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Original Research Paper

Utilization of Crumbs from Discarded Rubber Tyres as Coarse Aggregate in Concrete: A Review

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Abstract: This research work successfully reviewed twenty-five papers on waste rubber tyres and their related areas. The chemical and physical properties of concrete constituents such as cement, water, sand and rubber crumbs were reviewed together with their mix ratios. The use of Tyre Rubber Crumbs (TRC) to replace coarse aggregates makes concrete construction work cheaper and its low water absorption rate improves the concrete mix properties such as compressive strength and workability. Hence, in road pavement construction, the use of TRC in asphalt modification is the best and smartest innovation for sustainable development and waste material reuse. This research showed that waste TRC are very essential in the replacement of some aggregates in the construction industries resulting in very high-quality construction and as well minimize construction costs.

Keywords: Coarse Aggregates, Concrete, Crumbs, Rubber, Waste Tyre.

1. Introduction

The number of waste tyres is continually increasing because of the growing use of transport vehicles and almost one trillion tyres produced in the world annually were not recycled. This unrecycled tyre is expected to be up to 12 trillion by 2030. The disposal of waste tyres has become a global problem [1]. Discarded tyre rubber crumbs are waste materials that pose huge environmental hazards to the surroundings where they are deposited. Erosion of the existing topography usually results in flooding and landslides. Moreover, the filtration of rainwater achieved by deposits of natural sand and gravel is being lost, thereby causing contamination of water reserves used for human consumption. Hence, to prevent pollution authorities are imposing more and more stringent restrictions on the extraction of natural aggregates and their crushing [2].

In many countries, burying waste tyres is a common disposal method, which shortens the service life of the burial ground and causes a very serious threat to ecology. Therefore, effectively reusing waste tyres are an urgent and important issue for saving energy and protecting the environment [13]. Several methods of recycling waste tyres were proposed, including use as fuel in cement kilns and to produce carbon black. These are technically feasible while bringing great economic waste and environmental pollution [2]. Using recycled rubber as an additive to or replacement for construction materials is a highly preferable option. The initial trial of using crumb rubber disposals as a modifier of asphalt was very excellent but its high viscosity and higher temperature required during production made it impractical to be widely used. To reuse waste tyre rubbers effectively, one of the possible solutions is to incorporate them into cement-based material. Partial replacement of mineral aggregates in concrete with waste tyre rubber crumbs could control environmental pollution [4]. In general, concrete has low tensile strength, low ductility, and low energy absorption. Concrete also tends to shrink and crack during the hardening and curing process. These limitations are constantly being tested with hopes of improvement by the introduction of new admixtures and aggregates used in the mix [5].

2. Literature Review

The best way to overcome this problem of discarded rubber tyres is to find alternate aggregates for construction in place of conventional natural aggregates. Rubber aggregates from discarded tyre rubbers with sizes of 20-10 mm down can partially replace natural aggregates in cement concrete construction [6] The rougher the rubber particles used in concrete mixtures the better the bonding they develop with the surrounding matrix. Hence, the higher the compressive strength of rubberized concrete the better the bonding between rubber particles and the surrounding cement paste [6].

Aggregates vary from merely washing them with water to acid etching which implies that about 57% improvement in the compressive strength of concrete was obtained when rubber aggregates are treated with carbon tetrachloride (CCl_4) before use. The treatment increases the surface roughness of the rubber, which improves its attachment to the cement paste. One of the main causes of the lower compressive strength of rubberized concrete is loading weak bonding of rubber aggregates to the surrounding cement paste [7]. There are many ways in which rubber aggregate bonds can be improved such as factory recycling and others. The waste rubber recycling factories should supply the rubber aggregates in pretreated and specified grading for better performance. This will build confidence in users and improve the mass sale of rubber aggregates as a new construction material for cement concrete construction. Quality rubber aggregates should be manufactured and supplied by waste rubber recycling factories in grades of 20 - 10mm, 10-4.75mm and 4.75 mm downsizes [8].

The addition of rubber aggregate in concrete mixes reduces the concrete density, which can be utilized in lightweight concrete. Rubberized concrete reduces the concrete strength which may be needed where M-10 and M-15 grade concrete is required [9].

