ceiling and acoustic insulation board, conglasscrete and tiles in Japan, United Kingdom and United States respectively [17, 39] In general, compressive strength was found slightly higher

(2%) than the conventional concrete sample when mortar was replaced by optimum glass content. Moreover, glass addition can reduce cost of cement production up to 14% [22].

2.15 Reclaimed Asphalt Pavement (Rap)

Reclaimed Bituminous/Asphalt Pavement (RAP) is bituminous concrete material produced by crushing and screening the material to a 6–12 mm in size from pavements undergoing reconstruction or resurfacing. RAP is mixed with virgin aggregate and asphalt, as needed for use in bituminous roads, 25% to 30% amount of RAP is allowed for low volume roads, 50% RAP can be used for some non-critical mixes, such as the shoulder, base and sub-base and for surface courses, the amount used ranges from 10 to 15% for all but for the highest volume highways [2]. 20%–50% is the optimal percentage of RAP mostly adopted and also depends upon the composition of reclaimed bituminous material and type of layer in which it is to be used [53]. Rutting resistance is improved and better performance at high temperature is achieved as RAP increases the stiffness of asphalt mixes, due to the aged asphalt binder [1].

2.16 Recycled Aggregates

Recycled aggregate is produced by crushing concrete, and sometimes asphalt, to reclaim the aggregate. Recycled aggregate can be used for many purposes, majorly for road base [45]. The Federal Highway Administration (FHWA) projected an increase in aggregates to over 2.5 billion tons per year. Distributing the applied load and increasing the load capacity of the pavement to avoid damage to the sub grade is the basic task of recycled aggregates [7, 26]. Appropriate workability, strength and durability is seen when not more than 50% replacement of recycled aggregates in quantities with virgin aggregates is done as compared with concrete containing 100% virgin aggregate. Moreover, mix proportion influences splitting tensile and compressive strengths [39].

2.17 Rice Husk Ash

Rice husk ash is a by-product from the burning of rice husk at a temperature lower than 6000 C this means that it is in a form that is soft and easy to grind. Rice husk ash is rich in silica about 90%, 5% carbon and 2% K_2O. RHA blended concrete can improve the workability of concrete compared to OPC and can decrease the temperature effect that occurs during the cement hydration [43]. At 5% replacement level RHA-concrete building blocks could satisfy the Indian standards ASTM standards for load bearing building blocks, even though the incorporation of RHA in building blocks moderately decreases the compressive strength of blocks. Blocks casted with higher replacement levels (25%) also satisfy the IS specification for load bearing building blocks. RHA-concrete building blocks were lighter (2% to 10%) compared with conventional concrete building blocks and showed higher insulating properties [27].

2.18 Coconut Shell and Fiber (CS & CF)

Coconut shell, coconut fiber and coconut shell powder are new waste materials used in civil engineering works. In general, coconut shell and coconut fiber consequently enhances the engineering properties (such as stability, skid resistance and resilient modulus of the modified asphalt pavement) of asphalt mixtures when mixed with modified bitumen [57]. It was observed that, when optimum composition (9 wt% of coconut fiber) is reached, compressive strength of cement composite with fly ash content reinforced with coconut fiber increases [36]. Also, coconut Shell Powder (CSP) concrete was good in splitting tensile strength when used as a filler material in concrete as it reduces the workability of concrete because of higher level of water absorption of coconut shell [30].

2.19 Olive Ash

The normal consistency of the ordinary cement paste is just moderately higher than the cement pastes containing different percentage of olive waste is somehow lower than that of the ordinary cement paste. But, it can be utilized valuably [3]. As it keeps concrete behaviour, olive ash is used as an additive to concrete mix rather than an olive husk and its recommended percentage of replacement with sand is 25%. Also because of its ability in hardening process it is used as filler material for concrete [37].

2.20 Bagasse Ash

About 40–45% fibrous remnant is left, after the extraction of all economical sugar from sugarcane which is reused in the form of a fuel in boilers for generation of heat leaving behind 8–10% ash as waste, known as sugarcane bagasse ash (SCBA). The compressive strength of concrete increases due to pozzolanic properties of bagasse ash in 28 days as compared to 7 days when fine aggregates were effectively replaced with 10% and 20% bagasse ash. Further, due to porous nature of SCBA and the impurities in it, the sorptivity test result showed increase in sorptivity coefficient with increase in percentage of bagasse ash which stipulates more permeable concrete. And hence, therefore proves to be a budding constituent of concrete since it can be an effective replacement to cement and fine aggregate [35]. As compared to burnt clay bricks no efflorescence was spotted in SCBA un-burnt bricks with crusher sand moreover their compressive strength was higher than SCBA–river sand brick specimens and fly ash brick specimens with similar proportion [11].

