

Analysis and Testing of Waste Tire Fiber Modified Concrete

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Abstract: *There are very serious problems with the disposal of waste tires in India. Experiments were conducted to determine how the properties of concrete were affected by the inclusion of waste tires. Waste tires were used in the form of chips and fibers. The fibers were further divided into batches with different lengths to determine the effect of length has on the properties of concrete. There was a noticeable decline in the compressive strength of the concrete; however there was an increase in the toughness of the concrete. It was concluded that waste tire fibers were more suitable as additives than waste tire chips since they produced the highest toughness. An analytical model was performed to determine how properties such as the critical fiber length affect the ultimate tensile strength of the composite. The ultimate tensile strength of concrete is very important as it is the property that is responsible for the failure of concrete even in compression. A three-dimensional finite element analysis was performed using ANSYS. Results obtained from this analysis were used to determine the critical fiber length. The models were able to predict a value of ultimate tensile strength that was very close to the experimental result obtained.*

Keywords: Waste tire fiber, Ansys model, Strength, Concrete, Critical fiber length

1. Introduction

The management of worn tires poses a major problem for all worlds. Also, with the increasing number of vehicles, the industrial development which several countries are currently knowing, and the small percentage of recycled worn tires (retreaded or used for other purposes) due to the absence of an adequate plan for eliminating this waste, these countries know surely a major environmental problem. The absence of statistics on this subject does not enable us today estimate suitably the mass of worn tires thrown in nature or burned in public dumpsters. But if we compare these countries with the European Union countries which took this problem in charge, through legislation, recycling companies, research, we can say that many countries are postponing the solution to this problem, and that the mass of worn tires can only be considerable.

One of the recommended solutions to solve this environmental problem is to incorporate rubber aggregates resulting from cutting worn tires in the cement concretes. On this subject, several studies concerning the use of rubber aggregates resulting from crushing worn tires were carried out. These research works showed that the benefits of associating rubber-cement in the development of cementing composites with high deformability and on the durability of these composites.

Tires are bulky, and 75% of the space a tire occupies is void, so that the land filling of scrap tires has several difficulties:

- Whole tire landfilling requires a large amount of space.
- Tires tend to float or rise in a landfill and come to the surface.
- The void space provides potential sites for the harboring of rodents.
- Shredding the tire eliminates the above problems but requires high processing costs.

Because of the above difficulties and the resulting high costs,

tire stockpiles have turned up across the country. These waste tires represent a significant environmental, human health, and aesthetic problem. Waste tires pose a health hazard since tire piles are excellent breeding grounds for mosquitoes. Because of the shape and impermeability of tires, they may hold water for long periods providing sites for mosquito larvae development.

2. Literature Review

2.1 Experiments Done with Different Rubber Content

Experiments were conducted [Eldin, et al., 1993] to examine the strength and toughness properties of rubberized concrete mixtures. They used two types of tire rubber with different rubber content. Their results indicate that there is about an 85% reduction in compressive strength, whereas the tensile strength reduced to about 50% when the coarse aggregate was fully replaced by rubber. A smaller reduction in compressive strength (65%) was observed when sand was fully replaced by fine crumb rubber. Concrete containing rubber did not exhibit brittle failure under compression or split tension. A more in-depth analysis of their results indicates a good potential of using recycled rubber in Portland cement concrete mixtures because it increases fracture toughness. However, an optimized mix design is needed to optimize the tire rubber content in the mixture.

Recycled waste tire rubber was also investigated as an additive to Portland cement concrete [Zaher, et al, 1999]. Two types of waste tire rubber were used, fine crumb rubber and coarse tire chips. The study was divided into three groups. In the first group only crumb rubber was used and only replaced the fine aggregates. In the second group tire chips were used to replace the coarse aggregates. In the third and final group both crumb and chips were used. In this group the rubber content was equally divided between crumb and chips, and again the crumb replaced fine aggregates while the chips replaced the coarse aggregates. The rubber

content used in the three groups ranged from 5-100%. The aggregates were partially replaced by the rubber. They found that rubberized PCC can be made and are workable (even though greatly reduced) with the rubber content being as much as 57% of the total aggregate volume. Their results showed that the reduction in strength was too great, thus they recommended not replacing more than 20% by volume of the aggregate with waste tires.

