CHAPTER : ONE

1.0 Introduction

1.1 Background

Concrete is a low cost, versatile and durable material and is the most widely used construction material worldwide. The Concrete should have low unit weight, high strength, and toughness and impact resistance. However, these requirements are not always fulfilled. One possible solution to improve the property of concrete is to use waste automobile tyre chips as aggregate in concrete. With addition of rubber from tyres, concrete becomes comparatively ductile and elastic under load. These new mixed concrete can be used in architectural applications such as nailing concrete, in road construction where high strength is not necessary, in wall panels (Concrete Blocks) that require low unit weight, in construction elements that are subject to impact, in sound barriers, in road and bridge barriers works and in rail road to fix the rails to the ground.

One of the disadvantages of conventional concrete is the high self-weight of concrete. This heavy self-weight will make it to some extent an uneconomical structural material. Several attempts have been made in the past to reduce the self-weight of concrete to increase the efficiency of the concrete as structural material. It helps in reduction of dead load, increases the progress, lowers haulage and handling cost and finally reduces the final cost of structure. One of the best methods to make the concrete light is replacing the usual mineral aggregate by cellular porous or lightweight aggregate. Many developed countries nowadays are producing a large scale of artificial industrial light weight aggregate of varying quality by trade names such as Leca (Expanded clay), Aglite (Expanded Shale), Haydite (Expanded Shale), Lytage (Sincred Pulverized Fuel ash) which are costlier. The research work is on going to use the locally available material to make the conventional concrete light and have low thermal conductivity. In this regard, rubber aggregate may be one of the alternatives to replace the mineral aggregate to make it light if it cannot provide adverse effect in mechanical properties of concrete.

The waste management problem, now days, is becoming a great problem in Kathmandu Valley due to shortage of Dumping site. The Kathmandu Municipality is doing its best effort to solve the problem, but it becomes a great news for Nepalese people when it is not done with properly. The plastic polythene, rubber materials (tyres) that are not biodegradable materials increases the volume of waste as well as unused transportation cost. Uncontrolled combustion of tyres also tends to release significant amount of unburned hydrocarbons & emissions of noxious gases into atmosphere. Some of the people of Nepal burn these tyres to block the roads when they call Bandh & strike that has very bad impact in environment. So, there is a great need to re-use these used tyres in productive works that can contribute to the economic development of the country.

It is observed that the used tyre when reused as a fuel source for cement kilns, produce 20% more energy than coal. The developed country reused the rubber tyres in making rubber and plastic products, tyre retreading applications, highway crash barriers, breakwaters and the mixing of rubber and asphalt in pavement construction (EPA, 1991; Ahmed and Lovell, 1992; Ahmed, 1993). Small proportions of rubber are also used as an energy absorbing material in children's play areas to prevent injury.

Extensive investigation of the use of tyre rubber in asphalt materials has been conducted, either as a binder enhancement or an aggregate replacement (Goulias and Ali, 1994; Goulias, 1996). Early studies showed that rubberised asphalt had better skid resistance, increased durability, and reduced fatigue cracking and achieved longer pavement life than conventional asphalt (Adam et al., 1985; Esch, 1984; Estakhri, 1990; Khola and Trogdon, 1990). Approximately 480 million tons of asphalt are used each year in the United States (Singh, 1992) and in 1986, 25 200 tons of rubber were used in asphalt. However, the initial cost of rubberized asphalt is 40 to 100% higher than that of conventional asphalt and its long-term benefits are uncertain (Fedroff et al., 1996).

As previously mentioned, there is a very large market for concrete products, including non-primary structural applications for which products incorporating rubber aggregate could be feasible. So, there is a need to investigate engineering properties of concrete containing rubber aggregate and consider the potential of rubberized concrete in various civil engineering applications.

1.2 Objectives

The overall objective of the project is to investigate the effect rubber tyre chips as a replacement for natural mineral aggregates on mechanical properties of concrete.

The specific objectives of the project are as follows:

1. To establish the density of concrete mix with using rubber aggregate.
2. To evaluate the workability of concrete at different content of rubber aggregate.
3. To investigate the effect of content of rubber aggregate on mechanical properties of concrete.
4. To investigate the effect of coating the rubber aggregate with cement paste on mechanical properties of concrete.
5. To study the previous research works on Impact Resistance, Durability, and Deformability of Rubberized Concrete.

In addition to investigating the use of rubber aggregate in concrete mix design and the engineering properties of concrete mixes, an important consideration has been the development of rubberized concrete products in engineering application.

1.3 Scope of Work

The programme of work undertaken is summarized as below:

Characteristics of fresh rubberized concrete

In order to assess the characteristics of fresh rubberized concrete, the following aspects were considered:

- Mix design,
- Workability,

- Ease of preparation and finishing.

The workability was assessed using British Standard testing equipment and procedures.

Characteristics of hardened rubberized concrete

The following tests were carried out to establish the engineering properties of rubberized concrete:

- Compressive strength,
- Splitting tensile strength,
- Flexural strength,

The properties were determined using British Standard testing equipment and procedures.

Applications of rubberized concrete

With the help of known structural properties of concrete using rubber aggregate (From Literature Review and Experimental Works) the potential applications of rubberized concrete may be identified.

1.4 Terminology

The following terminology is used in this report, which is based on recommendations by the Scrap Tyre Management Council (STMC) (2001) and American Concrete Institute (1996).

Crumb rubber

Crumb rubber refers to any material derived by reducing scrap tyres or other rubber into uniform granules with the inherent reinforcing materials such as steel and fibre removed along with any other type of inert contaminants such as dust, glass or rock.

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Waste tyre

Waste tyre usually generated from both the products of the manufacturing process and Post-consumer (retired) products, mainly consisting of scrap tyres.

Scrap tyre

A whole tyre that can no longer be used for its original intended purpose. A whole used tyre that can be used, reused or legally modified to be reused for its original intended purpose is not a scrap tyre.

Rubber aggregate

Reduction of scrap tyres to aggregate sizes by two processing technologies: mechanical grinding or cryogenic processing. Such rubber aggregate can be fine or coarse rubber aggregate. Fine rubber aggregate is sometimes referred to as crumb rubber aggregate while coarse rubber aggregate is sometimes referred to as tyre chips.

Ordinary aggregate

Granular material, such as sand, gravel, crushed stone, crushed hydraulic-cement concrete or iron blast-furnace slag, used with a hydraulic cementing medium to produce either concrete or mortar.

Coarse aggregate

Refers to aggregate particles larger than 4.75 mm

Fine aggregate

Refers to aggregate particles smaller than 4.75 mm but larger than 75 μm

Rubberized asphalt

The use of tyre chips or crumb rubber in place of or in addition to other aggregates in the final asphalt mix.

Ordinary concrete

Concrete produced with natural sand as fine aggregate, gravel or crushed rock as coarse aggregate and cement.

Rubberized concrete

Concrete containing rubber aggregate or combinations of rubber aggregate and ordinary aggregate.

Mortar

A mixture of cement paste and fine aggregate. In fresh concrete, the material occupying the interstices among particles of coarse aggregate.

CHAPTER : TWO

2.0 Literature Review

Some previous research regarding the use of waste materials in OPC concrete mixes either as a replacement of fine and coarse aggregate or to reduce the content of binding material to enhance the properties of concrete gives a general overview in this research work. The literature regarding the use of rubber tyre aggregate in asphalt concrete and concrete blocks in some advance country is also helpful in this research work.

2.1 General Characteristics and Constituents of Concrete

Concrete is a low cost, versatile and durable material and is the most widely used construction material world-wide. Concrete consists of a hydraulic cement binder and filler, usually in the form of natural aggregates. The aggregates usually constitute between 50% and 80% of the volume of conventional concrete and may therefore greatly influence its properties. Artificial and replacement aggregates have long been used in concrete, such as waste materials from industrial processes e.g. pulverised fuel ash. More recently, the requirements of sustainability have led to the development of replacement aggregates such as recycled concrete and glass cullett. 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. Aggregate has been customarily treated as inert filler in concrete. However, due to increasing awareness of the role played by aggregates in determining many important properties of concrete, the traditional view of the aggregate as inert filler is being seriously questioned (Metha and Monteiro, 1993). Certain aggregate characteristics are required for proportioning concrete mixtures. These include density, grading and moisture state (Kosmatka and Panarese, 1990). Porosity or density, grading, shape and surface texture determine the properties of concrete . The mineralogical composition of aggregate affects its crushing strength, hardness, elastic modulus and soundness, which in turn influence the strength, and durability properties of hardened concrete.

The use of recycled rubber as a full or partial replacement for the natural aggregates in concrete will therefore necessitate an investigation of the changes in the properties of the concrete, in both fresh and hardened states, and how this affects the potential applications of rubberized concrete.

2.1.1 Material Constituents of Rubberized Concrete

This section describes the physical characteristics of the constituents of rubberized concrete used in investigations i.e. rubber aggregates, mineral aggregates and cement.

Cement

Ordinary Portland Cement (OPC) is by far the most important type of cement and is highly suitable for use in general concrete construction when there is no exposure to sulphates in the soil or groundwater (Neville, 1997). The OP Cement has been classified into three grades, namely 33 grade, 43 grade & 53 grade depending upon the strength of cement at 28 days when tested as per IS 4031-1988. The manufacturing of OPC is decreasing all over the world in view of popularity of blended cement on account of lower consumption, environmental pollution, economic and other technical reasons. Nowadays, Portland Pozzolana cement (PPC) is most widely used due to its better availability, improve the pre size distribution, reduce the micro cracks at the transition zone, reduce permeability and finally economic than OPC.

The content of cement directly affect the strength properties of concrete depending upon the degree of hydration of cement and its chemical and physical properties, the termperature at which the hydration takes place, the air content in case of air-entrained concrete and the formation of fissures and cracks due to bleeding or shrinkage.

Both the Ordinary Portland Cement and Pozzolana Portland Cement, were used for separate set of tests during the research work.

Rubber Aggregate

Rubber aggregates are obtained by reduction of scrap tyres to aggregate sizes using two general processing technologies: mechanical grinding at ambient conditions (at room temperature) or cryogenic grinding (Nagdi, 1993).

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 centimetres to fractions of a centimetre. The steel bead and wire mesh in the tyres is magnetically separated from the crumb during the various stages of granulation, and sieve shakers separate the fibre in the tyre.

Cryogenic processing is performed at a temperature below the glass transition temperature. This is usually accomplished by freezing of scrap tyre rubber using liquid nitrogen. The cooled rubber is extremely brittle and is fed directly into a cooled closed loop hammer-mill/multi-state screener to be crushed into small particles with the fibre and steel removed in the same way as in mechanical grinding (Leyden, 1991). 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 in any way from the original material (Owen, 1998). Eldin and Senouci (1993) argued that unlike mechanically processed rubber, the cryogenic process is an efficient means of obtaining rubber aggregate which is steel and fabric-free, uniformly geometric in shape and finely ground (down to powder size).

Ali et al.(1993) described various methods to process scrap tyres into rubber and presented typical comparisons between the chemical compositions of truck and car tyres.

According to Sherwood (1995), the rubber source and grinding process can influence the amount of steel and textile fibre in the rubber as well as the shape and texture of the rubber, and ultimately the properties of rubberised concrete.

The density of the rubber aggregates reported in the previous studies varied. Eldin and Senouci (1993) reported that the unit weight of the rubber used varied between 800 and 960 kg/m3. Also, the specific gravity of rubber used in the different investigations varied widely i.e. 0.65 (Topcu, 1995), 0.80 (Rostami et al., 1993), 1.06 to 1.09 (Ali et al., 1993) and 1.12 (Khatib and Bayomy, 1999). Fattuhi and Clark (1996) suggested that the ariations in specific gravity could be due to varying rubber quality and/or experimental errors.

Mineral Aggregates

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and affect economy. The mere fact that aggregates occupy 70~80% of the volume of the concrete, their impact on various characteristics and properties of fresh and hardened concrete is undoubtedly considerable. Aggregates can be classified as i) Normal weight aggregates, ii) Light weight aggregates & iii) Heavy weight aggregates.

Various sizes of coarse aggregate were used in the investigations i.e. 38 mm (Eldin and Senouci, 1993), 19 mm (Ali et al., 1993; Toutanji, 1996), 16 mm (Topcu, 1995) and 10 mm (Fattuhi and Clark, 1996).

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2.2 Influence of Properties of Aggregates on Fresh & Hardened Concrete

- Size and shape of aggregates

  Using the largest possible maximum size will resulting in i) Reduction of cement content ii) Reduction in water requirement , iii) Reduction of drying shrinkage. However, the reduction maximum size of aggregate that can be used in any given condition may be limited by i) Thickness of section, ii) Spacing of reinforcement iii) Clear cover and iv) Mixing, handling and placing technique.

