A review on wastes as sustainable construction materials

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Abstract. The necessity of construction materials is growing year by year. The construction materials are developing, but on the other hand, its cost is increasing too. The utilisation of proper waste as construction materials will reduce cost, conserving the natural resources, protecting the environment from waste impact and hazards, etc. The presented study provides exploitation related to wastes as replacing material in construction site and shows the opportunity of waste employment as a promising material to construct with it.

Keywords: Recycled Materials, Waste Materials, Environmental Concerns, Construction Materials

1. Introduction

Many solid wastes were generated from many advancing and advanced nations because of urbanisation, population growth, and living standards [1]. In contrast, solid wastes are discarded or unwanted materials which aren't gas or liquid. The wastes like bottles, paper, cans, glass, fabrics, metals, specific plastics, wood and clothes might be categorised within recyclable materials [2]. In addition, the solid wastes like metal, paper, glass, plastic and textile are constituting the majority of municipal solid wastes originating from business, schools, household and hospital activities. Demolition and construction, including wood waste and waste concrete, were specified as waste types in the environment now [3]. While the garbage wastes like containers, food packaging materials, plastic grocery bags, bottles and so on, were majorly resulting in pollution of the urban areas' environment because of their non-biodegradable nature [4]. Increase in production indicates an increase in waste, while more waste creates environmental concern with toxic threats. One of the economical, suitable solutions to such issue involves using waste materials for novel products, thus minimising the high burden on landfills. Waste material recycling saves natural resources, saves energy, decreases solid waste, decreases water and air pollutants and decreases greenhouse gases. The industry of constructions starts paying attention and benefiting from utilising waste and recycled materials [5]. When material's disposal was an expense, there must be some approaches for turning it into being useful, recycling them is a better way for disposing of such materials that were otherwise unusable, or nearly so.

The applications of civil engineering require large material volumes. Therefore, reutilization regarding possible waste and recycled materials instead of traditional raw materials is of high importance. It reduces the demands for natural resources, resulting in more sustainable developments, costly and possibly dangerous waste disposals are avoided.

Currently, a lot of recyclable material types are utilised in the applications of civil engineering like fly ash, silica fume, steel slag, ground granulated blast furnace slag, ground rubber tires, crushed glass, crushed marbles, cement kiln dust, rice husk ash, recycled concrete aggregates, and so on. [6].

Waste materials had been utilised in the construction sector, such as wood, brick, paper, concrete, plastics, glass, steel, etc. This review focuses on some waste materials, that have daily use and not easy to disposal, which impacts the environment. Steel slag, glass, crumb rubber and sludge are solid materials with good characteristics that may modify the construction materials. The above-selected materials could be utilised in different aspects of the construction sector beside it could replace cement, fine or coarse aggregate. This paper demonstrates the opportunities for utilising these materials.
1.1 Steel slag
The steel slag is considered as one of the solid wastes from steel production. It might be classified as stainless steel slag and carbon steel slag based on the steel type and other constituents. Steel slag density is in range of 3.3-3.6g/cm³, while the appearance of steel slag is of a loose collection, and it is wear-resistance and hard because of its increased content of Fe [7]. The types of slag are varying based on their chemical compositions, porosity and a certain weight. Majorly, the steel slag includes CaO, SiO₂, FeO, Fe₃O₄, MgO, Al₂O₃, P₂O₅ and MnO [8]. Also, the steel slag’s chemical component varies with furnace type, pre-treatment technique and steel grades. Different applications, according to its characteristics, have utilised steel slag such as Reclamation of waste steel. This component is utilised as one of the sinter ore fluxing agents, aggregate for the road and hydraulic construction, which is considered an aggregate of high-quality, similar to natural aggregates, cement, and concrete production etc. [9]. The two later applications may consider the most important applications beside it takes a large number of wastes. Kollaro [10] employed the slag in highway construction and compared the results with conventional hard aggregates’ outputs. He concludes that synthetic aggregates can be used improving the costs of road products while yielding significant energy savings and having mild impacts on the environment. Dubey et al. [11] explore using Steel Melting Shop (SMS) slag and Ground Granulated Blast Furnace Slag (GGBS) as partial replacements coarse aggregate and cement. The work is extended further via making plans regarding residential building on AUTOCAD where green concrete contains 50% of SMS and 55% of GGBS as partial replacements to coarse aggregate and cement was conducted. The building’s cost analysis was conducted that allow curtailing the concrete costs by 22.61%. A study conducted by Rosales et al. [12] shows the simplicity of utilising stainless-steel slag as one of the substitutes for limestone fillers in manufacturing self-compacting concrete. Considerable results have been acquired. Such study shows the potential applications regarding such stainless steel slags as one of the construction materials, enhancing sustainability and promoting circular economy processes, that have been done via minimisation of accumulation and waste disposal.

