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A Review on Replacement of Aggregates in Concrete using Waste Rubber Tyre

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ABSTRACT

Handling and disposal of waste tyres is one of the critical waste management problems being faced all over the world. Waste tyre is a source of pollution for the environment. As an effective measure for disposal, utilization of waste tyre in construction industry has become a focus area of research in the recent past. Researchers are trying to utilize waste tyre crumbs or tyre chips as a raw material for concrete. Apart from reducing the environmental impact of waste tyres, there are financial benefits associated with use of recycled tyre as a raw material for concrete. Since waste tyres are available in abundance, the cost of naturally occurring aggregates and the associated logistics cost for procurement can be reduced substantially. Current literature review shall focus on the replacement of aggregates in cement concrete using waste tyre crumbs or tyre chips.

Keywords: Tyre Aggregate, Waste Tyre, Concrete Aggregate Replacement

INTRODUCTION

In India infrastructure development involves reinforced cement concrete construction in large volume. This creates a huge demand of raw materials for concrete. Thus natural aggregates like river sand and crushed rock from rock strata are gradually getting exhausted. Because of lower availability of natural aggregates in many localities, the aggregates need to be transported from distant locations and the rising transportation cost adds to the cost of reinforced concrete construction. Depletion of these natural resources is a major environmental concern as well. To mitigate this issue, researchers in the recent past have looked at alternative materials for construction. Waste tyre is a material which is available abundantly and is a subject matter of interest as a replacement material for ingredient of cement concrete.

Manufacturing of automobiles have been rising rapidly due to the increase in demand all over the world. Rubber tyres are highly durable and hence it becomes a critical problem to manage waste tyres. In developed countries, the method of disposal of common waste is landfilling. Due to high durability of tyre, they decompose extremely slowly. The tyres can trap water and becomes breeding ground for insects, mosquitoes and bacteria. Stockpiles of waste tyres are a major environmental and fire hazard. Combustion of tyres causes massive volumes of unburnt hydrocarbon and toxic emissions. The melting of tyres is a source of contamination of soil and ground-water. Utilization of waste tyre in construction industry has become a focus area of research in the recent past, as this can be effective method of disposal. Researchers have attempted to use crumb rubber as partial substitution of fine aggregates and tyre chips as part replacement of coarse aggregate in concrete. As the density of rubber is lower than that of natural aggregates, it helps in developing light weight concrete. The current literature review work will focus on partial replacement of natural aggregates using waste tyre crumbs or chips.

WASTE TYRE FORMS

ASTM D6270-20 classifies the aggregates obtained from waste tyres as shown in Table below:

Definition	Size (mm)
Granulated or Ground Rubber	< 12
Tyre Chips	12 – 50
Tyre Shreds	50 - 305

Uniform granules or chips of rubber can be derived by cutting the scrap tyres into small pieces with the help of specialized high-powered shearing / shredding machines or cut manually as per required size & shape.

Tyre Rubber Properties

Tyres are manufactured using both rubbers - natural or synthetic. Natural rubber is obtained from latex from the sap of rubber tree. Synthetic rubber is made by polymerization of mineral oil. Some properties of synthetic rubber may differ from natural rubber. Types of synthetic rubber from mineral oil include - Ethylene-Propylene Rubber, Styrene-Butadiene Rubber and Nitrile & Butyl Rubber. Properties of rubber are - Elasticity, Elongation, High Tensile Strength, Tearing Resistance, Flexural Resistance, Abrasion Resistance, high Coefficient of Friction, Impermeable, Heat Insulation, Electrical Insulation, and high Coefficient of Thermal Expansion. With age, rubber undergoes loss in strength, extension capacity and other mechanical resistances. Main difference between waste tyre chips and naturally occurring coarse aggregate is that tyre chips have lower density and stiffness compared to natural coarse aggregates.

Research Gap

Extensive research is required for adopting new structural components in construction. Research on properties of concrete with partial replacement of aggregate by waste tyre crumbs or chips is limited. In structural engineering, application is limited due to low stiffness of rubber. Although many researchers have attempted to find the optimum replacement of tyre crumbs or chips in concrete, further studies are still required to achieve the best possible results as it has the two-fold advantage of preserving the natural resources like rock strata and river sand, as well as provides an effective way to dispose of waste tyre.

LITERATURE REVIEW

Literature related to use of waste tyres in concrete are discussed in this chapter. The advantages and applications of use of waste tyres are also identified and discussed.

Schimizze *et al.* (1994) prepared one concrete mix with fine rubber granules and second concrete mix with coarse rubber aggregate. The design parameters of the concrete mixes were selected arbitrarily and were not optimized. The results showed that there was reduction in compressive strength by 50% as compared to control concrete mix. There was reduction in Elastic Modulus for the coarse rubber aggregate concrete by 72% and fine rubber granule concrete by 47% in comparison to the control concrete. The reduction in elastic modulus is indicative of higher flexibility.