  The shape of aggregate is an important characteristic since it affects the workability of concrete. From the stand point of economy in cement requirement for given water cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strength and some time by greater durability as higher bond characteristics between aggregate and cement paste. Flat/ Flaky aggregates have particularly objectionable influence on the workability, cement requirement, strength and durability.

- Surface Texture of Aggregates

  Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough. As surface smoothness increases, contact areas decreases. Hence, highly polished particle will have less bonding area with the matrix than the rough particle of the same volume. A smooth particle, however, will required thinner layer of paste to lubricate its movement with respect to other aggregate paticles. It will therefore, permit denser packing for equal workability.

- Strength of aggregates

The mechanical properties of aggregates will highly influences the strength of concrete, provided the cement paste of good quality and its bond with aggregates is satisfactory. The specification for Roads and Bridges 2058 gives the requirement of strength of the aggregates for concrete works.

Aggregate Impact Value

With respect to concrete aggregates toughness is usually consider the resistance of materials to failure by impact. IS 283 -1970 specifies the aggregate impact value shall not exceed 45% by weight for aggregate used for concrete other than wearing surface and 30% by weight for concrete for wearing surface such as runways, roads and pavements.

Los Angeles Abrasion Value

Testing the aggregate with respect to wear is an important test for aggregate to be used for road construction. The abrasion value should not be more than 30% for wearing surface and not more than 50% for concrete other than wearing surface.

Modulus of Elasticity

Many studies have been conducted to investigate the influences of modulus of elasticity on properties of concrete. The modulus of elasticity of aggregate will influences the properties of concrete with respect to shrinkage and elasticity behavior and to very small extent creep of concrete. One of the studies indicated that the modulus of aggregate has a decided effect on the elastic property of concrete and the relationship of E of aggregate to that of concrete is not a linear function but may be expressed as equation of exponential type.

- Bulk Density of Aggregates

The higher the bulk density, the lower is the void content to be filled by sand and cement. The sample, which gives the minimum voids, is taken as the right sample of aggregates for making economical mix. The bulk density or unit weight of aggregate gives valuable information regarding the shape and grading of the aggregate. For a given specific gravity, the angular aggregates show a lower bulk density. Bulk density of aggregate is a of interest when we deal light weight and heavy weight aggregate. The parameter of Bulk density is also used in concrete mix design for converting the proportion by weight in to proportion by volume when weigh batching equipments are not available at site.

- Specific Gravity of Aggregates

In concrete technology, specific gravity is made use of in design calculation of concrete mix. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurement. Similarly, the specific gravity of aggregate is required to be considered when we deal with light and heavy weight concrete.

- Absorption and Moisture Content of Aggregates

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water / cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

- Soundness of Aggregates

Soundness refers to the ability of aggregates to resist excessive change in volume as a result of changes in physical condition. These physical conditions that affect the soundness of aggregates are the freezing and thawing, variation in temperature, alternate wetting and drying under normal condition and wetting and drying in salt water. Soundness test is specified in IS (Part V). As a general guide it can be taken that the average loss of weight after 10 cycles should not exceed 12% and 18% when tested with sodium sulphate and magnesium sulphate respectively.

- Thermal Conductivity of Aggregate

Many research works have studied the interaction of aggregates with different coefficient of thermal expansion with that of concrete. If concrete is subjected to high range of temperature differences, the thermal incompatibility between the aggregates and paste or between the aggregate and matrix may introduce serious differential movement and break the bond at the interface of aggregate and matrix. A linear thermal coefficient of expansion of concrete varies from 5.8×10^{-6} Per degree Celsius to 14×10^{-6} Per degree Celsius depending upon type and quantities of aggregate. Similarly, the range of coefficient of thermal expansion of hydrated cement paste may vary from 10.8×10^{-6} Per degree Celsius to 16.2×10^{-6} Per degree Celsius.

2.3 PROPERTIES OF RUBBERIZED CONCRETE (Previous Research Works)

2.3.1 Properties of Fresh Rubberized Concrete

Previous investigations have shown that rubberized concrete possesses good aesthetics, acceptable workability and a smaller unit weight than that of ordinary concrete.

2.3.1.1 Aesthetics

- Eldin and Senouci (1993) reported that rubberized concrete showed good aesthetic qualities. The appearance of the finished surfaces was similar to that of ordinary concrete and surface finishing was not problematic. However, the authors reported that mixes containing a high percentage of larger sized rubber aggregate required more work to smooth the finished surface. They also found that the colour of rubberized concrete did not differ noticeably from that of ordinary concrete.

2.3.1.2 Workability

- Khatib and Bayomy (1999) investigated the workability of rubberised concrete. They observed a decrease in slump with increased rubber aggregate content by total aggregate volume. Their results show that for rubber aggregate contents of 50% by total aggregate volume, the slump was close to zero and the concrete was not workable by hand. Such mixtures had to be compacted using a mechanical vibrator. However, they 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. They also observed that the size of the rubber aggregate and its shape (mechanical grinding produces long angular particles) affected the measured slump. The slump values of mixes containing long, angular rubber aggregate were lower than those for mixes containing round rubber aggregate (cryogenic grindings). Round rubber aggregate has a lower surface/volume ratio. Therefore less mortar will be needed to coat the aggregates, leaving more to provide workability. They suggested that the angular rubber aggregates form an interlocking structure resisting the normal flow of concrete under its own weight; hence these mixes show less fluidity. It is also possible that the presence of the steel wires protruding from the tyre chips also contributed to the reduction in the workability of the mix.

2.3.1.3 Concrete Density

- The replacement of natural aggregates with rubber aggregates tends to reduce the density of the concrete. This reduction is attributable to the lower unit weight of rubber aggregate compared to ordinary aggregate. Previous studies have found that the unit weight of rubberised concrete mixtures decreases as the percentage of rubber aggregate increases.. Eldin and Senouci (1993) reported a reduction in density of up to 25% was observed when ordinary aggregate was replaced by coarse rubber aggregate. Li et al. (1998) found that the density of rubberised concrete was reduced by around 10% when sand was replaced by crumb rubber to the amount of 33% by volume.

2.3.1.4 Air Content

- Ali et al. (1993) reported that when rubber aggregate was added to the concrete, the air content increased considerably (up to 14%). Fedroff et al. (1996) and Khatib and Bayomy (1999) observed that the air content increased in rubberised concrete mixtures with increasing amounts of rubber aggregate. Although no air-entraining agent (AEA) was used in the rubberised concrete mixtures, higher air contents were measured as compared to control mixtures made with an AEA (Fedroff et al., 1996).
- The higher air content of rubberised concrete mixtures may be due to the non-polar nature of rubber aggregates and their ability to entrap air in their jagged surface texture. When non-polar rubber aggregate is added to the concrete mixture, it may attract air as it repels water. 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 of 1.14, it can be expected to sink rather than float in the fresh concrete mix. However, if air gets trapped in the jagged surface of the rubber aggregates, it could cause them to float (Nagdi, 1993). This segregation of rubber aggregate particles has been observed in practice.

2.3.2 Properties of Hardened Rubberized Concrete

Previous investigations of hardened rubberized concrete focused on Impact Resistance, Durability, and Deformability and Strength properties of concrete. Some preliminary studies have also been carried out to investigate ITZ microstructure and dynamic properties of rubberized concrete.

2.3.2.1 Impact Resistance of Rubberized Concrete

- **H.E.M. Sallam, A.S.Sherbini, M.H.Seleem and M.M. Balaha** conducted an experiment to study impact resistance of rubberized concrete containing 10%, 20% and 30% by volume of aggregate as a partial replacement of sand. They conducted the tests on specimens containing with and without silica fume. The simplest of the impact tests was the “repeated impact” drop – weight test. The test yielded the number of blows necessary to cause the prescribed level of distress in the test specimen (First and Failure Crack). The number served as a qualitative estimate of the energy absorbed by the specimen at the levels of distress specified.

The statistical analysis of the results of first and failure crack are made on table given below.

Specimen	Rubber %	Silica Fume %	Mean blows to first crack	Mean blows to Failure Crack	Coefficient of Variance
C	0	0	35	37	1.74
SC		10	39	39	1.20
R1	10	0	290	300	1.21
SR1		10	62	65	1.80
R2	20	0	67	72	3.58
SR2		10	177	189	1.40
R3	30	0	140	147	2.32
SR3		10	63	72	1.32


Plain Concrete


Rubberized Concrete

It is clear from the table that there is a wide discrepancy in the results for all rubber replacement ratios. The addition of silica fume has not clear effect on the resistance of concrete to crack initiation under impact compression load. The replacement of sand by crumb rubber increased the resistance of concrete to crack initiation under impact compression. The ACI impact test failed to differentiate between the rubberized concrete with different content of rubber aggregate.

2.3.2.2 Toughness and Failure Mode

- Previous investigators have suggested that rubberised concrete exhibits enhanced toughness and a less brittle failure mode. Eldin and Senouci (1993) showed that when loaded in compression, specimens containing rubber did not exhibit brittle failure. A more gradual failure was observed, either of a splitting (for coarse rubber aggregate) or a shear mode (for fine crumb rubber). It was argued that since the cement paste is much weaker in tension than in compression, the rubberised concrete specimen containing coarse rubber aggregate would start failing in tension before it reaches its compression limit. The generated tensile stress concentrations at the top and bottom of the rubber aggregate result in many tensile microcracks that form along the tested specimen. These microcracks will rapidly propagate in the cement paste until they encounter a rubber aggregate particle. Because of their ability to withstand large tensile deformations, the rubber aggregate will act as springs delaying the widening of cracks and preventing full disintegration of the concrete mass. The continuous application of the compressive load will cause generation of more cracks as well as widening of existing ones. During this process, the failing specimen is capable of absorbing significant plastic energy and withstanding large deformations without full disintegration. This process will continue until the stresses overcome the bond between the cement paste and the rubber aggregates.
- Similar observations were made by Khatib and Bayomy (1999).
- Tantala et al. (1996) conducted a comparative study of the toughness of a control concrete and rubberized concrete with 5 and 10% rubber by volume of coarse aggregate. It was found that the toughness of both rubberized concrete mixtures was higher than that of the ordinary concrete. However, the toughness of the rubberized concrete with 10% buff rubber was lower than that of the rubberised concrete with 5% buff rubber because of the decreasing ultimate compressive strength. They also found that acid etching of rubber aggregate replacing the coarse aggregate lowered the toughness of rubberised concrete.

Results by Topcu and Ozcelikors (1991) show that 10% rubber-chip addition increased the toughness of concrete by 23%.

2.3.2.3 Deformation Property of Rubberized Concrete

- **Gintautas SKRIPKIUNAS, Audrius GRINYS, Benjaminas CERNIUS** investigated the effect of rubber aggregate on deformation properties under the static and dynamic load of concrete. Concrete mixtures with the same compressive strength as concrete without rubber aggregate additive were tested. The rubber additive was used as fine aggregate replacement in concrete mixtures by 3.2% of aggregate mass. Transducer for the longitudinal deformations measurement was attached on a special frame. The specimen was loaded until $f_c/3$. Concrete Prism (100 x 100 x 300) were loaded by cyclic stress with compressive strain by 1 N/mm^2.

Concrete static modulus of elasticity for investigated specimen is shown in table.

Concrete Properties	Concrete Mixture Slump, cm	Air Entrainment %	Prismatic Compressive Strength, MPA	Density Kg/ m3	Modulus of Elasticity, GPA	
					Static	Dynamic
With rubber additive	19	3.6	43.84	2342	29.58	37.04
Without rubber additive	19	3.0	44.49	2362	33.17	37.98

It was observed that the addition of rubber particles is effective mean for reduction of concrete modulus of elasticity and increasing deformability of concrete. The reduced both static and dynamic modulus of elasticity in concrete with waste rubber aggregates may be explained by low modulus of elasticity of small rubber which is much lower than fine aggregate.

