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Cementitious Composites Containing Recycled Tire Rubber: An Overview of Engineering Properties and Potential Applications

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ABSTRACT: One of the major environmental challenges facing municipalities around the world is the disposal of worn out automobile tires. To address this global problem, several studies have been conducted to examine various applications of recycled tire rubber (fine crumb rubber and coarse tire chips). Examples include the reuse of ground tire rubber in a variety of rubber and plastic products, thermal incineration of waste tires for the production of electricity or as fuel for cement kilns, and use of recycled rubber chips in asphalt concrete. Unfortunately, generation of waste tires far exceeds these uses. This paper emphasizes another technically and economically attractive option, which is the use of recycled tire rubber in portland cement concrete. Preliminary studies show that workable rubberized portland cement concrete (rubcrete) mixtures can be made provided that appropriate percentages of tire rubber are used in such mixtures. Achievements in this area are examined in this paper, with special focus on engineering properties of rubcrete mixtures. These include: workability, compressive strength, split-tensile strength, flexural strength, elastic modulus, Poisson's ratio, toughness, impact resistance, sound and heat insulation, and freezing and thawing resistance. The benefits of using magnesium oxychloride cement as a binder for rubberized concrete mixtures are discussed. Various applications in which rubcrete could be advantageous over conventional concrete are described.

KEYWORDS: compressive strength, freezing and thawing, recycling, rubcrete, solid waste, tire rubber, toughness, workability

Solid waste management has been a major environmental concern in cities around the globe. Recent studies indicate that roughly 4.6 billion tons of nonhazardous solid waste materials are produced annually in the United States (Epps 1994; Amirkhanian and Manugian 1994; Collins and Ciesielski 1994), among which waste tires constitute a significant portion. Indeed, there are more than 240 million scrap tires (200 million passenger tires and 40 million truck tires; 2.1 million tons and 1.9 million tons, respectively) generated each year in the United States alone (Epps 1994). In addition, about 3 billion used tires are currently stockpiled throughout the country (SHR 1992). These stockpiles are dangerous not only because they pose a potential environmental threat, but also are fire hazards and provide breeding grounds for mosquitoes (Tantala et al. 1996).

The practice of disposing of scrap tires in landfills is becoming unacceptable because of the rapid depletion of available sites for waste disposal. Moreover, tires can even "rise from the grave"—floating upward through a sea of trash to break through landfill covers—sometimes with explosive force (Tantala et al. 1996). Innovative solutions to cope with the tire disposal problem have long been in development. Among the most promising alternatives are: reuse of ground tire rubber in a variety of rubber and plastic products, thermal incineration of worn-out tires for the production of steam or electricity, and use of tire rubber in asphalt mixes. In addition, waste tires can be used as fuel for cement kilns, as feedstock for producing carbon black, and as reefs in marine environments (Paul 1985; Takallou and Takallou 1991; O'Keefe 1984). Because of the high capital investment involved, using tires as fuel is technically feasible but economically unattractive (O'Keefe 1984; Lee 1995). The use of rubber tires in the production of carbon black eliminates shredding and grinding costs, but the carbon black from tire pyrolysis is more expensive and has lower quality than that from petroleum oils (Paul 1985). Unfortunately, the generation of waste tires far exceeds its current uses. In addition, environmental concerns and public resistance have greatly impeded the option of incinerating waste tires. Although an economically attractive solution, the negative impact on the environment caused by tire incineration makes this alternative a compromise at best.

Early studies on the use of worn-out tires in asphalt mixes were very promising. They showed that rubberized asphalt had better skid resistance, reduced fatigue cracking, and achieved longer pavement life than conventional asphalt (Adams et al. 1985; Esch 1984; Estakhri 1990; Khosla and Trogdon 1990). However, the initial cost of rubberized asphalt is 40 to 100% higher than that of conventional asphalt, and its long-term benefits are uncertain (Fedroff et al. 1996). Likewise, the asphalt industry can currently absorb only 30 to 40% of the scrap tires generated (Anonymous 1993). Moreover, when pavements incorporating these materials are themselves recycled, disposal of the embedded rubber could itself become a serious environmental hazard (Fedroff et al. 1996).