It was observed by **Biel and Lee (1996)** that concrete with rubber particles 30%, 45% & 60% of fine aggregate showed diagonal failure as a result of gradual shear. Control concrete specimen underwent sudden brittle failure. Tensile and compressive strength tests were performed and it was found that by using magnesium oxychloride with cement, better bonding was achieved between rubber aggregate and cement.

Toutanji (1996) performed experimental investigation by replacing natural aggregates by 25%, 50%, 75% and 100% using rubber tyre chips. The size of the rubber tyre chips were 12.7mm. It was observed that compressive and flexural strength of concrete was reduced due to addition of rubber tyre chips. The compressive strength reduction was about double as compared to reduction in flexural strength. Slump tests showed reduction in workability with addition of tyre chips. The concrete specimen with rubber aggregate had ductile failure and underwent large deformation before crack.

Tantala *et al.* (1996) reported that control concrete has lower toughness, which is defined as capacity for energy absorption (area under load-deflection curve), compared to concrete with tyre rubber aggregate.

Goulias *et al.* (1997) suggested that with increase of rubber content, the rigidity and dynamic modulus of elasticity of concrete decreases. This is indicative of less brittle and less hardened concrete.

Topçu and Avcular (1997) showed that with the addition of rubber aggregates into concrete mix, there is improvement of impact resistance of concrete.

It was shown by **Li *et al.* (1998)** that when fine aggregates were replaced 33% by volume using crumb rubber, the density of the tyre rubber aggregate concrete got reduced in the range of 10%.

Goulias *et al.* (1998) reported that when fine aggregates in concrete are replaced with crumb rubber, the specimen showed more ductility compared to conventional concrete. Large deformation was observed without complete disintegration of the concrete specimen.

Lee *et al.* (1998) proposed Tyre Added Latex Concrete (TALC) where fine aggregate was replaced with crumb rubber and Styrene Butadiene Rubber (SBR) latex was added. TALC demonstrated higher flexural & impact resistance compared to conventional Portland cement concrete. Also TALC was shown to be less brittle.

Humphrey (1999) studied the properties of waste tyre chips and suggested that it can be a used as a fill material due to characteristics like high durability, high permeability, lower density and high compressibility. It is also more affordable than other materials.

Khatib and Bayomy (1999) performed experiment on workability of Tyre Rubber Aggregate Concrete (TRAC). It was shown that with increase of rubber aggregate in concrete, the slump value decreases. When rubber aggregate was 40% by total aggregate volume, the concrete was rendered non-workable; having nearly zero slump for hand mixing and mechanical vibrator was required for such mixes. They showed that with increase in rubber aggregate content, there was increase in air content of TRAC. The rubber aggregates can entrap air at their surface as they are non-polar in nature and repel water. They also observed systematic reduction in flexural and compressive strength due to increase in content of rubber in the mix. They showed that rubber aggregate should not exceed 20% by volume of total aggregate due to extreme reduction in strength.

To increase the adhesion of powder rubber with cement paste, **Segre and Joekes (2000)** modified the surface of powdered rubber. They used low cost reagents and procedures and found that Sodium Hydroxide (NaOH) solution provided the best results. The rubber particles were surface treated with saturated aqueous solution of NaOH for 20 minutes and this improved the adhesive properties of tyre rubber with cement paste. Compressive strength reduction of concrete was in the range of 33%, which was lower compared to contemporary research work.

Fairburn and Larson (2001) studied the restoration of cracked pavements using rubber aggregate concrete. The research showed that the rubber aggregate concrete was light, had better elastic property & slip resistance. Also this had the potential to be used as fireproofing material.

Olivares *et al.* (2002) suggested that concrete mechanical properties do not undergo huge variation due to addition of crumb rubber from waste tyre upto 5% volume fraction.

Güneyisi *et al.* (2004) suggested that density of concrete mix gets lowered when rubber aggregates are added. As the rubber content is increased, the density of the concrete gets further reduced. This happens due to the lower specific gravity of rubber compared to natural aggregate. They conducted experiment using rubber concrete mixed with silica fume. Part replacement varying from 2.5% ~ 50% was done where crumb rubber was used for fine aggregate and tyre chips for coarse aggregate. Silica fume was used to replace cement by 5% ~ 20%. With silica fume added, the rubber concrete showed better mechanical properties than conventional concrete and rate of loss of strength was reduced.