2.2 Bond Strength between Fiber and Matrix

The main factors controlling the theoretical performance of the composite material are the physical properties of the fibers and the matrix, and the strength of the bond between the two. Bond strengths vary with a wide variety of parameters, including time.

From several experiments conducted, one of the general conclusions was that there was a reduction in compressive, flexural and tensile strength. Several authors have suggested that the loss in strength might be minimized by prior surface treatment of the waste tire [Lee, et al. 1993 and Raghavan, et al. 1998]. The bonding between concrete matrix and waste tire is not very strong. A study was conducted [Segre, et al. 2000] in which the surface of powdered rubber tire was modified with several surface treatments including sodium hydroxide (NaOH), to increase the hydrophilicity of the rubber surface. It was assumed that by doing this, the sodium hydroxide would hydrolyze the acidic and/or carboxyl groups present on the rubber surface [Smith, et al. 1995]. The samples were cured for 28 days then tested.

2.3 Critical Fiber Length

A very important property of the reinforcements is their critical fiber length. When fibers are smaller than the critical length, the maximum fiber stress is less than the average fiber strength so that the fibers will not fracture, regardless of the magnitude of the applied stress [Agarwal, et al. 1980]. The composite failure occurs when the matrix or interface fails. In the case of discontinuous-fiber reinforced concrete, an additional factor influences the failure, namely, the large stress concentrations in the matrix produced as a result of the fiber ends. The result of the stress concentration is to further lower the composite strength [Agarwal, et al. 1980].

2.4 Finite Element Analysis Background

The main obstacle to finite element analysis of reinforced concrete structures is the difficulty in characterizing the material properties. Much effort has been spent in search of a realistic model to predict the behavior of reinforced concrete structures. Due mainly to the complexity of the composite nature of the material, proper modeling of such structures is a challenging task. Despite the great advances achieved in the fields of plasticity, damage theory and fracture mechanics, among others; a unique and complete constitutive model for reinforced concrete is still lacking [Barbosa, et al. 1998].

Software developers implement the nonlinear material laws into finite element analysis codes in one of two ways [Fanning, 2001]. One method is to program the material

behavior independently of the elements to which it may be specified. In this method, the choice of element for a particular physical system is not limited. This is the most versatile approach and does not limit the analyst to specific element types in configuring the problem of interest. The other method is to have specific specialized nonlinear material capabilities only with dedicated element types. The latter method is found in ANSYS. For concrete, it has a dedicated three-dimensional eight node solid element, SOLID65, to model the nonlinear response of brittle materials based on the constitutive model for the triaxial behavior of concrete proposed by Willam and Warnke [Willam, et al. 1975]. The element type used for rubber was SOLID185 which was defined by orthotropic material properties and eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities.

3. Experimental Work

3.1 Material and their preparation

Concrete strength is greatly affected by the properties of its constituents and the mixture design parameters. In performance of the experiments the raw materials used included Portland cement, Davanair 1000, mixture of aggregates (coarse and medium), sand, water and tire fibers. Tires from light vehicles, such as cars and from heavy vehicles such as trucks were used. The tires were cut by hand and a band saw obtained from the Engineering Workshop at Louisiana State University. Tires from light vehicles had smaller and fewer wires than those from heavy vehicles. They were cut into strips of 25.4mm (1in) x 5mm (0.2in) x 5 mm (0.2in), 50.8 mm (2in) x 5mm (0.2in) x 5mm (0.2in) and 76.2 mm (3in) x 5mm (0.2in) x 5 mm (0.2in).