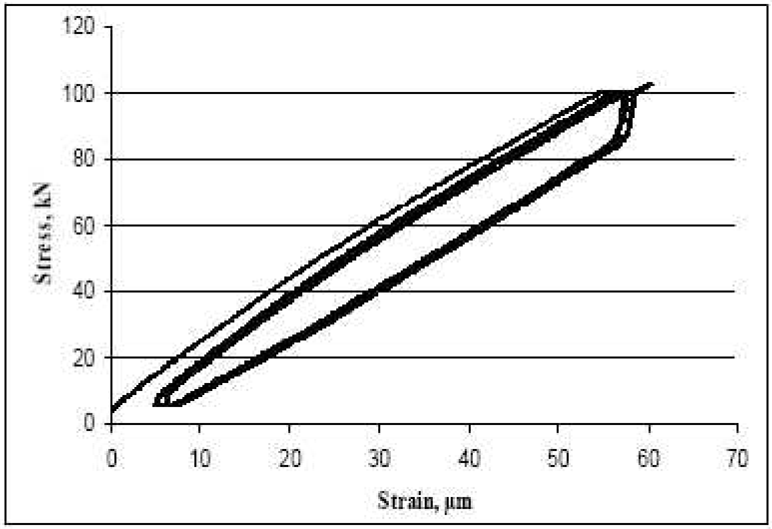

Fig. 1. Stress-strain relationship for concrete without rubber waste

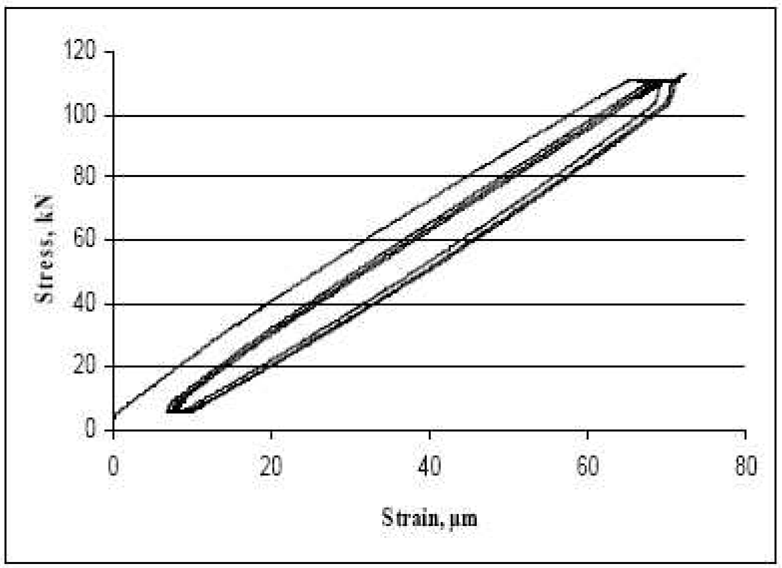

Fig. 2. Stress-strain relationship for concrete with rubber waste

Strains of Concrete with the same Compressive strength with rubber waste from used tyres(3.2 % from aggregate by mass) deformations are 56% - 63% higher after the static loading, while set deformations after the unloading is 219% - 360% higher than for the non rubberized concrete. Ultimate strains on concrete failure load are 36% - 47% higher for concrete with tyre rubber waste additive.

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

2.3.2.4 Durability Property of Rubberized Concrete

- **Ilker Bekir Topku and Abdulah Demir** performed an experiment to determine the durability property of concrete, including aggregate of discarded car tyres under environmental conditions. The effect of Freeze-Thaw action and temperature were investigated for concrete specimen with 10, 20, and 30% rubber aggregate in volume.

➢ Freeze and Thaw Effect on concrete

The specimens produced were exposed to 30 freeze-thaw cycles according to ASTM C 666 (1997). After freeze-thaw on the concrete with different rubber ratios,compressive strength experiments were performed. Cubes and Cylinders were prepared and tested for compressive strength under both exposed and non exposed to freeze – thaw conditions. It was found that the decreased percentages of compressive strength for all specimens was less in case of rubberized concrete under freeze-thaw action as shown in figure. The study of results of the specimens exposed to rapid freeze-thaw in Fedroff et al. (1996) are also included in figure. For these specimens, higher compressive strength decrease is observed.

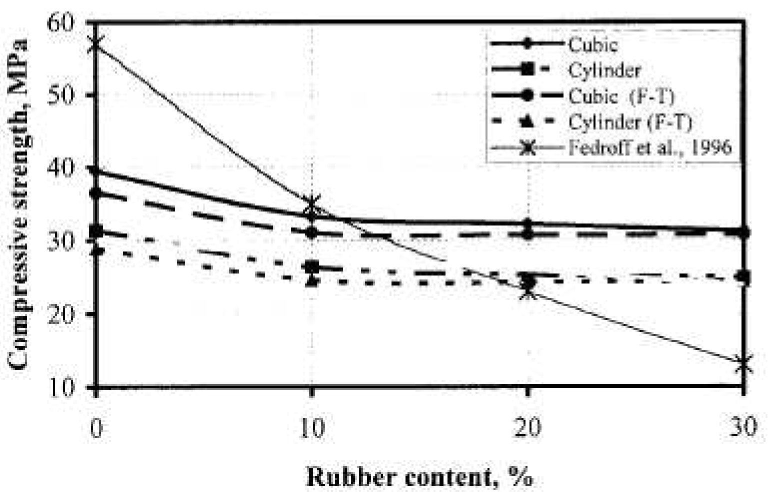

Fig. Change of compressive strengths with rubber content in freeze-thaw

Based on these results, it was determined that the damage as a result of freeze-thaw in the concrete of the RC-10 set was less than the damage the damage in control concrete. Thus, in spite of the decrease in compressive strength because of the increase in rubber ratio in it, an increase was observed in durability against freeze-thaw of RC-10 set concrete specimen.

➢ The decrease in the weights of the concrete specimens with different ratios of rubber additions was found as follows: In cylindrical specimens not exposed to freeze-thaw with 10, 20, and 30% rubber additions, respectively 1.44, 1.96 and 2.56% ; in the cubic specimens 2.43, 2.95, 2.89%, In cylinders exposed to freeze-thaw 1.5, 2.1 and 2.7% and in cubes exposed to freeze – thaw 2.3, 2.6, and 2.8%. It is clear from the results that when freeze – thaw durability is evaluated according to weight loss, the concrete specimen with RC-10 set gave better results. The research revealed that depending on the increase in cycles the difference between freeze-thaw durability according to weight loss also increases and this increase is clearer in cubic specimens.

Effect of High Temperature

The rubberized concrete were prepared by incorporating 10, 20 and 30% rubber aggregate by volume and the specimens were exposed to temperatures of 20, 150, 300 and 400 degree centigrade for 3 hours and then left to be air-cooled while their physical and mechanical properties were monitored and evaluated as their temperature decreased.

The rubber ratio increases in specimens containing 10, 20 and 30% rubber aggregate by volume are , respectively, 30, 55, and 75% in 20^0 C ; 28, 56, and 72% in 150^0 C ; 35, 53, and 69% in 300^0 C ; 44, 67, in 400^0 C ; and for each temperature in their compressive strengths, decreases according to their control specimens were observed . As seen in figure, in 300^0 C there is an increase in the compressive strength of each specimen. It is considered that the reason for this is that hydration of the mortar is completed in this temperature.

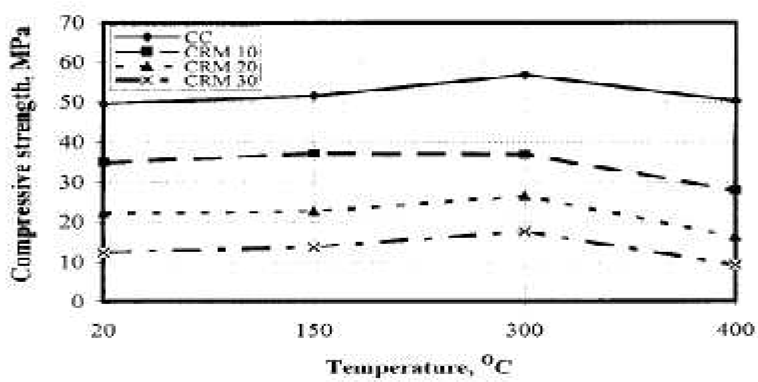

Fig. 8. Change of compressive strength with temperature increasing

- In conclusion related to this study, it was determined that, in terms of durability, use of concrete with the optimum amount of rubber aggregate to produce concrete, that is 10% in volume, is good for recycling.

2.3.2.5 Heat and Sound Insulation Property

- It can be expected that acoustic testing would substantiate the applicability of rubberised concrete for sound barriers to reduce the effects of acoustic emissions (Tantala et al., 1996). Wisconsin and Pennsylvania Departments of Transportation (DOTs) have studied the noise-absorption properties of whole rubber tyres as sound barriers with moderate success (Tantala et al., 1996). More research is required to study the sound insulation effects of rubberised concrete in buildings and other structures.
- The inclusion of rubber in concrete should also make the material a better thermal insulator, as suggested by Tantala et al. (1996), which if demonstrated could be very useful for meeting energy conservation requirements. However, there are currently no projects reported in the literature which investigate this possibility. In addition, fire tests carried out by Topcu and Avcular (1997) indicated that the flammability of rubber in rubberised concrete mixtures was much reduced by the presence of cement and aggregates. Although more testing is needed, it is believed that the fire resistance of rubberised concrete is satisfactory.

2.3.2.6 Mechanical Strength Testing

- Previous investigations have shown that the addition of rubber aggregate into the OPC concrete mixture produces a reduction in the mechanical strength of the rubberized concrete. It was found that the reduction in concrete strength increased with increasing the rubber aggregate volume content. Eldin and Senouci (1993) conducted experiments to examine the strength and toughness of rubberised concrete mixtures. Three sets of experiments were performed, the first set using coarse rubber aggregate (chipped tyres) of 19-38 mm size and the second and third sets using smaller diameter chips of 6 mm and 2 mm respectively. They found that when mixed with cement the rubber aggregate tends to act as a large void and did not have a significant role in the resistance to applied external loading. The compressive and tensile strengths of the concrete were strongly dependent on the volume of rubber aggregate. Reductions in strength of up to 85% of the compressive strength and 65% of the tensile were observed when the coarse aggregate was fully replaced by rubber aggregate. A smaller reduction in compressive strength (65%) was observed when sand was fully replaced by fine crumb rubber. The authors suggested that there is good potential for using recycled rubber in OPC concrete mixtures because the rubber increases the fracture toughness.

- Khatib and Bayomy (1999) used two types of rubber aggregate in their investigation , crumb rubber and tyre chips (coarse rubber aggregate). They found that the 28 days compressive strength of rubberised concrete mixtures was reduced by 93% when coarse aggregate was fully replaced by tyre chips and by 90% when fine aggregate was fully replaced by rubber crumb. They also found that the flexural strength of rubberised concrete decreased with increasing rubber aggregate content in a manner similar to that observed for the compressive strength.

Effect of Surface Texture of Rubber Aggregate

- Various studies have suggested that the rougher the rubber aggregate used in concrete mixtures the better the bonding developed between the particles and the surrounding matrix, and therefore the higher the compressive strength achieved. Tantala et al.(1996) argued that if the bond between rubber aggregate and the surrounding cement paste is improved, then significantly higher compressive strength of rubberized concrete could be obtained and to achieve enhanced adhesion, it is necessary to pretreat the rubber aggregate. However, Segre and Joekes (2000) suggested that low cost procedures and reagents should be applied in the process of surface treatment of rubber aggregate to minimise the final cost of the material.

- Pre-treatments vary from washing rubber aggregate with water to acid etching, plasma pre-treatment and various coupling agents (Tantala et al., 1996). The acid pretreatment involves soaking the rubber aggregate in an acid solution for 5 minutes and then rinsing it with water. As observed through a microscope, the pre-treatment of rubber aggregate with acid increased the surface roughness of rubber, which improves its attachment to the cement paste.
- Rostami et al. (1993) attempted to clean the rubber using water, water and carbon tetrachloride (CCL4) solvent and water and a latex admixture cleaner. Results show that concrete containing washed rubber aggregate achieved about 16% higher compressive strength than concrete containing untreated rubber aggregates. A much larger improvement in compressive strength (about 57%) was obtained when rubber aggregates treated with CCL4 were used.
- Li et al. (1998) employed coating the rubber with Methocel cellulose ether solution, a water-soluble polymer derived from cellulose. Little improvement was observed when using rubber aggregate coated with Methocel. The use of Methocel reduced the compaction of the fresh concrete due to the high viscosity of the rubberised solution. This coating might also hinder the further hydration of the cement during curing and thus further affect the strength of the concrete.
- Segre and Joekes (2000) surface-treated rubber aggregates with saturated sodium hydroxide (NAOH) aqueous solution for 20 minutes at room temperature. Abrasion resistance experiments were performed with test specimens containing plain rubber aggregate or NAOH-treated rubber. The results show that the mass loss of specimens containing NAOH-treated rubber was significantly lower than that of the specimens containing plain rubber aggregate. According to the authors, these results show the increased adhesion obtained by treatment of the rubber aggregate.

Effect of Using Special Cements

- A study conducted by Biel and Lee (1996) suggests that the type of cement used in the rubberised concrete mixtures greatly affects the mechanical strength. Recycled tyre rubber aggregates were used in concrete mixtures made with both Magnesium

Oxychloride Cement (MOC) and Ordinary Portland Cement (OPC). The percentage of fine aggregate substitution ranged from 0 to 90%, increasing by 15% for each set. It was observed that 90% loss of the compressive strength occurred for both the OPC rubberised concrete and MOC rubberised concrete when rubber replaced 90% of the fine aggregate (25% of the total aggregate). Whether with or without rubber aggregate inclusion, the MOC concrete exhibited approximately 2.5 times the compressive strength of the OPC concrete. The OPC concrete samples containing 25% of rubber by total aggregate volume retained 20% of their splitting tensile strength after initial failure, whereas the MOC concrete samples with similar rubber content retained 34% of their splitting tensile strength after initial failure. The ratio of the MOC rubberized concrete tensile strength to OPC rubberised concrete tensile strength rose from 1.6 to 2.8 with increased amounts of rubber. They argued that the high-strength and bonding characteristics provided by Magnesium Oxychloride Cement greatly improved the performance of rubberised concrete mixtures and that structural applications could be possible if the rubber content is limited to 17% by total volume of the aggregate.