Haung *et al.* (2004) noted that concrete with rubber aggregate has high toughness. With increase in content of rubber there is significant reduction of strength. Rubber chips having size 25.4 x 25.4 x 5 mm were used. When the coarse aggregates were replaced by 15% by volume using rubber chips, compressive strength was reduced by 45% and indirect tensile strength was decreased by 23%.

Kamil *et al.* (2004) studied the properties of Crumb Rubber Concrete (CRC). It was observed that with addition of every 50lbs of crumb rubber, the weight of concrete gets reduced by about 6% and the compressive strength also reduces. As the content of rubber increases, the strength reduction was partly due to air entrapment. Investigations showed that by using de-airing agent during concrete mixing, the reduction in strength could be decreased sufficiently.

Siddique and Naik (2004) showed that there was roughly 85% decrease in compressive strength and 50% decrease in split tensile strength after 100% substitution of coarse aggregate using coarse crumb rubber chips. Conversely, when fine crumb rubber is used to completely replace fine aggregates, a decrease of about 65% in compressive strength and 50% reduction in split tensile strength was noted. Both the mixes demonstrated a ductile pattern of failure due to the capacity to preserve more energy under compressive and tensile loads.

Ghaly and Cahill IV (2005) investigated the effect of mixing of crumb rubber (1 mm to 2 mm size) as a replacement of sand on the property of concrete. 5%, 10% and 15% by volume of crumb rubber replacement were studied. The water-cement ratios considered were 0.47, 0.54 and 0.61. It was observed that by using crumb rubber there was loss of strength of concrete compared to conventional concrete.

Tyre Rubber Aggregate Concrete (TRAC) has higher toughness and impact resistance as compared to conventional concrete. It has better resistance to water and acid. Also it has been noted that Rubber Modified Concrete has lower compressive and tensile strength. It has been observed that in spite of failure, Crumb Rubber Concrete (CRC) did not disintegrate. Such behaviour of CRC is desirable for structures which require higher impact resistance.

Use of Crumb Rubber Concrete in non-load bearing walls, green building pre-cast roofs and pre-cast side-walk panels was suggested by **Fuminori *et al.* (2005).**

It was shown by **Benazzouk *et al.* (2006)** that the reduction of density if concrete with increase in rubber content in not linear. This is attributed to the fact that degree of air-entrainment increases with volume of rubber. Thus reduction can be achieved in the Dead Load of the structure.

Chou *et al.* (2007) investigated different percentages of rubber replacement in concrete. It was concluded that the compressive strength reduces by addition of more rubber.

Topçu and Demir (2007) studied the durability of concrete and mortar with waste tyre aggregates under exposure to salt water, freeze-thaw and extreme temperature. The experiment was done with concrete having 300 kg/m^3 cement content, 0.5 water-cement ratio and volume replacement of natural aggregates using 0%, 10%, 20% and 30% rubber aggregate. It was concluded that 10% rubber replacement was optimum and feasible method to reuse waste tyres.

Li *et al.* (2008) examined the application of crumb rubber concrete having steel reinforcement for use in seismic resistant structures. It was shown that crumb rubber concrete with steel reinforcement was having more ductility compared to conventional concrete.

Zheng *et al.* (2008) investigated the effects of various types and content of rubber on the concrete properties like compressive strength and deformation. Coarse aggregates were partly replaced using rubber tyre-chips in 15%, 30% and 45% by volume. The strength and elastic modulus got reduced with the increase of rubber content. It was found that the strength of got reduced by 22.3%, 45.8% and 53.3% at rubber content levels of 15%, 30% and 45% respectively. Crushed rubber concrete had lower compressive strength and elastic modulus than ground rubber concrete. It was found that rubber concrete had lower brittleness index which is indicative of the fact that it has higher ductility than regular concrete.

Ganjian et al. (2009) examined the properties of concrete when aggregate and cement was replaced with rubber by 5%, 7.5%, and 10%. Two sets of specimen were examined. In the first set, aggregate was partially replaced by rubber chips. In the second set, cement was partly replaced by waste tyre powder. The results indicated that there is no considerable change in concrete properties by 5% replacement of rubber, in either of the sets. With further increase of rubber replacement, compressive strength gets reduced by 10% to 23 % in case of aggregate substitution and 20% to 40% in case of cement replacement. Elastic Modulus was reduced by 17% to 25% in case of 5% to 10% aggregate replacement. Elastic Modulus was reduced by 18% to 36% in case of cement replacement. It was observed that permeability to water got increased in case of coarse aggregate substitution but decreased when cement was replaced.

