IMPROVING THE IMPACT RESISTING CAPACITY OF CONCRETE USING TYRE RUBBER DUST

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submitted by

MOHIT LAMBA
ROLL NO. 2K11/STE/25

under the guidance of

DR. AWADHESH KUMAR

Department of Civil Engineering
DELHI TECHNOLOGICAL UNIVERSITY
SHAHBAD DAULATPUR, BAWANA ROAD
DELHI-110042, INDIA

JULY 2014

Department of Civil Engineering
Delhi Technological University
Delhi -110042 (India)

CANDIDATE'S DECLARATION

I do hereby certify that the work presented in this report entitled "**Improving Impact resisting capacity of concrete using tyre rubber dust**" in partial fulfillment of the curriculum of sixth semester of Master of Technology in Structural Engineering, submitted in the Department of Civil Engineering, DTU is an authentic record of my own work under the supervision of Dr. Awadhesh Kumar, Associate Professor Department of Civil Engineering.

I have not submitted this matter for the award of any other degree or diploma.

Date : July 2,2014

(Mohit Lamba)
2K11/STE/25

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. Awadhesh Kumar)
Associate Professor
Department of Civil Engineering,
Delhi Technological University

ACKNOWLEDGEMENT

The success of any project depends largely on the encouragement and guidelines of many others. Therefore I take this opportunity to express my sincere gratitude to the people who have been instrumental in the successful completion of the project.

I would like to express our sincere appreciation and gratitude to my guide Dr. Awadhesh Kumar without whose able guidance, tremendous support and continuous motivation the project would not have been carried to perfection. I sincerely thank him for spending all his valuable time and energies during the execution of project.

The successful compilation of major project depends on the knowledge and attitude inculcated in the total length of course. So I want to express my sincere gratitude to all the faculties who taught us during M. Tech.

Mohit Lamba
(2K11/STE/25)

ABSTRACT

Concrete is the most widely used construction materials in the world of which cement and aggregates are the major constituents. This has led to a continuous and increasing demand of natural materials used in their production. Also, the increasing utilization of these natural resources is emerging as growing concern for protecting the environment thereby; a need to preserve natural resources has arisen by using alternative materials such as recycled or waste materials.

Concrete structures are subjected to static and dynamic loads. Due to its low tensile strength, low ductility and low energy dissipating characteristics, impact resistance of concrete is very poor. In this research, a study has been carried out on the use of waste rubber tyre dust as a partial replacement for fine aggregates in concrete construction for improving its impact resistance property.

In the first part of this report, the background of the study and the extent of the problem were discussed. A review of relevant literatures was done to study previous works in the subject matter. The initial research was carried out by conducting tests on the raw materials to determine their properties and suitability for the experiment. Concrete mix designs are prepared using the IS guidelines (IS: 10262-2009) and a total of four concrete grades were prepared (M20, M25, M30, M35). The specimens were produced with 5, 10 and 15% replacements of the fine aggregate by rubber dust. Moreover, control mixes with no replacement of the aggregates were also produced to make a comparative analysis. The prepared samples were concrete cubes for compressive strength test and circular concrete discs for impact tests. The rubber surface was pretreated with sodium hydroxide (NaOH) of 1N solution for 20 minutes and then left to surface dry prior to mixing in concrete. This treatment modified the rubber surface allowing the rubber to better adhere to the cement paste.

Various tests were carried out and results were compared between conventional concrete and concrete prepared with various percentages of fine aggregates replaced with rubber tyre dust. Results show that there is a reduction in compressive strength upto 42% as the percentage of rubber dust was increased to 15%; also the workability of fresh concrete diminishes drastically.

However, with the increase in rubber dust percentage, impact strength of concrete improved. The overall results show that tyre rubber can be used in concrete if the percentage of replacement is restricted and the rubber surface is pretreated with chemicals to improve its bonding property in concrete. Its use should be restricted to particular cases where impact resistance or other improved property due to rubber is desirable.

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CHAPTER 1

INTRODUCTION

Concrete is the most widely used construction materials in the world of which cement and aggregates are the major constituents. This has led to a continuous and increasing demand of natural materials used in their production. Also, the increasing utilization of natural resources in manufacturing of aggregates and cement is emerging as growing concern for protecting the environment thereby; a need to preserve natural resources has arisen by using alternative materials such as recycled or waste materials.

Also, there is a huge concern over the disposal of non-degradable wastes such as tyres which are being dumped in landfills all over the world. This has posed a great health and environmental threat as it leads to increased breading of mosquitoes and other insects and rodents, or increase in fire hazards at their dumping locations. Also, it affects the fertility of the soil if dumped into the ground.

Waste tyres also pose great fire hazard. Waste tyre stock piles are difficult to ignite, but if once ignited their fire is very difficult to extinguish. Tyres, if burned, release toxic product and may harm the society by emitting green house gases increasing air pollution. Moreover, it can lead to uncontrolled fire.

Hence, there is a strong need to dispose of such materials in an environmental friendly way. The most promising use of these waste/recycled tyres is in engineering applications like artificial reefs, erosion control, and as an aggregate in concrete and asphalt.

Over the years different kinds of tyres have been employed as partial replacement of aggregates in concrete: scrap tire crumb obtained by simple grinding without further purifications thus including steel and textile fibers in their composition, crumb rubber obtained by cryogenic process, milled tyre rubbers treated with sodium hydroxide solution to achieve a better adhesion with the cement paste, crap truck tire rubber, tires tread, etc. However, regardless the different nature, size and composition of used tire rubbers, a meaningful decrease in concrete compressive strength with the increasing amount of rubber in the mixture was always detected. The reason been reported is the weak adhesion between rubber particles and cement paste, for which various types of treatment to modify rubber surface have been suggested.

Sodium Hydroxide (NaOH), also known as caustic soda, is one such material considered best for the treatment of rubber surface, for better bonding of rubber particles with cement.

Concrete strength is greatly affected by the properties of its constituents and the mix design parameters. Because aggregates represent the major constituent of the bulk of a concrete mixture, its properties affect the properties of the final product. There is a huge debate still going on whether rubber aggregates in concrete are better as fine aggregate replacement or coarse aggregate replacement. In fact one thing is clear that introduction of recycled rubber does changes the properties of concrete.

Several studies have reported that rubber concrete tends to have lower workability, reduced density and higher air content. The compressive and tensile strength of rubber concrete is affected by size, shape, surface textures and quantity of replacement being used. The higher the volume of rubber in concrete, the lesser is the strength properties. The reason of reduced strength reported as the weak bond between rubber particles and cement.

The aggregating of rubber will, however, increase concrete's flexibility, elasticity, and capacity to absorb energy. According to the results of the various researches, it was determined that the addition of rubber aggregate into concrete does in fact increase concrete's impact resistance. This resistance is derived from rubberized concrete's increased ability to absorb energy, safety, and insulate sound during impact. These altered characteristics are attributed to aggregated rubber because of its fiber structure, which gives the concrete its flexibility and capacity to take in strokes. This increase in elasticity and ability to absorb energy greatly reduces the damage incurred by vehicles colliding with parapets in highway barriers.

Though there is significant increase in the impact resistance of concrete due to the addition of rubber, impact resistance is still not considered as a design parameter, simply because it cannot be fully quantified due to the lack of a standard impact test for concrete. In this regard, ACI Committee 544 [26] has proposed a drop weight impact test to demonstrate the relative brittleness and to quantify the impact resistance of fiber-reinforced concrete (FRC). The test is widely used because it is simple and economical. The results obtained from this test are often noticeably scattered. The large variation in impact resistance as determined from this test is reported in the literature for different types of FRC. Large variation is a common problem in impact testing, and it is difficult to devise systems that give reproducible results. This might be attributed to the nature of the impact process itself and the number of factors controlling the impact resistance compared with other mechanical properties. The main objective of the present work is to study the effect of waste tyre rubber dust as a partial replacement of sand on the mechanical properties and impact resistance of concrete.

CHAPTER 2

OBJECTIVE, SCOPE AND METHODOLOGY OF STUDY

2.1 Objectives of the study

This study is carried out to check the feasibility of using crumb rubber dust as a partial replacement for fine aggregate in concrete. The general objective is to evaluate the fresh and hardened properties of the concrete produced by replacing part of the natural fine aggregate with tyre rubber dust will be evaluated.

Increase in urbanization has leaded to increase in the number of cars and consequently the amount of used tires. Hence, the non-environmental nature of these wastes is going to be a potential threat. This study can show an alternative way of recycling tires by incorporating them into concrete construction. Of course, the concept that the problem emerges from urbanization and the solution goes along with it can also be appreciated. Therefore, it is the aim of this study to introduce an environmental friendly technology, which can benefit the society and the nation.

