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Using Solid Waste as A Substitute for Raw Materials in Construction: A Review.

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Abstract— The main challenge is to protect the environment from future deterioration due to pollution and the lack of natural resources. Therefore, one of the most important things to pay attention to and get rid of its negative impact is solid waste. Solid waste is a double-edged sword according to the way it is dealt with, as neglecting it causes a serious environmental risk from water, air and soil pollution, while dealing with it in the right way makes it an important resource in preserving the environment. Accordingly, the proper management of solid waste and its reuse or recycling is the most important factor. Therefore, attention has been drawn to the use of solid waste in different ways, and the most common way is to use it as an alternative material for raw materials in engineering construction. Countless types of solid waste can be used in different ways and quantities according to the purpose for which they are intended, for example the use of rubber, construction waste, ash and many others. This study discusses the problem of solid waste and methods of its management, in addition to its use with building materials in order to improve their properties and reduce costs.

Keywords— solid waste, recycling solid waste, sustainable buildings, sustainability.

1. Introduction

For several centuries, the issue of solid waste was considered an inevitable consequence of the use of materials in daily life, and it was disposed of by landfill or in places out of sight, as the recycling and use of solid waste in another way was out of mind [19]. Solid waste management is one of the most important environmental barriers in many Asian countries. The increase in solid waste is due to population growth, high standards of living, urbanization, technological development and modern lifestyles. Various activities such as industry, agriculture, mining and household activities also contributed to changing the quantity and quality of solid waste generated [35]. Worldwide generation of solid waste is evaluated at 1.3 billion tons/year and increasing by 1% annually [4].

In 2019, the World Bank issued a report stating that there is a global increase of up to 70% in urban solid waste, which makes developing countries facing the most important challenges. It is also expected that by 2050 the amount of solid waste will increase from 2.01 billion tons per year today to 3.40 billion tons per year, which will raise annual global costs from 205 billion dollars to 375 billion dollars [20]. In general, waste is seen as causing the spread of pollutants in the environment in the form of organic and inorganic pollutants. One example of an organic pollutant is food waste which is a source of biomass, which can be used as biofuel, heat, electricity or fertilizer. Metalloids, polycyclic hydrocarbons (PAHs), mineral soils and polychlorinated biphenyls (PCBs) pose a major threat between organic and inorganic pollutants. As the effect of solid waste on humans and the environment is noticeable in the form of direct and indirect effects, respectively. In fact, direct effects are related to the degradation of solids and damage to human health. Indirect effects themselves are perpetual effects that can affect the ecosystem and climate change, which subsequently determine the structure of society and the sustainability of the respective continents as well as the economy [8]. The emission of methane gas is considered a harmful and dangerous environmental effect because it is a powerful greenhouse

gas that is generated as a result of the accumulation of solid waste, and the harmful effects of methane gas can be felt within a short period of time [21].

Waste management is one of the difficult problems in the rapidly developing world due to insufficient manpower, tools, machines and financial resources that lead to environmental pollution [14]. To decrease the whole amount of waste that goes to landfills, the volume of this waste generated must be reduced, then the existing materials should be reused or those materials should be recycled [5]. Recycling waste works to save energy and natural resources, reduce the amount of solid waste, reduce water and air pollution, and reduce greenhouse gases [10]. Modern building technologies are being developed to respond to the environmental and social issues associated with the excessive use of natural raw materials [11]. Recently, the construction industries have started to take advantage of solid waste that can be recycled and reused in a beneficial way. Currently, various recyclable solid wastes can be used in civil engineering applications such as silica fume, fly ash, steel slag, crushed rubber tires, crushed marble, crushed glass, cement kiln dust, recycled concrete batches, etc. [10].

