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Mechanical and Dynamical Properties of Rubber Concrete

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Abstract: **This paper reports on an experimental study to explore the effect of using recycled rubber powder as an alternate fine aggregate in concrete mixes. Natural sand was partially replaced by 5%, 10%, 15%, and 20% in concrete mixes. Physical properties like density, compressive strength, concrete fresh properties, split-tension, and impact load capacity are studied. Results showed a decrease in the compressive strength of concrete cylinders containing rubber. The dynamic performance of rubber concrete is important because of its highly resilient nature; rubber particles included in concrete have a positive effect on the dynamic performance. Conclusions derived from this research implicate potential applications where rubberized concrete can be used efficiently. Even tough rubberized concrete 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, and higher impact resistance compared to conventional concrete.**

Keywords: **Rubberized Concrete; Compressive Strength; Splitting Tensile Strength; Impact Load.**

INTRODUCTION

For many years, cities have been faced with increasing problems with the disposal of recycled materials, such as rubber, glass, and plastics. In 2010, the world's rubber consuming reached nearly 24.9 million tons. In the U.S. alone 3.9 million tons of scrap tires are produced per year from that 1.36 million tons are recycled and 2.54 million tons are burned or land filled. In spite of the large market for scrap tires, about a quarter of all scrap tires end up in landfills yearly numbering to approximately 27 million tires or roughly 6 million tons annually making up over 12% of all solid waste. When these materials are sent to landfills they become costly to dispose of, decrease the number of landfills, and become a risk towards the environment. Based on this information, rubber use in concrete and pavements provides an environmentally sustainable method for disposing the millions of tires generated annually.

Powdered rubber is an expression given to recycled rubber produced from scrap tires. Production of powder rubber consists of removing steel and fluff then using a granulator and/or cracker mill, with the aid of cryogenics or mechanical means, to reduce the size of the tire particles.

It is important to be cognizant that tires can be divided into two groups automobile and truck tires and they are different from each other. The description of the rubber source is very important and should always be specified in literature because it has an influence on shape and texture and consequently on the characteristics of the concrete

adjusted by the addition of the rubber. It was also important to underline that automobile tires and truck tires vary not only in shape, weight and size, but above all in the ratio of the components of the base mixture. Researchers have considered three wide categories of discarded tire rubber concrete mix design:

- Chipped Rubber: The rubber has a dimension of about 25 to 30 mm is used to replace the coarse aggregates in concrete.
- Crumb Rubber: These particles are highly irregular, in the range of 3 to 10 mm and are used to replace fine aggregates.
- Powdered Rubber: The rubber consists of particles smaller than 1 mm and was the powder formed during the crunch process, fallen from the machinery of the plant handling the waste rubber. This type of rubber could be used as filler in concrete due to its size

On the other hand, for years, material researchers have attempted to make concrete ductile. It appears, however, that given the brittle nature of concrete, the most direct and effective approach to creating damage tolerant concrete structures would be to embed intrinsic tensile ductility into concrete. If concrete behaves like steel in tension (highly ductile), while retaining all other advantages (e.g. extreme compressive strength), concrete structures with enhanced serviceability and safety can be readily realized.

This research will focus on looking for a solution for this worst limitation of concrete, i.e. brittleness and very low tensile strength. Making concrete ductile would also improve impact strength and toughness of the concrete. Another issue would be to seek ways of making the concrete "green" or environmentally friendly through the choice of materials while retaining the core advantages of concrete. Ductility is a desirable structural property because it allows stress redistribution and provides warning of impending failure. The ductile behavior will enable the concrete material to have the capacity to deform and support flexural and tensile loads, even after initial cracking. One of the material that has been suggested as a

possible replacement of mineral aggregates is rubber from used tires. This research would focus on the effect of replacing fine aggregates (sand) with powdered rubber. A significant difference between mineral aggregates and tire derived aggregates is that individual particles are much more deformable than those of sand, gravel, or rock. Another significant difference is that the unit weight is much lower; therefore, tire derived aggregates can be considered as lightweight aggregates.