Although the use of recycled tire rubber in asphalt pavements was emphasized in several publications, not much attention has been given to the use of rubber from scrap tires in portland cement concrete (PCC) mixtures, particularly for highway applications. However, large benefits can result from the use of worn-out tire rubber in PCC mixtures, especially in circumstances where properties like lower density, increased toughness and ductility, higher impact resistance, and more efficient heat and sound insulation are

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desired. The use of recycled tire rubber in PCC mixtures would not only make good use of an otherwise waste material and help alleviate disposal problems, but can also improve certain properties of concrete for particular design applications. It would also address the growing public concern about the need to preserve natural resources (such as aggregates) used in the production of concrete that are depleting rapidly due to excessive quarrying. The scope of this paper is to present a critical overview of results obtained in this area with special focus on engineering properties of rubberized portland cement concrete mixtures and their potential applications.

Properties of Fresh Concrete

Slump

Khatib and Bayomy (1999) investigated the workability of rubcrete mixtures. They observed a decrease in slump with increased rubber content by total aggregate volume (Fig. 1*a*). Their results show that at rubber contents of 40% by total aggregate volume, the slump was near zero and the concrete was not workable by hand. Such mixtures had to be compacted using a mechanical vibrator. Mixtures containing fine crumb rubber were, however, more workable than mixtures containing either coarse tire chips or a combination of crumb rubber and tire chips. In another study conducted by Raghavan et al. (1998), it was found that mortars containing rubber shreds achieved workability comparable to or better than a control mortar without rubber particles. It is not clear, however, whether the effect of rubber particles on the workability of concrete is attributed to a reduction in the density of concrete or to actual changes in the yield value and plastic viscosity of the mixture. Rheological measurements using fundamental techniques (e.g., rheometers) rather than the highly empirical slump test are therefore needed to clarify the effect of the rubber-aggregate content and particle size distribution on the rheology of fresh concrete.

Unit Weight

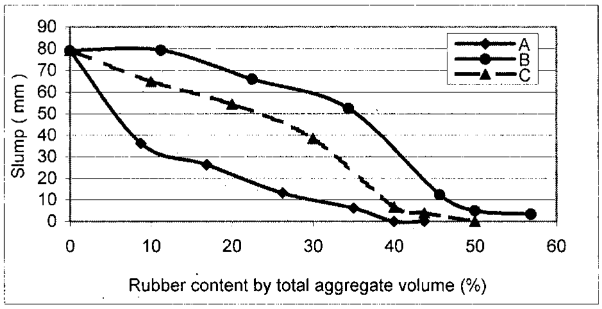
Due to the low specific gravity of rubber, the unit weight of rubcrete mixtures decreases as the percentage of rubber increases (Fig. 1*b*). In addition, the increase in rubber content increases the air content (see section below), which in turn further reduces the unit weight (Fedroff 1995). However, the decrease is almost negligible for rubber contents lower than 10 to 20% of the total aggregate volume. Figure 1*b* shows that data of unit weight versus rubber addition for rubberized concrete fits a straight-line curve when fine crumb rubber, coarse tire chips, or a combination of these is used as fine and/or coarse aggregate replacement in concrete.

Air Content

According to Fedroff et al. (1996), and Khatib and Bayomy (1999), the air content increased in rubcrete mixtures with increased amounts of ground tire rubber (Fig. 1*c*). Although no air-entraining agent (AEA) was used in rubcrete mixtures, higher air contents were measured as compared to control mixtures made with an AEA (Fedroff et al. 1996). The higher air content of rubcrete mixtures may be due to the nonpolar nature of rubber particles and their ability to entrap air in their jagged surface texture. When the nonpolar rubber is added to the concrete mixture, it may attract air as it repels water. The air may adhere to the rubber particles or perhaps gets trapped in their jagged texture. Therefore, increasing the rubber content results in higher air contents of rubcrete mixtures (Fedroff 1995). When a mixture of rubber, sand, and water was placed in a roll-a-meter, a large portion of the rubber floated to the top of the meter (Fedroff et al. 1996). Since rubber has a specific gravity of 1.14, it is expected to sink rather than float. However, if air gets trapped in the jagged surface of the rubber particles, it could cause them to float, which supports the theory discussed above.

