

Center for By-Products Utilization

PROPERTIES OF CONCRETE CONTAINING SCRAP TIRE RUBBER – AN OVERVIEW

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ABSTRACT

Solid waste management is one of the major environmental concern in the United States. Over 5 billion tons of non-hazardous solid waste materials are generated in US each year. Out of which more than 273 million scrap tires (approximately 3.6 million tons) are generated each year. In addition to this, about 3 billion tires are stockpiled. Several studies have been carried out to reuse scrap tires in a variety of rubber and plastic products, thermal incineration of waste tires for production of electricity, or as fuel for cement kilns, and use in asphalt concrete.

Studies in this direction show that workable rubberized concrete mixtures can be made with appropriate percentages of tire rubber. This paper presents an overview of the research carried out in an effort to utilize scrap tires in portland cement concrete. The benefits of using magnesium oxychloride cement as binder for rubberized concrete mixtures are presented. The paper also details the likely uses of rubberized concrete.

INTRODUCTION

More than 273 million scrap tires are produced in United States each year [1]. In addition to this, more than 300 million tires are currently stockpiled throughout the united States [1]. These stockpiles are dangerous not only from potential environmental threat, but also from fire hazards and provide breeding grounds for mosquitoes [2]. Over the years, disposal of tires has become one of the serious problems in environments, and landfilling is becoming unacceptable because of the rapid depletion of available sites for waste disposal. Used tire are required to be shredded before landfilling. Innovative solutions to meet the challenge of tire disposal problem have long been in development, and the promising options are; (i) use of tire rubber in asphalt mixes, (ii) thermal incineration of worn-out tires for the production of electricity or steam, and (iii) reuse of ground tire rubber in number of plastic and rubber products. In addition, scrap tires can also be used as fuel for cement kiln, as feedstock for making carbon black, and as reefs in marine environment [3-5]. Because of high capital investment involved in it, using tires as fuel is technically feasible but economically not very attractive [5]. The uses of rubber tires in making carbon black eliminates shredding and grinding costs, but carbon black from tire pyrolysis is more expensive, and has lower quality than that from petroleum oils [3]. Table 1 shows some of the fact and figures as of year 2000, as reported by rubber manufactures association.

A tire is a composite of complex elastomer formulations, fibers, textiles and steel cord. Tires are made of plies of reinforcing cords extending transversely from bead to

bead, on top of which is a belt located below the thread. Table 2 lists typical types of materials used to manufacture tires.

Table 1. Some Facts and Figure Concerning Tires

Facts	Figures
Number of scrap tires generated annually	273 million
Approximate weight of scrap tires	3.6 million tons
Number of scrap tires in stock piles	300 million
Number of tires processing facilities	498
Scrap tires used in Civil Engineering applications	30 million
Scrap tires processed into ground rubber	18 million
Scrap tires used for fuel	125 million
Number of states with scrap tires legislation/regulations	48
Number of states that ban whole tires from landfills	33
Number of states that ban all scrap tires from landfills	12
Number of states with no landfill restrictions	5

CLASSIFICATION OF SCRAP TIRES

Scrap tires

They can be managed as a whole tire, as slit tire, as shredded or chopped tire, as ground rubber or as a crumb rubber product. A typical automobile tire weighs 20 lb,

whereas a truck tire weighs around 100 lb. Table 3 gives the typical composition by weight of automobile and truck tires.

Table 2 Typical Materials Used in Manufacturing Tire

1. Synthetic Rubber
2. Natural Rubber
3. Sulfur and sulfur compounds
4. Phenolic resin
5. Oil
(i) Aromatic
(ii) Naphththenic
(iii) Paraffinic
6. Fabric
(i) Polyester
(ii) Nylon etc.
7. Petroleum waxes
8. Pigments
(i) Zinc oxide
(ii) Titanium dioxide etc.
9. Carbon black
10. Fatty acids
11. Inert materials
12. Steel wires

Slit Tires

These are produced in tire cutting machines. These machines can slit the tire into two halves or can separate the sidewalls from the tread of the tires.

Shredded or Chipped Tires

Tire shreds or chips involves primary and secondary shredding. The size of the tire shreds produced in the primary shredding process can vary from as large as 300 to 460

mm (12 to 18 inch) long by 100 to 230 mm (4 to 9 inch) wide, down to as small as 100 to 150 mm (4 to 6 inch) in length, depending on the manufacturer's model and condition of the cutting edges. Production of tire chips, normally sized from 76 mm (3 inch) to 13 mm (0.5 inch), requires both primary and secondary shredding to achieve adequate size reduction [6]

Table 3 Typical Composition By Weight

Composition by percent weight	Automobile tire	Truck tire
Natural rubber	14	27
Synthetic Rubber	27	14
Carbon black	28	28
Steel	14 to 15	14 to 15
Fabric, filler, accelerators, antiozonants	16 to 17	16 to 17

Ground Rubber

Ground rubber may be sized to particles as big as 19 mm (3/4 inch) to as small as 0.15 mm (No. 100 sieve). It depends upon the type of size reduction equipment and intended applications. Ground rubber particles are subjected to a dual cycle of magnetic separation, then screened and recovered in various sizes [7].

