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Application of Recycled Waste Materials for Highway Construction: Prospect and Challenges

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Abstract

Industrialization and continuous increase in population growth have contributed immensely to various kinds of solid waste generation which most times are indiscriminately dumped. These activities have negative effects resulting in environmental pollution which could be a menace to the environment. Moreover, to preserve the environment, many researchers have made efforts to ensure that some of these wastes are recycled and utilized in the production of various alternative materials as a means of sustainable technology. Among several alternative materials for construction, some of these wastes are considered to be very useful.

This study examines the various recycled waste materials that can be adopted for construction, including their prospects and challenges. Some of the recycled waste materials examined are plastic waste, mill tailings, geopolymers, waste glass, rubber tyre waste, shingles, construction and demolition wastes (C&D) and slag. These recycled materials have been accepted globally due to their characteristic properties which made the materials suitable in the construction industry. This review also examines some limitations relating to the adoption of these materials as alternative construction materials for highway/pavement construction. However, it is generally accepted that reuse of waste materials in construction industry has minimal environmental impact and their exploration would have huge economic impact.

Keywords: Industrialization, Sustainable Technology, Recycled waste materials, Highway construction, Waste Management

1. Introduction

Provision of social infrastructure such as road, buildings, and bridges are part of development which must be sustained. Sustainable development requires meeting up with everyday need, without any comprise to the future. In this wise, adequate measures should be put in place to ensure availability of construction materials for future development. In recent years, alternative construction materials have been the subject of consideration in which several studies have considered using solid waste materials as a substitute to the well-known materials.

Waste generated all over the world (solid or liquid wastes) is increasing day by day [33]. Solid waste was estimated to be 2.01billion tonnes in 2016 and is expected to rise up to 3.40 billion tonnes annually by 2050 [18]. There are various classifications of solid wastes such as industrial, agricultural and domestic wastes. Most of the industrial wastes such as steel slag, aluminium dross, and waste tyres are very useful and are recyclable [5]. .

Recycled materials are materials obtained from various methods of transforming used materials into new ones [7].There are prospective materials available for highway construction all over the world today. Most of these materials are readily available in form of waste and were in the time past underutilized of which 0 - 70% are recyclable [50] [51]. Some of them which are degradable contain substances that are harmful to the environment while majority are not degradable. This has become a major concern to all and following the recent trend in exploring potential resource from generated solid waste, some researchers came up with measures to recycle these materials which are largely available and applicable for highway construction. This thought was looked into considering the fact that most roads especially in the developing countries are bad and cost of conventional construction materials is on the high side. Besides, the high cost, massive use of these materials has negative effects on the environment; [17] therefore, use of recycled materials becomes an option [13]. Construction of highway pavements with greener and recycled materials is a sustainable practice [8]. The recyclable solid wastes that are considered for pavement construction in this work are plastic waste, waste glass, demolition waste, geopolymers, mill tailings, shingles, slag, and waste tyres. They are considered due to some notable engineering properties which they possess. These properties make them suitable for adoption in pavement construction and their usage will promote waste reduction, a cleaner environment, cost reduction in construction works and as alternative construction materials.

2. Prospects of Recyclable Materials

The use of recyclable like plastic wastes, waste tyres, steel slag and aluminium dross materials have been utilized by developed countries and some developing countries too. It is a possibility for every developing country to adopt this practice as it will ensure sustainability.

2.1 Plastic Waste

Common plastics are not biodegradable because of its long carbon chain. This makes it difficult for microorganism to degrade. Meanwhile, the period of natural degrading never gets completed before new sets of plastic wastes are produced. This situation consequently increases the volume of plastics in landfills [19]. Some plastic waste materials have been utilised by incorporating them into production of modified bitumen for pavement construction and are found to be very efficient [10][37] [40].. It was found that the pavement made by using plastic product gave better water-resistant property than the conventional pavement [18]. The properties of the pavement binder were improved by utilizing plastic waste in modified bitumen [21] [43]. An attempt was also made introducing recycled plastic fibres as stabilizer for expansive soils and result revealed that it increased both their tensile and compressive strength. The shrinkage crack resistance of expansive soils was improved by stabilization with recycled plastic. Research findings shows that the coarse aggregates are more stable due to their coating with plastic and the percentage of plastic waste utilized in modification of bitumen increased[44] [45] [46]..

2.2 Slag

Slag is a hard-solid waste material obtained from refining of metals like steel, copper, aluminium and so on. Copper slag is a waste material from the manufacturing process of copper. The slag has been found very useful in so many activities including highway construction [14] [26].