Plastic Shrinkage

Preliminary results of a study conducted by Raghavan et al. (1998) suggest that the addition of rubber shreds to mortar reduced plastic shrinkage cracking compared to a control mortar. The use of rubber shreds in mortar allowed multiple cracking to occur over the width of mortar specimens compared to a single crack in a mortar specimen without rubber shreds. In spite of the occurrence of multiple cracking, the total crack area in the case of the rubber-filled mortar decreased with an increase in the rubber mass fraction. Despite their apparently weak bonding to the cement paste, rubber shreds provided sufficient restraint to prevent microcracks from



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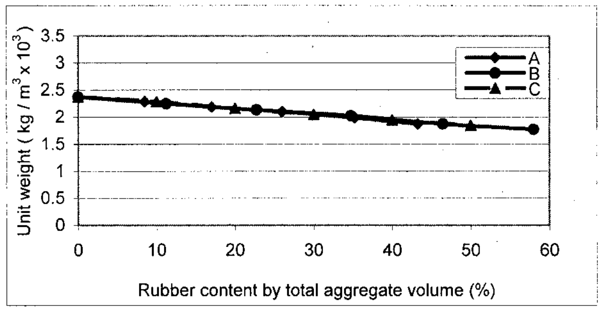

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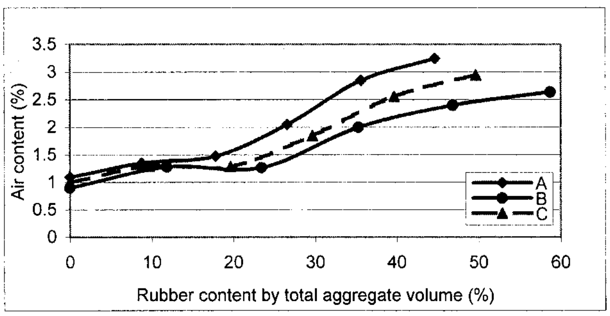


(c)

A: Coarse tire chips (replacing coarse aggregate volume)
B: Fine crumb rubber (replacing fine aggregate volume)
C: Crumb rubber & tire chips combine (replacing fine aggregate and coarse aggregate volume, respectively)

FIG. 1—*Effect of rubber type and rubber content on properties of fresh concrete (after Khatib and Bayomy 1999).*

propagating. It was observed (Raghaven et al. 1998) that the control mortar specimen developed a crack 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 found that the onset time of cracking was delayed by the addition of rubber shreds; the mortar without rubber shreds cracked within 30 min, while the mortar with a mass fraction of 15% rubber shreds cracked after 1 h. The higher the content of rubber shreds, the smaller the crack length and crack width, and the more the onset time of cracking was delayed. Although additional studies are necessary to confirm these observations, it appears that the addition of rubber shreds could be beneficial for reducing plastic shrinkage cracks of mortar and probably of concrete.

Mechanical Strength

The compressive strength of rubberized concretes was studied using different sizes and shapes of specimens. Cylindrical specimens of 75, 100, or 150 mm in diameter were used by Rostami et al. (1993), Ali et al. (1993), and Eldin and Senouci (1993), respectively. Topcu (1995) used both 150 mm diameter cylinders and 150 mm cubes. The compressive strength of ordinary concrete obtained from cube tests is higher than that obtained from cylinder tests (Neville 1997). Indeed, standards such as the European ENV-206 1992 include tables of equivalence of strengths for the two types of specimens. However, Topcu's (1995) results for rubberized concretes unexpectedly indicated the reverse. This discrepancy remains to be explained.

Results of various studies indicate that the mechanical strength of rubcrete mixtures is greatly affected by the size, proportion, and surface texture of rubber particles, and the type of cement used in such mixtures. The effect of these parameters is discussed below.

Effect of Rubber Content and Particle Size

Various published results show that coarse grading of rubber granules lowered the compressive strength of rubcrete mixtures more than fine grading. For instance, results obtained by Eldin and Senouci (1993) indicate that there was about 85% reduction in compressive strength and 50% reduction in tensile strength when the coarse aggregate was fully replaced by coarse rubber chips (Fig. 2*a,b*). However, specimens lost up to 65% of their compressive strength and up to 50% of their tensile strength when the fine aggregate was fully replaced by fine crumb rubber (Fig. 3*a,b*). Topcu (1995), and Khatib and Bayomy (1999) 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 of tests carried out by Ali et al. (1993), and Fatuhi and Clark (1996) indicate the opposite trend. All results (Khatib and Bayomy 1999; Ali et al. 1993; Eldin and Senouci 1993; Fatuhi and Clark 1996) show that the greater the rubber content used in rubcrete mixtures, the lower the compressive and tensile strengths achieved (Figs. 2 and 3).