Crumb Rubber

Crumb rubber consists of particles ranging in size from 4.75 mm (No. 4 Sieve) to less than 0.075 mm (No. 200 Sieve). Generally, these methods are used to convert scrap tires into crumb rubber. These methods are (i) cracker mill process, (ii) granular process, and (iii) micro mill process. The cracker mill process tears apart or reduces the size of tire rubber by passing the material between rotating corrugated steel drums. By this process an irregularly shaped torn particles having large surface area are produced. The size of these particles varies from 5 mm to 0.5 mm (No. 4 to No. 40 Sieve), and are commonly known as ground crumb rubber.

Granular process shears apart the rubber with revolving steel plates, producing granulated crumb rubber particles, ranging in size from 9.5 mm (3/8 inch) to 0.5 mm (No. 40 Sieve) [7].

MANAGEMENT OPTION

Disposal

Disposing of scrap tires in landfills is becoming unacceptable because of rapid depletion of available sites for waste disposal. Approximately 45 percent of 273 million tires are disposed of in landfills, stockpiles or illegal dumps. As of year 2000, 48 states have legislation/regulations related to landfilling. Thirty three states ban whole tires from landfills. Twelve states ban all scrap tires from landfills. Five states have no landfill restrictions. Thirty states charge for landfilling, whereas seven states allow monofills [1].

Recycling

According to the figures of year 2000, about 15 million of the 273 million scrap tires generated yearly are exported, 8 million are recycled into new products, 18 million are processed into ground rubber, 125 million are used as tired-derived fuel, and 30 million in civil engineering applications [1]. 18 million scrap tires are processed into ground rubber each year. Ground rubber is used in making rubber products such as floor mats, carpet padding, and vehicles mud-guards etc., plastic products, and as a fine aggregate addition (dry process) in asphalt friction courses. Crumb rubber is used as an asphalt binder modifier (wet process) in hot mix asphalt pavements [8]. Of the 30 million tires that are not discarded each year, most of them go to the retreaders, who retread about one-third of the tires received [8].

RESEARCH FINDINGS

Early investigations on the use of worn-out tires in asphalt mixes had been very encouraging. Results showed that rubberized asphalt had better skid resistance, reduced fatigue cracking, and achieved longer pavement life than conventional asphalt [9-12]

Fresh Concrete Properties

Slump

Raghavan, et al. [13] have reported that mortars incorporating rubber shreds achieved workability comparable to or better than a control mortar with out rubber particles

. Khatib and Bayomy [14] investigated the workability of rubcrete, and reported that there is a decrease in slump with increase in rubber content by total aggregate volume. They further mentioned that at rubber contents of 40% by total aggregate volume, slump was almost zero, and concrete was not workable manually. It was also observed that mixtures made with fine crumb rubber were more workable than those with coarse tire chips were or a combination of tire chips and crumb rubber.

Air Content

Fedroff, et al. [15] have reported higher air content in rubcrete mixtures than control mixtures even without the use of air-entraining admixture (AEA). The similar observation were also made by Khatib and Bayomy [14]. This may be due to the nonpolar nature of rubber particles and their tendency to entrap air in their rough surface, and when rubber is added to concrete mixture, it may attract air as it has the tendency to repel water. This way air may adhere to the rubber particles. Therefore, increasing the rubber content results in higher air contents of rubcrete mixtures.

Unit Weight

Because of low specific gravity of rubber particles, unit weight of mixtures containing rubber decreases with the increase in the percentage of rubber content. Moreover, increase in rubber content increases the air content, which in turn reduces the unit weight of the mixtures. The decrease in unit weight of rubcrete is negligible when rubber content is lower than 10 to 20% of the total aggregate volume [14].

Shrinkage

Literature is not available concerning the plastic shrinkage of concrete containing rubber particle. However, Preliminary results reported by Raghvan, et al. [13] suggest that incorporation of rubber shreds to mortar help in reducing plastic shrinkage cracking in comparison to control mortar. They further reported that control specimens developed cracks having an average width of about 0.9 mm, while the average crack width for specimens with a mass fraction of 5% rubber shreds was about 0.4 to 0.6 mm. It was also reported that onset time of cracking was delayed by the addition of rubber shreds. Mortar without rubber shreds cracked within 30 minutes, while mortar with 15% fraction by mass cracked after one hour. It was further indicated that the higher the content of rubber shreds, the smaller the crack length and crack width, and more onset time of cracking was delayed.