Summary of the Literature Review

- The previous research shows that the rubberized concrete is aesthetically good, can be finished close to same standard with lower content of rubber and has lower unit weight.
- It was also found that the toughness of rubberized concrete was higher than that of ordinary concrete. The specimen was capable of absorbing significant plastic energy and withstanding large deformations without full disintegration.
- The rubberized concrete has high resistance of impact; the replacement of sand by crumb rubber increases the resistance of concrete to crack initiation under impact compression.
- The incorporation of rubber aggregate into concrete cause reduction of concrete modulus of elasticity and increasing deformability of concrete. Ultimate strains on concrete failure loads are 36%-47% higher for concrete with tyre rubber additives.
- The damping capacity of concrete seemed to be decrease with increase in rubber content.
- In spite of the decrease in compressive strength because of the increase in rubber ratio in it, an increase was observed in durability against freeze-thaw . There was an increase in compressive strength under the effect of high temperature.
- The previous studies have shown that the inclusion of rubber aggregate in concrete as a full or partial replacement for natural aggregates reduces the compressive strength of the concrete. These studies also indicate that the mechanical strength of rubberized concrete is greatly affected by the size, proportion and surface texture of the rubber aggregate and the type of cement used. This strength reduction can be expected primarily because rubber aggregate is much softer (elastically deformable) than the surrounding cement paste. Secondly, the bonding between the rubber aggregate and the cement paste is highly likely to be weak, so that soft rubber aggregate may be viewed as voids in the concrete mix. It has also been recognized that, in general, the strength of concrete depends greatly on the density, size and hardness of the coarse aggregate.

Due to better capacity in absorbing significant plastic energy and withstanding large deformation, high resistance to Impact, improved durability, low unit weight and improved acoustic and thermal insulation; but reduced mechanical strength of rubberized concrete; it was, therefore, decided to prevent too great loss in compressive strength in this present study so that the rubberized concrete can be used at least in non- primary structures such as road and bridge barriers, wall panels (concrete block).

Previous studies have investigated the use of special cements and surface treatment of rubber aggregate particles to improve the compressive strength of the concrete. However, there is no doubt that use of additives and surface treatment processes will significantly increase the production costs of rubberized concrete and thereby discourage the use of the material. The effect of content of rubber for its proper applications was investigated considering the simplicity in construction work. The effect of coating the aggregate particles with cement paste was also investigated as a potentially simple method of improving the performance of the material, thereby avoiding the use of additional or costly additives which may adversely affect the production costs.

CHAPTER : THREE

3.0 Methodology

The aim of the study was to produce rubberized concrete with sufficient strength to be used in a variety of structural applications. A thorough study of literature regarding the test of impact resistance, durability, toughness, deformability of rubberized concrete was done. The results of those tests are referred to identify the potential applications of rubberized concrete in civil works.

Most of the structures in Nepal are designed taking M20 concrete. So, A 20 MPa target compressive strength was used to design the control mixes, and the mixes were designed according to Indian Standard SP23: 1982 (Design of concrete mix). While doing mix design for control concrete, certain percentage by volume of coarse aggregate was replaced by rubber aggregate and other conditions remain same for other materials for comparing the properties of rubberized concrete with respect to control plain concrete.

3.1 Mechanical Properties of Materials

The materials used to develop the concrete mixes in this study were fine aggregate, coarse aggregate, rubber aggregate, water and cement.

Cement

PPC Jaypee Buland cement (55 MPA) cement was used for two set of tests during investigation. The initial and final setting time of cement used was 210 minutes & 350 minutes. The 7 and 28 days compressive strength observed was 27 MPA & 38 MPA respectively.

Ordinary Portland Cement of Brand Jagadamba 53 grade was used for one set of the investigation.. The initial and final setting time of cement used was 140 minutes & 250 minutes. The 7 and 28 days compressive strength observed was 25.73 MPA & 34 MPA respectively.

The specific gravity of both of cement was taken as 3.15.

Water

Water used in tests was distilled water free from any deleterious chemical.

Aggregate

i.) Fine aggregate

The Sand used in tests was from Tinau river, Butwal. It was washed and air dried in the Laboratory. The gradation and clay content test were performed and it was found that the sand used was conforming grading zone II of IS and free from clay content. The specific gravity of sand was taken 2.72 .

ii.) Coarse aggregate

The coarse aggregate used was river aggregate from Tinau river, Butwal conforming to 100% passing through 20 mm sieve and retained on 10 mm sieve. The specific gravity was taken 2.64. Test for determination of aggregate crushing value & loss angeles value were conducted & it was found 21% & 22% respectively. The coarse aggregate was of more or less rounded in shape.

The crushed aggregate of size 20 mm & 10 mm from Muktinath crusher Udyog, Butwal was also used for one set of test during investigation. The specific gravity was found to be 2.62. Test for determination of aggregate impact value & loss angeles value were also conducted & it was found 23% & 24% respectively. The coarse aggregate was angular in shape.

iii.) Rubber aggregate

Coarse rubber aggregate (tyre chips) of 20 mm passing and 10mm retained was used in this investigation. The rubber aggregate was achieved through cutting of used tyres of four wheel pickup. The shape of rubber aggregate was irregular with specific gravity of 1.08. The crushing value and loss angeles abrasion value was very low in compare to coarse aggregate. and it was 0.77% & 1.2%.

3.2 Concrete Mix Design

Concrete without rubber aggregate was used as the control concrete. Three mixes were designed with a targeted compressive strength of 20 MPa and the design was carried out according to Indian Standard SP 23 : 1982 (Concrete Mix Design). The mix proportions vary in each case due to use of two different types cement, aggregates (round and crushed), specifically the water/cement ratio .The mixture proportions of the basic ingredients i.e. cement, water, coarse aggregate and fine aggregate for each set of tests, were the same for the control concrete and rubberised concrete.

Three mix designs namely, A, B and C were prepared for this investigation. For Mix A, the mix ratio of cement: fine: coarse: water = 1: 1.35 : 3.61 : 0.48 was used as per mix design calculation. Likewise, for Mixes B and C, the mix ratio of cement: fine: coarse: water 1: 1.136 : 3.34 : 0.44 and 1: 1.47 : 2.95 : 0.48 were used . Coarse aggregate of 10-20 mm size (rounded) and Jaypee Buland 55 MPA Cement was used in Mixes "A" ,where as Jagdamba OPC Nepali cement was used for mix "B". Similarly, Crushed aggregate 10- 20 mm size with Jaypee Buland 55 MPA Cement was used for Mixes "C".

Table 3.1 shows the quantities of the constituents of the three control mix designs, A, B and C for one cubic metre of concrete. Each of the control mixes formed the basic preparation of two groups of rubberised concrete mixes, groups C and P. For group C, the coarse aggregate of the control mix was replaced by rubber aggregate coated with cement paste. For group P, plain rubber aggregate replaced the coarse aggregate of the control mix. For each group, three batches were made in which the 10-20 mm coarse aggregate was replaced by rubber aggregate at 10, 25 and 40% by volume of 20 mm aggregate. No mineral or chemical admixtures were added.

Table 3.2 summarises the rubber contents for rubberised concrete mixes.

Table 3.1 Mix proportions of the control mixes

Materials	**Mix Proportions (Kg / m3)**		
	A (w/c: .48)	**B (w/c : 0.44)**	**C (w/c : 0.48)**
Jaypee Buland 55 MPA (PPC)	367.917		399.125
OPC Jagdamba 53 grade		401.36	
Fine Aggregate (grade II)	496.77	456.00	586.75
Water	176.6	176.6	191.58
Coarse Aggregte (rounded)	1330.469	1342.04	
Coarse aggregate (Crushed)			1177.42

Table 3.2 Summary of Rubber Contents for Rubberized Concrete Mixes

Mixes	**Group**	**Specimen Coding**	**% of rubber**
A (w/c: 0.48)	Control	A	0
	P	AP 10	10
		AP 25	25
		AP 40	40
	C	AC 10	10
		AC 25	25
		AC 40	40
B (w/c : 0.44)	Control	B	0
	P	BP 10	10
		BP 25	25
		BP 40	40
	C	BC 10	10
		BC 25	25
		BC 40	40
C (w/c : 0.48)	Control	C	0
	P	CP 10	10
		CP 25	25
		CP 40	40
	C	CC 10	10
		CC 25	25
		CC 40	40

3.3 Mix Preparation

Rubber aggregates coated with cement paste were produced as follows. The rubber aggregates were first immersed in water for 24 hours until all particles were fully saturated (wetted both inside and surface). The plain rubber aggregate was then taken to the saturated surface dry (SSD) condition by spreading them in a thin layer on a wooden board and leaving them to air-dry for 24 hours. In this condition, the rubber aggregate can absorb no more water without a film of water forming on the surface, thus requiring no alteration to the quantity of mixing water (Murdock et al. 1991). The rubber aggregates were then thoroughly coated with a thin layer of cement paste, a mixture of cement powder and water. The coated rubber aggregates were then air-dried by spreading them on a wooden board for about 24 hours. The rubber aggregate particles, plain and coated with cement paste, are shown in Fig.3.1 & 3.2

Fig. 3.1 Plain Rubber Aggregate

Fig. 3.2 Rubber Aggregate Coated with Cement

All mixtures were mixed in a conventional tray manually. Mixing procedures were the same for all of the concrete mixes. First of all, cement and sand were mixed thoroughly. The coarse aggregate and rubber aggregate were mixed separately and then mixed with cement sand mix. Water was then added gradually to the mix for a period of 2 minutes and followed by mixing for 5 minutes to produce a uniform mix.

Standard 150 mm cubes, cylinders (150 mm diameter x 300 mm long) and beams (100 mm x 100 mm x 400 mm) specimens were prepared for compressive strength, splitting tensile strength and flexural strength respectively. Moulds were filled with fresh concrete in three layers and vibrated on a vibrating table to drive out air trapped in the mix. Immediately after casting, the specimens were covered with a polythene sheet to prevent water evaporation. The specimens were then demoulded 24 hours later and cured in a water tank at a room water temperature.

3.4 Workability Tests

The SLUMP tests were conducted to assess the workability of the fresh plain concrete and the concrete containing rubber aggregates accordance with IS 1199. The mould for the slump test is in the form of a frustum of a cone, which is placed inside a hollow cylinder on the top of a table. The mould is filled in three equal layers and each layer is tamped 25 times with a tamping rod. Surplus concrete above the top edge of the mould is struck off with the tamping rod. The cone is immediately lifted vertically and the amount by which the concrete sample slumps is measured. The value of the slump is obtained from the distance between the underside of the round tamping bar and the highest point on the surface of the slumped concrete sample. The types of slump i.e. zero, true, shear or collapsed are then recorded.

3.5 Mechanical Properties of Rubberised Concrete

This section describes the test programme to establish the mechanical properties of the various rubberized concrete mixes .

3.5.1 Test Programme

The following tests were carried out to establish the mechanical properties of rubberized concrete:

- Compressive strength,
- Splitting tensile strength,
- Flexural strength,

The above three properties were determined using British Standard testing equipment and procedures, as outlined below.

i.) Compressive strength

The compressive strengths of concrete specimens were determined after 7 and 28 days of standard curing. A 1000 KN capacity Contass compression testing machine (Western Regional Road Laboratory, Butwal) was used for determining the maximum compressive loads carried by various cubes.

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ii.) Splitting tensile strength

The splitting tensile strengths of concrete specimens were determined after 14 days of standard curing. The tests were carried out by splitting the cylinders in the machine used for compressive testing in accordance with Indian standard. The testing machine was fitted with an extra bearing bar to distribute the load along the full length of the cylinder. From the maximum applied load at failure the splitting tensile strength is calculated as follows:

$$\sigma = 2F/\pi ld$$

where σ = splitting tensile strength, N/mm^2

F = maximum applied load in N

l = length of cylinder in mm

d = diameter in mm

iii.) Flexural strength

The flexural strengths of concrete specimens were determined after 7 and 28 days of standard curing. Direct measurement of tensile strength of concrete is difficult. Neither specimen nor testing apparatus have been designed which assure uniform distribution of the 'pull'applied to concrete. While a number of investigation involving the direct measurement of tensile strength have been made, beam tests are found to be dependable to measure flexural strength property of concrete. The beams of sizes 10 x 10 x 40 cm were tested in the laboratory. The systems of loading used in finding out the flexural tension were central point as well as third point loading. In this test, a load is applied through two rollers at the third points of the span until the specimen breaks. Under these conditions, the lower surface of the beam is in tension. The beam fails by the growth of a crack from the tensile zone through the concrete. Using standard beam formulae, the failure stress can be calculated from the beam dimensions and the failure load.