1.2 Glass
The glass is specified as one of the inorganic products of fusion thaw. It was cooled to a rigid condition with no crystallisation [13]. Glass has some properties like hard, brittle, transparence, and specific gravity 2.19 and Density 1672 kg/m³, it mainly consists of SiO₂, Al₂O₃, Fe₃O₄, CaO, Na₂O, K₂O, MgO and another compound according to application. It might be identified in various forms: cathode ray tubes, windshields, jars, windows, bottles, bulbs and so on,[14] and should be recycled for avoiding the environmental issues associated to their landflling or stockpiling. Using waste glass has attracted the construction industry worldwide due to concrete consumption in large quantities for widespread construction sites [15].

Seri Ganis and Gunalaan [16] examined the test results at 7, 14, 28 days of specimens' curing. They contain waste glass powder as a partial cement replacement. Their results specified 20% glass powder mix amount showing a positive value related to compressive strength at 28 days compared to other ratios 10% and 15% isn’t possible even with the minor increase from 14-days results.

Vijayakumar G. et al. [17] suggested that the cement replaced up to 40% via glass powder showing an increase in compressive strength at 28-days and 60-days curing age compared to traditional concrete.

Malik et al. [18] addressed the cement industry's ecological and financial challenges by utilising waste glass as a partial substitution related to fine aggregates in concrete. The samples were tested for splitting tensile strength, compressibility strength, and density at 28 days of curing age. Specimens with the glass showed better compressive strength up to 30% replacement of fine aggregates weight for the particle size of 0.1-1.18 mm.

Ganiron Jr. et al. [19] studied the crushed glass bottles were replaced of coarse aggregates, and its impact on the mechanical and physical properties of concrete are noted. The experimental outcomes specified that optimum replacement of coarse aggregates with recycled glass bottles is up to 10% weight
of coarse aggregates. A mixture design of 5% by weight added to the concrete mix provides the desirable results for compressive strengths.

Bhagyasri et al. [20] carried out a research in which the cement is replaced (partially) by 90 µm glass powder in the concrete as glass powder exhibits pozzolana properties, so it was utilised as partial cement substitution in the concrete. The laboratory test results specified that the maximum compressive is identified at 20% of glass powder in the concrete. Additional quality of the cement was tested by the ultrasonic pulse velocity (UPV) test. The results also showed that the solid using waste glass powder could enhance cement's strength and quality.

Fahad and Ali [21] investigated the sheet glass wastes as replacing materials rather than natural gravel and showed that the glass waste might be replacing the gravel in concrete. In addition, the glass concrete specimens have been less absorbing compared to gravel concrete in the case when tested, while the maximum immersion time was the best for enhancing the characteristics to gravel concrete and series glass.

1.3 Crumb rubber
Crumb rubber has been made through a shredding scrap tyre, one of the materials free of steel and fibre. The rubber particle was graded as well as identified in various shapes and sizes. Crumb rubber was measured or described through a mesh screen or sieve size through that it is passing throughout the process of production. Generally, there is a high importance in reducing the tyres' size for producing a crumb rubber. There were two approaches for producing crumb rubbers: cryogenic process and ambient grinding [22].

The chemical composition related to waste tier were wire, fabric, natural rubber, synthetic rubber, carbon black as well as other chemical compounds. Using waste tires, one of the cement-based material additives was a likely disposal solution since the waste tire management was a considerable aesthetic, health and environmental problem that was complex to solve. One of the main benefits to incorporate tire rubber wastes to the cement materials has been the increase in flexibility and ductility, even though the compressive strength was decreased; the tire rubber has been majorly provided in the engineering structures. Furthermore, researches provided rubber concrete in rigid pavements, steel-concrete composite beams and airport pavement [23].

