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# Comparative Analysis and Testing of Waste Tire Fiber and Chips 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. 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. 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:** Molasses, Compressive, Strength, Accelerator, Retarder

## I. INTRODUCTION

Waste management becomes the huge sector for research and developing new technique, method and alternative to utilize or minimize the waste by product. Side by side one or another means of safe disposal of such a material which can cause environmental pollution is discovered. 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.

A major reason for the growing interest in the performance of fibers in cement desire to increase the toughness or tensile properties of the basic matrix. Fiber reinforced concrete was created to combine the tensile strength of rubber with the compressive strength of concrete. It was also intended to increase the toughness of concrete by including waste tires as fibers into the matrix. Waste tires possess high toughness and this property is hoped to be imparted to the concrete. This is an example of a fiber-reinforced composite.

Composites consist of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement or reinforcing material, whereas the continuous phase is called the matrix [United States Environmental Protection Agency, 1993].

The resultant properties of composites are strongly influenced by the properties of their constituent materials, their distribution, and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents, or the constituents may react in a synergistic way so as to provide properties in the composite that are not accounted for by a simple volume-fraction sum of the properties of the constituents. Thus in describing a composite material as a system, besides specifying the constituent materials and their properties, we need to specify the geometry of the reinforcement with reference to the system. The geometry of the reinforcement may be described by the shape, size, and size distribution.

One of the most important factors determining the properties of composites is the relative proportion of the matrix and reinforcing materials. The relative proportions can be given as the volume fraction. Volume fractions are used in the theoretical analysis of composite materials. If the volume ( $v_c$ ) of a composite material that consists of volume ( $v_f$ ) of the fibers and volume ( $v_m$ ) of the matrix material, then the volume fraction can be denoted by $V$ . Therefore, the volume fractions are defined as follows:

$$V_f = \frac{v_f}{v_c}, \quad V_m = \frac{v_m}{v_c}$$

where $v_c = v_f + v_m$ .

$V_f$ = Volume fraction of fiber

$V_m$ = Volume fraction of matrix

In composites, loads are not directly applied on the fibers but are applied to the matrix material and transferred to the fibers through the fiber ends and also through the cylindrical surface of the fiber near the ends. In the case of short-fiber composites, the end effects cannot be neglected and the composite properties are a function of the fiber length.

Experiments were conducted using both chips and fibers in the concrete. The fibers used were of various lengths and aspect ratios. A finite element analysis was conducted on a representative section of the composite sample. Results from these simulations were used in a numerical model that was created. A numerical analysis was conducted to determine a few of the most important properties of the fibers that directly affect the characteristics of the composite, such as the critical fiber length and the ultimate tensile strength of the composite. Cox's shear lag theory was used to create the model [Cox, 1952]. The critical fiber length is a very important parameter as this has direct implications on the ultimate tensile strength of the samples, which controls the cracking phenomenon.

### 1.1 Factors Influencing the Strength and Stiffness of Fiber Reinforced Concrete

Factors influencing the strength and stiffness of fiber reinforced concrete are [Agarwal, 1980]:

1. Misorientation of fibers
2. Fibers of non-uniform strength
3. Discontinuous fibers
4. Interfacial conditions
5. Residual stress

Agarwal found that fiber orientation directly affects the distribution of loads between the fibers and the matrix. He deduced that there was maximum contribution to the composite properties from the fibers only when they are parallel to the loading direction. The strength and stiffness of the composite will be reduced when the fibers are not parallel to the loading direction. The extent to which the strength and stiffness may be reduced depends on the angle to the loading axis or the number of fibers that are not parallel to the loading direction.

## II. LITERATURE REVIEW

Concrete is one of the two most commonly used structural materials [Neville, 1996]. During the 1970's with the onset of the energy crisis and along with the increase in environmental consciousness a lot of focus was placed on the use of industrial waste products such as waste tire as an additive to concrete [Topcu, 1995]. Topcu in his study investigated the changes of the properties of rubberized concretes in terms of both size and amount of the rubber chips. The compressive strength when tested at 28 days was 29.50MPa, it was however shown that that with the addition of 15, 30 and 45% of coarse rubber chip, that value was reduced to 14.60, 8.91 and 5.51 MPa respectively. This represents a 51, 70 and 81 percent reduction in compressive strength.

It was considered that the rubberized concrete would be very suitable to be used in jersey barriers in which high strength is not necessary, however toughness is desired as it is subjected to direct impact in crashes. The rubberized concrete could reduce the damage to vehicles and also reduce the loss of lives from accidents.

The disposal of waste tires represents a major issue in the solid waste dilemma because there are more than 242,000,000 scrap tires, approximately one tire per person, generated each year in the United States (Epps, 1994). Therefore, over the past few years, a number of researches have been focused on the use of waste tires in different shapes and sizes in concrete.

### 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 a 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 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].

### 2.3 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.

## III. EXPERIMENTAL SETUP AND RESULT DISCUSSION

### 3.1 Materials 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 SGI.

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.

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.

### 3.2 Batch Specifications

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. The details of the composition are given in Table 1.

Table 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 |

### 3.3 Testing Procedures

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.

Slump tests were also conducted to measure the workability or consistency of concrete. Workability is the relative ease or difficulty of placing and consolidating concrete. When placed, all concrete should be as stiff as possible, yet maintain a homogeneous, voidless mass. Too much stiffness, however, makes it too difficult or impossible to work the concrete into the forms and around reinforcing steel. On the other hand, too fluid a mixture is also detrimental. The measure of the workability or consistency of concrete is its slump, which is a design consideration that is inversely proportional to the stiffness of the mix. The slump should never exceed six inches (15.24 cm). Slump test was performed according to ASTM C 143.