Application of used tyres in concrete construction is a new technology and a well developed mix design for material proportioning is not available. Through this study, it is intended to arrive at a suitable mix proportion and percent replacement using locally available materials by partial replacement of the natural aggregates with rubber aggregates. Hence the possibility of using waste tyres as an alternative construction material will be investigated.

By conducting different laboratory tests on prepared specimens, it is intended to analyze the results. Moreover, from the properties of the concrete the advantages and disadvantages of using it will be figured out.

2.2 Scope of the study

1) This study is concentrated on improving the impact resisting capacity of concrete using tire rubber dust with minimal compromise on the strength.

2) The influence of different gradations of the rubber aggregate on concrete properties has not been evaluated in this study but it should be considered in future researches.

3) All the waste tyres collected were chosen from those manufactured by A.P. Rubber Industries to avoid any inconsistent properties that may arise by mixing materials from different sources. The properties of waste tires from other tire manufacturers were not included in this study.

4) The study will be done on four grades of concrete (M20, M25, M30 and M35). The influence of using recycled tires in high strength concrete will not be covered in the present study. The percentage replacements will be limited to three categories i.e. 5, 10 and 15% replacement of the natural fine aggregate.

2.3 Steps of the study

The different steps utilized in this research include the following:

1) Literature review

Literature survey was carried out to review previous studies related to use of tyre rubbers in concrete.

2) Material Procurement

All the required materials were collected and delivered to the laboratory. These are, Cement, fine aggregate, coarse aggregate, used tyre rubber dust and admixture.

3) Experimental Arrangements

All the moulds and machines to be required during the course of study were arranged. Tests were conducted on the raw materials to determine their properties and suitability for the experiment. Impact testing machine was fabricated in workshop along with the moulds as per the specifications mentioned in ACI-544r.

4) Mix Proportioning (Mix Design)

Concrete mix designs were prepared using the IS guidelines (IS: 10262-2009). Mixes of four grades of concrete (M20, M25, M30 and M35) were produced. They were prepared with fine aggregate replacements of 5, 10 and 15 % by the rubber aggregate along with a control mix with no rubber aggregate replacement for each grade to make a comparative analysis.

5) Specimen preparation

The concrete specimens were prepared in the Delhi Technological University, Civil Engineering Department, Material Testing laboratory. The prepared samples consist of concrete cubes of 150mm size and discs as per ACI Committee 544 proposal.

6) Testing of Specimen

Laboratory tests were carried out on the prepared concrete samples. The tests to be conducted are unit weight, compressive strength, and impact resistance tests.

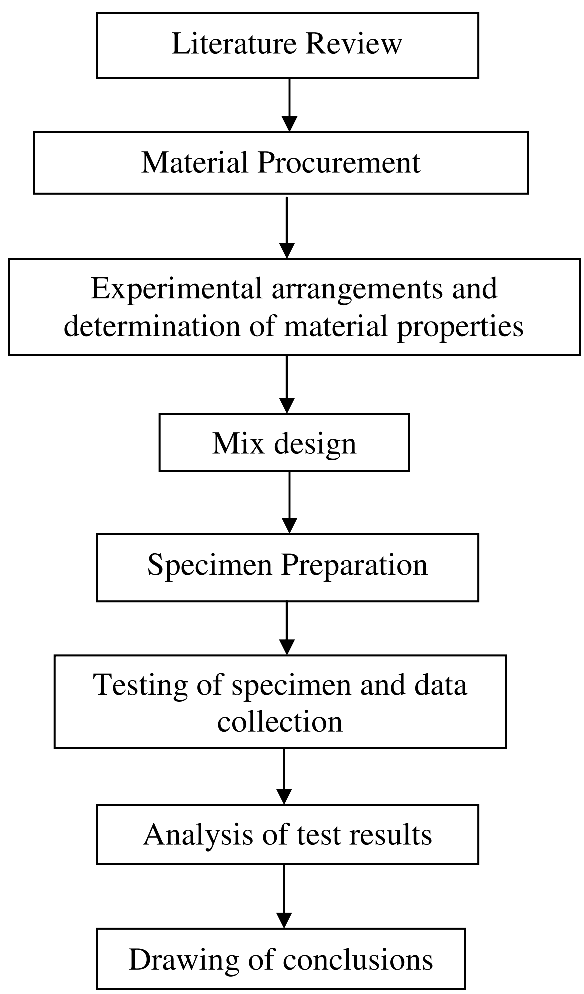
7) Data collection

The data collection was mainly based on the tests conducted on the prepared specimens in the laboratory.

8) Data Analysis and Evaluation

The test results of the samples were compared with the respective control concrete properties and the results are presented using tables, pictures and graphs.

2.4 Work Flowchart



CHAPTER 3

LITERATURE REVIEW

3.1 Overview

Concrete is a composite material composed of coarse granular material embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. It is the most commonly used structural material because of its ability to be casted to any desired shape and configuration. Good quality concrete is a very durable material and should remain maintenance free for many years when it has been properly designed for the service conditions and properly placed.

By using different choices of aggregates different desirable properties of concrete can achieved. For example, concrete can be made inherently resistant to physical attack, such as from cycles of freezing and thawing or from abrasion and from chemical attack such as from dissolved sulfates or acids attacking the paste matrix or from highly alkaline pore solutions attacking the aggregates. Judicious use of mineral admixtures greatly enhances the durability of concrete.

The main advantages of concrete as a construction material are the ability to be cast, being economical, durability, fire resistance, energy efficiency, on-site fabrication and its aesthetic properties. The disadvantages are low tensile strength, low ductility, volume instability and low strength to weight ratio.

Constituents of Concrete

1. **Cement:** The Ordinary Portland Cement (OPC) 43 grade is used in the investigation.
2. **Aggregates:** Aggregates generally occupy the major volume of concrete and can therefore is expected to have an important influence on properties of concrete. Locally available crushed stone dust was used as fine aggregate and machine crushed granite consisting of 20mm maximum size were used as coarse aggregates. Both aggregates were tested for physical and mechanical properties such as Specific Gravity and fineness modulus.

3. **Water:** Water is a key ingredient in the manufacture of concrete. Attention should be given to the quality of water used in concrete. Locally available potable water was used for investigation.
4. **Super plasticizer:** Super Plasticizer Glenium 111 was used in concrete to improve its workability.

3.2 Recycled Materials in Concrete Construction

Over the last few decades, there have been drastic changes in the way industrial wastes are being handled. Concrete which is one of the world's most commonly used construction materials has emerged as one the evolving material as well. New techniques and methods are continuously being worked upon to utilize various industrial wastes and other wastes to help improve the various properties of concrete and simultaneously addressing the issue of waste disposal. The use of recycled materials generated from transportation, industrial, municipal and mining processes in transportation facilities is an issue of great importance. As the useable sources for natural aggregates for concrete are depleted, utilization of these products will increase.

Utilization of fly ash and ground granulated blast furnace slag in concrete addresses this issue in addition to improving concrete properties. The replacement of Portland cement by fly ash reduces the volume of cement utilized which is a major benefit since cement manufacturing is a significant source of carbon dioxide emissions worldwide. Silica fume is a comparatively expensive product and it is added in smaller quantities in concrete mixture rather than as a cement replacement. It was also emphasized that the possibility of using solid wastes as aggregates in concrete serves as one promising solution to the escalating solid waste problem. The use of concrete for the disposal of solid wastes has concentrated mostly on aggregates, since they provide the only real potential for using large quantities of waste materials. The effect of waste materials on concrete properties must be considered. For example, the lower modulus of elasticity of glass compared to that of good quality rock will lower the elastic modulus of concrete. Crushed recycled concrete has been used as an aggregate, producing concrete with strength and stiffness equal to about two-thirds of that obtained using natural aggregates.

These effects will be much more pronounced if low strength, low modulus materials such as rubber and plastics are used. Scrapped tires have been proposed for use in concretes where high resiliency rather than strength are required.

All of these applications greatly emphasize the different attempts of using recycled materials in concrete and their respective advantages achieved so far. One of today's major problems and which will continue to do so for the foreseeable future is the environmental pollution resulting from industrial wastes and waste living materials. Particularly among the waste materials in the advancement of civilization are discarded waste tires. The main reason for this is that the amount of waste tires is increasing at an alarming rate due to the large number of cars and trucks.

3.3 Rubber Aggregate

Rubber aggregates are obtained by reduction of scrap tires to aggregate sizes using two general processing technologies: mechanical grinding or cryogenic grinding.

Mechanical grinding is the most common process. This method consists of using a variety of grinding techniques such as 'cracker mills' and 'granulators' to mechanically break down the rubber shred into small particle sizes ranging from several centimeters to fractions of a centimeter. The steel bead and wire mesh in the tires is magnetically separated from the crumb during the various stages of granulation, and sieve shakers separate the fiber in the tire.