Effect of Surface Texture of Rubber Particles

Various studies show that the rougher the rubber particles used in concrete mixtures the better the bonding they develop with the surrounding matrix and, therefore, the higher the compressive strength achieved. For instance, Tantala et al. (1996) argued that if the bond between rubber particles and the surrounding cement paste is improved, then significantly higher compressive strength rubcrete mixtures could be obtained (Fig. 4). To achieve enhanced

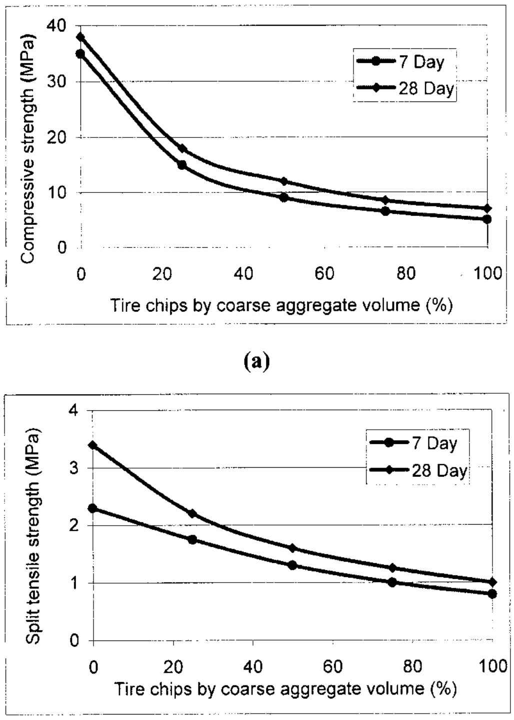


FIG. 2—*Effect of replacement of coarse aggregate by tire chips on* (a) *compressive strength, and* (b) *split tensile strength at 7 and 28 days (after Eldiu and Senouci 1993).*

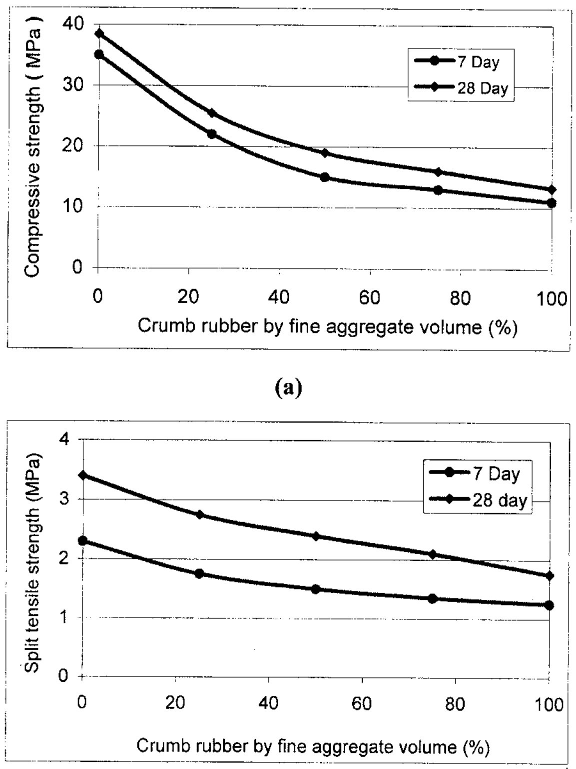


FIG. 3—*Effect of replacement of fine aggregate by crumb rubber on* (a) *compressive strength, and* (b) *split tensile strength at 7 and 28 days (after Eldin and Senouci 1993).*

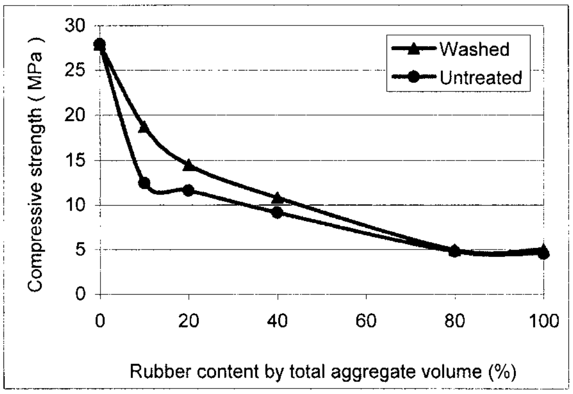


FIG. 4—*Effect of washing rubber particles with water on compressive strength of rubcrete mixtures (after Tantala et al. 1996).*