## IV. ANALYTICAL MODELLING

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.

### 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, lc , 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 lc , 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 lc 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, lc , 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]

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

### 4.2 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.

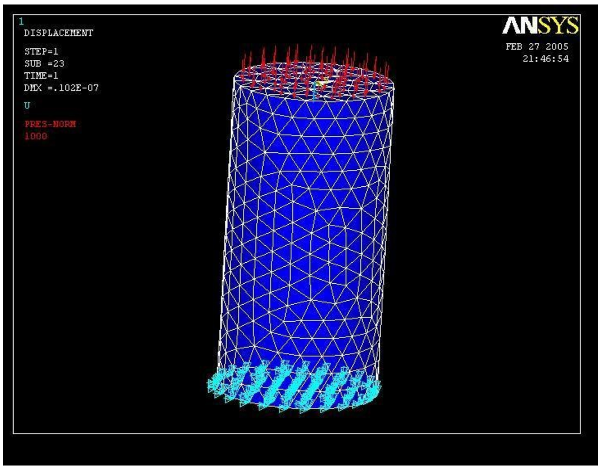


Figure : Constraints and load applied to model.


Figure: First cracks formed in concrete surrounding fiber on application of load

## V. RESULTS AND DISCUSSION

### Compressive and Tensile Strength of Concrete

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

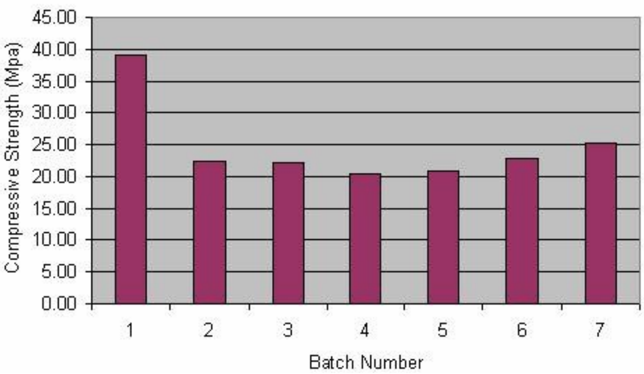


Figure: Variation of the compressive strength of concrete

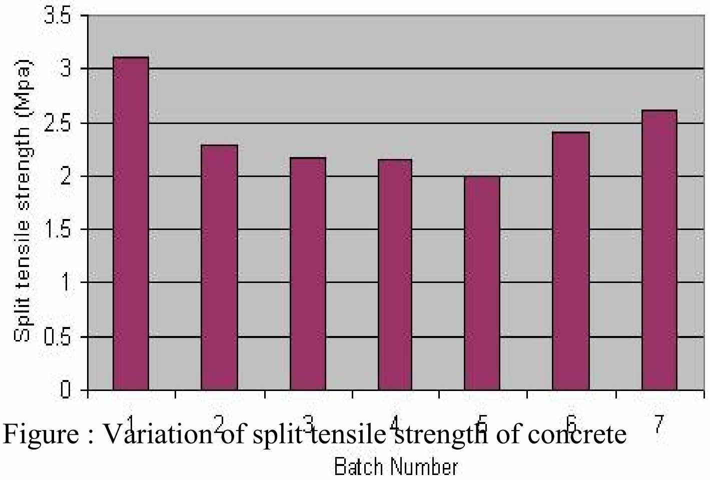


Figure : Variation of split tensile strength of concrete

Figure shows that the control samples had the highest split tensile strength. Batches 3-5, which consisted of waste tires without steel wire, had the lowest split tensile strengths. Batch 7 had the highest split tensile strength of all the rubberized concrete samples. This batch consisted of the waste tires with the highest modulus of elasticity and had the most steel wires included.

This implies that it is advantageous to include waste tires with wires and high modulus of elasticity into the concrete. This is further supported by the fact that batch 6 which contained car tires with wires had a higher split tensile strength than batches 3-5 which contained car tires without wires. The introduction of waste tires into concrete reduced its split tensile strength. The reduction of strength can however be minimized by including tires with higher elastic modulus such as truck tires and specifically tires that contain wires.

The strength was reduced in waste tire modified concrete for several reasons including:

- The inclusion of the waste tires acted like voids in the matrix. This is because of the weak bond between the waste tire and concrete matrix. With the increase in void content of the concrete, there will be a corresponding decrease in strength. The weakness of the bond between the waste tires and cement matrix can be seen by how easy it is to remove the fibers from the crushed sample by simply using ones fingers.

- Waste tires act as weak inclusions in the hardened cement mass and as a result produced high internal stress that are perpendicular to the direction of applied load.

The tensile strength of concrete is much lower than the compressive strength, largely because of the ease with which cracks can propagate under tensile loads. Although tensile strength is usually not considered directly in design, its value is still needed because cracking in concrete tends to be of tensile behavior. Concrete can be considered as a brittle material, and the tensile strength of a brittle material is due to the rapid propagation of a single flaw or microcrack.

## VI. 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 critical fiber length as obtained from the numerical analysis was 7 inch. It was not however feasible to use this length of fiber due to fiber entanglement that would result and because of the size of the formwork used to make the samples. It is recommended not to use fiber lengths exceeding 3 inches.

## VII. CONCLUSION

The proposed payment system combines the Iris recognition with the visual cryptography by which customer data privacy can be obtained and prevents theft through phishing attack [8]. This method provides best for legitimate user identification. This method can also be implemented in computers using external iris recognition devices.

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