Madurwar et al. [18] conducted a review in 2012 on the use of agricultural waste as a sustainable building material, in which it was shown that materials produced using agricultural waste have beneficial properties such as being lightweight, durable, low thermal conductivity and environmentally friendly as well as being relatively cheaper. In 2013, Torkaman et al. [33] studied the production of lightweight concrete blocks by replacing part of Portland cement with waste limestone powder, rice husk ash and waste wood fibers, and the results of partial replacement of cement using these wastes showed good physicochemical properties, which is evidence that recycling this waste is not only an environmental solution, but also a good economical alternative to building design. Also, Ganiron et al. [11] conducted a study in 2017 on the use of agricultural waste in the development of alternative building materials for the purpose of reducing environmental and social problems, as they worked on the use of coconut husks and fibers as an alternative to aggregates in the development of concrete hollow blocks. Their laboratory tests showed the possibility of applying coconut husks and fibers as an alternative to aggregates in concrete hollow blocks, as they showed very good indicators in terms of texture, shape, light weight, crack resistance, surface moisture, grades, absorption, freezing and heating resistance, in addition to gaining higher compressive strength than conventional concrete blocks after 28 days.

In 2021, Abdullah et al. [3] conducted a review on the use of waste bricks as a partial substitute for cement or as an alternative material for aggregates and it was concluded that due to the pozzolanic activity of clay brick powder, it can be used as a substitute for cement at substitution level up to 10%. For natural coarse aggregate, recycled aggregate can be used instead, but with a limited replacement rate. This study aims to shed light on solid waste and its management methods, in addition to the possibility of using solid waste with building materials to improve their properties and reduce the proportion of raw materials used in them, and thus reduce production costs.

2. Municipal solid waste management

Municipal solid waste includes domestic waste, waste from business centers and commercial offices and non-hazardous industrial waste, all of which are generally managed by the local municipal authority [39]. In general, solid wastes are heterogeneous in nature and, therefore, have variable physical and chemical properties depending on their original sources. It consists of food waste, yard waste, plastics, metals, leather, paper, rubber, wood, batteries, textiles, inert materials, and demolition materials. Constructions, paint containers, and other things that are hard to classify. The heterogeneity of this generated solid waste is the main obstacle in the process of sorting and reusing them as materials. It is therefore necessary to separate and sort this waste before any useful treatment process. The composition of Municipal solid waste varies greatly from one municipality to another and from one country to another. This difference mainly depends on the lifestyle, waste management systems, economic situation and industrial structure. In 2013, the Environmental Protection Agency estimated the quantity of municipal solid waste generated in the United States at 254 million tons. Figure 1 shows the composition and material classification of this solid waste [1].

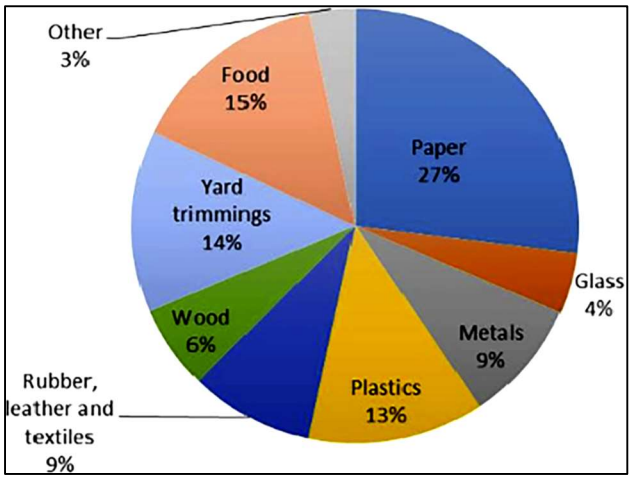

Figure 1. Municipal solid waste classification by EPA in US in 2013 [1]

Municipal solid waste management includes many stages such as collection, sorting, storage, transportation, treatment and final disposal of waste generated from municipal sources by following the guiding technical principles with a focus on environment, economy and health, to name a few [8, 34].

Conventional solid waste treatment techniques are composting, incineration and landfilling, all of which have collateral damage to the environment [40]. Improper

management of municipal waste leads to serious health, urban and environmental problems such as bad odor, risk of explosion in landfills, groundwater pollution due to leachate leaching [5]**.** There are several factors affecting solid waste management such as sources, social factors, enabling policies, cultural, political and other factors. In order to ensure a sustainable environment, technical and non-technical factors must be addressed seriously and accurately [8].