CHAPTER : FOUR

4.0 Observation, Test Results & Analysis

Characteristics of fresh rubberized concrete

4.1 Workability of the Mixes

- **Test Results**

The degree of workability of the control mixes for all the three mixes were found in the range of medium as per IS code. However, the value was high in case of round aggregate. Similarly, the degree of workability of rubberized concrete varies from medium to low according as the increment of incorporation of rubber aggregate. The result showed that the increasing the percentage of rubber aggregate reduces the workability of concrete, with a rubber content of 40% producing a low slump value. Workability of rubberized concrete was found to be increased using cement coated rubber aggregate as compared to plain rubber aggregate. The test results of workability test for all the three mixes for control and rubberized concrete are summarized in Table 4.1.

- **Analysis of Results:**

The reduction in the workability of the concrete can be attributed to a combination of lower unit weight of the wet mix and higher friction between the rubber aggregate and the mixer due to rough surface texture and irregular (polygonal) shape of rubber aggregate. The irregular rubber aggregate has higher surface area / volume ratio and more mortar is needed to coat the aggregates to make the flow normal.

4.2 Unit Weight of Mixes

- **Test Results**

The results obtained showed that there is reduction in unit weight of concrete as the percentage of rubber aggregate increases as compared to control mix. The reduction in unit weight upto 3.12% was observed replacing 10% of mineral aggregate by rubber aggregate. A reduction of unit weight up to 10.84% in case of cube & 10.5% in case of cylinder were observed when 40% by volume of the coarse aggregate was replaced by rubber aggregate.

The unit weight of cubes and cylinders prepared for testing of mechanical properties of concrete are summarized in Table 4.2

- **Analysis of Results:**

  The low value of unit weight of rubberized concrete is observed due to low specific gravity of rubber chips.

Characteristics of hardened rubberized concrete

4.3 Mechanical Properties of Rubberised Concrete

This section describes the results of the test programme to establish the mechanical properties of the various rubberized concrete mixes detailed in the preceding section.

4.3.1 **Compressive Strength**

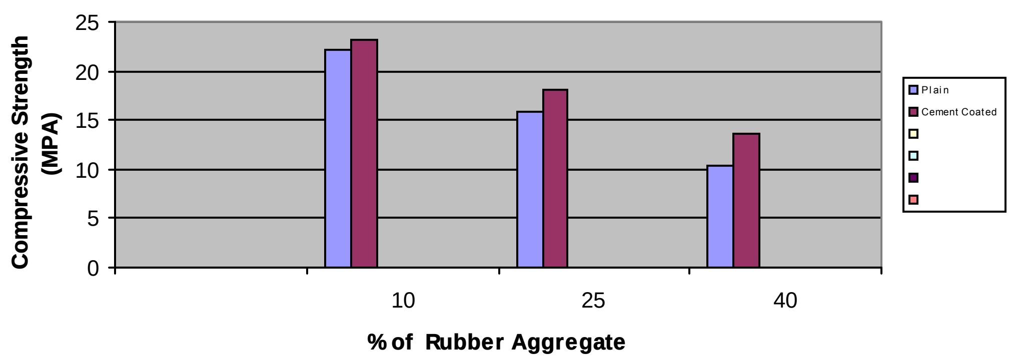
- **Test Results**

The test results are summarized in Tables 4.3 and presented in Figures 4.1 – 4.2. The 28 days Compressive Strength of concrete containing 0, 10, 25 and 40% of plain rubber aggregate by volume for Mix A, is 27.85, 20.88, 16.52 and 12.74 MPA, for Mix B is 27.19, 20.59, 15.93 and 12.30 MPA, for Mix C is 31.26, 22.07, 15.78 and 10.44 MPA respectively. The 28 days Compressive Strength of concrete containing 0, 10, 25 and 40% of cement coated rubber aggregate by volume for Mix A, is 27.85, 22.52, 16.08, and 14.29 MPA, for Mix B is 27.19, 21.63, 14.74 and 12.81 MPA, for Mix C is 31.26, 23.11, 18.00 and 13.70 MPA respectively.

❖ **Analysis of Results:**

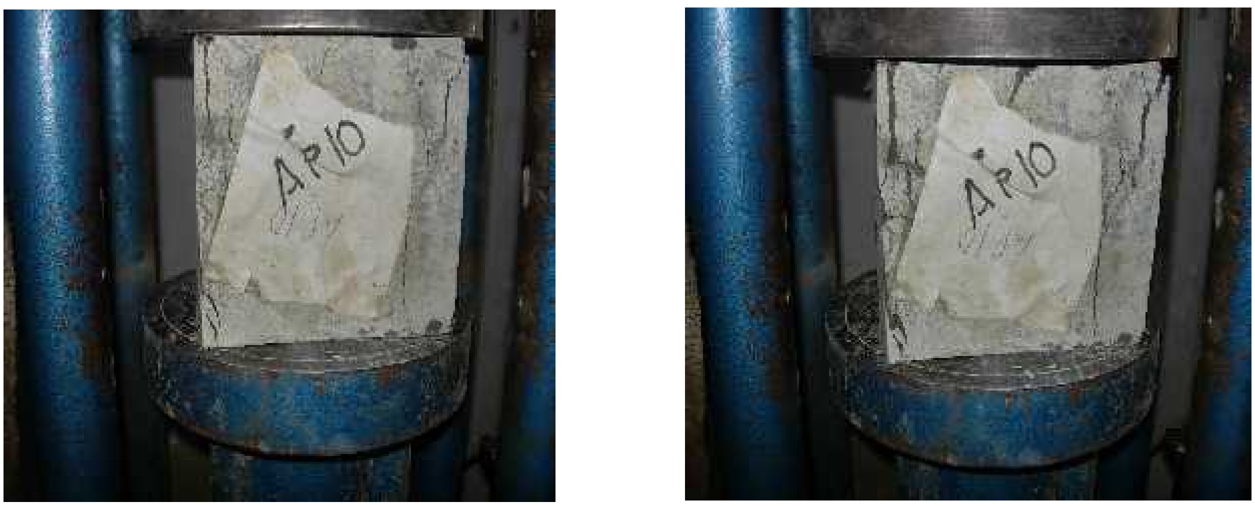
- The 28 days of compressive strength of all the three control mixes are similar and exceeds target strength (27 MPA). The compressive strength of mixes C seems to be high as compared to mixes A & B (Table 4.3 & Fig. 4.1 & 4.2) , which is probably due to use of Indian Jaypee cement having high strength as well as crushed aggregate with rough surface than rounded aggregate with polished surface. The results also showed that there is significant reduction in concrete compressive strength of rubberized concrete as compared to control concrete. It is also observed that the reduction increased with increasing percentage of rubber aggregate. Table 4.4 & Fig. 4.3 & 4.4 showed the percentage loss of compressive strength with different content of plain rubber aggregate. Losses of compressive strength upto 54.25% for mix A was observed when 40% of coarse aggregate was replaced by plain rubber aggregate. Similarly, the percentage of losses for Mix B and Mix C using 40% of rubber aggregate were 54.76% and 66.60%. Likewise, for rubberized concrete using 40% of rubber aggregate coated with cement, the losses upto 48.69% (Mix A), 52.89% (Mix B) and 56.17% (Mix C) were observed. But the losses of strength were found to be below 25% for rubberized concrete containing 10% rubber aggregate. and the average increment is 5.87% and 15.84% for rubberized concrete containing 10 and 40% by volume of coated rubber aggregate(Table 4.5 and Fig 4.5 & Fig. 4.6).

Figure 4.6: Variation of Compressive Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate , Mix C



- There is variation in compressive strength of rubberized concrete with same content of plain rubber aggregate and rubber aggregate coated with cement. Fig. 4.5 and 4.6, Table 4.5 showed the variation in the strength. The result shows that coating the river aggregate with cement paste increases the compressive strength and reduces the percentage loss of strength as compared to control concrete and the average increment is 5.87% and 15.84% for rubberized concrete containing 10 and 40% by volume of coated rubber aggregate.

Fig 4.7: Failure Mode of Concrete Cubes under Compressive Loading



Sample AP10

Sample AC 25

- Figure 4.7 shows the failure mode of concrete cubes using rubber aggregate. Remarkable change in compressive failure behavior was observed visually with rubberized concrete. There was no brittle failure as in case of control mix. Further loading shows that there were a number of alternative cracks developed instead of increasing crack width of existing and it is therefore decided that rubberized concrete does not exhibit brittle failure.

4.3.2 Splitting Tensile Strength

- **Test Results**

The test results are summarized in Tables 4.6 and presented in Figures 4.8 – 4.9. The 28 days tensile strength of concrete containing 0, 10, 25 and 40% of plain rubber aggregate by volume for Mix A, is 2.88, 2.40, 1.53 and 1.15 MPA, for Mix B is 2.69, 2.19, 1.32 and 1.18 MPA, for Mix C is 3.02, 2.52, 1.53 and 1.20 MPA respectively. The 28 days Compressive Strength of concrete containing 0, 10, 25 and 40% of cement coated rubber aggregate by volume for Mix A, is 2.88, 2.43, 1.60, and 1.25 MPA, for Mix B is 2.69, 2.24, 1.39, and 1.25 MPA, for Mix C is 3.02, 2.55, 1.67 and 1.34 MPA respectively.

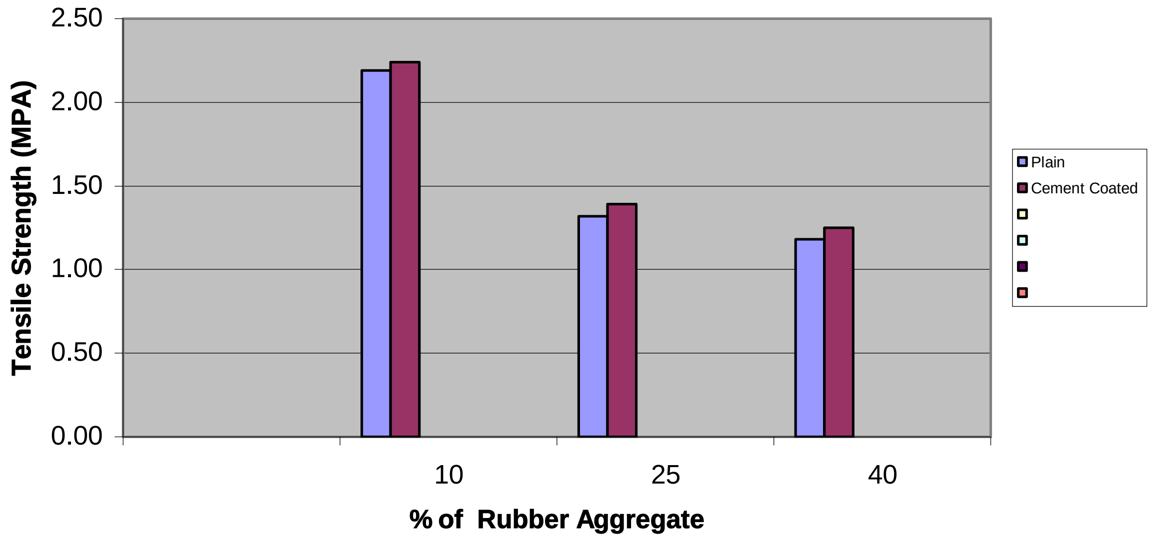
- **Analysis of Results:**

The Splitting Tensile strength of mixes C seems to be little high as compared to mixes A & B (Table 4.6 & Fig. 4.8 & 4.9) , which is probably due to use of Indian Jaypee cement having high strength as well as crushed aggregate with rough surface than rounded aggregate with polished surface. The results also showed that there is significant reduction in concrete tensile strength of rubberized concrete as compared to control concrete. It is also observed that the reduction increased with increasing percentage of rubber aggregate.

Table 4.6 & Fig. 4.10 & 4.11 showed the percentage loss of tensile strength with different content of plain rubber aggregate. Losses of tensile strength upto 60.07% for mix A was observed when 40% of coarse aggregate was replaced by plain rubber aggregate. Similarly, the percentage of losses for Mix B and Mix C using

40% of rubber aggregate were 56.13% and 60.26%. Likewise, for rubberized concrete using 40% of rubber aggregate coated with cement, the losses upto 56.60% (Mix A), 53.53% (Mix B) and 55.63% (Mix C) were observed. The average loss of strength was found to be 17.60, 49.05 and 58.82% for rubberized concrete containing 10, 25 and 40% of plain rubber aggregate. Similarly, average loss was 15.97, 45.82 and 55.25% in case of using cement coated rubber.