Daravair® 1000 is a liquid air-entraining admixture that provides freeze-thaw resistance, yield control, and finishability performance across the full range of concrete mix designs. Air-entrained concrete is one in which minute air bubbles are intentionally trapped by the addition of an admixture to the cement during the batching and mixing of the concrete. The presence of a properly distributed amount of these bubbles imparts desirable properties to both freshly mixed and hardened concrete. In freshly mixed concrete, entrained air acts as a lubricant, improving the workability of the mix, thereby reducing the amount of water that needs to be added.

In the experiments, fifteen percent by volume of fibers was used. This value was chosen for the fact that from experiments that have been conducted [Khatib, et al. 1999] it was found that if greater than 20 percent was used the strength and toughness of the concrete would be so low that the material would not be usable. On the other hand, if less than ten percent was used it would not be economically viable. In introducing the fibers into the mix, it was ensured that there was single fiber addition and the fibers reached the mixer individually and were immediately removed from the

point of entry by the mixing action, so as to produce uniform fiber distribution.

The concrete mixed used was rated at 40MPa compression strength. A control PCC mix was designed using American Concrete Institute Standard 211.1 mix design methods for the modified batches to be compared with. In the modified batches, fifteen percent of the coarse aggregates were replaced by tires as mentioned previously. The mix ratio by weight for control concrete was cement: water: gravel: sand: DARAVAIR 1000 = 1: 0.50: 3.50: 1.88: 0.001. The mix ratio by weight for rubberized concrete was cement: water: gravel: waste tire: sand: DARAVAIR 1000 = 1: 0.50: 3.40: 0.10: 1.88: 0.001.

Two different size samples were made. The dimensions of the samples were 6-inch diameter by 12-inch length and 4-inch diameter by 8-inch length. They were cured for 28 days in a controlled environment at the Louisiana Transportation Research Center. This time was chosen since concrete hardens and gain strength as it hydrates. The hydration process continues over a long period of time. It happens rapidly at first and slows down as time goes by. To measure the ultimate strength of concrete would require a wait of several years. This would be impractical, so a period of 28 days was selected by specification writing authorities as the age that all concrete should be tested. At this age, a substantial percentage of the hydration has taken place.

After the concrete was mixed, it was placed in a container to set. A satisfactory moisture content and temperature (between 50°F and 75°F) must be maintained, a process called curing. Adequate curing is vital to quality concrete. Curing has a strong influence on the properties of hardened concrete such as durability, strength, water tightness, abrasion resistance and volume stability. Surface strength development can be reduced significantly when curing is defective. Curing the concrete aids hydration; most freshly mixed concrete contains considerably more water than is required for complete hydration of the cement; however, any appreciable loss of water by evaporation or otherwise will delay or prevent hydration. If temperatures are favorable, hydration is relatively rapid the first few days after concrete is placed; retaining water during this period is important. Good curing means evaporation should be prevented or reduced.

3.2 Batch Specification

Seven batches of six-inch radius by twelve-inch height cylinders were prepared. One batch was made without waste tires to be the control while six batches were prepared using waste tire chips or fibers. Thirty were prepared using fibers of lengths one inches, two inches and three inches while one batch was made using chips. Chips used were from light duty vehicle (cars) and heavy duty vehicles (trucks) approximately in a one to one ratio. Steel belts were included in some of these tires.

Table 3.1: The dimensions and distribution of tires and chips in each batch

Batch number	Waste tire shape	Fiber/chip length (in)	Fiber/chip width (in)	Fiber/chip height (in)
1	N/A	N/A	N/A	N/A
2	Truck and car rubber chips with steel wires	1	1	0.2
3	Car tires without steel wires	1	0.2	0.2
4		2	0.2	0.2
5		3	0.2	0.2
6	Car tires with steel wires	2	0.2	0.2
7	Truck and car tire with steel wires	2	0.2	0.2

The fibers were from car tires only or a mixture of car and truck tires in a one to one ratio. Different fiber lengths were used to determine the effect of fiber aspect ratio on the properties of concrete such as stiffness and strength.