3. Reduce, reuse and recycle solid waste (3R)

The correct management of solid waste must follow a hierarchy, where this hierarchy is represented by the 3 R's, which are recycling, reusing and reducing waste, but according to the hierarchy another R is added which is recovery. The hierarchy is influenced by financial, social, environmental and administrative factors. Working in a hierarchical system reduces greenhouse gas emissions, Figure 2 indicates the waste hierarchy [7].

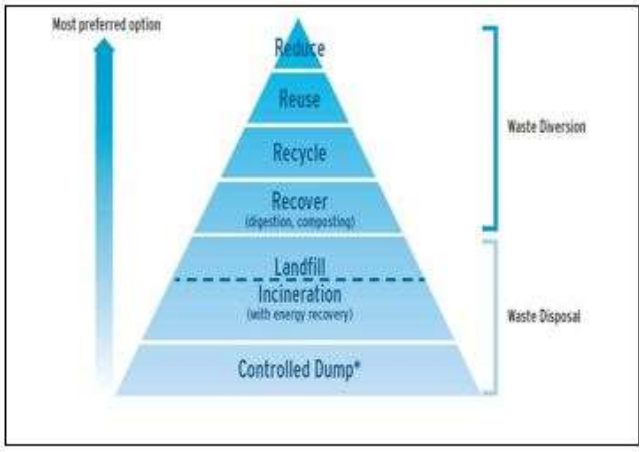

Figure 2: The waste hierarchy [7].

The implementation of the 3R principle will have a significant social and economic impact [35]. Dealing with 3Rs puts solid waste management strategies into different categories which mainly depend on the individual's desire to implement them, as the society can get many benefits from waste recycling and reuse practices such as tax revenue, income and jobs [20]. Reducing waste means to reduce the waste generated as well as reduce the resources used as solid waste management consists in controlling consumption. Reuse means using the materials in their original form on the same place or in another place more than once [20, 35].

Various methods are used in the reuse mechanism like resource retrieval, energy retrieval, pyrolysis, sustainability and biological reprocessing to recycle the used materials, examples are reusing paper, recycled bottles and cans to conserve valuable natural resources. Previously used materials can also be entered as raw materials for new products, such as reusing the gray water produced by homes in irrigation [20]. Recycling refers to obtaining new useful products from used old products [35] as Recycling is now considered an essential tool in reducing solid waste and providing the industrial sector with the necessary raw products [20]. The goal of solid waste recycling and reuse is to achieve a clean environment and reduce waste areas as well as reduce the use of natural resources. Some examples of materials that are recycled and used in building materials are textiles, aggregates, metals, glass, plastics and many more [21].

4. Sustainable building concept

The rapid development in many countries has resulted in the generation of large construction waste that cannot be controlled, and thus created significant negative effects on the environment, for example increasing air, soil and water pollution, which contributed to climate change and environmental imbalance as well as health risks. Also, poor design and construction practices have significant environmental and economic impacts on the life cycle, leading to waste of material and energy resources [6].

The use of a large number of natural resources to meet the rapidly growing construction and waste generation activities has put inevitable pressures on the natural environment [14]. The material most consumed by humans after water is concrete, as no construction work can be carried out without its use. Therefore, it is the most important material in construction due to its workability in addition to its durability and high strength. In order to preserve natural materials as much as possible, it has become important to obtain a partial alternative to traditional concrete components [36]. In addition, the price of building materials is increasing daily due to high demand, high energy prices and scarcity of raw materials. Currently, from the point of view of energy saving and natural resource conservation, the use of alternative components in building materials is a global concern, as many authorities and investigators are working recently to obtain the concession of reusing waste in ways that are economically and environmentally sustainable. The use of solid waste in construction is one such innovative effort, therefore a lot of research and development work is underway for the purpose of exploring new components that are required to produce sustainable and environmentally friendly building materials [26].