Figure 4.13: Variation of Tensile Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate, Mix B



There is variation in compressive strength of rubberized concrete with same content of plain rubber aggregate and rubber aggregate coated with cement. Fig. 4.12, Fig 4.13 and Fig 4.14, Table 4.7 showed the variation in the strength. The result shows that coating the river aggregate with cement paste increases the tensile strength and reduces the percentage loss of strength as compared to control concrete. In this research work, 11.67 % increment of tensile strength was observed using cement coated rubber aggregate in compare to plain rubber when 40 % by volume of aggregate was replaced by rubber aggregate.

Figure 4.15 shows the failure mode of concrete cylinder using rubber aggregate. Remarkable change in tensile failure behavior was observed visually with rubberized concrete. There was no brittle failure as in case of control mix. Further loading showed that there was no clean split of cylinder sample into two halves as in case of control concrete sample. Several line of cracks were observed before the complete failure of sample.

Fig. : 4.15 Splitting Tensile Strength Samples

Control Concrete

Rubberized Concrete

Splitting Testing

Rubberized Concrete (40%)

4.3.3 Flexural Strength Testing

- **Test Results**

The test results are summarized in Tables 4.8 and presented in Figures 4.16 – 4.17. The 28 days Flexural strength of concrete containing 0, 10, 25 and 40% of plain rubber aggregate by volume for Mix C is 3.27, 3.40, 3.07 and 2.22 MPA respectively. The 28 days Flexural Strength of concrete containing 0, 10, 25 and 40% of cement coated rubber aggregate by volume for Mix C is 3.27, 3.67, 3.20 and 2.53 MPA respectively.

- **Analysis of Results:**

Figure 4.16 describes the variation of flexural strength with different content of rubber for rubberized concrete containing plain or cement coated rubber. The flexural strength of rubberized concrete containing 10 % rubber aggregate was found to be increased compared to control mix. The gain of strength was 4.04 % for plain rubber aggregate where as it was 12.24 % for rubber aggregate coated with cement. But, the strength was found to be decreasing as in previous case of compressive and splitting tensile strength when the content of rubber aggregate was increased. The loss of strength was found to be 6.12 % and 32.16% for rubberized concrete containing 25% and 40 % of plain rubber aggregate.

The results (table 4.10) showed that the flexural strength of rubberized concrete was enhanced when plain rubber aggregate was replaced with cement coated rubber aggregate.

Figure : 4.18 Flexural Strength Samples for Testing

Failure of Control Concrete

Failure of Rubberized Concrete

Summary of Strength Test Results

The results of tests conducted to investigate the effect of content of rubber aggregate and the effect of coating the rubber aggregate with cement on mechanical properties of concrete are summarized in table 4.11. The Relative Strength, S_R, has been used to quantify the changes in the concrete strength in comparison to the control concrete. However these values are specific to the present study.

It is evident from the test results that adding rubber aggregate into concrete has a marked effect on the strength properties of the concrete, specifically a significant reduction in the compressive and splitting tensile strength. However, there is marginal effect on strength of concrete using 10% rubber aggregate. The study shows that there is slight increase in flexural strength at lower rubber content but it decreases significantly when the rubber content is increased from 25% to 40%.There is no effect of using either OPC or PPC cement. Coating the rubber aggregate with cement paste enhances the mechanical properties of concrete but the effect was less. Due to the other better properties of rubberized concrete, the use of rubber content is limited to 10.

Table 4.11 Summary of Strength test results

Mixes	Samples	Compressive Strength (MPA)		Splitting Tensile Strength (MPA)		Flexural Strength (MPA)	
		Average Strength	Relative Strength, S_r	Average Strength	Relative Strength, S_r	Average Strength	Relative Strength, S_r
A (w/c: 0.48)	A	27.85	1.00	2.88	1.00		
	AP 10	20.88	0.75	2.4	0.83		
	AP 25	16.52	0.59	1.53	0.53		
	AP 40	12.74	0.46	1.15	0.40		
	AC 10	22.52	0.81	2.43	0.84		
	AC 25	16.08	0.58	1.6	0.56		
	AC 40	14.29	0.51	1.25	0.43		
B (w/c: 0.48)	B	27.19	1.00	2.69	1.00		
	BP 10	20.59	0.76	2.19	0.81		
	BP 25	15.93	0.59	1.32	0.49		
	BP 40	12.30	0.45	1.18	0.44		
	BC 10	21.63	0.80	2.24	0.83		
	BC 25	14.74	0.54	1.39	0.52		
	BC 40	12.81	0.47	1.25	0.46		
C (w/c: 0.48)	C	31.26	1.00	3.02	1.00	3.27	1.00
	CP 10	22.07	0.71	2.52	0.83	3.40	1.04
	CP 25	15.78	0.50	1.53	0.51	3.07	0.94
	CP 40	10.44	0.33	1.2	0.40	2.22	0.68
	CC 10	23.11	0.74	2.55	0.84	3.67	1.12
	CC 25	18.00	0.58	1.67	0.55	3.20	0.98
	CC 40	13.70	0.44	1.34	0.44	2.53	0.77

Figure 4.19: Variation of Relative Strength Sr with different content of plain rubber aggregate

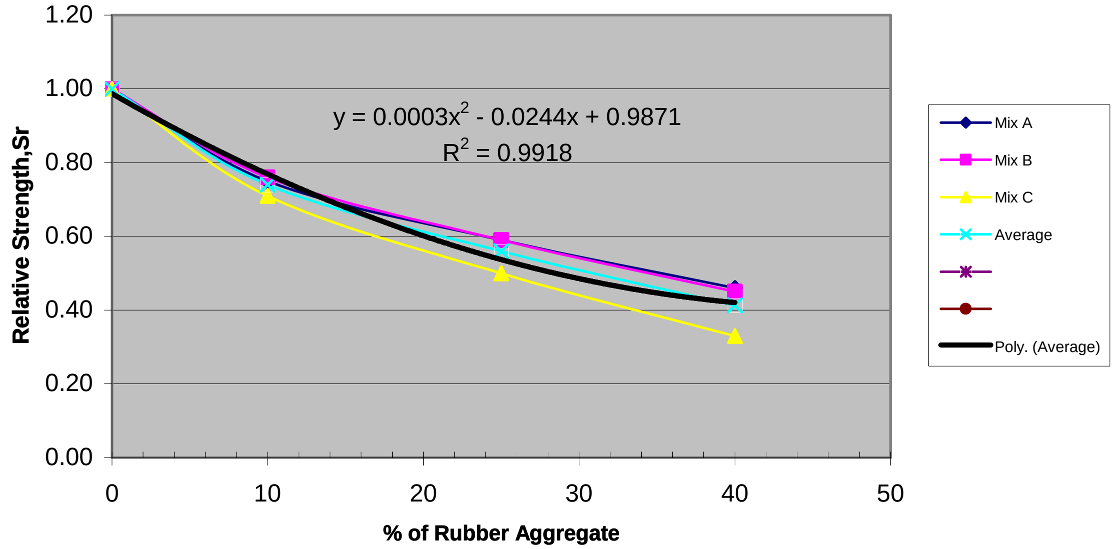
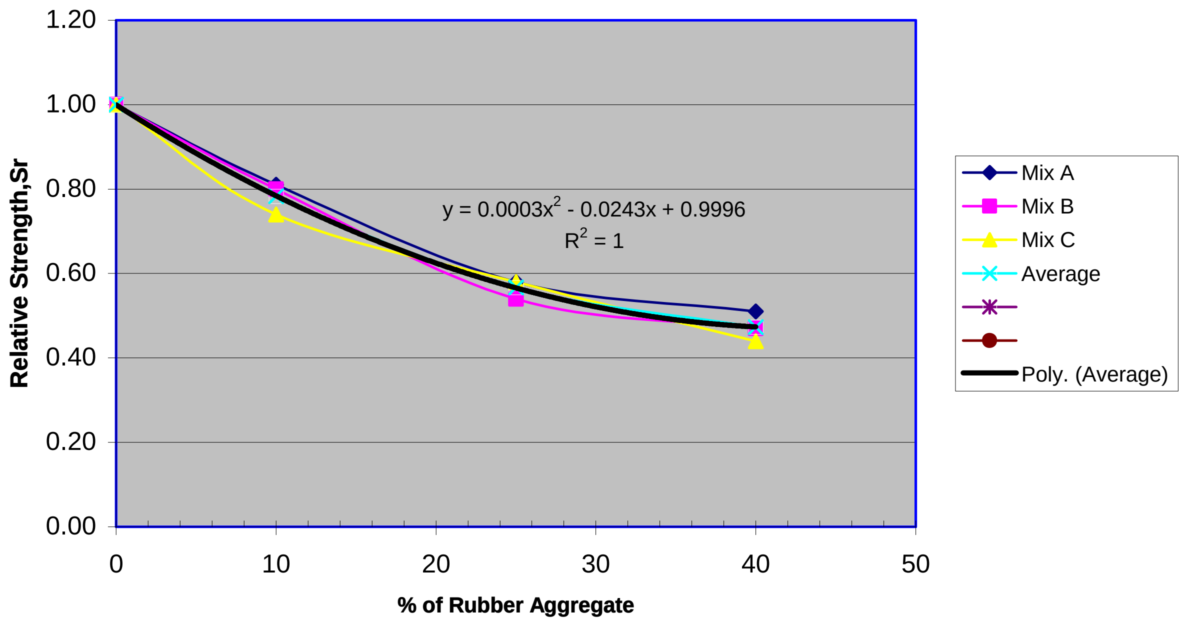
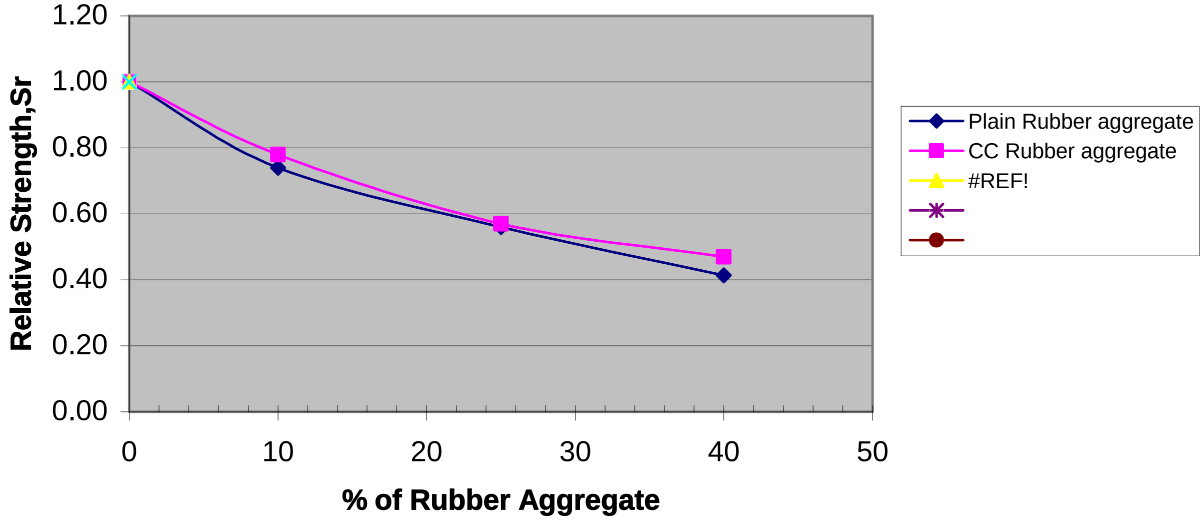


Figure 4.20: Variation of Relative Strength Sr with different content of cement coated rubber aggregate



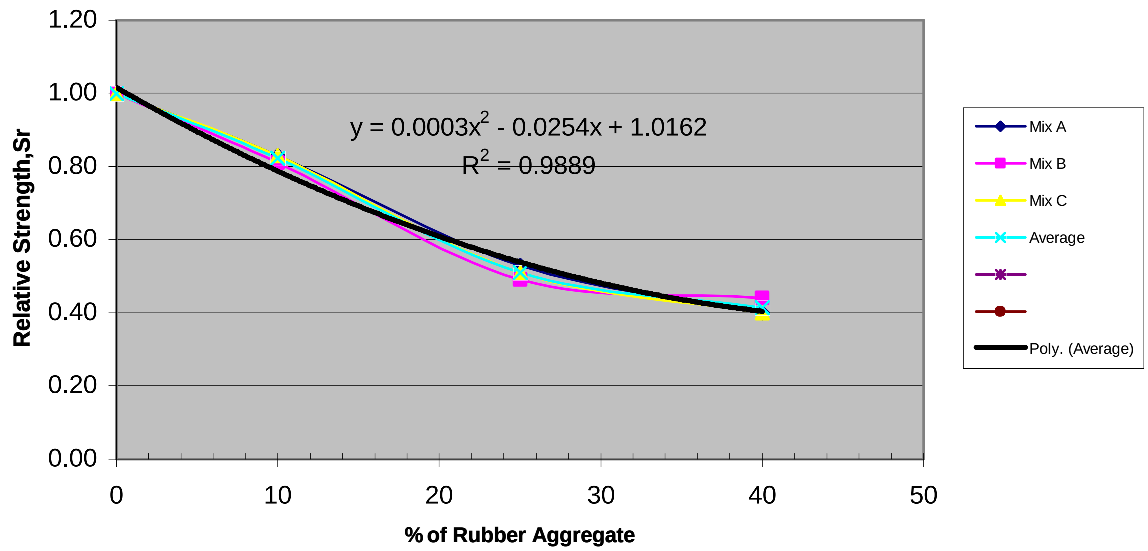
Compressive Strength

Figure 4.21: Variation of Relative Strength Sr with same content of plain and cement coated rubber aggregate