Cryogenic processing is performed at a temperature below the glass transition temperature. This is usually accomplished by freezing of scrap tire rubber using liquid nitrogen. The cooled rubber is extremely brittle and is fed directly into a cooled closed loop hammer-mill to be crushed into small particles with the fiber and steel removed in the same way as in mechanical grinding. The whole process takes place in the absence of oxygen, so surface oxidation is not a consideration. Because of the low temperature used in the process, the crumb rubber derived from the process is not altered from the original material.

Surface Treatment of Rubber Aggregates

To obtain rougher surface of rubber aggregate for better bonding with concrete matrix, studies have suggested that the rubber surface should be treated prior to mixing in concrete, and therefore the higher the compressive strength can be achieved.

Various methods of pre-treatments vary from washing rubber aggregate with water to acid etching, plasma pre treatment and various coupling agents.

The acid pre-treatment involves soaking the rubber aggregate in an acid solution for 20 minutes and then rinsing it in water. When observed through a microscope, earlier studies reported that the pre-treatment of rubber aggregate with acid increased the surface roughness of rubber, which had improved its attachment to the cement paste. '*Neville A.M.*'[1], suggested that it is generally found that as the paste- aggregate bond increases so does the strength.

Saturated NaOH solution can also be used to treat rubber particles. It does the same treatment as done by acids, i.e. it makes the surface of rubber particle rough to improve its bond with concrete and thus improving the strength and toughness in waste tire dust modified cement mortar. '*Michelle Danko'* et al [21] applied pre-treating of the rubber with a sodium hydroxide solution to modify its surface, affecting the interfacial transition zone and allowing the rubber to better adhere with the cement paste. The use of treated tire rubber as addition to cement paste shows satisfactory results in concrete mechanical properties such as impact resistance and ductility.

Carbon tetrachloride can also utilized for pretreatment of rubber aggregates. It was shown by the various studies that when the rubber aggregates were treated with calcium tetrachloride compressive strength improved by upto 57% as compared to concrete containing untreated rubber particles.

The overall results show that using proper coupling agents to treat the surface of rubber particles is a promising technique, which produces a high performance material suitable for many engineering applications.

3.4 Summary of previous research findings

The previous researches have shown that, though there is reduction in strength of concrete on addition of rubber due to lack of bonding between rubber particles and concrete paste, many properties of concrete are improved, such as, freeze thaw resistance, sound absorption damping properties and reduced water absorption. Following are some major properties discussed as per previous investigations:

3.4.1 Workability

A decrease in slump was observed with increase in rubber aggregate content was reported by Khatib and Bayomy [11]. They also mentioned that at 40% rubber aggregates by total aggregates by volume, slump was almost zero and the concrete was not workable manually. Mixtures containing fine crumb rubber were, however, more workable than mixtures containing either coarse rubber aggregate or a combination of crumb rubber and tire chips. It was found that increasing the size or percentage of rubber aggregate decreased the workability of the mix and subsequently caused a reduction in the slump values obtained.

3.4.2 Air content

In Khatib and Bayomy [12] research work it was found that there is a higher air content in concrete mixtures containing rubber when compared tocontrol mixtures. Even without any air-entrainment admixtures being introduced, it has been reported that the air content is significant. This may be due to the non polar nature of rubber particles, when it is added in concrete mixture, it may attract air as it has tendency to repel water. In this way air may adhere to rubber particles.

This increase in air voids content would certainly produce a reduction in concrete strength, as does the presence of air voids in plain concrete. Since rubber has a specific gravity greater than 1, it can be expected to sink rather than float in the fresh concrete mix. However, if air is trapped in the jagged surface of the rubber aggregates, it could cause them to float.

3.4.3 Unit Weight

The replacement of natural aggregates with rubber aggregates tends to reduce the density of the concrete because of the lower unit weight of rubber compared to ordinary aggregate. The unit weight of rubberized concrete mixtures decreases as the percentage of rubber aggregate increases. Moreover, increase in rubber content increases the air content, which in turn reduces the unit weight of the mixtures. However Khatib [12] in his report mentioned that the decrease in unit weight of rubber concrete in negligible when rubber content is lower than 10-20% of the total aggregate volume.

3.4.4 Compressive Strength

Lot of studies has been carried out over compressive strength of concrete with rubber aggregates [4-9]. Earlier studies show that the compressive strength decreased as the rubber content increased. Eldin and Senouci [13] reported that there was upto 85% compressive strength reduction when coarse aggregate was completely replaced by rubber chips and rubber crumb. However, when fine aggregates were completely replaced with fine rubber crumb compressive strength reduction was only upto 65%. Topcu [14] in his study showed that coarse rubber chips reduced the strength more than the addition of fine crumb rubber.

Strength reduction was mainly contributed by entrapped air and weak bond of rubber particles with concrete. Investigative efforts showed that the strength reduction could be substantially reduced by adding a de-airing agent into the just prior to the placement of the concrete.

It was indicated in studies that if rubber particles are pre-treated to make the rubber surface coarser, improved bonding may be developed and hence reduction in strength can be controlled up to some extent. Also, Biel and Lee [17] in their report mentioned that magnesium hydroxide cement may provide higher strength and better bonding to rubber concrete as compared to Portland cement.

3.4.5 Tensile Strength

Michelle Danko et al. [21], .reported that the tensile strength of rubber containing concrete is affected by the size, shape, and surface textures of the aggregate along with the volume being used indicating that the strength of concretes decreases as the volume of rubber aggregate increases . As the rubber content increased, the tensile strength decreased, but the strain at failure also increased. Higher tensile strain at failure is indicative of more energy absorbent mixes.

3.4.6 Impact Strength

Ling and Hasanan [18], in their investigations have shown that the addition of rubber aggregate into the concrete mixture produces an improvement in toughness, plastic deformation, impact resistance and cracking resistance of the concrete. Owing to the very high toughness of waste tires, it is expected that adding crumb rubber into concrete mixture can increase the toughness of concrete considerably.

Topcu and Avcular [19] in their studies reported that impact resistance of concrete increased when rubber aggregates were incorporated.

H.E.M. Sallam et al. [20], after conduction laboratory tests concluded that presence of crumb rubber in concrete increased the resistance of concrete to crack initiation under impact loading.

3.4.7 Thermal and sound properties

Rubber concrete exhibit good thermal and sound properties as compared to plain concrete by decrease in thermal conductivity coefficient and increase in sound absorbing coefficient as reported by Sukontasukkul [23, 24] in his study. Also in another study conducted by Han, Z., Chunsheng, it was shown that crumb rubber panels can be effectively used as traffic noise barriers.

3.5 Applications of Rubber Concrete

Rubber concrete can possibly be used in the areas where vibrations damping is required like foundation pads for machinery and in railway stations or in the areas where resistance for impact or blast is required e.g. railway buffers, jersey barriers and bunkers. Being light in weight, rubber concrete can also be suitable for architectural applications like nailing concrete, false facades, and interior construction.

Shock absorbing property of rubber concrete can be utilized in highway construction as a shock absorber in sound barriers and also in buildings as an earthquake shock wave absorber.

Various projects have been taken up around the world using rubber concrete. one such experimental construction is that of an outdoor tennis court in Phoenix. In the construction of this court a series of slabs were casted with rubber content varying between 20 to 130 kg of crumb rubber per m3 of concrete and series of experiments were conducted which included compressive strength, flexural strength, indirect tensile strength, and thermal coefficient of expansion tests. The results showed that the introduction of waste tire rubber considerably increased toughness, impact resistance, and plastic deformation of concrete, offering a great potential for it to be used in sound/crash barriers, retaining structures and pavement structures.

In the recent times rubber concrete has found a potential use in areas of playgrounds and landscapes as small amount increases the energy absorption in children's play areas and prevent injuries. The waste tire rubberized concrete is also used in precast sidewalk panel, non-load bearing walls in buildings and precast roof for green buildings.

All the applications discussed above show that there is a huge potential advantage that can be exploited from the use of rubberized concrete. It is a very promising technology that can deliver various outstanding benefits to the construction sector.

3.6 Impact testing

A thorough study was done on impact testing of concrete by Dr. Nemkumar P. Banthia [25]. He classified loading into two categories: dead loads or quasistatic loads and suddenly applied loads called dynamic loads. He further classified dynamic loadings into two categories: single cycle and multi-cycle. An example of single cycle dynamic loading is mass impacting against structural element. However, a structure undergoing an earthquake would have its elements subjected to multi-cycle dynamic loading. Single cycle dynamic loading is called impact loading.

And impact loadings further classified as: single point impact loading and distributed impact loading. A structure hit by a missile-like object would undergo a single point impact, whereas blasts or explosions would result in a distributed impact load. His work was primarily concerned with single point impact loading, which is also the requirement in our present study.