3.3 Testing

There are a series of standardized testing procedures for determining concrete material properties. The response of a reinforced concrete structural element is determined in part by the response of plain concrete in compression. As a result, standard practice in the United States [ACI, 1992] recommends characterizing the response of concrete on the basis of the compressive strength of a 6 inch diameter by 12 inch long (152.4 mm by 304.8 mm) concrete cylinder. For typical concrete mixes, the standard cylinder is sufficiently large that the material is essentially homogeneous over the critical zone. Additionally, while the standard procedure (ASTM C39) does not require efforts to reduce frictional confinement induced during testing at the ends of the specimen, the specimen is considered to be sufficiently long that approximately the middle third of the cylinder experiences pure compression.

After being cured, the samples were then subjected to split tensile strength, compressive strength and compressive modulus tests. An MTS machine was used to perform these tests.

4. Analytical Model

There are several parameters that affect the performance of concrete. Two of the most important parameters are the ultimate tensile strength and the critical fiber length. Analytical models will be developed to predict both these properties. By knowing how these parameters affect the performance of waste tire modified concrete then the design can be optimized to produce a better composite.

In developing these models, assumptions were made that the fibers were uniformly distributed in the concrete matrix and were of uniform strength. The tensile strength is extremely important because it is considered to be the factor that is responsible for the failure of the concrete, even in

compression. This is so since when concrete is uniaxial tested by compression, Poisson's effect causes tensile stresses to be developed perpendicular to the application of load. Since the tensile strength of concrete is approximately one tenth of its compressive strength the sample will fail due to tension before the sample is crushed as a result of compression.

Knowing the above properties and knowing how they vary and what affects them, then suitable modifications can be made to produce a superior composite.

Due to the introduction of coarse aggregates in the concrete, the distribution of fibers in the space will be disturbed by the coarse aggregates. The space already occupied by the coarse aggregates cannot be occupied by the fibers again. The fibers can distribute only in the remaining space. This space is called the effective space. The effective space is determined based on the mixture ratio of every component in concrete and the aggregate gradation.

4.1 Critical fiber length

The reinforcing efficiency of fibers is closely related to fiber length. For discrete fiber reinforced concrete, a critical fiber length, l_c , is defined as the minimum fiber length required for the build-up of a stress (or load) in the fiber which is equal to its strength (or failure load). If fiber length is smaller than l_c , there is no sufficient embedded length to generate a stress equal to the fiber strength, and the fiber is not used efficiently. Only if the length of fibers considerably exceeds l_c does the stress along most of the fibers reach its yield or tensile strength, thus mobilizing most of the potential of the fiber reinforcement.

Critical fiber length is the maximum value of load-transfer length. It is an important system property and affects ultimate composite properties. Over this length the fiber supports a stress less than the maximum fiber stress.

There is a critical length, l_c , which the fibers must have to strengthen a material to their maximum potential. Critical fiber length is twice the length of fiber embedment that would cause fiber failure in a pull out test [Hannant, 1978]. This critical length is given by equation (1) below. According to Kelly [Kelly, et al. 1971] parentheses flush with the right margin, as in (1). First use the equation editor to create the equation. Then select the "Equation" markup style. Press the tab key and write the equation number in parentheses.

$$E = \sum_{p=1}^P \sum_{k=1}^K (\delta_{pk}^o)^2 \quad (1)$$

5. Finite Element Analysis of Equivalent Fiber

5.1 Modeling

Finite element analysis, determines the overall behavior of a structure by dividing it into a number of simple elements, each of which has well-defined mechanical and physical properties. The simulations were performed with ANSYS 8.1 finite element software. The fibers used in conducting the experiments were of a square cross sectional area. This

geometry had to be converted to an equivalent circular geometry for analysis. The rubberized concrete was treated as a two-phase composite with waste tires dispersed in concrete matrix. The element chosen to simulate concrete was SOLID65 while SOLID185 was used to simulated rubber. SOLID65 has the ability to include non-linear material model such as the Drucker-Prager model that was used to model the plastic behavior of concrete. A simulation was run in ANSYS first for an element of the square model. A cylindrical model was created in ANSYS with all the same properties as the square model. The Young's modulus was varied until similar results were obtained as the square model. When this value was obtained, it was inputted into the equations derived in the analytical model to calculate the critical fiber length and the ultimate tensile strength. The values obtained were compared to the values obtained from the experimental analysis.