2.1. Strength of Rubber Tyre Crumbs as a Partial Replacement of Course Aggregates

Crumb rubber aggregates mortars and concrete has been widely recommended for use where vibration damping or resistance to impact/blast or high plastic energy absorption is required for effective and efficient blending. Concrete with rubber aggregate has also been recommended for applications such as trench filling and pipe bedding, low-strength flowable concrete, nailing concrete and stone backing [10]. The use of rubber aggregates reduces the flexural strength of concrete and even though rubber particles decrease the flexural strength of concrete. The RC specimens do not collapse under bending load during the flexural test due to the high deformations of rubber particles [11].

On the other hand, the decrease in flexural strength of concretes at 28 days is insignificant until the rubber content of 30% in a low w/c ratio of 0.40 and 0.43 is wet. This is possible because the rubber particles which are well distributed in the mixture help in preventing cracks like steel and fibres. Moreover, the brittleness index decreased with rubber additions after 15% and it shows that there is a transition from brittle-ductile behavior. Increasing the rubber content regardless of its size, type and replacement level, the fresh properties of Self Compacting Concrete will remain the same such as passing ability, segregation resistance, and flowability will decrease and viscosity will increase. The compressive strength decreases with an increase in the percentage of the tyre rubber crumbs in the range of 28.95 % to 55.21%. However, the compressive strength is still in the reasonable range for the 5% replacement [5].

2.2. Physical and Chemical Properties of Rubberized Concrete

2.2.1. Shrinkage properties

The rubber aggregate with low stiffness plays an important role in limiting the number of cracks resulting from shrinkage by reducing the internal restraint, lowering the elastic modulus, and bridging the cracks that propagate within the concrete. The low elastic modulus of materials has been proven to reduce thermal and shrinkage stresses. Although the addition of RA can reduce the modulus of elasticity and subsequently reduce the shrinkage stress and control the shrinkage cracks up to a reliable limit by using 20% of rubber aggregate to replace the natural aggregates which will improve the resistance of the material to shrinkage cracking. The plastic shrinkage of rubberized concrete decreases along with the addition of rubber aggregate. The plastic shrinkage gradually increases after exceeding the 20–25% replacement level [12].

By contrast, previous studies reveal that the addition of rubber aggregate can increase the drying shrinkage in concrete. The drying shrinkage in concrete increases along with the RA and water content. The analysis of the test results obtained reveals that the shrinkage may increase by 43% when rubber aggregate replaces 15% of fine aggregate. These authors also reported that RA significantly affects the shrinkage of concrete until a full drying shrinkage takes place (evaporation of water from concrete); after this point, RA does not produce any noticeable effect on the shrinkage of concrete [13].

2.2.2. Workability

Workability is the ease with which freshly prepared concrete can be transported and placed for the work and compacted to a dense mass. The replacement of coarse aggregate with scrap tyre rubber affects the workability of the concrete. The result of the normal concrete mix showed an increase in workability, but it can be summarized that the workability is adversely affected by the incorporation of chipped tyre rubber [14]. By increasing the rubber aggregates the passing ability and viscosity increased but flowability decreased due to roughness and friction in rubber particles' surfaces.

The researcher in [15] achieved the same results as [14] as the researcher concluded that due to the sharp edge shape of rubber particles, the blockages occurred in fresh SCC when flowability and passing ability decreases and the energy consumption amount increases for moving rubber particles. To maintain the fresh properties of SCC, 15% rubber replacement and 20% replacement have been reported by most researchers and only a limited number of researchers have conducted studies on replacing more than 40% of natural aggregates with rubber aggregates. This is because the fresh SCC properties remained similar by using various types of chemical admixtures such as superplasticizer (SP), viscosity-modified admixture (VMA) or high-range water reducer admixture.

The bonding between rubber aggregates and binder is improved by pre-treating rubber aggregates with polyvinyl alcohol water soak or sodium hydroxide (NaOH) method [14]. Although the researcher in [16] proposed water soak method as an efficient method for improving the rubber and binder bonding but [14] reported the reduction in flowability of SCC-contained rubber particles treated with NaOH and introduced the water soaking method as a cost-effective method to improve bonding.