He summarised that so far various methods have been employed by investigators which include: freefall drop weight tests, explosive tests, Charpy or Izod tests, Hopkinson split bar tests, and use of fracture mechanics as an analytical tool. But, unfortunately the earlier tests of this type were not fully instrumented which made investigators realize that much important information can be lost in absence of proper instrumentation.

In this regard, in the very recent study ACI Committee 544 [26] has proposed drop weight impact test to demonstrate the relative brittleness and to quantify the impact resistance of fibre-reinforced concrete (FRC). The test is widely used because it is simple and economical. The results obtained from this test are often noticeably scattered. The large variation in impact resistance as determined from this test is reported in the literature for different types of FRC. Large variation is a common problem in impact testing, and it is difficult to devise systems that give reproducible results. This might be attributed to the nature of the impact process itself and the number of factors controlling the impact resistance compared with other mechanical properties. The drop weight impact test is adopted in this investigation.

3.7 The Drop Weight Impact Testing Machine (ACI-544 method)

The simplest of the impact tests is the “repeated impact, "drop-weight test. This test yields the number of blows necessary to cause prescribed levels of distress in the test specimen. This number serves as a qualitative estimate of the energy absorbed by the specimen at the levels of distress specified. The test can be used to compare the relative merits of different fiber-concrete mixtures and to demonstrate the improved performance of FRC compared to conventional concrete. It can also be adapted to show the relative impact resistance of different material thicknesses.

Equipment - Referring to Figure 1 and 2, the equipment for the drop-weight impact test consists of:

1. A standard, manually operated 10 lb (4.54 kg) compaction hammer with an 18-in. (457-mm) drop.
2. A 21/2 in. (63.5 mm) diameter hardened steel ball.
3. A flat base plate with positioning bracket similar to that shown in Figure 1 and 2.

In addition to this equipment, a mold to cast 6 in. (152 mm) diameter by 21/2 in.(63.5 mm) thick [±1/8 in., ± (3 mm)] concrete specimens is needed. This can be accomplished by using standard ASTM C 31 or C 470 molds.

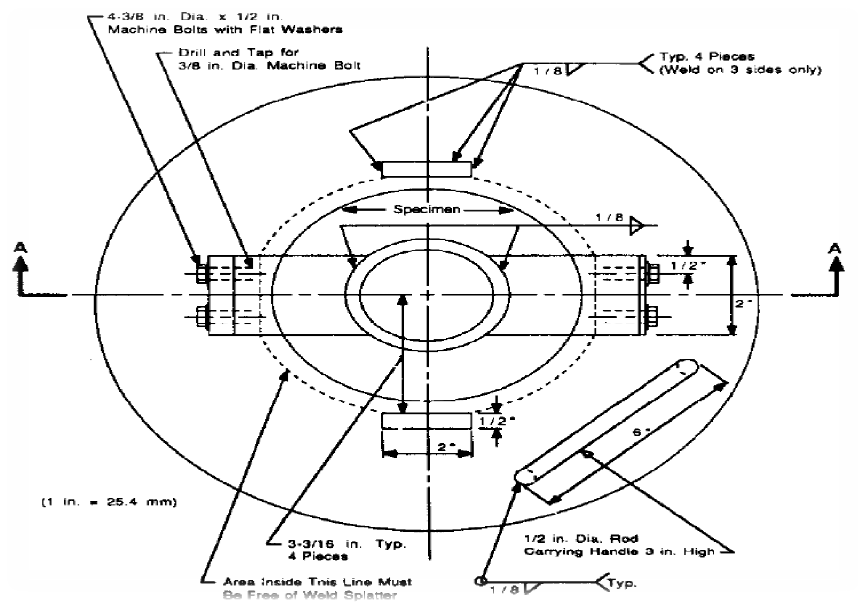


Figure 1: Plan view of test equipment for impact strength.[26]

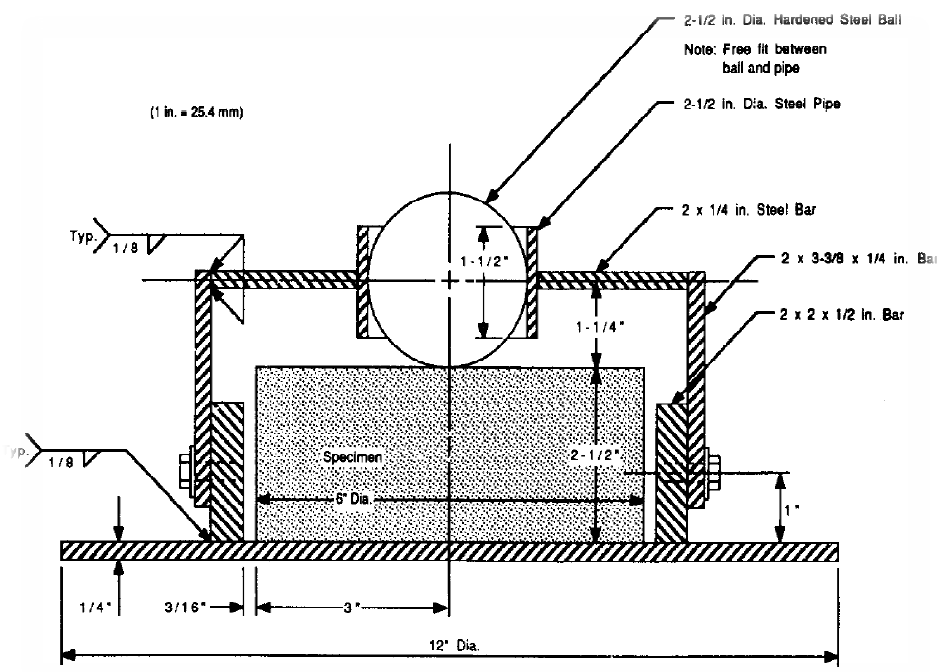


Figure 2: Section through test equipment for impact strength.[26]

CHAPTER 4

EXPERIMENTAL PROGRAM

4.1 Materials

4.1.1 General

Concrete mix designs are prepared using the BIS guidelines (IS: 10262-2009) and a total of four concrete grades were prepared (M20, M25, M30, M35). The specimens were produced with 5, 10 and 15% replacements of the fine aggregate by rubber dust. Moreover, control mixes with no replacement of the aggregates were produced to make a comparative analysis. The prepared samples were, concrete cubes for compressive strength test and circular concrete discs for impact tests. The rubber surface was pretreated with sodium hydroxide (NaOH of 1N) solution for 20 minutes and then left to surface dry prior to mixing in concrete. This treatment modified the rubber surface allowing the rubber to better adhere to the concrete matrix.

4.1.2 Cement

Cement used in the experimental work is Ordinary Portland Cement – 43 grade.
The specific gravity of the cement was calculated to be 3.12.

4.1.3 Aggregates

The following tests were carried out on aggregates:
- Sieve analysis for fine aggregate and fineness modulus
- Specific gravity and absorption capacity for fine aggregate
- Moisture content for fine aggregate

- **Sieve Analysis for Fine Aggregate and Fineness Modulus**

Sieve analysis determines the particle size distribution of aggregates using a series of square or round meshes starting with the largest. It is used to determine the grading, fineness modulus, an index to the fineness, coarseness and uniformity of aggregates. Calculations are shown in Table 1.

Table 1: Sieve analysis of fine aggregates

Sieve size	Wt. retained (gm)	%wt retained	Cumulative wt retained	%Finer
4.75 mm	37.70	3.77	3.77	96.23
2.36 mm	180.30	18.03	21.08	78.92
1.18 mm	231.10	23.11	44.91	55.09
600 mic	137.30	13.70	58.64	41.36
300 mic	145.60	14.56	73.20	26.80
150	208.00	20.80	94.08	5.92
Pan	59.70	5.97	100.00	0.00

Fineness modulus (F.M) = Σ cumulative coarser (%)/100

F.M. = 295/100 =2.95

- **Specific gravity of fine aggregate**

The specific gravity of a substance is defined as the ratio between the weight of the substance to that of weight of the same volume of water. This definition assumes that the substance is solid throughout. Specific gravity test of fine aggregates was determined in accordance to IS: 2386 part-3 and found as 2.69. Water absorption was determined as 4.38%.

Properties of the coarse aggregate

In a similar manner like the fine aggregate, laboratory tests were carried out to identify the physical properties of the coarse aggregate and the results are shown in Table 2, which are summarized as:

a) Specific gravity = 2.8

b) Fineness Modulus = 6.73

c) Water absorption = 0.52%

Table 2: Sieve analysis of coarse aggregate

Sieve size (mm)	Wt. retained (gm)	%wt retained	Cumulative wt retained	%Finer
20	308.10	15.00	8.50	91.50
16	804.00	29.27	37.77	62.23
12.5	643.80	50.95	88.72	11.28
10	199.40	9.93	98.65	1.35

4.75	38.00	1.13	99.77	0.22
Pan	6.70	0.23	100.00	0.00

4.1.4 Rubber aggregate

This study was planned for the performance of a various gradations of crumb rubber for which samples were collected from A.P. Rubber Industries, Haridwar. The sizes of rubber particles were 30-Mesh (595 microns), 60-mesh (250 microns) and 80-Mesh (177 microns).