Since concrete deforms plastically, both linear elastic properties and plastic properties were defined. In the linear region, the concrete was treated as linear isotropic so only Young's modulus and Poisson's ratio were used. The compressive strength of the concrete was used as 40MPa, initial Young's modulus was 30GPa, and Poisson's ratio was 0.2. Once the concrete yields, the three parameter Drucker-Prager plasticity model takes over the behavior of the concrete. The three parameters necessary to define the Drucker-Prager model are the cohesion, angle of internal friction and the dilatancy angle. The cohesion was used as 12 MPa, the angle of internal friction as 32° and the dilatancy angle as 8°.

5.2 Meshing

Mesh generation for the three-dimensional models was performed using ANSYS preprocessor. Adequate mesh refinement is always an issue when conducting a finite element analyses. The idea is to have enough refinement to capture all strain gradients of interest, but to avoid excess refinement, which can lead to unnecessarily long run-times.

For a coarse mesh (fewer elements) ANSYS has less number of equations to solve simultaneously so the processing time will be shorter than if a fine mesh was used (more elements). The coarser mesh may not accurately capture the behavior of the model though. A very finely meshed model will usually capture the necessary detail in the system but at the expense of processing time. Therefore, it is necessary to find a compromise when meshing the model. To do this the model was run initially with a coarse mesh. It was run again with a finer mesh a few more times and the results compared each time with the previous result to compare the deviations.

5.3 Simulation

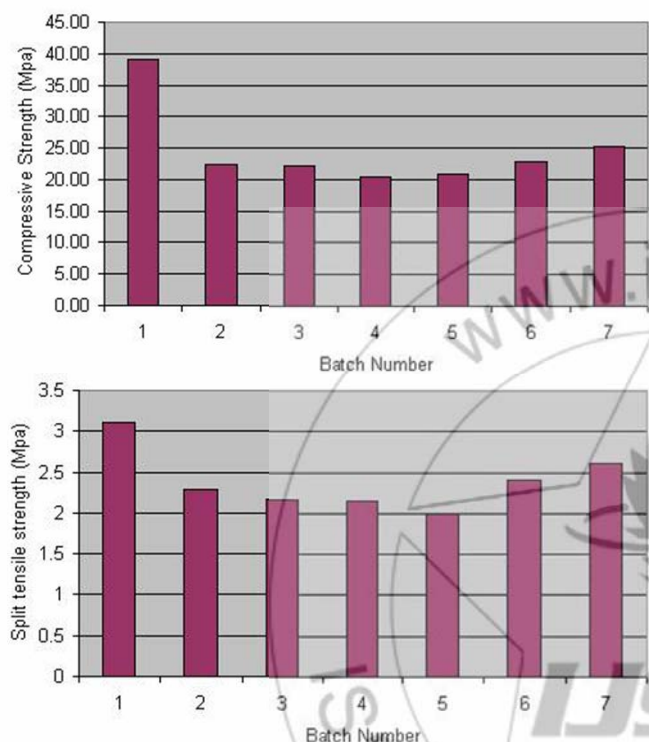
All the degrees of freedoms at one end were constrained to represent one end held fixed and a compressive load was applied to the other end as shown in Figure 8. A large static displacement linear analysis was performed. This was to ensure that any effects of large deflections were included in the results. The Automatic Time Stepping feature was turned on; this enables ANSYS to determine appropriate sizes to

break the load steps into. Decreasing the step size usually ensures better accuracy, however this increases the processing time. The Automatic Time Step feature was used to determine an appropriate balance. The number of substeps used for the simulation was 100.

6. Results and Discussion

6.1 Compressive and Tensile Strength of Concrete

The results of the tests for strength performed on the samples in the experiments are shown below.