Compressive Strength

Figure 4.22: Variation of Relative Strength Sr with different content of plain rubber aggregate



Splitting Tensile Strength

Figure 4.23: Variation of Relative Strength Sr with different content of cement coated rubber aggregate

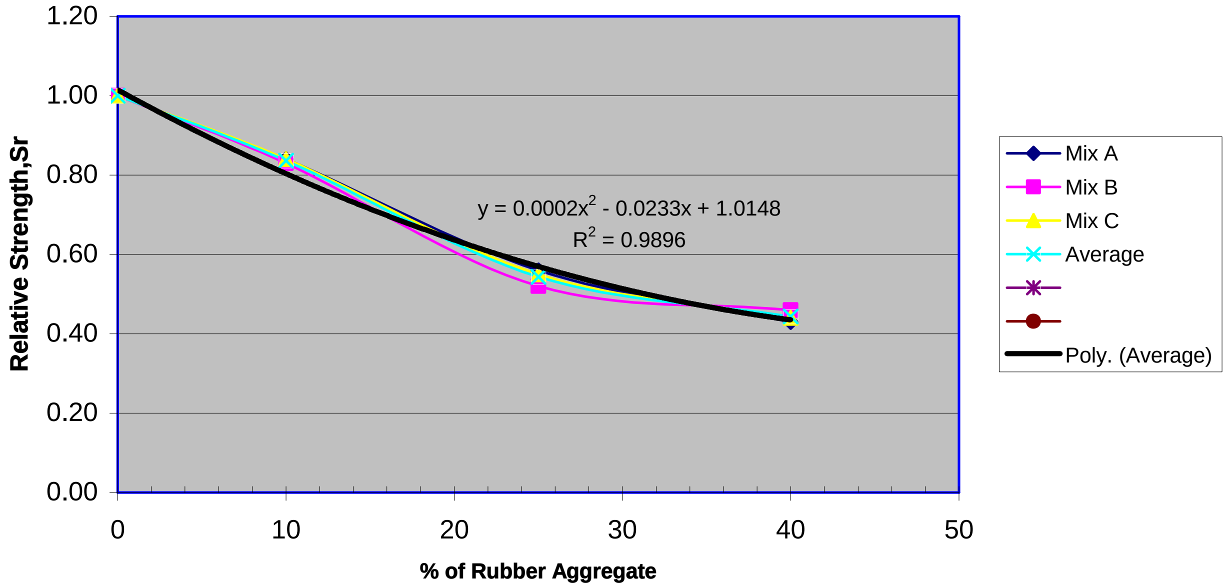
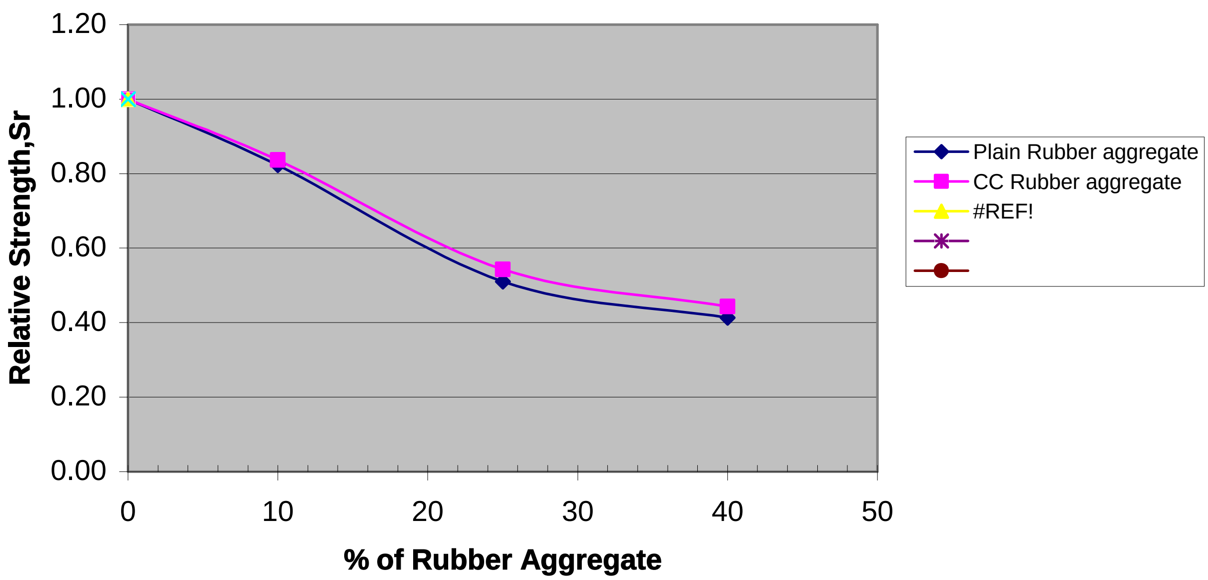
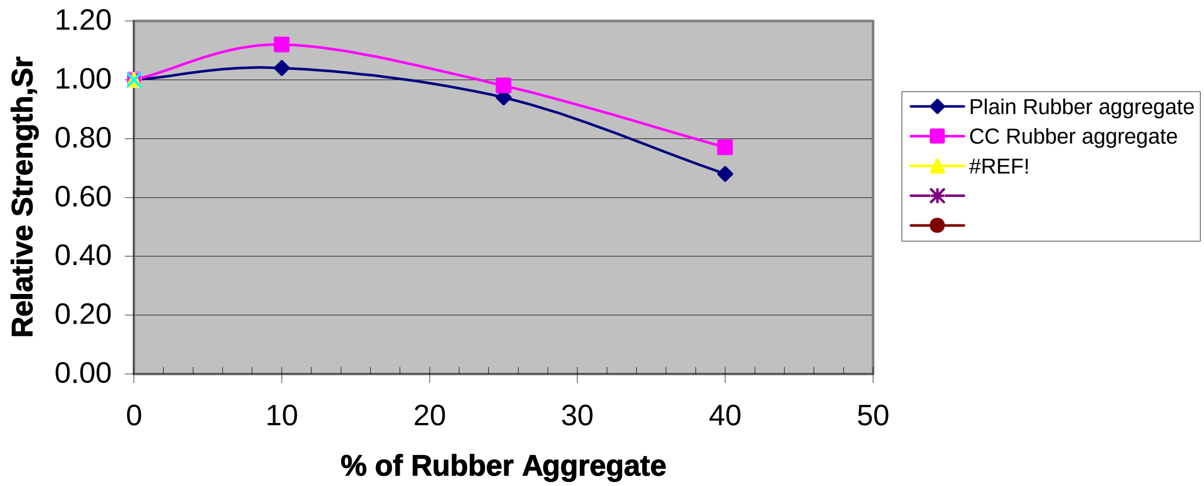


Figure 4.24: Variation of Relative Strength Sr with same content of plain and cement coated rubber aggregate



Splitting Tensile Strength

Figure 4.25: Variation of Relative Strength Sr with same content of plain and cement coated rubber aggregate



Flexural Strength

5. Conclusions and Recommendations

The overall objective of this research work was to investigate the effect of content of rubber aggregate and the effect of coating the rubber aggregate with cement on mechanical properties of concrete. The impact resistance, toughness, durability and deformation property of rubberized concrete was also studied from previous research works. The conclusions are summarized as below:

5.1 Conclusions

Workability :

- The study shows that the rubberized concrete can be finished closed to the same standard as plain concrete with lower content of rubber aggregate.

Unit Weight

- The unit weight of rubberized concrete is found to be lower as compared to normal concrete. But, the weight is still higher than the value of light-weight concrete i.e.1850 kg / m^3. It is therefore, the rubberized concrete can not be categorized under light weight concrete.

Compressive Strength

- The result shows that the incorporation of rubber aggregate into concrete mixes has a marked effect on the compressive strength of the concrete. The reduction in strength is higher as the content of rubber is increased. However, there is marginal effect on strength of concrete using 10% rubber aggregate. Coating the rubber aggregate with cement paste enhances the compressive strength of concrete but the effect was less.

Splitting Tensile Strength

- Similar observations were found for splitting tensile strength as in case of compressive strength.

Flexural Strength

- In the present study, it was observed that the flexural strength of rubberized concrete with lower content of rubber aggregate was slightly higher than that of plain concrete. But, the strength is reduced when the content of rubber aggregate is increased from 25% to 40%. It is therefore concluded that the benefit of improved flexural strength can be utilized for non-primary structural applications if the rubber content is limited.

  - A rigorous study of previous research work shows that the rubberized concrete has better capacity in absorbing significant plastic energy and withstanding large deformation, high resistance to Impact, improved durability, and improved acoustic and thermal insulation. The current study shows that the use of rubber aggregate is limited to 10% by volume of mineral aggregate to prevent too great loss in mechanical properties of concrete. It is finally concluded that the rubberized concrete can be used at least in non- primary structures such as road and bridge barriers, wall panels (concrete block).

5.2 Recommendations

- **Recommendation to Department of Roads**

  The rubberized concrete containing 10% of rubber aggregate by volume can be used as Road and Bridge Barriers, Road Delineators Post on curve, wearing course on top of bridge slab.

➢ Recommendations for Further Work

In this research work, the scope of work was limited to some fresh and hardened concrete properties. However, following further investigation are required to evaluate the further properties of concrete.

- The mix design for current study was based on IS SP : 23 1982. None of the codes (ACI, BS, IS) have developed the mix design for rubberized concrete. So, further work will be undertaken to develop a suitable mix design procedures for rubberized concrete.
- Both, ordinary Portland cement and Pozzolana Portland cement, crushed and river aggregate were used during the investigation. But, tyre aggregate from used tyre of four wheel pick-up of sizes 10~20 mm were only used. Further investigations are required with other sources of tyres like truck, buses, heavy equipments. Similarly, similar tests can be performed using other sizes of rubber aggregate either as a replacement of coarse aggregate or fine aggregate..

References

"Standard Specification for Roads and Bridges Works", HMG, DOR, July 2001

Neville, A. m., "Properties of Concrete," 4th Ed., *Longman*, London, 1995

M.S.SHETTY , " Concrete Technology" New Delhi 2005

H.E.M. Sallam, A.S. Sherbini, M.H. Seleem and M.M. Balaha, " Impact Resistance of Rubberized Concrete"Materials Engineering Departments, Zagazig University, Egypt July 2008.

Mehmet EMIROGLU, M. Halidun KELESTEMUR and Servet YILDIJ " An Investigation on ITZ Microstructure of the concrete containing waste vehicle tyres" Firat University , Turkey November 2007.

Gintautas SKRIPKIUNAS, Audrius GRINYS, Benjaminas CERNIUS , " Deformation Properties of concrete with rubber waste additives" Kunas University of Technology, Lithuania August 2007.

Ilker Bekir Topcu and Abdulah Demir, " Durability of Rubberized mortar and concrete" Proc. Concrete 2004 Congress Istambul, Turkey.