The effect of Copper slag on the rutting potential of pavement was investigated by replacing the fine component of the bituminous concrete with 40% copper slag. Results showed that it satisfied the requirements for rutting [1] [53]. Steel slag also showed noticeable improvement in resistance to permanent deformities as well as increased resilient modulus [3] [27]. Blast furnace and electric arc steel slag from research is very efficient in control of storm water for flood prone regions [34]. Aluminium dross is another by-product obtained from the manufacturing process of aluminium. Aluminium dross, when incorporated as fillers into concrete for rid pavement construction improved its corrosion tendency as well as mechanical properties [35] [49]. When used as filler in flexible pavement, aluminium dross proved to be durable under various temperatures [48].

2.3 Waste Tyres

About 1.4 billion tyres are sold worldwide each year and a number ultimately fall into the class of end of life tyres (ELTs) [41]. These tyres are among the principal and most challenging sources of waste, because of the huge volume manufactured [38]. The insufficient transfer and disposal of used tyres may, every now and then in some cases, represent a probable danger to human health (fire risk, a safe haven for rodents or other pests such as mosquitoes) and possibly increase environmental and ecological risks. The physical and chemical properties of these used tyres have impact on its application in pavement construction [54].

Sound absorption and toughness of flexible pavements was examined by application of tyre crumbs in modified bitumen. Results expressed that these properties were improved and it was stated that alteration of bitumen with tyre crumbs should not exceed 20% [36]. In wet process, recycled waste tyres when used in binder for pavement rehabilitation had high impact in minimizing noise [36]. The thickness of a pavement depends on its California bearing ratio (CBR). A soil with good subgrade CBR reduces the pavement thickness. In this light, the application of waste tyre crumbs was introduced into expansive soils to strengthens the subgrade and was found to be effective [25]. The utilization of waste tyres in highway has been proved to reduce accident risk due the quality of the wearing course as it improves the pavements skidding resistance [37].

2.4 Waste Glass

Glass and Cement factories face a lot of challenges due to the huge volume of greenhouse gases being released into the atmosphere, profound energy usage and the intensive use of the earth's natural resources [6] [32].. The usual habit of disposing waste glass to landfills is also an environmental unfriendly practice, due to the non-biodegradable nature of the waste glass. Moreover, the chemical composition and the pozzolanic properties which waste glass possess make it useful for the cement and concrete industries [16]. Glass due to its engineering properties, can revive different stages of pavement life. With the introduction of waste powdered glass alongside butadiene rubber, the mechanical and physical properties of hardened concrete were noticed to improve drastically. The workability of concrete reduces monotony as the replacement percentage of cement by glass powder is increased. The replacement of cement up to about 20% has positive effects on the compressive strength as well as reduces the rate at which it takes in water [45].

2.5 Demolition wastes

In the bid to construct, renovate or rehabilitate, some level of demolition takes place and this generates a lot of waste whose disposal in the long run poses environmental concern.

Construction and Demolition wastes are generated all-through the lifespan of a project. At the maintenance stage, generated waste is minimal except renovation processes are on – going. As a result of the volume of waste generated, three basic waste generation activities can be classified: (i) New buildings construction, (ii) Old buildings demolition, and (iii) civil and infrastructural works .According to [11], it was discovered that the bearing capacity, resilient modulus and resistance to permanent deformation increased with the introduction of recycled demolition waste. [42], discovered that leaching of the pavement underlays could be taken care of by using recycled demolition waste. Different types of demolition wastes were collected, worked on, and results howed that they met the criteria for quarry subbase materials .Quarry waste was incorporated as aggregate in asphalt without any noticeable polishing effect.

2.6 Geopolymers

The word Geopolymer was coined from polymer. Polymer is a large molecule constructed from many smaller structural units called monomers, covalently bonded together in a conceivable pattern [52] Geopolymer is known to be a term covering a class of synthetic aluminosilicate materials. It is a novel family of building materials, a new material for coatings and adhesives, new binders for fibre composites, waste encapsulation and new cement for concrete [12] [23]. They also refer to materials that give semi-permanent, crosslinkage, non-crystalline system. Obsidian is a typical illustration for naturally occurring geopolymers [22]. Fly ash geopolymers were used to investigate the strength and leaching effect for reclaimed asphalt and were discovered to reduce the leaching effect of heavy metals [4]. For rapid road repair, early strength being a key factor, was achieved by the introducing geopolymer mortar (metakaolin) mixed with parawood ash [28]. High compressive strength with low drying shrinkage were also observed when geopolymers are mixed with mine tailings [30] [2].