Green concrete has begun to be widely adopted in construction and has become in great demand because it possesses distinctive properties that are not available in traditional concrete, which increases the speed of project completion and reduces costs, time, maintenance and other matters that increase productivity and the life span of the project. Green concrete offers many advantages, including but not limited to increased durability, reduced permeability, reduced cracks, increased strength, increased workability, etc. [16, 30]. Figure 3 shows some of the advantages of green concrete [25].

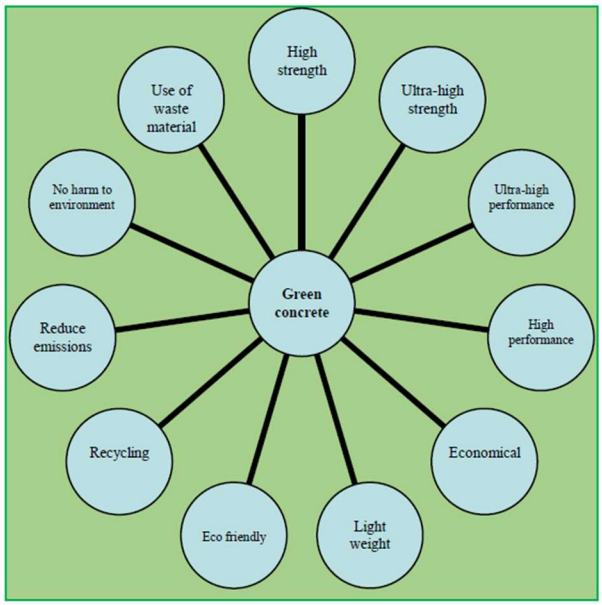

Figure 3: The advantages of green concrete [25].

Many solid wastes have been tested as alternatives to conventional concrete components in one form or another, such as furnace slage, construction and demolition waste, crushed marble dust, crushed animal bones, egg shells, electronic waste, sludge, human hair, and other waste materials [36].

Advances in structural design and material technology with environmental concerns require the use of environmentally friendly, lightweight composite materials that meet building material requirements and are cost-effective. These include strength, workability of the material, durability, sound insulation properties and thermal properties [29]. So, the main focus in sustainable design and construction is on minimizing the negative impacts of buildings from an environmental, economic and social point of view [6].

5. Solid waste as an alternative sustainable building material

With the growing importance of green building concept, sustainable building has proven great benefits to the environment and economy. The main objective of sustainable building is to reduce the consumption of natural resources as well as the impacts on ecosystems [14, 38]. The destiny of waste mostly depends on its environmental quality. Bottom ash is often categorized as non-hazardous and therefore can be used in different applications such as road construction as a base material and substitutes for sand and gravel [12]. As a building material, steel slag can modulate the strength, and crumb rubber can produce lightweight concrete by reducing its density, while sand can be replaced by glass without changing the properties, both crumb rubber and glass can reduce water absorption [10]. Agricultural waste is also used as alternatives to building raw materials, whereby components are produced that are relatively cheaper and environmentally friendly and have certain characteristics such as being light in weight, low thermal conductivity and durability, among others [18]. Fly ash is used in many applications as a substitute for aggregates or as a partial substitute for cement in the manufacture of various types of concrete [28].

Typical wastes examined include ground coffee waste, rice husk, coconut shell, banana skin, waste wood fibers, coconut and durian fibers, primary cellulose sludge generated on paper, pulp mills, lignocellulose waste, wool fibers, sisal fibers, carpet fibers, also some researchers have considered human hair fibers as cement-based additives to improve the engineering properties of building materials [12]. Many agricultural industrial wastes can enter the brick industry, which includes sawdust, cocoa husks, sugar cane and rice husks [17]**.** Grinding shredded rubber pieces into granules of different sizes is the most widely used method for recycling rubber and using it as an alternative to fine or coarse aggregates [32]. The use of waste plastic in concrete for the manufacture of paving blocks gave a compressive strength similar to ordinary concrete and this procedure reduces the cost of construction using this type of concrete in addition to reduce the cost of disposal of plastic waste [23]. Also, waste materials such as blast furnace slag, fly ash, lightweight aggregate and other materials that can be used in the production of building compounds that have little environmental impact during their life cycle [22].