LITTERATURE OVERVIEW

It is estimated that, in the USA, each person discards one car tire per year. With a population of over 300 million people, it indicates that every year there are a total of 300 million tires that need to be disposed [1–3]. In recent years, some innovative ways of using these tires have been developed. Some of these include tire derived fuel for cement kilns and boilers [1] and tire derived aggregates used as raw materials for civil engineering projects [3]. However not all tires are consumed in these beneficial ways and the scrap tires that remain are disposed in various legal and illegal means (disposal of tires in an unpermitted area). Whole tires are difficult to landfill because they tend to float back to the surface with time. Stockpiles of scrap tires result in public health, environmental, and aesthetic problems in addition to being fire hazards [2].

It is with this environmental concern that the US government through the Environmental Protection Agency (EPA) encourages more studies on methods of recycling tires [2]. One beneficial use of tires that has been proposed is the use of rubber crumb as a replacement of mineral aggregates in concrete [4, 5]. However, none of the studies have elucidated in any detail the beneficial aspects of rubber crumb and the mechanism by which

the properties of rubber crumb reinforced concrete differ from traditional concrete. Rubber crumb can be a lightweight substitute for mineral aggregates as its density is less than half of that of mineral aggregate. Mineral aggregates have a unity density ranging from 1600 to 2080 kg/m3 while rubber crumb unit density ranges from 640–720 kg/m3 [6].

Khatib and Bayomy [7] studied the effect of adding two kinds of rubber crumb and chipped rubber. They made three groups of concrete mixtures, in group A: crumb rubber was used to replace fine aggregate, in group B: chipped rubber was used to replace coarse aggregate and in group C: both types of rubber were used in equal volumes. All the three groups had eight different rubber contents in the range of 5-100%. It was found that there was a decrease in slump with increase in rubber content admixtures made with fine crumb rubber were more workable than those with coarse tire chips or a combination of tire chips and crumb rubber.

Herrnandez et al. [8] investigated the dynamic characteristics of rubberized concrete material. Because of the unique elasticity properties of rubber material, the rubberized concrete showed possible advantages in reducing or minimizing vibration and impact effect.

Topcu [9] examined the physical and mechanical properties of rubberized concretes with initial compressive strength of 20MPa. The amounts of the rubber used were15%, 30%, and 45% by volume of the total aggregates. This study concluded that a general reduction in the compressive strength.

Most of the research as mentioned above has shown a significant decrease in the mechanical properties of concrete after addition of tire rubber particles as aggregates. The use of only coarse rubber particles affects the properties more negatively than do only fine particles. Moreover, plastic energy capacity of the normal concrete was increased by adding rubber. Due to

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their high plastic energy capacities, these concretes showed high strains, in particularly under impact effects.

Fattuhi and Clark [10] have proposed that rubberize concrete could possibly be utilized in the following applications:

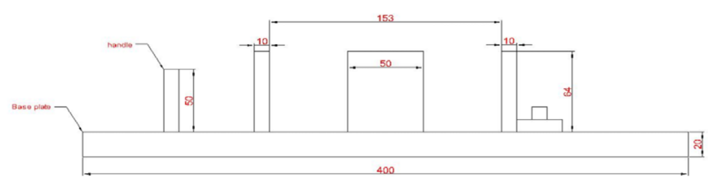
- Where vibrations damping is needed, such as in foundation pad for machinery, and in railway stations.
- For trench filling and pipe bedding, pile heads and paving slabs.
- Where resistance to impact or blast is required such as in railway buffers, barriers and bunkers.

EXPERIMEINTAL OVERVIEW

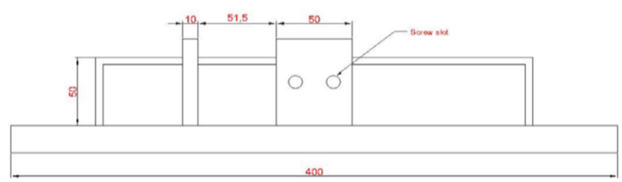
The main purpose of this study was to explore the feasibility of incorporating scrap tire in form of rubber powders as fine aggregates in concrete mixes and to determine its effect in the mechanical properties of the concrete mix. The parameters that were monitored comprised the influence of the rubber content on the mechanical properties of rubberized concrete starting with the 0% rubber content (without rubber) and up to 20% rubber content. The hardened concrete properties like compressive strength, split tensile strength, and impact load were scrutinized.