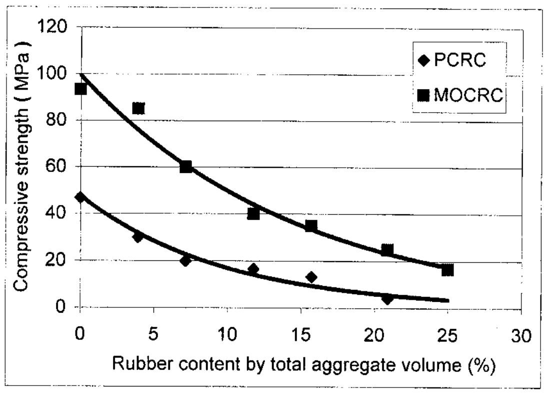
adhesion, it is necessary to pretreat the rubber. Pretreatments vary from merely washing rubber particles with water to acid etching, plasma pretreatment, and various coupling agents (Tantala et al. 1996). The acid pretreatment involves soaking the rubber particles in an acid solution for 5 min and then rinsing it with water. This increases the strength of rubcrete mixtures through a microscopic increase in surface roughness of the rubber, which improves its attachment to the cement paste. Eldin and Senouci (1993) soaked and thoroughly washed rubber aggregates with water in order to remove any contaminants, while Rostami et al. (1993) attempted to clean the rubber using water, water and carbon tetrachloride (CCl_4) solvent, and water and a latex admixture cleaner. Results show that concrete containing washed rubber particles achieved about 16% higher compressive strength than concrete containing untreated rubber aggregates. A much larger improvement in compressive strength (about 57%) was obtained when rubber aggregates treated with CCl_4 were used.

Effect of Using Special Cements

A study conducted by Biel and Lee (1996) suggests that the type of cement used in rubcrete mixtures greatly affects the mechanical strength. Recycled tire rubber particles were used in concrete mixtures made with both magnesium oxychloride cement and portland cement. The percentage of fine aggregate substitution ranged from 0 to 90%, increasing by 15% for each set. It was observed that 90% loss of the compressive strength occurred for both the portland cement rubber concrete (PCRC) and magnesium oxychloride cement rubber concrete (MOCRC) when 90% of the fine aggregate (25% of the total aggregate) was replaced by rubber (Fig. 5*a*). Whether with or without rubber inclusion, the magnesium oxychloride cement concrete exhibited approximately 2.5 times the compressive strength of the portland cement concrete (Fig. 5*a*). The portland cement concrete samples containing 25% of rubber by total aggregate volume retained 20% of their splitting tensile strength after initial failure, whereas the magnesium oxychloride cement concrete samples with similar rubber content retained 34% of their splitting tensile strength after initial failure. The ratio of the MOCRC tensile strength to PCRC tensile strength rose from 1.6 to 2.8 with increased amounts of rubber. It was argued (Beil and Lee 1996) that the high-strength and bonding characteristics provided by magnesium oxychloride cement greatly improved the performance of rubcrete mixtures and that structural applications could be possible if the rubber content is limited to 17% by total volume of the aggregate. The effects of using blended cements, fiber reinforcement, chemical admixtures, polymer resins, and other additives in rubcrete remain to be investigated.

Mechanisms of Strength Reduction

Khatib and Bayomy (1999) found that the 28-day compressive strength of rubcrete mixtures was reduced by about 93% when 100% of the coarse aggregate volume was replaced by rubber, and by 90% when 100% of the fine aggregate volume was replaced by rubber. They hypothesized that there are three major causes for this strength reduction. First, because rubber is much softer than the surrounding cement paste, upon loading, cracks are initiated quickly around the rubber particles due to this elastic mismatch, which propagate to bring about failure of the rubber-cement matrix. Second, due to weak bonding between the rubber particles and the cement paste, soft rubber particles may be viewed as voids in the concrete mix. The assumed increase in the void content would certainly cause a reduction in strength. The third possible reason for the reduction in strength is that the strength of concrete depends greatly on the density, size, and hardness of the coarse aggregate (Mehta and Monteiro 1993). Because aggregates are partially replaced with relatively weaker rubber, a reduction in strength is anticipated. It was also found (Khatib and Bayomy 1999) that the flexural strength of rubcrete mixtures decreased with an increase in the rubber content in a fashion similar to that observed for compressive strength, perhaps due to similar mechanisms.