The study conducted by Du and Tan in 2014 showed that it is possible to add 15 percent of glass powder to obtain concrete with high performance in terms of strength and durability against chloride penetration, because glass waste powder contributes to improving the pozzolanic reaction of concrete [9]. Salve et al. in 2019, found that it was appropriate to replace 2% of concrete aggregate with plastic aggregate [27]. Tamanna and Tuladhar in 2020 showed that recycled crushed glass can be used instead of cement in concrete by up to 10 percent, as this replacement significantly improved the concrete's resistance to chloride penetration, in addition to achieving the required strength [31]. The results of the study conducted by Kassed and Ali in 2021 showed that 30 percent of the fine aggregate in concrete can be replaced with crushed glass, as laboratory tests proved that the tensile and compressive strength of the concrete was very good at the age of 28 days [13].

In 2022, Verma and Kujur conducted a study to determine how much concrete strength improves when using rice husk ash. The results showed that the compressive strength during 7 days increased by 7.2%, and after 7 days and after 28 days the increase reached 8.9%. The separate tensile strength also increased to a rate of 8.4 % within 7 days and to a rate of 11.9 % within 28 days when replacing the cement with 15 % of rice husk ash. The flexural strength also increased to 1.96% in 7 days and to 1.06% in 28 days when 10% of the cement was replaced by rice husk ash [37].

Also, in 2022, Abdulazeez and others concluded, through their laboratory experiments, that 10 percent of rice husk

ash is the optimal percentage as a substitute for cement in concrete, as it gives the concrete a compressive strength at day 28 equivalent to 26.8 Newtons/mm2 [2]. In 2023, Raham et al. studied the properties of concrete by adding different percentages of fly ash as a substitute for fine aggregate. They found that it is very suitable for use in producing green concrete, which is characterized by high strength. It was found that the compressive strength of concrete was achieved for a period ranging between 14 and 28 days when the percentage of fly ash was 12% of fine aggregate [24].

6. Conclusion

Solid waste is considered the problem of the times, its disposal has become a problem for some countries, while other countries consider it a wealth that can be used in various industries. One of the most common ways is to replace part of the raw components with solid waste in the construction industry, thereby obtaining certain properties. Using solid waste in this way leads to multiple benefits, including reduced environmental pollution, reduced household gases, reduced use of raw materials, as well as reducing the cost of buildings by moving towards sustainable and environmentally friendly buildings.

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استخدام المخلفات الصلبة كبديل عن المواد الخام في البناء: مراجعة

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الخلاصة – التحدي الرئيسي هو حماية البيئة من التدهور المستقبلي بسبب التلوث ونقص الموارد الطبيعية. لذلك فإن من أهم الأمور التي يجب الانتباه لها والتخلص من تأثيرها السلبي هو النفايات الصلبة. تعتبر المخلفات الصلبة سيف ذو حدين حسب طريقة التعامل معها ، حيث أن إهمالها يسبب مخاطر بيئية جسيمة من تلوث المياه والهواء والتربة ، بينما التعامل معها بالطريقة الصحيحة يجعلها موردا هاما في الحفاظ على البيئة. وعليه ، فإن الإدارة السليمة للنفايات الصلبة وإعادة استخدامها أو إعادة تدويرها هي العامل الأكثر أهمية. لذلك ، تم لفت الانتباه إلى استخدام النفايات الصلبة بطرق مختلفة ، والطريقة الأكثر شيوعًا هي استخدامها كمواد بديلة للمواد الخام في البناء الهندسي. يمكن استخدام أنواع لا حصر لها من النفايات الصلبة بطرق وكميات مختلفة وفقًا للغرض المقصود منها ، على سبيل المثال استخدام المطاط والخشب ومخلفات البناء والرماد وغيرها الكثير. تناقش هذه الدراسة مشكلة المخلفات الصلبة وطرق إدارتها ، بالإضافة إلى استخدامها مع مواد البناء لتحسين خصائصها وتقليل التكاليف.

الكلمات الرئيسية – النفايات الصلبة ، إعادة تدوير النفايات الصلبة ، المباني المستدامة ، الاستدامة.