4.2 Mix Design

Concrete mix designs were prepared using the IS guidelines (IS: 10262-2009) for M20, M25, M30 and M35 grade of concrete. Controlled mix proportioning of concrete for 1 m^3 concrete are given in Table 3. Other mix details are given in Tables 4 to 7.

Table 3: Mix design for control mix

Material	Control Mix (M20)	Control Mix (M25)	Control Mix (M30)	Control Mix (M35)
Cement(kg)	300.00	330.00	360.00	400.00
Fine Aggregate(kg)	828.50	804.31	779.00	746.70
Coarse Aggregate(kg)	1293.60	1255.80	1216.32	1165.00
Water (ltr.)	135.00	148.50	162.00	180.00
W/C ratio	0.45	0.45	0.45	0.45
Super plasticizer(kg)	Nill	1.65	1.80	2.00

Table 4: Mix design for M20 grade concrete with different percentage replacements of fine aggregate by rubber dust

Material	Control Mix (M20)	5% REPLACEMENT	10% REPLACEMENT	15% REPLACEMENT
Cement(kg)	300.00	300.00	300.00	300.00
Fine Aggregate(kg)	828.50	787.07	745.65	704.225
Coarse Aggregate(kg)	1293.60	1293.60	1293.60	1293.60
Water (ltr.)	135.00	135.00	135.00	135.00
W/C ratio	0.45	0.45	0.45	0.45

Super plasticizer(kg)	Nill	Nill	Nill	Nill
Rubber	Nill	41.42	82.85	124.27

Table 5: Mix design for M25 grade concrete with different percentage replacements of fine aggregate by rubber dust

Material	Control Mix (M25)	5% REPLACEMENT	10% REPLACEMENT	15% REPLACEMENT
Cement(kg)	330.00	330.00	330.00	330.00
Fine Aggregate(kg)	804.31	764.09	723.88	683.66
Coarse Aggregate(kg)	1255.80	1255.80	1255.80	1255.80
Water (ltr.)	148.50	148.50	148.50	148.50
W/C ratio	0.45	0.45	0.45	0.45
Superplasticizer(kg)	1.65	1.65	1.65	1.65
Rubber	Nill	40.22	80.43	120.65

Table 6: Mix design for M30 grade concrete with different percentage replacements of fine aggregate by rubber dust

Material	Control Mix (M30)	5% REPLACEMENT	10% REPLACEMENT	15% REPLACEMENT
Cement(kg)	360.00	360.00	360.00	360.00
Fine Aggregate(kg)	779.00	740.05	701.10	662.15
Coarse Aggregate(kg)	1216.32	1216.32	1216.32	1216.32
Water (ltr.)	162.00	162.00	162.00	162.00
W/C ratio	0.45	0.45	0.45	0.45
Superplasticizer(kg)	1.80	1.80	1.80	1.80
Rubber	Nill	38.95	77.90	116.85

Table 7: Mix design for M35 grade concrete with different percentage replacements of fine aggregate by rubber dust

Material	Control Mix	5%	10%	15%

	(M35)	REPLACEMENT	REPLACEMENT	REPLACEMENT
Cement(kg)	400.00	400.00	400.00	400.00
Fine Aggregate(kg)	746.70	709.36	672.03	634.70
Coarse Aggregate(kg)	1165.00	1165.00	1165.00	1165.00
Water (ltr.)	180.00	180.00	180.00	180.00
W/C ratio	0.45	0.45	0.45	0.45
Super plasticizer(kg)	2.00	2.00	2.00	2.00
Rubber	Nill	37.34	74.67	112.00

4.3 Testing Arrangement

4.3.1 Casting of test specimens (As per IS: 516-1959)

- *All materials were brought to the room temperature.*
- *The materials i.e. cement and aggregates were first mixed dry thoroughly in the mixer available in the lab, and care was taken that no foreign matter is intruded in the mix.*
- *The proportions of all the materials, including water, used in concrete mix, were made similar in all respects to those to be employed in the work.*
- *The concrete was mixed in a laboratory batch mixer after priming, avoiding any loss of water or other materials. Each batch of concrete was of such a size as to leave at least about 10 percent excess after molding the desired number of test specimens.*
- *The moulds were rigidly clamped before putting on the vibrating table in such a manner that they distribute the frequency and amplitude of vibration of the table to the fresh concrete.*
- *The period of vibration depends on the efficiency of the vibrating table, the consistency of fresh concrete and the height of the filled concrete.*
- *In general, the samples were vibrated till the laitenance layers are about to form at the top surface.*
- *The compaction was considered adequate when concrete started showing movement as a whole mass when top surface of concrete is pressed strongly by the trowel and moved. Also there was cessation of escape of air bubbles and the top surface of concrete appeared smooth with greasy appearance.*

4.3.2 Curing of test specimens (As per IS: 516-1959)

- *The test specimens were stored at a place free from vibration, for 24 hours from the time of adding the water to the ingredients, at room temperature.*
- *After the period of 24 hours, they were removed from the moulds, marked for later identification and stored in clean water.*

4.4 Tests for Compressive Strength of Concrete Specimen

- *Specimens stored in water were tested immediately on removal from the water and while they are still in the wet condition.*
- *Surface water and grit was wiped off the specimens.*
- *The bearing surfaces of the testing machine cleaned.*
- *The cubes specimens were placed in the machine in such a manner that the load was applied to opposite sides of the cubes as cast.*
- *The load was applied without shock and increased continuously at a rate of approximately 140 kg/sq cm/min until the resistance of the specimen to the increasing load broke down and no greater load could be sustained.*
- *The maximum load applied to the specimen was recorded and the appearance of the concrete and any unusual features in the type of failure was noted.*
- *The compressive strength of the specimen was calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area (15 cm X 15cm).*
- *Average of three specimen values was taken as the representative of the batch.*

4.5 Tests for Impact Strength of Concrete Specimen (As per ACI-544)

- *Specimens were prepared in the moulds of dimensions as specified in ACI-544 report.*
- *Specimens were tested at 28 days of age.*
- *Curing and handling of the specimens were similar to that used for compressive tests recommended in IS code.*
- *The sample was placed in the positioning bracket and positioning lugs and the hardened steel ball was placed on the top of the specimen within the bracket.*
- *The drop hammer was 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 was bolted into the concrete floor.*
- *The hammer was 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 sufficiently so that the pieces of concrete are touching three of the four positioning lugs on the base plate.*

CHAPTER 5

RESULTS AND OBSERVATIONS

5.1 Unit Weight

Unit weights of the samples (150x150x150 mm cubes) were recorded after 28 days curing. The results are as shown in Table 8.

Table 8: Unit Weights of concrete samples

No	Spec	Grade	%Rubber	Unit Weight (kg/m^3)	% Reduction in weight
1	Set-1	M-20	0	2459.26	**0**
2	Set-2	M-20	5	2370.37	**3.61**
3	Set-3	M-20	10	2281.48	**7.23**
4	Set-4	M-20	15	2234.90	**9.12**
5	Set-5	M-25	0	2510.78	**0.00**
6	Set-6	M-25	5	2419.33	**3.64**
7	Set-7	M-25	10	2385.21	**5.00**
8	Set-8	M-25	15	2340.74	**6.77**
9	Set-9	M-30	0	2548.15	**0.00**
10	Set-10	M-30	5	2459.26	**3.49**
11	Set-11	M-30	10	2429.63	**4.65**
12	Set-12	M-30	15	2379.16	**6.63**
13	Set-13	M-35	0	2573.41	**0.00**
14	Set-14	M-35	5	2518.52	**2.13**
15	Set-15	M-35	10	2488.89	**3.28**
16	Set-16	M-35	15	2414.80	**6.16**

As seen from the results shown in Table 8, it is observed that there is approximately 6-9 % reduction in unit weight of the concrete when 15% of fine aggregates is replaced by rubber dust. This reduction in weight is expected because of the low specific gravity of rubber dust as compared to fine aggregates which reduces the mass density of the mix.

This property might be of minor importance in low rise buildings, but in high rise building design, this property can be of greater importance. Low density supporting elements will require lesser cross-section as compared to standard concrete, and also reduced footing sizes. Also, with lighter weight concrete, formwork will require to withstand lower pressure, which will consequently increase the productivity. Therefore, rubber concrete can provide with all the benefits which are associated with a low density construction material.