2.7 Mill tailings

Mill tailings are wastes obtained after the total extraction of ore has been carried out. It is usually sand-like. There are various instances in which mill tailings have been introduced into road construction for sustainability. Copper tailings were employed alongside electric arc furnace steel in pavement construction and it was found that the duo can be utilized as aggregates [31]. Highway soil stabilization is another area where tailings are being used.

Soil stabilization was achieved by mixing clay soil with mine tailings in various percentages and lime-cement added as a stabilizer. It was noticed that the leaching effect of metals on soil was reduced because of its compactable ability. Also, copper mine tailings with geopolymers were used to stabilize soil for road base course and it was found that the requirements for road base were met [24].

2.8 Shingles

Shingles is a kind of roof covering which uses asphalt as waterproof membrane. It is produced by suspension method and it is very cheap to use. Meanwhile, once it has exceeded its life span as roofing material, it becomes waste. This waste generated instead of causing environmental pollution is being utilized in road construction as a means of having a cleaner environment and sustainability of construction materials. [29] in their study discovered that addition of asphalt tear-off roofing shingles resulted to stiffer binder in the mixture, thereby increasing material stiffness, stability, and rutting resistance. [9] replaced 14% of binder by shingles and it was reported that the shingle wastes improved the pavement fatigue life as well as rheological properties of bitumen.

3. Challenges in Application of Selected Recyclable Wastes

3.1 Plastic wastes

Despite the advantages derived from using plastic wastes, some noticeable challenges were also recorded when used for modification of bitumen. Amongst the challenges are poor stability and low aging resistance [20]. It was also found that the plastic wastes had reducing effect on both the stiffness and fatigue properties of asphalt mixes [25].

3.2 Slags Wastes

Locally, in civil works, the improvement of the quality of soils have been done with the aid of steel slags, for road beds arrangements, bases and rolling layers for roads and rural paths and even for railway beds. According to [43], the production of asphaltic concrete with the addition of more than 35% copper slag causes reduction in ductility. Also, Steel slag has been found to expand and if not properly cured might distort the whole asphaltic concrete mix. As against, the naturally available aggregate concretes, the Electric Arc Furnace slag developed a slightly higher porosity in the cement matrix giving room for infiltration which is not required.

3.3 Waste glass

Cement in concrete was partially replaced with powdered waste glass of 10%, 20%, 30% & 40%, respectively and its effects on compressive strength, split tensile strength, workability and flexural strength were observed. It was discovered that initially, the compressive, flexural and split tensile strengths of concrete increased with percentage replacement of cement by glass powder until it reached a maximum of about 20% and later dropped. This implies that 20% addition of waste glass must not be exceeded [45].

3.4 Waste Tyres

Application of waste tyres in modified bitumen for flexible pavement has tremendously passed with a lot of advantages. Meanwhile, in concrete roads, the cement paste and tyre crumbs happen to be incompatible thereby causing problem with mixing and quantities of tyre crumb utilization. The glaring difference in stiffness causes stress concentration [18]. [47]. Some of the properties of wastes tyres such as low bulk density and low modulus of elasticity prevent easy compaction of the asphaltic concrete. The manufacturing procedure of waste tyres in hot asphalt mixtures requires accurate temperature of the time needed for mixing and storing [15]. Insoluble rubber wastes can cause handling and pumping apart from the compaction challenges which it generates.

3.5 Demolition Wastes

The demand rate for construction materials is higher than the rate of generating and recycling demolition wastes. Also, the need for energy involved in the recycling of demolition waste is another challenge. To take care of energy challenge, [55] presented a method of option of involving developer, property Management Company and the energy service company.

4. Conclusion

To have sustainable development, the construction industries need to be equipped with materials which will enable continuity. The conventional construction materials such as sand, gravel, and limestone have been in use for a long time and still are in use till date. These conventional construction materials if continuously used, will have negative environmental impacts and gradually deplete thereby limiting our natural resources as well as affecting the level of productivity in the construction industries. Therefore, the use waste for materials such as slag, waste tyres, demolition wastes, plastics wastes, mill tailings, shingles, geopolymers and glass as reasonable alternatives is essential due to the various areas in which they have been successfully utilized. Despite the challenges attached to the use of these materials, with improvement in technology, sustainability is ensured.

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