Hardened Properties

Compressive and Tensile Strength Properties

Compressive strength of rubberized concretes has been reported by several authors [16-19]. Results of various studies indicate that compressive strength of rubcrete mixtures is greatly affected by the size, proportions, and surface texture of rubber particles, and the type of cement used in such mixtures. Eldin and Senouci [18] have reported that concrete mixtures with tire chips and crumb rubber aggregate exhibited lower compressive and split tensile strength than regular portland cement concrete. There was approximately 85% reduction in compressive strength and 50% reduction in split tensile strength when coarse aggregate was fully replaced by coarse

rubber chips. However, there reduction of about 65% in compressive strength and up to 50% in split tensile strength when fine aggregate was fully replaced by fine crumb rubber. However, the mixes demonstrated a ductile failure and had the ability to absorb a large amount of plastic energy under compressive and tensile loads. Topcu [19] and Khatib and Bayomy [14] also showed that the addition of coarse rubber chips in concrete lowered the compressive strength more than the addition of fine crumb rubber. However, results reported by Ali, et al. [16] and Fatuhi and Clark [20] indicate the opposite trend.

Studies have indicated that if the rubber particles have rougher surface or given a pretreatment, the better and improved bonding may develop with the surrounding matrix, and that may result in higher compressive strength. Pretreatments may vary from washing rubber particles with water to acid etching, plasma pretreatment, and various coupling agents [2]. In acid pretreatment, rubber particles are soaked in an acid solution for 5 minutes, and then rinsed with water. This enhances the strength of concrete containing rubber particles through a microscopic increase in the surface texture of the rubber particles. Eldin and Senouci [18] soaked and thoroughly washed rubber aggregates with water to remove contaminants, while Rostami, et al. [17] used water, water and carbon tetrachloride solvent, and water and a latex admixture cleaner. Results showed that concrete containing washed rubber particles achieved about 16% higher compressive strength than concrete containing untreated rubber aggregates, whereas this improvement in compressive strength was 57% when rubber aggregates treated with carbon tetrachloride were used.

Segre and Jockes [21] have worked on the use of tire rubber particles as addition of cement paste. In their work, the surface of powdered tire rubber was modified to increase its adhesion to cement paste. Low cost procedures and reagents were used in the surface treatment to minimize the final cost of the material. Among the surface treatments tested to enhance the hydrophilicity of the rubber surface, a sodium hydroxide (NaOH) solution gave the best result. The particles were surface-treated with NaOH saturated aqueous solutions for 20 minutes, and then, scanning electron microscopy (SEM), water absorption, density, flexural strength, compressive strength, abrasion resistance, modulus of elasticity and fracture energy measurements were performed using test specimens (w/c= 0.36) containing 10% of as-received or 10% of NaOH-treated rubber. The test results showed that the NaOH treatment enhances the adhesion of tire rubber particles to cement paste, and mechanical properties such as flexural strength and fracture energy were improved with the use of tire rubber particles as addition instead of aggregate. The decrease in the compressive strength was significantly lower than that have been reported in the earlier literature.

Lee, et al. [22] developed tire-added latex concrete to incorporate recycled tire rubber as part of concrete. Crumb rubbers from tires were used in TALC as a substitute for fine aggregates or styrene-butadiene rubber (SBR) latex while maintaining the same water-cement ratio. TALC showed higher flexural and impact strengths than those of portland cement and latex modified and rubber-added concrete. Microscopic pictures taken using the scanning electron microscopic (SEM) seem to support that there is better

bonding between crumb rubbers and portland cement paste due to latex. TALC showed potential of becoming a viable construction material to enhance brittle concrete while incorporating waste tires.

Biel and Lee [23] have reported that type of cement greatly affects the compressive strength of rubber concrete. They used two types of cement; magnesium oxychloride cement and portland cement in making rubber concrete. The percentage of fine aggregate substitution varied from 0 to 90%. It was observed that 90% loss in compressive strength occurred for both portland cement rubber concrete (PCRC) and magnesium oxychloride cement rubber concrete (MOCRC) fine aggregates (90% of fine aggregate and 25% of total aggregate) was replaced by rubber. Magnesium oxychloride cement concrete exhibited approximately 2.5 times the compressive strength of portland cement concrete for both inclusion of rubber and without inclusion of rubber in the concrete. In case with split tensile strength, portland cement concrete specimens made with 25% of rubber by total aggregate volume retained 20% of their split tensile strength after initial failure, whereas the magnesium oxychloride cement concrete specimens with same rubber content retained 34% of their split tensile strength. They further mentioned that use of magnesium oxychloride cement may provide high strength and better bonding characteristics to rubber concrete, and rubber concrete made with magnesium oxychloride cement could possibly be used in structural applications if rubber content is limited to 17% of the total volume of the aggregate.