5.2 Compressive Strength

The compressive strength of concrete specimens was determined after 7 and 28 days of normal curing. The results of individual specimens are shown in Appendix A.

In the first phase of testing, the effect of fineness of rubber particles was determined. Concrete cubes of 15x15x15 cm were casted for M25 mix with 15% replacement of fine aggregates by 30 Mesh, 60 Mesh, and 90 Mesh rubber dust respectively. A control mix specimen was also casted. The results obtained are as shown in the Table 9. A significant decrease in compressive strength is observed, upto 42%, on addition of rubber dust in concrete. It is also observed that as the size of rubber particles decrease, the concrete mix becomes less workable and also the compressive strength reduces further. The results are summarized in Figure 3.

Table 9: Compressive strength test results with different gradations of rubber dust

(a) Plain Concrete

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-T-1	25	15	30.55	39.25
2	Set-T-2	25	15	28.11	38.86
3	Set-T-3	25	15	30.06	39.02
			Mean	**29.57**	**39.04**

(b) 30 Mesh rubber particle size

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-T-4	25	15	21.88	27.17
2	Set-T-5	25	15	22.32	26.70
3	Set-T-6	25	15	21.45	26.14
			Mean	**21.88**	**26.67**

(c) 60 Mesh rubber particle size

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-T-7	25	15	20.08	26.28
2	Set-T-8	25	15	19.46	25.10
3	Set-T-9	25	15	19.40	26.88
			Mean	**19.65**	**26.09**

(d) 80 Mesh rubber particle size

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-T-10	25	15	18.90	22.68
2	Set-T-11	25	15	18.55	23.46
3	Set-T-12	25	15	17.56	22.09
			Mean	**18.34**	**22.74**

In the second phase of testing, casting was done for M20, M25, M30 and M35 mixes, with one control mix and three mixes with 5%, 10% and 15% replacement of fine aggregates by rubber dust, each. The rubber dust used was pre-treated with NaOH of 1N solution for half an hour prior to mixing. The results obtained are summarized in the Table 10. As observed in first phase of testing also, the compressive strength of the concrete reduces significantly on addition of rubber dust. This reduction in compressive strength increases with the increase in percentage of rubber replacement.

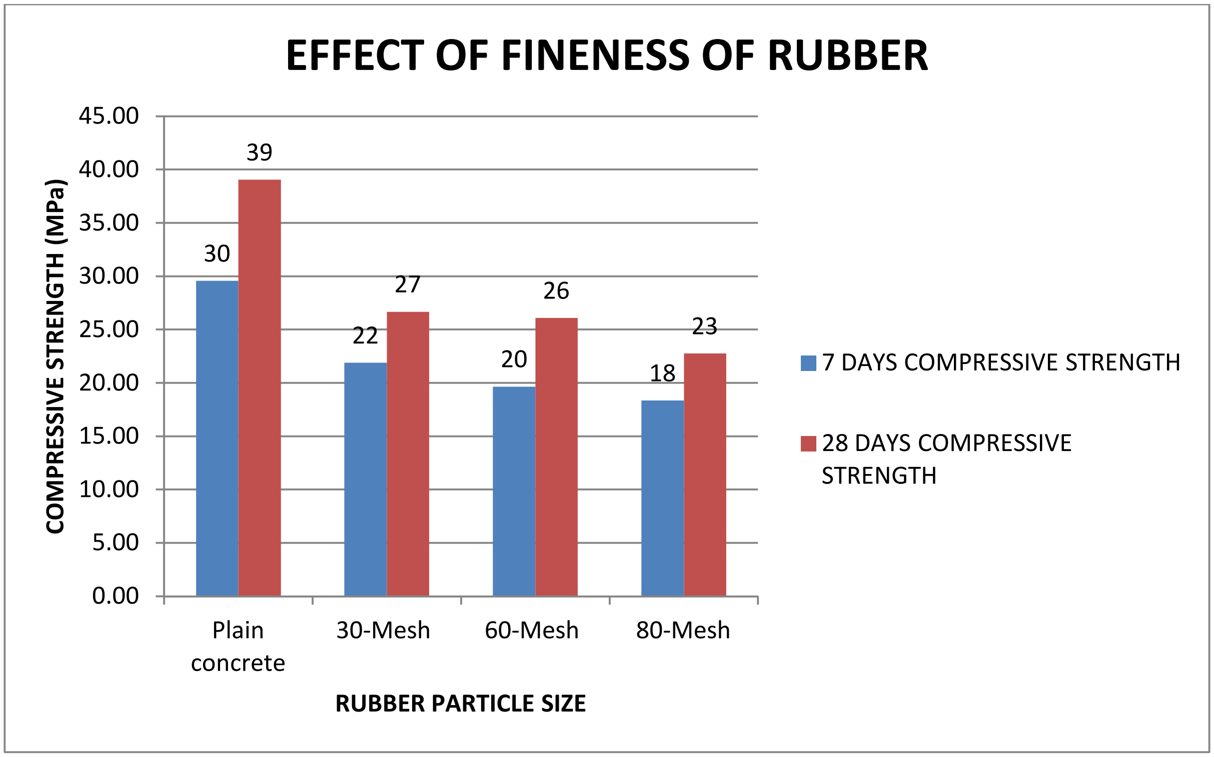


Figure 3: Effect of fineness of rubber particles on compressive strength

Table 10: Results of compressive strength tests

NO.	Spec.	Concrete Grade	% Rubber	Compressive Strength		% Reduction in strength	
				7 Days	28 Days	7 Days	28 Days
1	Set-1	M20	0%	20.12	27.87	**0.00**	**0.00**
2	set-2	M20	5%	18.19	21.60	**9.58**	**22.50**
3	Set-3	M20	10%	15.00	17.13	**25.43**	**38.52**
4	Set-4	M20	15%	10.13	12.79	**49.64**	**54.11**
5	Set-5	M25	0%	28.67	40.62	**0.00**	**0.00**
6	Set-6	M25	5%	24.67	33.41	**13.95**	**17.73**
7	Set-7	M25	10%	22.82	28.56	**20.41**	**29.69**
8	Set-8	M25	15%	18.83	21.08	**34.30**	**48.10**
9	Set-9	M30	0%	35.78	47.62	**0.00**	**0.00**
10	Set-10	M30	5%	31.32	39.50	**12.46**	**17.05**

11	Set-11	M30	10%	24.30	33.56	**32.10**	**29.53**
12	Set-12	M30	15%	19.92	24.59	**44.33**	**48.37**
13	Set-13	M35	0%	37.17	51.81	**0.00**	**0.00**
14	Set-14	M35	5%	32.52	45.13	**12.51**	**12.89**
15	Set-15	M35	10%	25.05	38.33	**32.60**	**26.01**
16	Set-16	M35	15%	21.12	28.09	**43.17**	**45.78**

As can be seen from the results, 5% replacement reduces the 28 days compressive strength by 13-23%, 10% replacement causes reduction by 26-39% and 15% replacement reduces the compressive strength by over 45%.

The trend of strength reduction is explained with the help of Figure 4, where the results obtained for various grades of concrete with different % replacements are shown.

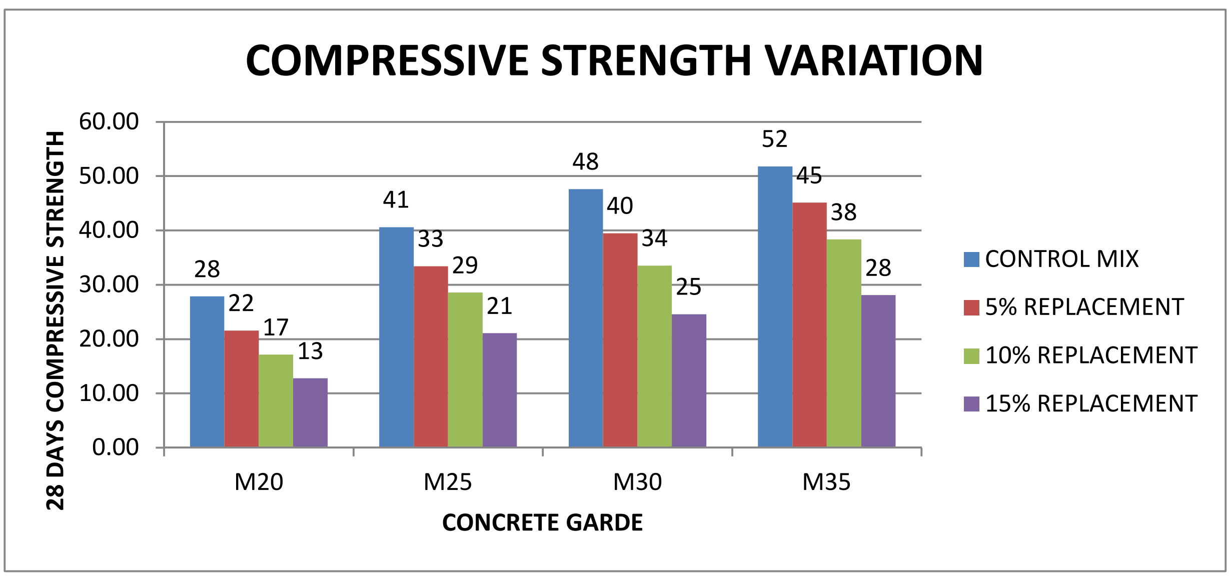


Figure 4: Comparison of compressive strength test results

The strength reduction can be attributed to following reasons:

- Intrusion of rubber particles reduces the quantity of solid load carrying material.
- Tyre rubber particles acted as voids in the matrix because of the lack of adhesion at the boundaries of rubber aggregate.