A special impact mechanism (Figure 1) was designed and fabricated according to ACI [11] recommendations relating to the adoption of drop weight impact test technique. A summary of the impact test is that, the concrete samples are plated on the bottom of the mechanism (Figure 2) with a thin layer of petroleum jelly or a heavy grease and placed on the base plate within the positioning lugs with the finished face up (if appropriate). The positioning bracket is then bolted in place, and the hardened steel ball is placed on top of the specimen within the bracket. The drop hammer is placed with its base upon the steel ball and held there with just enough down pressure to keep it from bouncing off the ball during the test. The base plate should be withdrawn to a rigid base, such as a concrete floor or cast concrete block. The hammer is dropped repeatedly, and the number of blows required to cause the first visible crack on the top and to cause ultimate failure are both recorded. Ultimate failure is defined as the opening of cracks in the specimen enough so that the pieces of concrete are touching three of the four positioning lugs on the base plate. Results of these tests display a high variability and may vary greatly with the different types of mixtures.

Figure 2: The Fabricated Impact Mechanism



a) Base Plate Front View



b) Base Plate Side View

Figure 1: Schematic of Impact Mechanism (Dimensions in mm)

EXPERIMENTAL SETUP

In this experimental study a total of 20 designated concrete mix designs containing 0,

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5, 10, 15 and 20 % of partial replacement of fine aggregates with powdered rubber were realized. Ordinary Portland Cement (OPC) with a specific gravity of 3.15 was used throughout this study. Sand used for the experimental program was locally available material with a water absorption rate of 1%. The coarse aggregate utilized was crushed angular stone aggregates with a maximum size of 20mm having a specific gravity of 2.67 with a water absorption rate of 0.5%.

The source of the rubber aggregate was recycled tires which were collected from a local tire recycling plant. The gradation of powdered rubber was determined based on the ASTM C136 Standard [12]. The term powdered rubber stands for recycled tire rubber with particle size less than 1mm. Sieve analysis was performed on powdered rubber to fit sand grain size distribution. The rubber was used without any surface treatment to investigate the effect of untreated tire particles on the mechanical properties of concrete. Drinking water with pH value of 7.0 was used in the concrete mix and the curing process of the concrete cylinders. The water was free of acids, organic matter, suspended solids, alkalis and impurities which when present may have side effects on the strength of concrete.

Casting of 100 concrete cylinders of 150 by 300mm was conducted based on ASTM C192 [13].The cylinders were casted into three layers and each layer was tamped, using a steel rod, 25 times moving all around the layer. Tamping of the next layer was done without crossing into the previous layer. The surface was finished by rolling the tamping rod over the surface to trim the concrete. The impact resistance of the specimen was determined by using drop weight method of Impact test recommended by ACI committee 544 [11]. The size of the specimen recommended is 152 mm in diameter and 63.5 mm in thickness and the weight of hammer deployed is 4.54 Kg with a drop height of 457mm.

Curing aims to prohibit the water in the concrete to disperse and reduce the hydration of cement or to relief concrete from any water loss. In the curing process the cylinders mold for the concrete cylinders were covered with plastic sheets (Figure 3) to prevent the evaporation of water. The next day, the concrete cylinders were removed from the mold and placed in a water tank at a controlled temperature for 28 days. Each specimen was labeled with or without rubber and the date of the mix.

Figure 3: Cylinders Covered in Plastic Sheets for Curing

EXPERIMENTAL PROCEDURE

In the mixing process the concrete was dry mixed using a mechanical mixer after then water was added gradually and mixed till the homogenous mix obtained. Powdered rubbers mixed with cement and then with aggregate finally mixed with water in order to prohibit the low specific gravity powdered rubber initially mixed with aggregate from floating to the top of mixture.

The specimens of standard cylinders of 150 by 300mm were utilized to determine the compressive and split tensile strength of the concrete mix. However, cylinders of 152 by 63.5mm were utilized to determine the impact load capacity. The mix proportions of different types of percentages of replacement percentage of fine aggregates with powdered rubber are summarized in Table 1.