Aiello and Leuzzi (2010) replaced fine and coarse aggregates in concrete with various percentage volumes of tyre aggregates. Rubber aggregates of size between 10mm to 25mm were used. Rubberized concrete mix was found to have lower density compared to plain concrete. The concrete specimens with substitution of 50% and 75% of coarse aggregates using rubber aggregates demonstrated 54% and 62% reduction of compressive strength in comparison to control concrete. Substitution of fine aggregates resulted in a reduction of 28% and 37 % compressive strength in comparison to control concrete.

Abaza and Shtayeh (2010) suggested that crumb rubber from waste tyre can be mixed with Portland Cement Concrete for use as non-structural plain cement concrete. Fine aggregates may be replaced by different percentage volumes using crumb rubber. As the percentage of crumb rubber increased, the compressive strength as well as unit weight decreased. Increase in water absorption, noise insulation and thermal insulation was observed with the increase in percentage of crumb rubber. It was suggested that crumb rubber can be used as concrete blocks, floor materials, partitions and other non- structural purposes.

It was observed by **Siringi (2012)** that Tyre Derived Aggregate (TDA) upto size of 2‖ and partial replacement between 7.5% to 10% could achieve 27.5 MPa target compressive strength of concrete, by addition of silica fume. It was noted that with increase of tyre aggregate, the strength gets reduced. With silica fume added, the strength loss of concrete with 7.5% tyre derived aggregate was about 10% when compared with conventional concrete. The modulus of elasticity also got reduced around 20% while toughness and ductility improved. At elevated temperature, the performance of concrete with TDA declined. On exposure to heat the TDA concrete demonstrated cracks, spalling and pop-out. The compressive strength of concrete with TDA reduced by 23% at 100^{o}C in comparison to conventional concrete which underwent 12% loss of strength when exposed to 200^o C for the same duration.

It was shown by **Onuaguluchi *et al.* (2014)** that when rubber content was increase in the concrete mix, the water penetrability got increased. Due to the non-polar nature of rubber, it repels water and entraps air at the surface. Voids are thereby formed between the rubber particles and the concrete matrix when it solidifies. As a result of change of microstructure and additional air entrapment, the porosity of the concrete mix increases. For water movement more conduits become available.

Su *et al.* (2015) showed that as compared to rubber aggregate, the density of natural aggregate is around 2.5 times. Thus by replacing natural aggregate by volume using rubber aggregate, the weight per unit volume of concrete will be lower. Researchers have in general found that concrete density decreases consistently as proportion of rubber in the mix increases.

Liu *et al.* (2016) showed that there is increase in the ductility of concrete with addition of rubber pieces in the mix.

Asutkar *et al.* (2017) noted that density of concrete reduces with increase of rubber aggregate content. With increase in percentage of rubber aggregate, the compressive strength got reduced whereas there was increase in toughness. It was recommended that up to 15% replacement of rubber aggregate was optimum. It was suggested that this type of concrete may not be used in structural elements with requirement of high strength.

Sofi (2018) experimentally investigated the partial replacement of natural aggregates using rubber aggregates from scrap tyres. Control concrete showed brittle failure. Concrete with rubber aggregate did not demonstrate brittle failure. There was decrease in flexural strength when rubber content was increased. Nature of cracks for control concrete was diagonal whereas for rubber concrete horizontal cracks were observed. It was also noted that with increase in size of rubber particles, there was reduction in water absorption. By testing in Sulphuric Acid solution, it was seen that conventional concrete specimens underwent maximum weight loss. On the other hand, concrete specimens with 20% crumb rubber suffered minimal weight loss. The crumb rubber particles in rubberized concrete could arrest the crack formation. Thus such type of concrete may find best use in concrete pavements.

It was examined by **Farnoosh *et al.* (2019)** to partially replace cement and natural coarse aggregate using zeolite and crumb rubber respectively. 5%, 10% and 15% replacement percentage was used for both zeolite and crumb rubber. It was observed that with increase of higher replacement percentages, there was reduction in the mechanical properties.

CONCLUSION

Size, density and hardness of aggregates have a major influence on concrete quality. It has been observed in past studies that compressive strength of concrete reduces with replacement of natural aggregate with rubber aggregate. The proportion, size and texture of aggregate affect the compressive strength largely. The strength reduction can be attributed to the fact that rubber aggregates are elastically more deformable as compared to the surrounding cement matrix. The bond of the soft rubber with the cement paste being weak results in voids in the concrete mix. Studies also show that workability of concrete diminishes with increase of rubber aggregate. Density of rubber being lower than that of natural aggregates, it helps in developing light weight concrete.

It is clear that proportion of rubber aggregates need to be optimized to achieve desired compressive strength and workability. Research with focus on partial replacement of natural aggregates using waste tyre aggregates in structural concrete is at a very nascent stage. For improving the mechanical properties of such concrete, mineral admixtures like pozzolanic materials and chemical admixtures like super plasticizers may be explored.

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