2.3. Properties of Rubber Tyres

a. Density: Tyres are slightly heavier than water and will sink in water unless entrapped air provides enough buoyancy to allow them to float. This generally occurs only with whole tyres or fine crumb rubber

b. Moisture absorption: Tyres and shreds can trap water on the surface and in irregular contours, but they are relatively impervious to actual absorption. The maximum moisture absorption of rubber tyres is between 2-4%.
c. Thermal Insulation: Rubber has poor thermal conductors but conversely provides better thermal insulation than soil and aggregates.
d. Acoustic Insulation: Rubber Tyres have a poor acoustic conductor but a good insulator.
e. Temperature Tolerance: Tyres rubber has the ability to withstand an extreme range of ambient temperatures without undergoing permanent property change/damage. Some properties like flexibility change as a function of temperature but the change is reversible and repeatable at the end of the process.
f. Leaching Characteristic: Tyre shreds' leaching characteristics have been examined under a wide range of pH conditions and no record of deleterious impact has been confirmed.
g. Flammability: Tyre shreds have a reported flashpoint of 3060C higher than some other building materials used for Architectural purposes such as wood, paper, foam, and fabrics. When crumb rubber is combined with cement and sand, this controls the flammability of the resulting product [17].

2.4. Cement

Cement has in long existence been used as a building material as a binder and has proved effective since it sets, hardens, and adheres to other materials binding them together. Cement is used to make composite materials like concrete, which has been used in structural and nonstructural elements [18].

Cement consists of a mixture of calcium silicates, aluminate, and ferrite compounds which integrate Calcium, Aluminum, silicon and iron that are bound to react with water [19]. Cement is broadly classified into hydraulic cement (Portland cement) and non-hydraulic cement. The non-hydraulic cement is resistant after setting to chemical attack and does not set easily in wet conditions but sets as it dries and reacts with carbon dioxide in the air [20]. Portland cement is the most commonly used cement because of its basic ingredient in concrete, mortars and numerous plasters. Portland cement and related materials are made by heating limestone with clay or shale (a source of Silicon, Iron, and Aluminum) and grinding this product (clinker) with a source of sulfate most preferably gypsum [21]. There are other commonly used types of cement recognized by BIS such as; (1) Ordinary Portland Cement 33, 43, & 53 grade OPC, (2) Blended cement (PPC and PSC) (3) Sulphate Resisting Cement (SRC) (4) Low Heat Portland cement (LHPC) (5) Hydrophobic Portland cement (6) Colored Cement (White Cement) [9].

2.5. Water

Water is a substance composed of chemical elements such as hydrogen and oxygen that exists in gaseous, liquid or solid states. Water is a natural solvent which when combined with a cementitious material forms a cement paste by the process of hydration [22] [23] [24]. The cement paste glues the aggregate together, fills voids within it, and makes it flow more freely. Therefore, water is used in the hydration of cement to form the desired binding matrix. The portable water/ sea water water-cement ratio depends on the grade of concrete, its workability, durability, nature, type of aggregates and so on [25][26][27]. A lower water-to-cement ratio yields stronger and more durable concrete whereas more water gives a freer-flowing concrete with a higher slump. Impure water used to make concrete can cause problems when setting which results in premature failure of the structure.

Hydration involves many different reactions that occur at the same time. Hence, as the reactions proceed, the products of the cement hydration process gradually bond together with the individual sand, gravel particles and other components of the concrete to form a solid mass [20].

2.6. Chemical Reactions

Cement Chemist Notation: $C_3S + H \rightarrow C\text{-}S\text{-}H + CH$

Standard notation: $Ca_3SiO_5 + H_2O \rightarrow (CaO) \cdot (SiO_2) \cdot (H_2O)\ (gel) + Ca\ (OH)_2$

Balanced: $2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO) \cdot 2(SiO_2) \cdot 4(H_2O)\ (gel) + 3Ca\ (OH)_2$

Note: The exact ratios of the CaO, SiO_2, and H_2O in C-S-H can vary

The properties and characteristics of aggregates are discussed in Table 1. Table 1 shows that there are six major properties of aggregates known as composition, size and shape, surface texture, specific gravity, bulk density and impact value.