2.21 Plastic Waste

Effectively utilizing the hard plastic waste particles for flexible pavements as bitumen modifier, improves pavement performance and its longevity. The advantageous properties of bituminous concrete mix such as strength, fatigue life, marshall stability and other gets to be upgraded when modified bitumen with the addition of processed waste plastic of about 5–10% by weight of bitumen is used. Also, waste plastics are utilized in the manufacturing of laminated roofing [18]. The bitumen content is reduced to 10%

while using plastic mix. Moreover, vehicular pollution is minimized by using smoke absorbent material (titanium dioxide) by 10% of polymer content [33]. Also, in the production of concrete the use of plastic wastes in the form of fibre, granular and powder, effects remarkably in some cases as improvement in compressive and flexural strength, higher strength to weight ratio, workability, thermal, insulation and reduction in self weight was observed [39].

2.22 Carpet Waste

Instead of sending carpet waste to a landfill, the use of low-cost waste fiber for concrete reinforcement used for floor slabs, driveways, and walls of the building could lead to improved infrastructure with better durability and reliability [62]. The toughness and tensile properties and other parameters such as reduction of shrinkage, improved fatigue strength, wear resistance and durability, improved significantly by adding carpet waste fiber to concrete [7]. Alternatively, in the process of cement making, post-consumer carpeting can be used as a form of a fuel source [23].

2.23 Textile Waste

Textile waste along with other reusable materials has different possibilities of application in the building construction. Concrete with improved mechanical behaviour, mortar with improved physical, mechanical and durability properties similar to glass or polypropylene can be produced by utilizing textile fibre with adequate consideration of its thermal, mechanical and physical properties in the correct proportion. Increased compressive strength high energy absorbing capacity, good thermal stability and 30 min fire resistance bricks were produced with combination of cotton with materials such as paper, limestone powder, barite and fly ash. Also, a noteworthy increase in the thermal insulation of double wall was observed [39].

2.24 Steel Scrap

The process of making new products, reusing old metal material, mainly aluminium and steel is known as metal recycling. Old metal products significantly have less energy consumption (i.e. 95% less) in recycling rather than manufacturing it from new materials. Steel has an advantageous factor different from other materials which is repeated recycling, which gains its 100% recyclability. Steel reinforcement and steel sections are roughly 100% and 25% made from recycled scrap as reported by steel organization [39]. SIFCON (Slurry infiltrated concrete) similar to Fiber Reinforced Concrete for small jobs can be made from small elongated pieces of steel scrap and metal waste [2].

2.25 Electronic Waste

70% non-metals and 30% metals are found approximately in E-wastes like printed circuit boards (PCBs). The pulverized PCB waste posses pozzolanic action and improves the strength and can be utilized in concrete making and hence solve a potential disposal problem. Also, it's a classic replacement of fine aggregate in concrete as it contain large quantity of silica in its refined form, which will further result in reducing the dead weight of the structure [14, 49]. It was observed that compressive, splitting tensile and flexural strength were reduced with increase in percentage of E-plastic in replacing coarse aggregate in concrete. So, to achieve the characteristic strength of concrete it is recommended to do 30% replacement by volume [9].

2.26 Paper Waste

Papercrete is a new composite material consists of waste paper in the form of re-pulped paper fiber as a partial replacement of Portland cement. Due to its light weight, good water absorption and insulation capacity, less shrinkage, high strength to weight ratio it reduces dead load for the main structure and makes environment friendly building material as it reduces the use of cement [50]. Nevertheless, more analysis is required to upgrade the high moisture absorption of fibre and composite, low compatibility of fibre with cement but waste paper is used as a component of construction materials such as fibre reinforced cement composite, building block, wall panel, brick, low density board and thin cement sheet [39].

2.27 Animal Fat

Renewable diesel is made with the help of animal fat, under high temperature and pressure, tallow is reacted with hydrogen, known as hydrogenation of fats. A synthetic molecule, chemically identical to conventional diesel and a pure hydrocarbon is formed as a result. And this, renewable diesel can go directly into the petroleum pipeline and refining infrastructure [6]. Animal fats reduces the percentage of carbon dioxide (88%) as compared to fossil fuels and are considered as the most sustainable raw materials for biodiesel [64]. Animal fat has a tough bond with cement providing a chemical adsorption interaction and has been used in the construction industry since roman times. Also, referred as tall oil [7].