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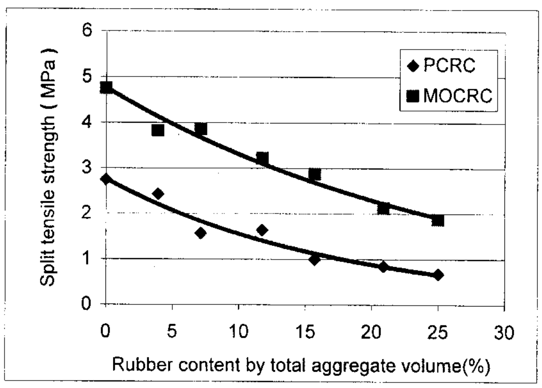

(b)

FIG. 5—*Effect of cement type on* (a) *compressive strength, and* (b) *split tensile strength (after Beil and Lee 1996).*

Toughness and Failure Mode

Although the reduction in strength of rubcrete mixtures may limit their use in some structural applications, one can rather appreciate their future potential in their enhanced toughness and failure mode. Eldin and Senouci (993) showed that when loaded in compression, specimens containing rubber did not exhibit brittle failure. A more gradual failure was observed, either of a splitting (for coarse tire chips) or a shear mode (for fine crumb rubber). It was argued that since the cement paste is much weaker in tension than in compression, the rubcrete specimen containing coarse tire chips would start failing in tension before it reaches its compression limit. The generated tensile stress concentrations at the top and bottom of the rubber aggregates (Fig. 6*a*) result in many tensile microcracks that form along the tested specimen (Fig. 6*b*). These microcracks will rapidly propagate in the cement paste until they encounter a rubber aggregate. Because of their ability to withstand large tensile deformations, the rubber particles will act as springs (Fig. 6*c*), delaying the widening of cracks and preventing full disintegration of the concrete mass. The continuous application of the compressive load will cause generation of more cracks as well as widening of existing ones. During this process, the failing specimen is capable of absorbing significant plastic energy and withstanding large deformations without full disintegration. This process will continue until the stresses overcome the bond between the cement paste and the rubber aggregates.

Biel and Lee (1996) reported that the failure of plain concrete cylinders resulted in explosive conical separations of cylinders, leaving the specimens in several pieces. As the amount of rubber in concrete was increased, the severity and explosiveness of the failures decreased. 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 plane. The cylinders did not separate and continued to sustain load after the initial failure. Upon release of the load, the cylinders rebounded back to near their original shape. The samples containing 75 and 90% fine aggregate substitution with rubber failed through a gradual compression that appeared like a true crushing, resulting in a post failure material that was sponge-like and elastic in nature.

In another experimental study conducted by Goulias and Ali (1997), it was found that the dynamic moduli of elasticity and rigidity decreased with an increase in the rubber content, indicating that a less stiff and less brittle material was obtained. The 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 the rubber content. Conversely, Topcu and Avcular (1997a), and Fatuhi and Clark (1996) recommended using rubberized concretes in circumstances where vibration damping is required, such as in buildings as an earthquake shockwave absorber, in foundation pads for machinery, and in railway stations. Results of Poisson's ratio measurements indicated that cylinders with 20% rubber had a larger ratio of lateral strain to the corresponding axial strain than that of 30% rubber concrete cylinders (Goulias and Ali 1997a). It was also found (Goulias and Ali 1997) that the higher the rubber content, the higher the ratio of the dynamic modulus of elasticity to the static modulus of elasticity. The dynamic modulus was then related to compressive strength, providing a high degree of correlation between the two parameters. This suggests that nondestructive measurements of the dynamic modulus of elasticity may be used for estimating the compressive strength of rubcrete. A good correlation between compressive strength and the damping coefficient calculated from transverse frequency was also found, indicating that the damping coefficient of rubcrete may likewise be used for predicting the compressive strength.

Khatib and Bayomy (1999) observed that as the rubber content increased, rubcrete specimens tended to fail gradually in either a conical or columnar shape failure mode. The samples sustained much higher deformations than the control mix without rubber. With a rubber content of 60% by total aggregate volume (fine and/or coarse), the samples exhibited significant elastic deformation, which was retained upon unloading. Thus, flexibility and ability to deform at peak load were increased significantly by rubber addition. Experimental results of Schimizze et al. (1994) showed that the elastic modulus of a concrete mixture containing coarse rubber granules replacing 100% of the coarse aggregate volume was reduced to about 72% of that of the control mixture, whereas for a concrete containing fine rubber granules replacing 100% of the fine aggregate volume, the elastic modulus was reduced to