Toughness and Impact Resistance

Tantala, et al. [2] investigated the toughness of a control concrete mixture and rubber concrete mixtures with 5 and 10% buff rubber by volume of coarse aggregate. They reported that toughness of both rubber concrete mixtures was higher than the control concrete mixture. However, the toughness of rubber concrete mixture with 10% buff rubber was lower than that of rubber concrete with 5% buff rubber because of the decreasing compressive strength.

Based on their investigations on use of rubber shreds and granular rubber in mortar, Raghvan, et al. [13] reported that mortar specimens with rubber shreds were able to withstand additional load after peak load. The specimens were not separated into two pieces under flexural loading because of bridging of cracks by rubber shreds, but specimens made with granular rubber broke into two pieces at peak load. This indicates that post-crack strength seemed to get enhanced when rubber shreds were used instead of granular rubber.

Khatib and Bayomy [14] reported that as the rubber content is increased, rubber concrete specimens tend to fail gradually, and failure mode shape is either a conical or columnar. With a rubber content of 60% by total aggregate volume, the specimens exhibited elastic deformations, which the specimens retained after unloading.

Eldin and Senouci [18] demonstrated that failure of specimens containing rubber was not brittle, but more of a gradual failure. Biel and Lee [22] reported that failure of concrete specimens with 30, 45, and 60% replacement of fine aggregate with rubber

particles occurred as a gradual shear that resulted in a diagonal failure, whereas failure of plain concrete specimens was explosive, leaving specimens in several pieces.

Goulias and Ali [24] found that dynamic modulus of elasticity and rigidity decreased with an increase in the rubber content, indicating a less stiff and less brittle material. They further reported that damping capacity of concrete (a measure of the ability of the material to decrease the amplitude of free vibrations in its body) seemed to decrease with an increase in rubber content. But Topcu and Avcular have recommended the use of rubberized concretes in circumstances where vibration damping is required. Similar observations were also made by Fatuhi and Clark [20].

Topcu and Avcular [25] reported that the impact resistance of concrete increased when rubber aggregates were incorporated in to the concrete mixtures. The increase in resistance was derived from the enhanced ability of the material to absorb energy, and insulate sound during impact. Eldin and Senouci [18] and Topcu [20] also reported similar results.

Freezing and Thawing Resistance

Savas, et al. [27] carried out investigations to study the freezing and thawing (ASTM C 666, Procedure A) durability of rubber concrete. Various mixtures were made by incorporating 10, 15, 20, and 30% ground rubber by weight of cement to the control mixture. Based on their studied they concluded that (i) rubcrete mixtures with 10 and 15% ground rubber exhibited durability factors higher than 60% after 300 freezing and thawing cycles, but mixtures with 20 and 30% ground rubber by weight of cement could

not meet the ASTM standards, (ii) Air-entrainment did not provide significant improvements in freezing and thawing durability for concrete mixtures with 10, 20, and 30% ground tire rubber, and (iii) increase in scaling (as measured by the reduction in weight) increased with the increase in freezing and thawing cycles.

USES OF RUBBER CONCRETE (RUBCRETE)

Fattuhi and Clark [20] have suggested that rubcrete could possibly be used in the following areas:

- (i) Where vibrations damping is needed, such as in foundation pad for machinery, and in railway stations.
- (ii) For trench filling and pipe bedding, pile heads and paving slabs
- (iii) Where resistance to impact or blast is required such as in railway buffers, jersey barriers and bunkers.

Rubcrete because of its light unit weight may be suitable for architectural applications like (i) nailing concrete, (ii) false facades, (iii) stone backing, and (iv) interior construction.

Topcu and Avcular [25] have suggested that it may be used in highway construction as a (i) shock absorber, in sound barriers, (ii) as a sound booster, and (iii) also in buildings as an earthquake shock-wave absorber. However, more significant research is needed before strong recommendations can be made

CONCLUSIONS

Reduced compressive strength of concrete due to the inclusion of rubber aggregates do limit its use in some structural applications, but it has few desirable characteristics such as lower density, higher impact and toughness resistance, enhanced ductility, and better sound insulation etc. These properties can be advantageous to some construction applications. It is also possible to make relatively high-strength rubber concrete using magnesium oxychloride cement, which gives better bonding characteristics to rubber and significantly improves the performance of rubcrete. Moreover, adhesion between rubber particles and other constituents materials can be improved by giving pre-treating the rubber aggregates.

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