Table 1. Properties of Aggregate

S/N	Properties	Characteristics
1	Composition	Aggregate should be free from materials that react with alkali in cement because it may lead to cracking, excessive expansion, and deterioration of concrete mix.
2	Size & Shape	The maximum size of aggregates that can be used in PCC and RCC are: 1. 1/4th of the minimum dimension of the concrete member. 2. 1/5th of the minimum dimension of the reinforced concrete member
3	Surface Texture	Proper bonding of aggregate with concrete depends upon surface texture, surface roughness, and porosity. When the surface of aggregate is rough and porous, it provides maximum strength and good bonding to concrete.
4	Specific Gravity	Lower specific gravity indicates porous and weak materials and high specific gravity indicates strong and durable materials. The value of specific gravity should lie between 2.6 to 2.9.
5	Bulk Density	The bulk density of coarse aggregate depends upon: 1. The shape of aggregate 2. Grading of the aggregate 3. Degree of the compaction
6	Impact Value	Impact value gives the resistive value of aggregate towards crushing. A higher impact value indicates the higher toughness of coarse aggregate

2.7. Properties of Hardened Concretes

The properties of hardened concrete include are as follows:

a. Compressive Strength: It mostly depends upon the amount and type of cement used in the concrete mix. Concrete compressive strength is measured in pounds per square inch (psi). It is also affected by (1) Water-Cement Ratio (1) Placing of Concrete (3) Curing of Concretes.
b. Concrete tensile strength ranges from 7% to 12% of compressive strength and tensile strength and bending strength can be increased by adding reinforcement
c. Durability: Durability is defined as the ability to maintain satisfactory performance through extended design life. Different concretes require different degrees of durability depending on the environmental exposure and properties.
d. Creep: Deformation of a concrete structure under sustained load is defined as a concrete creep. Long-term pressure or stress on concrete can change its shape. This deformation usually occurs in the direction the force is applied.
e. Shrinkage: Shrinkage is the volume decrease of concrete caused by drying and chemical changes. In other words, the reduction of volume for the setting and hardening of concrete is called shrinkage.
f. Impermeability: Is directly related to the durability of concrete. The lesser the permeability the higher the durability of concrete whereas the ability of an external media (water, chemicals, Sulphate) to penetrate into concrete is known as the permeability of concrete.

2.8. Concrete Mix Design

This is the science of estimating the relative proportions of the ingredients of concrete needed to achieve the desired properties in fresh, hardened as well as economic wise. Concrete is obtained by mixing cement, fine aggregate, coarse aggregate, water and admixtures in required proportions. The mixture when placed in forms and allowed to cure becomes hard like stone. The hardening is caused by chemical action between water and cement as concrete grows stronger with age. Crumb rubber modifier is rubber from waste tyres, which could be truck tyres, car tyres, etc. The crumb rubber contains synthetic rubber, natural rubber, total rubber hydrocarbon and acetone extractable which makes it have high durability, viscosity, high softening point and better resilience [28].

Crumb rubber modifier (CRM) can be used in the secondary application as asphalt mixtures either as a binder modifier (wet process) or as fine and/or coarse aggregate replacement (dry process). Presently, the large volume of waste tyres resulting from an increase in vehicle ownership and traffic volume around the world becomes a serious problem that impacts the environment as a result of their volume, non-biodegradability, and indiscriminate disposal. Records show that each year between 700,000 and 850,000 scrap tyres are added to the waste stream [29].

3. Methodology

A sequential, critical and systematic review method was adopted in this research. This research reviewed twenty-five research articles on rubber recycling, concrete crumbs and aggregates. The selected reviewed articles take into account the properties of some ingredients that constitute concrete and many other characteristics were drawn from it.

4. Finding and Discussion

This research work observed that some of the wasted products from tyres are very good aggregates for concrete mixing. Rubber wastes can be used as an aggregate replacement element in concrete mix for the construction of both buildings and infrastructures such as roads. Tyre rubber wastes when appropriately refined and mixed produce good quality concrete with a reduced reasonable amount of aggregate resulting in minimized construction costs. This research reviewed that the use of waste tyre rubber crumbs to substitute coarse aggregates reduces the constructional and infrastructural cost which is the earnest desire of an engineer.

5. Conclusion

The use of tyre rubber crumbs to replace coarse aggregates makes concrete cheaper and its lower water absorption rate improves the mix properties of concrete such as compressive strength and workability. The use of crumb rubber in asphalt modification is the best and smartest innovative method of recycling rubber waste material.

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