Table 1: Mixture Proportions for Concrete with Waste Tire Replacing Sand

No.	f'c (M Pa)	Cement (Kg)	Water (Kg)	Gravel (Kg)	W/C	Sand (Kg)	Rubber (Kg)	Rubber (%)
1	15	31.68	16.32	87.49	55%	53.32	0	0%
2						50.65	2.67	5%
3						47.99	5.33	10%
4						35.08	8.00	15%
5						42.66	10.66	20%
6	20	34.84	16.37	87.5	50%	50.12	0	0%
7						47.61	2.51	5%
8						45.11	5.01	10%
9						42.6	7.52	15%
10						40.1	10.02	20%
11	25	38.71	16.43	87.49	45%	46.19	0	0%
12						43.88	2.31	5%
13						41.57	4.62	10%
14						39.26	6.93	15%
15						36.95	9.24	20%
16	30	43.55	16.51	87.5	40%	46.19	0	0%
17						39.21	2.06	5%
18						37.14	4.13	10%
19						35.08	6.19	15%
20						33.02	8.25	20%

EXPERIMENTAL RESULTS

Subsequently to the concrete cylinders reached 28 days strength, three types of experiment were employed to measure the compressive, tensile and impact load of specimens. To measure the compressive strength of the concrete cylinders, a uniaxial compressive load testing was conducted according to ASTM C39 [14]. Prior to testing; the area of the 150 mm diameter by 300 mm height cylinders was measured to be incorporated in the computation concrete compressive strength. Cylinders were then placed in the universal testing machine. According to ASTM C1231 [15], cylinders should be capped using a neoprene pad caps to

provide a uniform load distribution during the loading process. The cylinders were subjected to a steady stress rate varying between 0.2 to 0.4 MPa/ Sec. Once the maximum load was achieved, the loading process automatically stopped, and the values were recorded. As a result, break patterns was generated due to the failure of the cylinders that produced cracks in several directions.

Although concrete is known to be weak in resisting direct tension; it is important to measure its tensile strength due to the cracking that will be developed from the applied loading or other kinds of effects. For the cylinder specimens, split-cylinder test was conducted according to ASTM C496 [16] to determine the tensile strength of concrete since uniaxial tension is difficult to be conducted. Concrete cylinders 300 by 150mm were placed horizontally between the platens of compression testing machine based (Figure 4). In order to provide a uniform distribution of the applied load and to lessen the stresses at the surface of application, steel strips were placed between the horizontal cylinders and the platens of the machine (Figure 5). The compressive load was applied and increased gradually along the total length of the cylinder until failure occurred. Due to the indirect tension stresses, the failure occurred along the vertical diameter of cylinder which caused it to split into two halves (Figure 6). Therefore, the splitting tensile strength (f'_{ct}) of specimen was calculated using the following equation:

$$f_{ct}^{r} = \frac{2P}{\pi DL}$$

Where

P= load at failure (N)

L=length of the cylinder (mm)

D= Diameter of the cylinder (mm)

Figure 4: Cylinder Placed in the Steel Strips

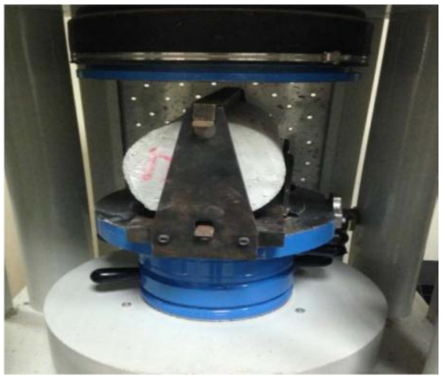

Figure 5: Tensile Testing Machine

Figure 6: Tensile Testing

The simplest of the impact tests is the “repeated impact,” drop-weight test. This test yields the number of impact blows delivered by a drop hammer that is accumulated until the first visible crack occurs and until the test specimen is forced to separate by continued impacting. This number offers a qualitative estimate of the energy absorbed by the specimen at the levels of the specified distress level (Figures 7, 8, and 9). The impact energy (IE) exposed to by the specimen is calculated using the following equation:

IE = N m g h

Where:
IE = impact energy (N m) N =the number of blows
m = mass of the drop hammer (kg)
g = gravitational acceleration = 9.81 m/sec2
h = height of drop hammer (m)

Figure 7: Rubberized Concrete Impact Failure

Figure 8: Plain Concrete Impact Failure

Figure 9: Portion of the Specimens Subsequently to Impact Load Failure

ANALYSIS OF RESULTS

As previously indicated, one of the main aims of this study is to realize an optimal powder rubber ratio for the partial replacement of the fine aggregates in concrete mix design with an ultimate objective to increase the ameliorative effects on impact resistance and make it suitable for specific engineering applications. The limit of compressive strength of the concrete depends on both, the strength of the matrix and the particle tensile strength of the aggregates. The strength of the concrete is usually related to the mix content and water to cement ratio. The 28 days compressive strengths of the concrete mixes are provided in Table
2. Figures 10 through 13 summarize graphically the comparison between the calculated compressive strength and the experimental results as a function of sand replacement with powdered rubber.