A study conducted by Al-Tayeb et al., [24] examined the impact of partial replacements related to cement and sand via waste rubber on concrete's fracture characteristics; also they identified that adding waste tire in the concrete improved the fracture properties, whereas flexural and compressive strengths are reduced.

Abas et al. [25] examined the potential of reusing discarded waste tires in the concrete engineering applications via improving the concrete mix's properties as a partial replacement of fine aggregate with two types of the waste tire (chips and grounded shape). They found that the decrease in concrete's compressive strength and increment in toughness with excellent approach characteristics and reducing the additive material costs, also solving one of the serious issues via waste tires.

Sofi [26] investigated effects of using scrap rubber tyre instead of Natural Aggregates in concrete. When rubber content increased from 20-30%, the flexural and compressive strength decreases. Water absorption decreases upon an increase in the rubber particles' size, and it arrested the formation of cracks.

Siddiqui [27] studied adding rubber aggregate in the concrete mixtures to reduce the concrete's density and reduce the concrete strength to be utilised as lightweight concrete. There is also a lack of bonding between rubber particles and cement paste. Introduction of rubber concrete mix reduces the slump and workability of various mixed samples. Reduction in unit wt. of 14.33% was observed corresponding to 15% by volume of coarse aggregate replaced by rubber aggregate.

Vidat and Abhay [28] found that with the increase of the rubber content workability decreases. Tensile strength decreases, but max. Energy absorption during tensile loading increases. Reduction in strength is due to voids created between rubber aggregate and concrete mix, and so de-airing agents can also be added. It produced lightweight concrete.
Abdulkareem et al.[29] this research studied the effect of rubber tier waste and waste glass together on cement mortar characteristics, and both of them cement replacement. Results that have been obtained from the study that compressive strength decreases when increasing the percentage of additives of mortar. The water absorption increased when the percentage of additives increased. The density decrease when both percentage of additive increase in mortar cement. Also, the setting time increases when the percentage of additives increases.

1.4 Waste sludge
A variety of researchers confirmed the employment of waste sludge in the industry of constructions in different ways. The most important utilisation of sludge produced from water treatment is in brick production and manufacturing of concrete.

1.4.1 Waste sludge in brick production. Bricks are made from the clay. The sludges from the water treatment plant nearly equal the clay of the bricks. Therefore, waste sludge may be sufficiently utilised as clay brick replacement. [30].

Chiang et al. [31] use agricultural waste and rice husk ash with dried sludge from water treatment plants to produce novel lightweight bricks. The mechanical characteristics results have shown that the bricks with 40% wt. Rice husk display high strength for lightweight bricks. Tay et al. [32] develop a new brick using the clay and dried wastewater sludge. Cusido et al.[33] produce bricks using forest debris and sewage sludge as a raw material. The product has lower weight value, greater acoustic and thermal insulations than the traditional clay brick. Results have shown considerable increases in the greenhouse gas emission level of about 20 times higher than the conventional ceramic firings. Abdul et al. [34] find that sewage sludge as raw material is within the needed standards, but using sludge content of higher than 30% has not been advised because it has high brittleness. Chihpin et al. [35] mixed the excavation waste soil with the water treatment sludge for making bricks. Conclusions have stated that 15% has been the maximal water treatment sludge and the quality's achievement with bricks of the first degree. Cheng- Fang et al. [36] utilised Bottom Ash (BA)and water treatment sludge in the brick production. The bricks could be used as pavement bricks in urban areas. Kung-Yuh et al. [37] mix water treatment sludge and rice husk to manufacture lightweight bricks. The bricks were high compressive strength and low bulk density. Lazaro & Joan [38] have tested environmental effects of the bricks that are produced from the sludge of the sewage, taking under consideration the toxicity and leachability. Results have shown that sludge may be used to produce bricks with sludge addition between (5% and 25%) in wt. Shrutakirti and Husain [39] used the automotive (ETP) dry sludge to produce bricks. The Sludge bricks have better compressive strength when compared with the normal bricks.