- Mineral aggregates usually have high crushing strength and are relatively incompressible. On the other hand, rubber particles are ductile, compressible and resilient.

It was also observed that due to the low specific gravity and high surface area of rubber dust, water requirement to maintain workability was significantly higher than that of concrete without rubber.

Although the strength reduction increases on increasing the percentage replacement of fine aggregates with rubber dust, it can be reasonable to include rubber dust upto 15% replacement in the concrete mix as intended compressive strength can be achieved.

5.3 Impact Test

The concrete samples were casted in circular disc moulds as recommended by ACI-544 [26] report, having 152mm diameter and 63.5mm thickness. The specimens were prepared with same concrete mixes as that for compressive strength test, and were tested after 28 days of curing. The ultimate failure is defined as the opening of cracks in the specimen, such that the pieces of concrete are touching three of the four positioning lugs on the base plate. Numbers of blows required for ultimate failure were recorded. The results are shown in Table 14. The impact energy delivered to the sample can be calculated [27] as follows:

$$E_I = Nmgh$$

Where E_I is the impact energy (Nm), N is the number of blows, m is the mass of drop hammer (kg), g is gravity acceleration (m/s^2), and h is the height of the drop hammer (m). The energy absorption is also shown in Table 11.

Table 11: Results for Impact Resistance Test

No	Spec	Grade	%Rubber	No. of blows	Energy absorbed(Nm)	% increase in energy absorbed
1	Set-1	M-20	0%	180	3660	0
2	Set-2	M-20	5%	276	5612	53
3	Set-3	M-20	10%	320	6507	78
4	Set-4	M-20	15%	419	8519	133

5	Set-5	M-25	0	351	7137	0
6	Set-6	M-25	5	486	9882	38
7	Set-7	M-25	10	517	10512	47
8	Set-8	M-25	15	673	13684	92
9	Set-9	M-30	0	621	12627	0
10	Set-10	M-30	5	799	16246	29
11	Set-11	M-30	10	930	18910	50
12	Set-12	M-30	15	1080	21959	74
13	Set-13	M-35	0	750	15250	0
14	Set-14	M-35	5	876	17812	17
15	Set-15	M-35	10	1047	21288	40
16	Set-16	M-35	15	1260	25619	68

The results show that impact resistance of concrete is significantly improved on addition of rubber dust as compared to the control mix. As the percentage of rubber aggregate increases, the impact resistance of concrete also increases. The observations are explained with the Figure 5.

Also, it is observed that the percentage increase in impact energy absorbed is reducing as the concrete grade of the sample increases, for the same percentage replacement. The results are shown in Figure 6. The percentage increase in impact energy absorbed is 133% for M20 grade concrete with 15% replacement of aggregates by rubber dust, whereas it is just 68% increase for M35 grade concrete with same percentage replacement. The reason for this can be attributed to increase in impact strength of the control concrete as the grade increases.

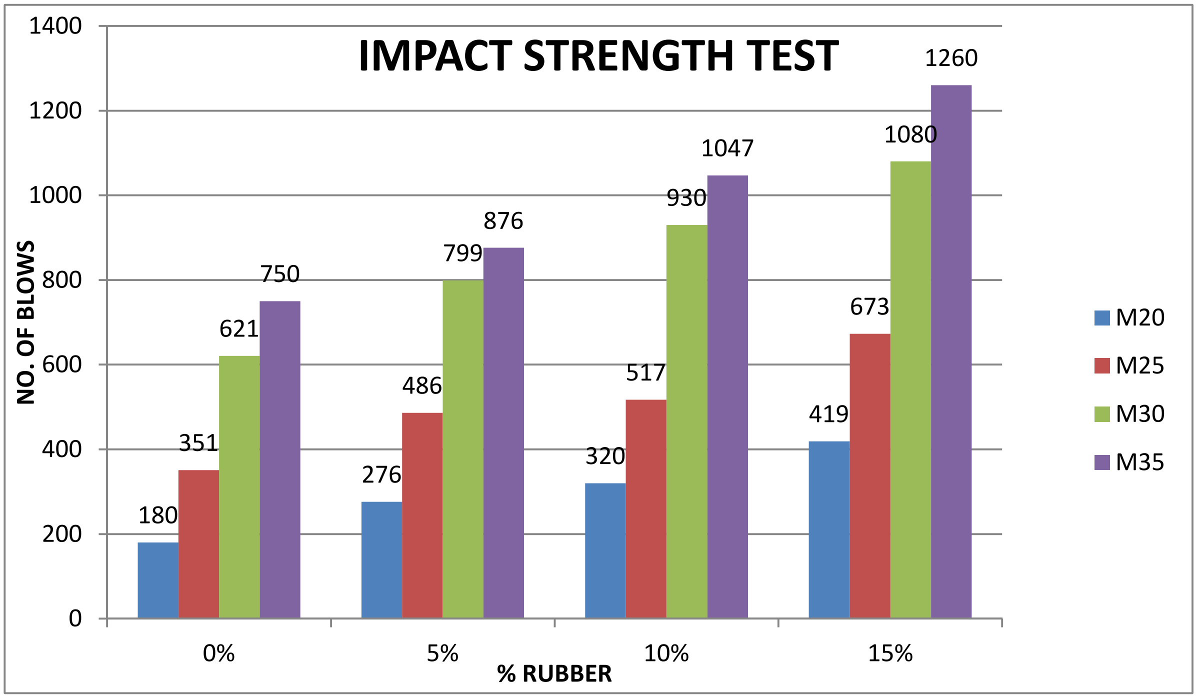


Figure 5: Impact resistance test results on various grades of concrete for different fine aggregate replaced specimens

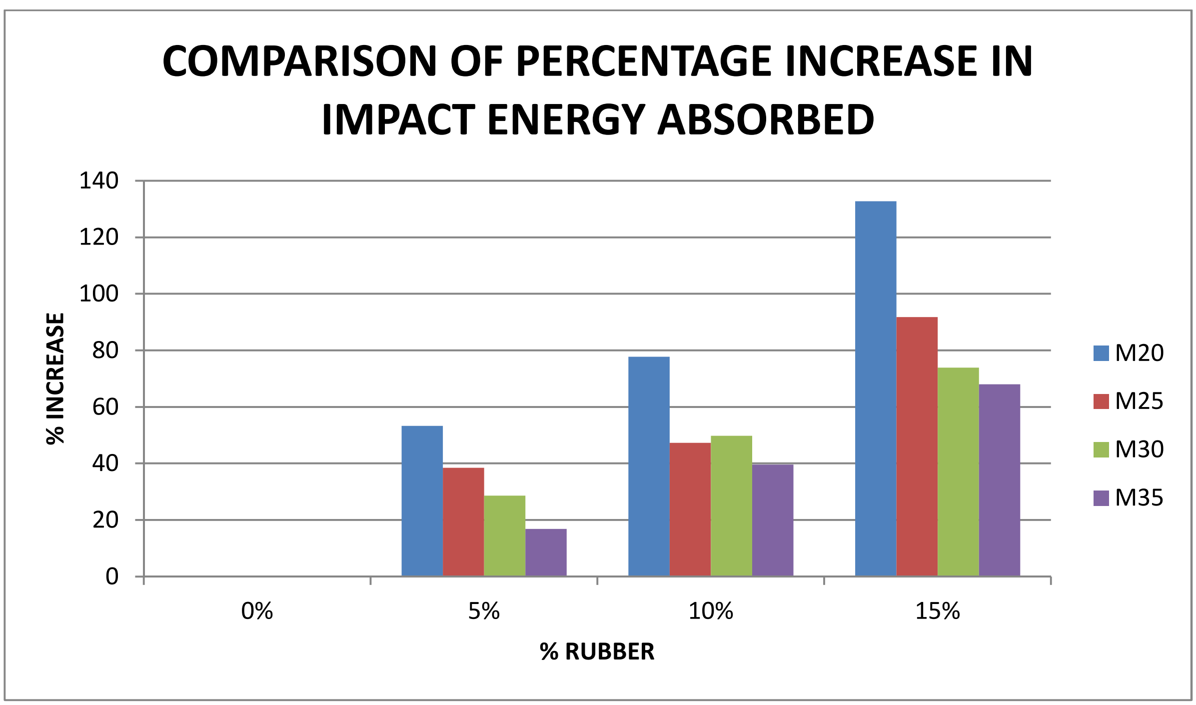


Figure 6: Comparison of percentage increase in impact energy absorbed for different grades of concrete with different percent replacement of rubber dust

CHAPTER 6

CONCLUSIONS

The objective of this research was to improve the impact resisting capacity of concrete using tyre rubber dust by partial replacement with fine aggregates. The conclusions withdrawn from the present work are given in next section.