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Table 2: Compression Results for the Concrete Cylinders

Rubber (%)	MIX1 No.	f'c (MPa)	Avg. MPa	MIX2 No.	f'c (MPa)	Avg. MPa	MIX3 No.	f'c (MPa)	Avg. MPa	MIX4 No.	f'c (MPa)	Avg. MPa
0%	1	32.16 28.68	30.42	6	36.90 37.47	37.19	11	42.27 44.56	43.42	16	50.65 52.43	51.54
5%	2	15.41 16.88	16.15	7	27.46 26.3	26.88	12	32.40 33.73	30.07	17	40.09 39.8	39.95
10%	3	13.55 14.08	13.82	8	25.76 22.5	24.13	13	28.40 27.90	28.15	18	35.45 33.80	34.63
15%	4	12.55 11.20	11.88	9	20.36 18.70	19.53	14	22.58 21.67	22.13	19	25.28 22.63	23.96
20%	5	9.40 8.54	8.97	10	14.50 12.80	13.65	15	15.70 16.90	16.30	20	18.31 19.55	18.93

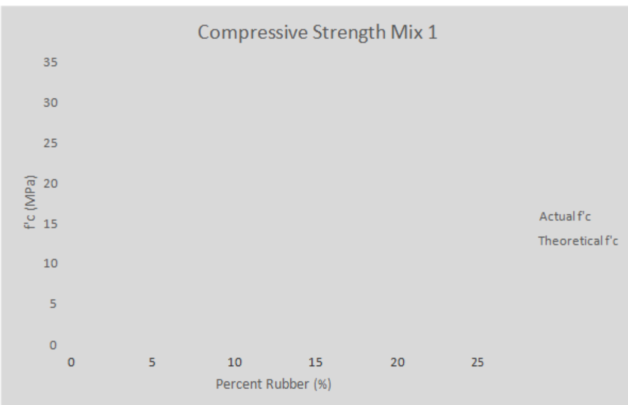

Figure 10: Average Compressive Strength for Mix 1

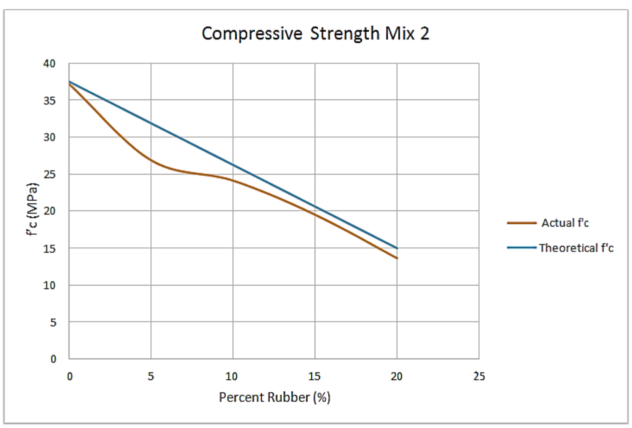

Figure 11: Average Compressive Strength for Mix 2

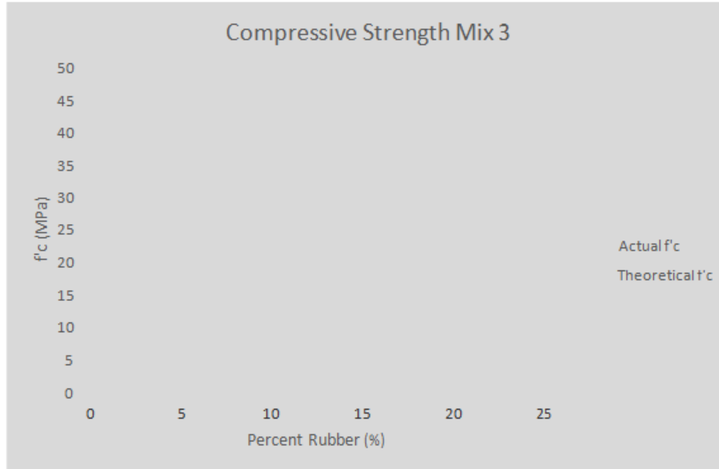

Figure 12: Average Compressive Strength for Mix 3

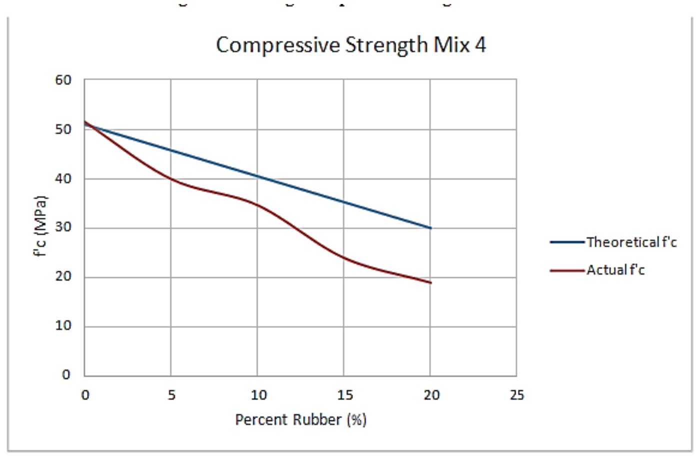

Figure 13: Average Compressive Strength for Mix 4

The 28 days splitting tensile strength of the powder rubber concrete cylinders with different percentage replacement of powder rubber of fine aggregates in normal concrete are tabulated in Table 3. During splitting tensile tests, the concrete cylinders without rubber failed by splitting into two halves (Figure 14), whereas the rubberized concrete cylinders displayed a more cohesive behavior that is failing without splitting (Figure 15).

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Table 3: Splitting Tensile Strength (f'ct) Results

Rubber (%)	MIX1 No.	fct (MPa)	Avg. MPa	MIX2 No.	fct (MPa)	Avg. MPa	MIX3 No.	fct (MPa)	Avg. MPa	MIX4 No.	fct (MPa)	Avg. MPa
0%	1	3.152 2.91	3.031	6	3.59 3.68	3.635	11	4.221 4.456	4.339	16	5.435 5.134	5.285
5%	2	2.433 2.55	2.492	7	2.73 2.62	2.675	12	3.541 3.244	3.393	17	4.307 4.166	4.327
10%	3	1.825 1.773	1.8	8	2.524 2.455	2.49	13	3.178 3.251	3.215	18	3.782 3.529	3.656
15%	4	1.755 1.822	1.789	9	2.234 2.356	2.295	14	2.883 2.791	2.837	19	3.173 2.856	3.015