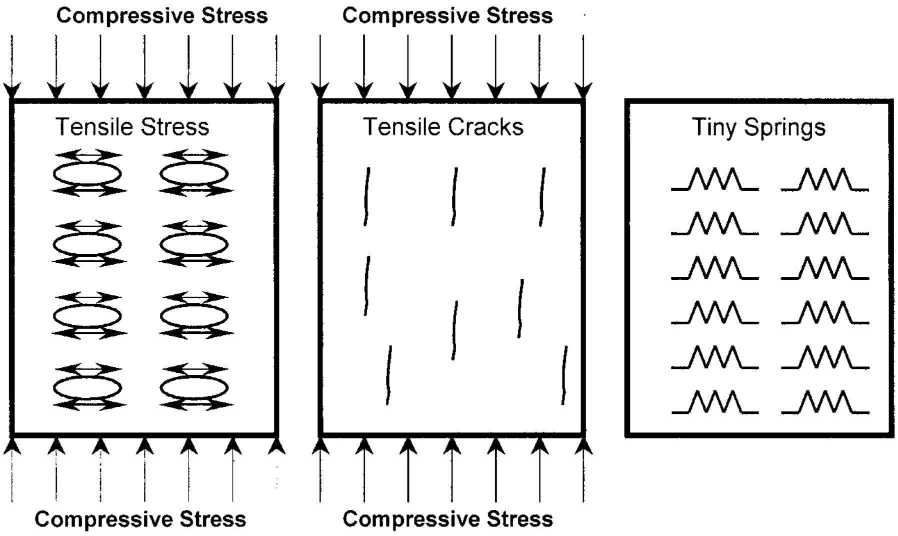

FIG. 6—*Modeling the behavior of rubcrete specimens under compression (after Eldin and Senouci 1993).*

about 47% of that of the control mixture. The reduction in the elastic modulus indicates higher flexibility, which may be viewed as a positive gain in rubcrete mixtures that could be used in stabilized base layers of flexible pavements. Tantala et al. (1996) conducted a comparative study of the toughness of a control concrete mixture and rubcrete mixtures with 5 and 10% buff rubber by volume of coarse aggregate. It was found that the toughness of both rubcrete mixtures was higher than that of the ordinary concrete mixture. However, the toughness of the rubcrete mixture with 10% buff rubber was lower than that of the rubcrete mixture with 5% buff rubber because of the decreasing ultimate compressive strength. It was also found (Tantala et al. 1996) that acid etching of rubber particles replacing the coarse aggregate lowered the toughness of rubcrete mixtures. Results by Topcu and Ozcelikors (1991) show that 10% rubber-chip addition increased the toughness of concrete by 23%.

Raghavan et al. (1998) conducted an experimental study on the use of rubber shreds and granular rubber in mortar. They found that mortar specimens with rubber shreds were able to withstand additional load after peak load. The specimens did not physically separate into two pieces under flexural loading because of bridging of cracks by rubber shreds. However, specimens with granular rubber broke into two pieces when the peak load was attained. Therefore, the post-crack strength seemed to improve when rubber shreds were used instead of granular rubber.

Impact Resistance, Heat and Sound Insulation

According to Topcu and Avcular (1997b), the impact resistance of concrete increased when rubber aggregates were added to the mixture. It was argued that this increased resistance was derived from an increased ability of the material to absorb energy and insulate sound during impact (Eldin and Senouci 1993; Topcu 1995; Rad 1976; Acar 1987). The increase became more prominent in concrete samples containing larger-size rubber aggregates.

It was expected that acoustical tests would substantiate the applicability of rubcrete mixtures for roadway sound barriers to reduce the effects of acoustic emissions (Tantala et al. 1996). Wisconsin and Pennsylvania Departments of Transportation (DOTs) have studied the noise-absorption properties of whole rubber tires as sound barriers with moderate success (Tantala et al. 1996). More research is required to study the sound insulation effects of rubcrete in buildings and other structures.

Rubber inclusion in concrete also makes the material a better thermal insulator, which could be very useful especially in the wake of energy conservation requirements (Tantala et al. 1996). However, no pilot projects to take advantage of this property in practice are available in the open literature. Also, fire tests (Topcu and Avcular 1997a) indicated that the flammability of rubber in rubcrete mixtures (if any) was much reduced by the presence of cement and aggregates. Although more testing is needed, it is believed that the fire resistance of rubcrete mixtures is satisfactory.