6.1 Conclusions

- A reduction in unit weight, upto 9% was observed when 15% fine aggregate was replaced by rubber dust. Further reduction in weight can be achieved by increased percentage replacement of fine aggregate by rubber dust, if lightweight concrete is required for non structural applications.
- The test results show that increase in rubber dust content decreased the compressive strength of the concrete significantly. The pattern of strength reduction was similar for different grades of concrete. After 28 days of curing, compressive strength reduction was upto 54% on 15% replacement, as observed for M20 grade concrete. The reason for reduction in compressive strength can be attributed to the reduced strength of load carrying material and poor bonding of rubber particles in concrete matrix which make the rubber particles behave as voids, resulting in a reduction of compressive strength.
- The visual observations revealed that the control concrete shows a typical failure behavior with clear well defined cracks. Whereas, in rubber concrete the failure pattern was not well defined, it was gradual as compared to brittle failure of control concrete. This may indicate more ductility in rubber concrete than the normal concrete.
- Impact resistance capacity of concrete increases significantly as the percentage of rubber particles increase in concrete. The results also show that for lower grades of concrete the increase in impact resistance capacity is much more significant than for higher grades of concrete. As can be seen from the results, the increase in energy is absorbed is 133% for M20 grade of concrete against 68% for M35 grade for 15% replacement of FA with rubber dust.

- Though compressive strength of concrete is reduced on addition of rubber particle, which limits its use for structural applications, still it has few desirable characteristics such as lower density and higher impact strength, which can be utilized.
- The possible area of application of rubber concrete can be amongst partition walls, sidewalks, culverts, driveways and some road construction applications. Rubber concrete can also be used in the areas where vibrations damping is required like foundation pads for machinery and in railway station platforms or in the areas where resistance for impact or blast is required e.g. railway buffers, jersey barriers and bunkers.
- On addition of rubber dust to the concrete, the workability of the concrete reduces and more water is required in the mix to maintain workability. Addition of super plasticizer can be an alternative to keep water-cement ratio low.
- The use of rubber in concrete reduces the environment threat caused by the waste tyres, and also introduces an alternative source of aggregates for concrete.
- The study shows that it is possible to use rubber dust as a partial replacement of fine aggregates, to improve impact resistance capacity of concrete. However, the percentage of replacement has to be limited as higher percentage replacement reduces the compressive strength which limits the use of rubber aggregates in various areas of applications of concrete.

6.2 Recommendations

- To achieve properties like high impact strength, high strength concrete is incorporated even if such high strength is not required, for example in areas such as parking lots and light weight structures for a particular application. Such issues can be addressed by using rubber concrete as an alternative.
- Using waste tyre rubber aggregate in concrete can address the issue of disposing the large dumps of waste tyres pilling up, and posing a threat to the environment.
- Since the strength of concrete reduces significantly, and also long term performance is unknown, the initial use of rubber concrete should be restricted to non structural elements.

- Though, rubber concrete production is costlier than standard concrete, but if the overall estimation is made of the cost incurred by the government in disposing and managing the waste tyre dump, the utilization of rubber in concrete can prove to be economical.

6.3 Future scope

- This study was concentrated to improve the impact resisting capacity of the concrete. Further investigations to improve the compressive strength of rubber concrete should be carried out so that rubber concrete can be incorporated in structural elements also.
- It was observed in the study that failure of rubber concrete under compression test showed fine cracks of narrower crack widths. The ductility tests should be conducted to confirm the same.
- The tests were conducted for 7 and 28 days of curing. The long term effect on the properties of rubber concrete needs to be studied.
- The effect of air entraining can also be investigated using microscopical investigations which may help in improving freeze-thaw effect.
- The effect of rubber crumb, rubber chips and rubber fibers as replacement of aggregates in concrete can also be studied in future investigations.
- Since the use of tyre rubber particles in concrete is not common in India, more studies are required to be carried out on various properties of rubber concrete.

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APPENDIX A

Compressive strength test results for various grades of concrete with different percentage replacement of fine aggregates with rubber dust:

Table 12: Compressive strength test results for M20

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-1-1	M20	0	20.07	27.00
2	Set-1-2	M20	0	20.10	28.00
3	Set-1-3	M20	0	20.18	28.6
			Mean	**20.12**	**27.87**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-2-1	M20	5	19.10	22.30
2	Set-2-2	M20	5	17.60	21.40
3	Set-2-3	M20	5	17.87	21.09
			Mean	**18.19**	**21.60**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-3-1	M20	10	14.60	17.40
2	Set-3-2	M20	10	15.50	17.00
3	Set-3-3	M20	10	14.90	17.00
			Mean	**15.00**	**17.13**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-4-1	M20	15	9.39	12.80
2	Set-4-2	M20	15	11.20	12.56
3	Set-4-3	M20	15	9.80	13.00
			Mean	**10.13**	**12.79**

Table 13: Compressive strength test results for M25

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-5-1	M25	0	30.00	41.60
2	Set-5-2	M25	0	27.00	40.00
3	Set-5-3	M25	0	29.00	40.25
			Mean	**28.67**	**40.62**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-6-1	M25	5	24.00	34.09
2	Set-6-2	M25	5	26.00	30.75
3	Set-6-3	M25	5	24.00	35.40
			Mean	**24.67**	**33.41**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-7-1	M25	10	22.78	28.40
2	Set-7-2	M25	10	22.67	28.39
3	Set-7-3	M25	10	23.00	28.88
			Mean	**22.82**	**28.56**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-8-1	M25	15	19.72	20.90
2	Set-8-2	M25	15	18.60	21.00
3	Set-8-3	M25	15	18.18	21.34
			Mean	**18.83**	**21.08**

Table 14: Compressive strength test results for M30

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-9-1	M30	0	35.88	47.00
2	Set-9-2	M30	0	35.26	47.83
3	Set-9-3	M30	0	36.21	48.03
			Mean	**35.78**	**47.62**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-10-1	M30	5	31.40	36.99
2	Set-10-2	M30	5	29.90	41.45
3	Set-10-3	M30	5	32.67	40.06
			Mean	**31.32**	**39.50**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-11-1	M30	10	23.49	33.81
2	Set-11-2	M30	10	23.81	34.87
3	Set-11-3	M30	10	25.59	32.00
			Mean	**24.30**	**33.56**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-12-1	M30	15	18.30	25.50
2	Set-12-2	M30	15	21.42	24.81
3	Set-12-3	M30	15	20.04	23.45
			Mean	**19.92**	**24.59**

Table 15: Compressive strength test results for M35

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-13-1	M35	0	35.31	51.98
2	Set-13-2	M35	0	37.80	52.41
3	Set-13-3	M35	0	38.40	51.04
			Mean	**37.17**	**51.81**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-14-1	M35	5	32.00	46.41
2	Set-14-2	M35	5	33.26	46.36
3	Set-14-3	M35	5	32.30	42.62
			Mean	**32.52**	**45.13**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-15-1	M35	10	25.26	38.00
2	Set-15-2	M35	10	24.80	38.00
3	Set-15-3	M35	10	25.10	39.00
			Mean	**25.05**	**38.33**

NO.	Sample	Concrete grade	% Rubber	7 Days strength (MPa)	28 Days strength (MPa)
1	Set-16-1	M35	15	21.10	28.39
2	Set-16-2	M35	15	19.87	29.88
3	Set-16-3	M35	15	22.40	26.00
			Mean	**21.12**	**28.09**

APPENDIX B

Photographs:

Figure 7: Self weight testing for concrete cube

Figure 8: Compressive Strength test

Figure 9: Compressive strength testing machine

(a) Rubber concrete **(b) Control concrete**

Figure 10: Failure pattern under compressive strength test- Close view

Figure 11: Failure pattern under compressive strength test- Rubber concrete

Figure 12: Failure pattern under compressive strength test- Control conrete

(a) **(b)**

Figure 13: Impact Test

Figure 14: Impact testing machine fabricated in accordance to specifications given in ACI-544.

Figure 15: Impact testing machine and molds fabricated according to the specifications given in ACI-544 report