1.4.2 Waste sludge in concrete. Yaque et al. [40] have researched concrete durability with the sludge as one of the concrete additives to evaluate the long-term efficiency. Results have shown that the sludge concrete is of similar durability with the reference concrete. Chatvera et al. [41] have evaluated treated wastewater usage in the concrete. The research has revealed that the sludge water may be utilised as a substitute at a range between 0% and 100%. Sludge waters have adverse effects on the resistance to the concrete acid attack as well as drying shrinkage. Yiming et al. [42] have researched the impacts of the dried sewage sludge as one of the additives to the cement characteristics in the clinker burning process. Results have shown that there have been similarities between eco cement clinker components and the ordinary portland cement. The results of the sample show lower compressive strengths. Ghannam [43] used the wastewater treatment plant in concrete. Results have not found any significant loss in the strength in using low organic dry sludge used to make the sludge concretes. The compressive strength decrease when treated water was used. pizon et al. [44] used metallurgical waste sludge or rounded or crushed (RCA) as a recycled concrete aggregate component to produce concrete. The results show that RCA concrete had high compressive strength, and utilisation of the RCA negatively affected the concretes' permeability and absorbability.

This paper deals with different waste that could be used in different construction applications. The following table summarised the waste materials, their replacement in the construction materials,
application…etc. This table also focuses on the compressive strength, since it's the most important construction material property.

Table 1. Literature review of different wastes utilised in various construction applications.

| No. | Author | Reference no. | waste | Replacement | Applications | Compressive strength |
|-----|--------|---------------|-------|-------------|--------------|---------------------|
| 1   | Kollaro | 2016          | steel slag | coarse aggregate | highway construction | improved |
| 2   | Dubey | 2019          | steel slag | cement and coarse aggregate | Concrete | improved |
| 3   | Rosales | 2020         | steel slag | limestone filler | self-compacting concrete construction field | improved |
| 4   | Seri Ganis | 2013 | glass | Cement | construction field | Increase |
| 5   | Vijayakumar G | 2013 | glass | Sand | construction field | Increase |
| 6   | Malik | 2013         | glass | Coarse aggregate | construction field | increase |
| 7   | Ganiron | 2014        | glass | Cement | construction field | increase |
| 8   | Bhagyasri | 2016      | glass | Coarse aggregate | construction field | increase |
| 9   | Fahad | 2020         | glass | Cement | construction field | Increase |
| 10  | M. Al Tayeb | 2012  | crumb rubber | Cement and Sand | construction field | decrease |
| 11  | Falak O | 2015        | crumb rubber | Sand | construction field | decrease |
| 12  | Sofi | 2016         | crumb rubber | Cement and Sand and Coarse aggregate | airport pavement | decrease |
| 13  | Siddiqui | 2016     | crumb rubber | Coarse aggregate | lightweight concrete construction field | decrease |
| 14  | V. Choudhary | 2017  | crumb rubber | Sand | construction field | decrease |
| 15  | Abdulkareem | 2018 | crumb rubber | Cement | construction field | decrease |
| 16  | Chiang | 2000        | sludge | with agricultural waste and rice husk ash | Brick | improved |

Table 1. Literature review of different wastes utilised in various construction applications (continue..)

| No. | Author | Reference no. | waste | Replacement | Applications | Compressive strength |
|-----|--------|---------------|-------|-------------|--------------|---------------------|
| 17  | Tay | 2002        | sludge | with clay | Brick | improved |
| 18  | Cusido | 2003      | sludge | with forest debris | Brick | improved |
| 19  | Abdul | 2004       | sludge | with clay | Brick | within the standard improved |
| 20  | Chihpin | 2005     | sludge | with excavation waste soil | Brick | improved |
| 21  | Cheng-Fang | 2006    | sludge | with Bottom Ash | Brick | improved |
| 22  | Kung-Yuh | 2009    | sludge | with rice husk | Brick | improved |
| 23  | Joan and Lazaro | 2009  | sludge | with clay | Brick | improved |
2. Conclusions

Different wastes are generated from various activities. The utilisation of waste materials is developing according to knowledge and exploring the possibility of materials. The basic step of utilising any waste materials is selecting the proper waste that results in a certain application's best performance. The large scale of wastes is demonstrated in various applications. Steel slag can be used in different fields because of its strength, wear abrasion, density etc.

As construction materials; steel slag can modify the strength, glass can substitute the sand without altering the properties, while crumb rubber could produce lightweight concrete by reducing its density. Both glass and crumb rubber could reduce water absorption. Utilising sludge in the construction industry is one of the sludge disposals, and treatment alternatives since sludge treatment involve massive costs and complexity.

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