20%	5	1.275 1.362	1.319	10	2.188 1.943	2.066	15	2.364 2.415	2.39	20	2.316 2.405	2.361

Figure 14: Non Rubberized Concrete Cylinders Splitting into Two Halves.

Figure 15: Rubberized Concrete Cylinders without Splitting After Failure

The replacement of sand by powdered rubber increased the occurrence of concrete to crack starting under impact drop load. The failure occurs rapidly in rubberized concrete. Therefore, it could be deduced that the rubber with small size (no particle bridging) has a little effect in delaying the crack spirit in concrete. All specimens are spitted into separate parts under the effect of impact force. No visible cracks were noticed in each of the separated parts and no dislocated dolomite particles were found across the fractured surface. This may be due to the good bond between the mortar and the dolomite. Therefore, the favorable crack path is across the dolomite particles not around the surface of the particles. There is no particle bridging found in the case of rubberized concrete because the small size of the powder rubber. The results of the Impact strength and number of blows are shown in Table 4.

Table 4: ACI Drop Weight Impact Test Results

Rubber (%)	MIX1 No.	N Blows	Energy NM	MIX2 No.	N Blows	Energy NM	MIX3 No.	N Blows	Energy NM	MIX4 No.	N Blows	Energy NM
0%	1	59	1190	6	77	1553.42	11	93	1876.2	16	27	544.71
5%	2	36	726.27	7	50	1008.71	12	60	1210.46	17	112	2259.52
10%	3	29	585.05	8	40	806.979	13	49	988.54	18	73	1472.72
15%	4	23	464	9	33	665.75	14	38	766.62	19	61	1230.63
20%	5	18	363.13	10	25	504.36	15	31	625.4	20	43	867.49

CONCLUSIONS

After extensively exploring this topic and studying different aspects of rubber concrete properties and behaviors, a series of conclusions were derived.

1. Partial fine aggregates replacement in concrete mix by powdered rubber leads to a reduction in the density of the final product, because of the specific gravity of rubber used was less than that of fine aggregates.