2.28 Sewage Sludge

Sewage-sludge products were used in lightweight cement-based mixes for construction produced by partially or fully replacing the natural aggregates with lightweight materials as well as by using natural or chemical additives that normally form air voids when reacting with cement [20]. It is observed from the various literatures, in construction industry, production of bricks and production of ceramic and glass are the major applications of waste sludge [24].

2.29 Swine Manure

Surface water, groundwater and air quality are the main environmental effects of swine manure storage systems and are affected by odours and gaseous emissions from large-scale swine production operations. By replacing petroleum based adhesives with swine manure converted into bio-binder known as biodegradable adhesive, is a solution found by the scientists and co- researchers from North Carolina A and T State University to address these concerns. The viscosity of bio-modified binder lowers consequently than that of non-modified binder which further boosts the mixture durability by upgrading the binder wettability. Also, by adding 2% bio binder, high temperature grade of binder is achieved which reduces the possibility of low temperature cracking by increasing relaxation capability of binder and decreasing the stiffness [7]. A petroleum derivative that makes up about 7% of asphalt can be replaced by swine waste which acts as a binding or adhesive material [5].

2.30 Roofing Shingles

Roofing shingles are made from a fibreglass or organic backing, asphalt cement, sand-like aggregate and mineral fillers such as limestone dolomite and silica [7]. The primary end-use for recycled shingles is paving. The addition of recycled shingles to aggregate base, hot mix asphalt (HMA) and cold patch materials has been shown to increase pavement's resistance to wear, increase pavement's resistance to moisture, decrease deformation and rutting, and decrease thermal and fatigue cracking. Depending upon the location and the purpose of use, independent testing is required to investigate the effect of adding recycled shingles on a pavement performance. Study in the past shows that the test pavements with batches containing a maximum of 5% shingles by weight of mixture have performed at least as well as traditional pavement [58].

3 Latest Best Out of Waste Based Materials Being Used

3.1 Newspaper Wood

In this plasticizers and solvent free glue is used for coating individual sheets of old newspaper and then the glued sheets are tightly rolled into logs. After the wood is sealed, it's waterproof and flame-retardant and can be treated like most other wood products by cutting, milling, sanding, and finishing with paint or varnish and can be used to build anything which is normally build with wood [10].

3.2 Recy Blocks

Recy blocks are made from old plastic bags, extremely difficult to recycle in any other way and are a sort of colourful bricks. After placing the recycled bags or plastic packaging in a heat mould, they are forced together to form into the shape of the blocks. They can be used to divide up rooms or outdoor areas, instead of acting as load-bearing walls as they are too lightweight [10, 46].

3.3 Blood Bricks

In this idea animal blood is considered as a waste product, as it contains high levels of protein, blood is one of the strongest bio-adhesives. Blood in the form of powder (freeze-dried blood) is mixed with sand to form a paste; and this paste is then casted into bricks. This idea is proposed by British architecture student Jack Munro. No matter this is an extremely humiliating idea but the carnivores are munching away and still wasting loads of animal blood, especially in societies without industrialized food production systems [10].

3.4 Bottle Bricks

This proposal is a little disparate, as it depends on producing a consumer good specifically so that its later utilized as a building material. It was first started with beer company Heineken in the 1960s – Alfred Henry Heineken, owner of the brewery, practiced to build a wall, using company beer bottles instead of the bricks. And now, many companies make bottles in cuboid or other tessellation shapes, to make them easier to transport and to be used later on when they are considered as post-consumer waste [10].

3.5 Mushroom Wall

In this, the designers found bacteria called mycelium which originates in rotting organisms like tree trunks and agricultural by-products which is used to grow wall insulator and packing materials. These organic matters grow to the desired shape within a couple of days, if placed in a mould and can then be ceased using a hot oven. Moreover, this material is biodegradable as compared to traditional insulating and packing materials which tend to be non-biodegradable, or, in the case of asbestos, poisonous [10, 34].

3.6 Plasphalt

Asphalt which uses grains of plastic produced from unsorted plastic waste, instead of using the sand and gravel in asphalt production is known as plasphalt. Also, it was observed that plasphalt roads were resilient to wear and tear than traditional asphalt, because plastic forms a better bond with asphalt emulsion as compared with gravel or sand [10].

3.7 Wine Cork Panels

As the world apparently consumes around 31.7bn bottles of wine a year, it's a good practical idea, to recycle granulated cork with whole wine corks to make a sustainable building product such as wine cork panels for wall or floor tiles [10].