Freezing and Thawing Resistance

Savas et al. (1996) investigated the freezing and thawing durability of rubcrete. Various mixtures were obtained by adding 10, 15, 20, and 30% ground rubber by weight of cement to the control concrete mixture. Freezing and thawing tests in accordance with ASTM C 666, Procedure A, Test Method for Resistance of Concrete to Rapid Freezing and Thawing were conducted on the various mixtures. The following conclusions were drawn:

- As the percentage of mechanically ground waste tire rubber in concrete was increased, the freezing and thawing durability was decreased. Rubcrete mixtures with 10 and 15% ground tire rubber by weight of cement exhibited durability factors higher than 60% after 300 freezing and thawing cycles. However, mixtures with 20 and 30% ground tire rubber by weight of cement did not meet this minimum acceptable limit set forth by the ASTM standard.
- For rubcrete mixtures with 10, 20, and 30% ground tire rubber, air entrainment did not provide significant improvements in freezing and thawing durability.
- During freezing and thawing tests, scaling (as measured by the reduction in weight) increased with the increase in the number of freezing and thawing cycles and amount of ground rubber in concrete.

A target air content of 5 to 7% is often selected to provide adequate freezing and thawing resistance for ordinary concrete mixtures. However, it was found that rubcrete mixtures with compressive strength lower than 28 MPa (4000 psi) are not considered resistant to freezing and thawing whether they are air-entrained or not (ACI 1991). It should be noted that although rubcrete mixtures usually have high air contents, the large-size and nonuniform distribution of trapped air voids might be a possible reason for their lack of freezing and thawing resistance, especially for mixtures with high contents of rubber (Topcu and Avcular 1997b).

Potential Applications of Rubcrete

The unique qualities of rubcrete (e.g., light unit weight) suggest that it may be suitable for architectural applications such as nailing concrete, false facades, stone backing, and interior construction. It is also anticipated that rubcrete will find new areas of usage in highway construction as a shock absorber, in sound barriers as a sound absorber, and also in buildings as an earthquake shock-wave absorber (Topcu and Avcular 1997a). However, more research is required before such recommendations can be made.

Fatuhi and Clark (1996) suggested various interesting applications where cement-based materials containing rubber could possibly be used. These include areas:

- Where vibration damping is required, such as in foundation pads for machinery, and in railway stations.
- Where resistance to impact or explosion is required, such as in jersey barriers, railway buffers, and bunkers.
- For trench filling and pipe bedding, in artificial reef construction, for pile heads and paving slabs.

The present authors are currently conducting research exploring new areas of application for rubcrete mixtures, which potentially can use large volumes of this material. Focus is particularly on emerging geotechnical construction methods in which buffer layers of a low-strength high-ductility material are required to absorb excessive delayed deformations.

Concluding Remarks

Although a rubcrete mixture generally has a reduced compressive strength that may limit its use in certain structural applications, it possesses a number of desirable properties, such as lower density, higher toughness, higher impact resistance, enhanced ductility, and more efficient sound and heat insulation compared to conventional concrete. Such engineering properties are advantageous for various construction applications. If rubcrete is used to its potential in projects that require these unique attributes, this can contribute to alleviating the exacerbated solid waste disposal problems associated with worn out rubber tires. However, this requires a paradigm shift from the traditional misconception that the most important property of concrete is its compressive strength to a design by function approach, which will allow rubcrete to be viewed as a preferred solution over conventional concrete for particular projects.

Structural applications involving rubcrete may still be possible if appropriate percentages of rubber aggregates are used. It is also possible to produce relatively high-strength rubcrete mixtures by using magnesium oxychloride cement, which achieves better bonding characteristics to rubber and greatly improves the performance of rubcrete mixtures. In addition, the adhesion between the rubber particles and other constituents of the rubcrete matrix can be improved by pretreating the rubber aggregates. For instance, acid etching of rubber granules improves compressive strength markedly. However, further research is still needed to optimize the effect of the percentage of rubber, particle size distribution, type of cement, pretreatment method of rubber particles, and use of chemical and mineral admixtures on the properties of rubcrete.

Rubcrete mixtures usually absorb significant plastic energy and undergo relatively large deformations without full disintegration. This property can be utilized in various structural and geotechnical projects in which the deformation at peak load is a primary design concern. Using rubcrete as a flexible sub-base for pavements, as pipe bedding, for tunnel linings, and other major construction work has the potential to make good use of the billions of worn-out tires stockpiled worldwide. However, further studies are needed before one can draw final recommendations and set forth design guidelines for such applications.

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