Toughness describes how a material will react under sudden load. With its increased toughness, rubberized concrete will be able to resist crack propagation, catastrophic failures and absorb dynamic loads more than the control.

It was observed that the samples tend to fail more gradually with the addition of waste tires. Waste tire modified samples were able to undergo a higher deformation than the control mix. The ability of the sample to deform elastically has thus increased.

The high elastic energy capacity of normal concrete was reduced after adding rubber while the plastic energy capacities began to increase. As a result of their high plastic energy capacities these concrete showed high strains especially under impact effects.

7. Conclusion

Concrete mixes were prepared both with and without waste tire rubber. For those with waste tires, there was one batch made with waste tires in the form of chips while the others were made with waste tires as fibers with different aspect ratios. Numerical analysis, finite element analysis and

experimentations were conducted. Several conclusions were reached:

- The toughness of waste tire modified concrete was much greater than unmodified concrete. It was thus able to absorb more energy when loaded than the control sample.
- Owing to the fibers bridging over the cracks, the crack opening width can be controlled. In addition the three dimensional distribution of fibers in concrete provides the reinforced concrete with improved performance in all directions.
- Waste tire modified concrete failed in a ductile manner rather than a brittle manner.
- The sample with waste tire as fibers performed better than those with chips thus, waste tires should be used as fibers instead of chips.
- It is not very beneficial to include fibers in cement matrices to increase the first tensile strength. The effect of the fibers on the concrete is not fully realized until cracking has occurred, as this is when the load carrying ability of the fiber comes into effect.
- The finite element model clearly showed the development of microcracks in the concrete. The model can be used to try and keep the formation of cracks to a minimum, thus increasing the strength at which concrete fails.
- Waste tire modified concrete had lower compressive and tensile strength than the control mix. It was however shown that it was advantageous to use stiffer fibers as they had higher strengths.
- Waste tires can be included to increase the ductility in compressive failure. One of the major benefits of waste tire fibers is the holding together of a cracked area after minor impacts.
- The present model used in the analytical modeling is valuable and useable to predict the ultimate tensile strength of fiber reinforced concrete.
- From the results obtained from this study it was determined also that the geometry of the fibers also had an influence on the strength of the concrete. The aspect ratio of the waste tire fibers needs to be increased.
- In fiber reinforced concrete, the major effect of the fibers has been noted in the post-cracking case, where the fibers bridge across the cracked matrix.

References

- [1] Eldin, N. N., and Senouci, A. B., „Rubber-tire particles as concrete aggregate.” Journal of Material in Civil Engineering, ASCE, 5(4), 1993, 478–496.
- [2] Lee, B. I, Burnett, L., Miller, T., Postage, B., Cuneo, J., “Tire rubber/cement matrix composites,” Journal of Material Science Letter, Vol. 12, No. 13 (1993) pp. 967-968.
- [3] Raghavan, D., Huynh, H., Ferraris, C.F., “Workability, mechanical properties and chemical stability of a recycled tire rubber-filled cementitious composite,” Journal of Material Science, Vol. 33 (1998) pp.1745-1752
- [4] Segre N., Joekes N., “Use of tire rubber particles as addition to cement paste,” Cement and Concrete Research, Vol. 30 (2000) 1421-1425.

- [5] Smith, D. M., and Chughtai, A. R., "The surface structure and reactivity of black carbon", Colloid Surface A, (1995), pp. 47-77.
- [6] Barbosa, Antonio F., Ribeiro, Gabriel O., "Analysis of reinforced concrete structures using ANSYS nonlinear concrete model," Computational Mechanics, New Trends and Applications, Barcelona, Spain 1998.
- [7] Fanning, P., "Nonlinear Models of Reinforced and Post-tensioned Concrete Beams," Electronic Journal of Structural Engineering, 2 (2001), pp. 111-119
- [8] Edginton, J., Hannant, D.J., and Williams, R.I.T., "Steel-fiber-reinforced concrete," Building Research Establishment Current Paper CP 69/74, July 1974.

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