3.8 Nappy Roofing

Some polymers can be used to create fibre-based construction materials like the roofing tiles which are separated out from the, organic waste such as nappies and sanitary products by special recycling plants. The waste is turned into plastic and cellulose organic residue for green energy, during the recycling process. And this plastic, is also be used for decking and cladding [10, 21, 61].

4 Implementation in Real Projects – Case Studies

4.1 Indian Scenario

Though, there seems a wide gap between the ongoing research during the past decades and the implementation in real projects, but still few interesting projects on the ground can be seen. Amongst the list of such real projects is a small home called 'Kachra Mane' of G V Dasarathi. This man has truly taken the idiom "one man's trash is another man's treasure" to a whole new level. This home is called Kachra Mane, which literally means Trash Home. This man strongly believes in "Reduce, Reuse, Recycle and Rethink" principle, and has made his house literally from trash that he collected from demolished houses and second-hand markets. The other such example from this list is a Collage house in Mumbai. This home in Mumbai is built around a central courtyard and has a facade made from the doors and windows of homes that were demolished in the city. The home makes use of other recycled materials, including 100-year-old salvaged stone columns, flooring made from the beams of old houses, fabric waste and waste slivers of cut stone [41].

4.2 Scenario Outside India

Contrary to the Indian scenario, quite a number of such projects can be seen in the outside world. One such example is The Governor – Rotterdam in the Netherlands. This townhouse looks brand-new, but its bricks are made of 15 tons of waste and rubble, including ceramics, glass and clay. The waste products were gathered from around the country, grounded them up and formed them into bricks [65]. Another such mesmerizing structure is the Bottle Houses – Cap-Egmont in Prince Edward Island. These fairytale-like structures were built out of more than 25,000 recycled glass bottles that were gathered from around the community. Constructions on all three buildings took about four years and are now visited as a tourist attraction [65]. Next amongst the list is the Container Guest House in San Antonio, Texas. This guest house was designed for a client who wanted to reuse a one-way shipping container. The eco-friendly building sits on a foundation built from recycled telephone poles, and has a deck made of recycled soda bottles. Scrap aluminium gives the castle its dazzle. Furthermore, bicycle reflectors add notes of colour. Countless beer cans, carefully cut apart, predominate. The tops and bottoms are nailed to the walls in repeating patterns; the middles have been turned inside-out and hammered flat to create aluminium siding [65]. Another building in the list is the Waste House on the University of Brighton campus on the south coast of England. It was built between 2012 and 2014 as a project involving hundreds of students and apprentices and was designed by Duncan Baker-Brown, an architect who also lectures at the university. The materials consist of a wide range of construction industry and household waste—from toothbrushes and old jeans to cassettes and bicycle inner tubes and it is the first public building in Europe to be built primarily of such products [63].

5 Concluding Remarks

- Review of several studies established the possibility that recycled and waste materials if used in proper manner and quantities can be utilized as an effective constituent of building materials. The appropriate use of these recycled and waste materials will improve the intrinsic properties of the building materials concerned, thus leaving a positive impact through different aspects.
- The application of these construction materials in real construction is limited as many companies are not aware of the availability, quality of the materials' performance, cost savings, or any other benefits including environmental benefits. There is a need for more research to study the actual behaviour or performance of solid waste based building materials in their practical applications which will be focused on promoting the acceptability of these kinds of construction materials to the public and international building standards.
- Furthermore, properties like durability which has to do with long-term performance can be best studied through this means, thus further encouraging practical application of the building materials containing recycled wastes. Additionally, enhancing sustainability of the construction industry while reducing cost, providing solutions to environmental pollution and reducing the need for natural resources. It can be done by incorporating laboratory experimentation, statistical analysis and modeling of such construction material to validate the outcome of experimentation in a real life condition.
- An investigation of the applicability of recycled and waste materials for the production of lightweight building material with properties suitable for use as non-load bearing wall unit, with focus on sustainability has been proposed. So, the use of these types of recycled and waste materials in construction industry results in reduction in environmental pollution as CO_2 emission is almost nil, conservation of valuable land fill spaces, conservation of natural resources and energy, minimized use of Portland cement as well as reduction in construction cost.

  And if this kind of investigation continues at this rate; the possibility of achieving zero waste in the nearest future could be a reality.

Acknowledgements. The authors extend a sincere thanks to everyone who has contributed directly or indirectly towards development of this overview.

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