2. Decreasing in rubberized concrete strength (compressive and tensile strength) with the increasing powdered rubber content in the mixture was always detected (figures 16 and 17). The strength reduction may be attributed to two reasons. First, because the rubber particles are much softer (elastically deformable) than the surrounding mineral materials, on loading, cracks are initiated quickly around the rubber particles in the mix,

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which accelerates the failure of the rubber–cement matrix. Second, due to the lack of adhesion between the rubber particles and the cement paste, soft rubber particles may behave as voids in the concrete matrix.

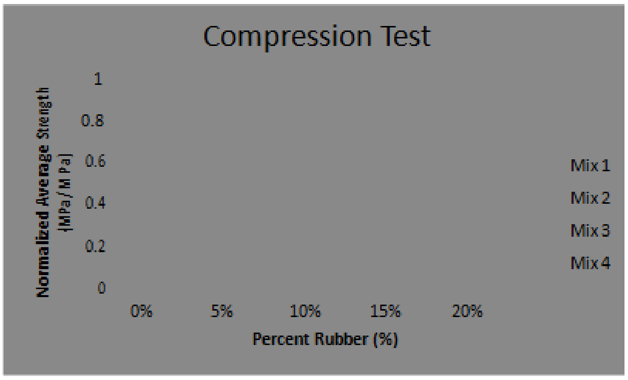

Figure 16: Normalized Concrete Compressive Strength with Plain Concrete Mix.

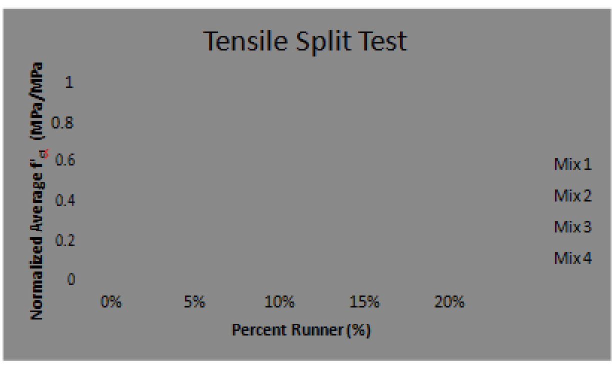

Figure 17: Normalized Concrete Tensile Strength with Plain Concrete Mix.

3. For design mix strength greater 30 MPa up to 50 MPa, the reduction in compressive strength with the increase in percent powdered rubber is consistent and almost at a constant ratio. The reduction in strength was an average of 30, 35, 50, and 63 % vs. a powdered rubber replacement of fine aggregates at 5, 10, 15, and 20 %.

4. The addition of powdered rubber influenced a slight improvement in concrete tensile strength at all rubber percentages but still resulted in less compared to the compressive strength reduction rate.

5. Adding powdered rubber to concrete had a negative effect on the modulus of elasticity. The decrease of elasticity reflects the capability of rubberized concrete to behave in an elastic manner when loaded in tension thus improving the failure manners of typical concrete.

6. Rubberized concrete exhibits enhanced energy absorption since the concrete did not undergo a typical brittle failure yet it encountered a ductile, plastic failure mode. As a matter of fact, according to figure 18, concrete of compressive strength greater than 50 MPa, definitely display a much better resiliency for rubberized concrete than plain concrete. This is not true for concrete of compressive strengths below 50 MPa, which display a consistent reduction in resiliency.

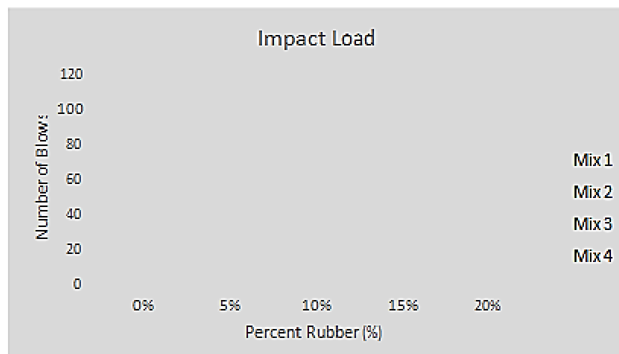

Figure 18: Impact Load Blows as a Function of Rubber Replacement.

rubberized concrete can be used efficiently. Even tough rubberized concrete 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, and higher impact resistance compared to conventional concrete.

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Compliance with Ethical Standards

There was no external funding for this study.

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