Leyden, J., "Cryogenic Processing and Recycling," *Rubber World*, Vol.203, No. 6, March 1991, pp.28-29

Eldin, N. N. and Senouci, A. B., "Engineering Properties of Rubberised Concrete," *Canadian Journal of Civil Engineering*, Vol. 19, 1992. Pp.912-923

British Standard Institution, BS 1881-116:1983, "Method for Determination of Compressive Strength of Concrete Cubes," London

British Standard Institution, BS 1881-117:1983, "Method for Determination of Tensile Splitting Strength," London

British Standard Institution, BS 1881-118:1983, "Method for Determination of Flexural Strength," London

Indian Standard IS 456 : 2000 " Plain and Reinforced Concrete – Code of Practice"

Indian Standard SP23 : 1982 " Concrete Mix Design"

Annexes

Annexes I

Table 4.1 Summary of Workability Test Results

Mixes	Group	Samples	Slump Tests		
			Slump (mm)	**Type of Slump**	**Apparent Workability**
A (w/c: 0.48)	Control	A	64	True	Medium
	P	AP 10	52	True	Medium
		AP 25	38	True	Medium
		AP 40	14	True	Low
	C	AC 10	54	True	Medium
		AC 25	38	True	Medium
		AC 40	17	True	Low
B (w/c : 0.44)	Control	B	58	True	Medium
	P	BP 10	45	True	Medium
		BP 25	32	True	Medium
		BP 40	8	True	Low
	C	BC 10	44	True	Medium
		BC 25	37	True	Medium
		BC 40	12	True	Low
C (w/c : 0.48)	Control	C	55	True	Medium
	P	CP 10	34	True	Medium
		CP 25	24	True	Low
		CP 40	8	True	Low
	C	CC 10	35	True	Medium
		CC 25	25	True	Medium
		CC 40	11	True	Low

Table 4.2 Unit Weights of Control Concrete and Rubberized Concrete

Specimen	Mixes	Group	Samples	Avg. Weight of Specimen (gms)	Avg. Unit Weight (Kg/m^3)	% Reduction
Cubes	**A (w/c: 0.48)**	Control	A	8215	2434.07	0
		P	AP 10	8000	2370.37	2.62
			AP 25	7565	2241.48	7.91
			AP 40	7350	2177.78	10.53
		C	AC 10	7935	2351.11	3.41
			AC 25	7660	2269.63	6.75
			AC 40	7425	2200.00	9.62
	B (w/c : 0.44)	Control	B	8185	2425.18	0
		P	BP 10	7935	2351.11	3.05
			BP 25	7660	2269.63	6.41
			BP 40	7250	2148.15	11.42
		C	BC 10	8125	2407.41	0.73
			BC 25	7825	2318.52	4.40
			BC 40	7350	2177.77	10.20
	C (w/c : 0.48)	Control	C	8165	2419.26	0
		P	CP 10	7910	2343.70	3.12
			CP 25	7550	2237.04	7.53
			CP 40	7280	2157.04	10.84
		C	CC 10	7935	2351.11	2.82
			CC 25	7610	2254.81	6.80
			CC 40	7290	2160.00	10.72

Table 4.2 Unit Weights of Control Concrete and Rubberized Concrete

Specimen	Mixes	Group	Samples	Weight of Specimen (Kg)	Unit Weight (Kg/m^3)	% Reduction
Cylinders	C (w/c : 0.48)	Control	XC	12755	2405.95	0
		P	XP 10	12575	2372.00	1.41
			XP 25	11850	2235.24	7.09
			XP 40	11415	2153.19	10.50
		C	XC 10	12580	2372.94	1.37
			XC 25	11915	2247.50	6.59
			XC 40	11550	2178.65	9.45

Table 4.3 Compressive Strength of control and rubberized concrete

Mixes	Group	Samples	Average Compressive Strength (MPA)	
			7- days	28-days
A (w/c: 0.48)	Control	A	21.40	27.85
	P	AP 10	14.52	20.88
		AP 25	10.52	16.52
		AP 40	9.85	12.74
	C	AC 10	15.63	22.52
		AC 25	11.63	16.08
		AC 40	10.88	14.29
B (w/c : 0.44)	Control	B	19.55	27.19
	P	BP 10	13.03	20.59
		BP 25	9.92	15.93
		BP 40	9.18	12.30
	C	BC 10	15.18	21.63
		BC 25	11.26	14.74
		BC 40	9.70	12.81
C (w/c : 0.48)	Control	C	22.52	31.26
	P	CP 10	15.33	22.07
		CP 25	10.82	15.78
		CP 40	9.03	10.44
	C	CC 10	18.67	23.11
		CC 25	11.63	18.00
		CC 40	11.18	13.70

Table 4.4 Percentage loss of compressive strength of rubberized concrete

Mixes	Group	Samples	% loss of Strength	
			7- days	28-days
A (w/c: 0.48)	Control	A	0	0
	P	AP 10	32.15	25.03
		AP 25	50.84	40.68
		AP 40	53.97	54.25
	C	AC 10	26.96	19.14
		AC 25	45.65	42.26
		AC 40	49.16	48.69
B (w/c : 0.44)	Control	B	0	0
	P	BP 10	33.35	24.27
		BP 25	49.25	41.41
		BP 40	53.04	54.76
	C	BC 10	22.35	20.45
		BC 25	42.40	45.79
		BC 40	50.38	52.89
C (w/c : 0.48)	Control	C	0	0
	P	CP 10	31.93	29.40
		CP 25	51.95	49.52
		CP 40	59.90	66.60
	C	CC 10	17.10	26.07
		CC 25	48.36	42.42
		CC 40	50.35	56.17

Table 4.5 Percentage increase in strength of rubberized concrete coated with cement

Mixes	% of rubber content	Strength of rubberized concrete (MPA)				% increase in strength	
		Plain rubber		Cement coated rubber			
		7 days	28 days	7 days	28 days	7 days	28 days
A (w/c: 0.48)	10	14.52	20.88	15.63	22.52	7.64	7.85
	25	10.52	16.52	11.63	16.08	10.55	- 2.66
	40	9.85	12.74	10.88	14.29	10.45	12.17
B (w/c: 0.44)	10	13.03	20.59	15.18	21.63	16.50	5.05
	25	9.92	15.93	11.26	14.74	13.51	- 7.47
	40	9.18	12.30	9.70	12.81	5.66	4.15
C (w/c: 0.48)	10	15.33	22.07	18.67	23.11	21.79	4.71
	25	10.82	15.78	11.63	18.00	7.49	14.07
	40	9.03	10.44	11.18	13.70	23.81	31.22

Table 4.6 : Splitting Tensile Strength of control and rubberized concrete

Mixes	Group	Samples	Average Tensile Strength (MPA)	% loss of Strength
A (w/c: 0.48)	Control	A	2.88	0
	P	AP 10	2.4	16.67
		AP 25	1.53	46.88
		AP 40	1.15	60.07
	C	AC 10	2.43	15.63
		AC 25	1.6	44.44
		AC 40	1.25	56.60
B (w/c : 0.44)	Control	B	2.69	0.00
	P	BP 10	2.19	18.59
		BP 25	1.32	50.93
		BP 40	1.18	56.13
	C	BC 10	2.24	16.73
		BC 25	1.39	48.33
		BC 40	1.25	53.53
C (w/c : 0.48)	Control	C	3.02	0.00
	P	CP 10	2.52	16.56
		CP 25	1.53	49.34
		CP 40	1.2	60.26
	C	CC 10	2.55	15.56
		CC 25	1.67	44.70
		CC 40	1.34	55.63

Table 4.7 Percentage increase in strength of rubberized concrete coated with cement

Mixes	% of rubber content	Strength of rubberized concrete (MPA)		% increase in strength
		Plain rubber	Cement coated rubber	
A (w/c: 0.48)	10	2.40	2.43	1.25
	25	1.53	1.60	4.58
	40	1.15	1.25	8.70
B (w/c: 0.44)	10	2.19	2.24	2.28
	25	1.32	1.39	5.30
	40	1.18	1.25	5.93
C (w/c: 0.48)	10	2.52	2.55	1.19
	25	1.53	1.67	9.15
	40	1.20	1.34	11.67

Table 4.8 Flexural Strength of control and rubberized concrete

Mixes	Group	Samples	Average Compressive Strength (MPA)	
			7- days	28-days
C (w/c : 0.48)	Control	C	2.53	3.27
	P	CP 10	2.53	3.40
		CP 25	2.47	3.07
		CP 40	1.53	2.22
	C	CC 10	2.67	3.67
		CC 25	2.60	3.20
		CC 40	1.80	2.53

Table 4.9 Percentage variation of flexural strength of rubberized concrete as compared to control concrete.

Mixes	Group	Samples	% loss or gain of Strength	
			7- days	28-days
C (w/c: 0.48)	Control	C	0	0
	P	CP 10	0	+4.08
		CP 25	-2.63	-6.12
		CP 40	-39.47	-32.16
	C	CC 10	+5.26	+12.24
		CC 25	+2.63	-2.04
		CC 40	-28.95	-22.45

Table 4.10 Percentage increase in strength of rubberized concrete coated with cement (28 days)

Mixes	% of rubber content	Strength of rubberized concrete (MPA)		% increase in strength
		Plain rubber	Cement coated rubber	
C (w/c: 0.48)	10	3.40	3.67	7.94
	25	3.07	3.20	4.23
	40	2.22	2.53	13.96

Annexes II

Figure 4.1: Variation of Compressive Strength with different content of plain rubber aggregate

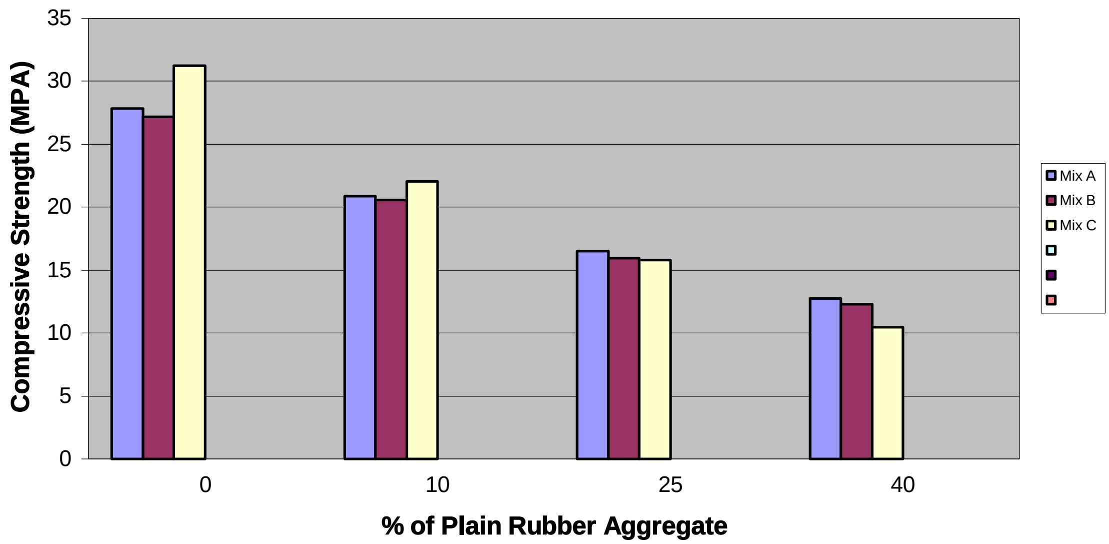


Figure 4.2: Variation of Compressive Strength with different content of Cement coated rubber aggregate

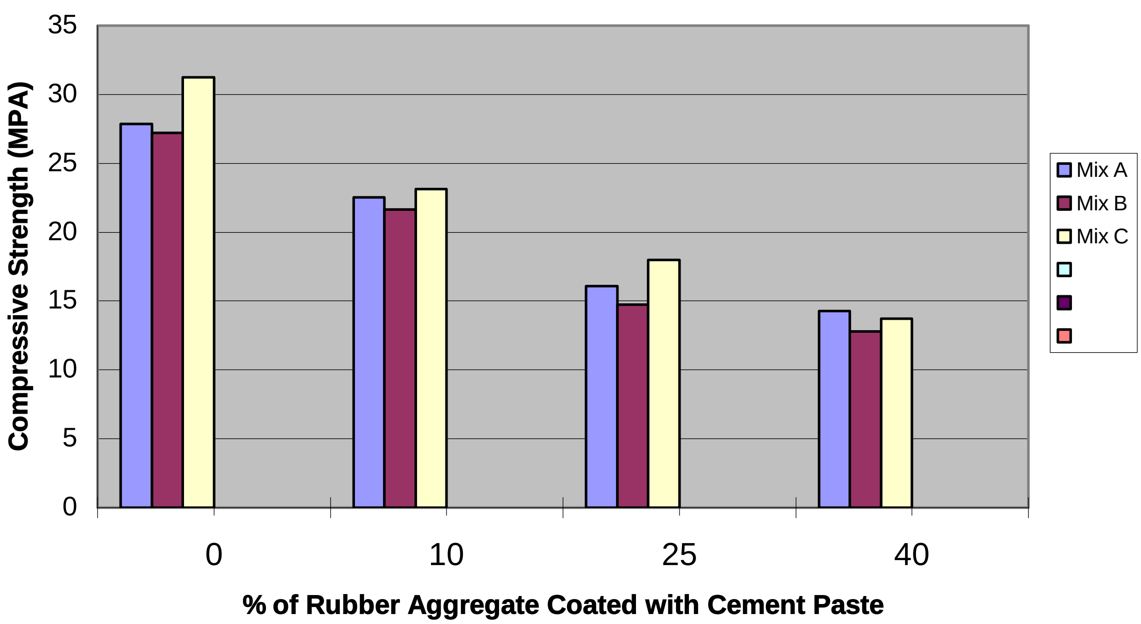


Figure 4.3: Percentage Loss of Compressive Strength with different content of plain rubber aggregate

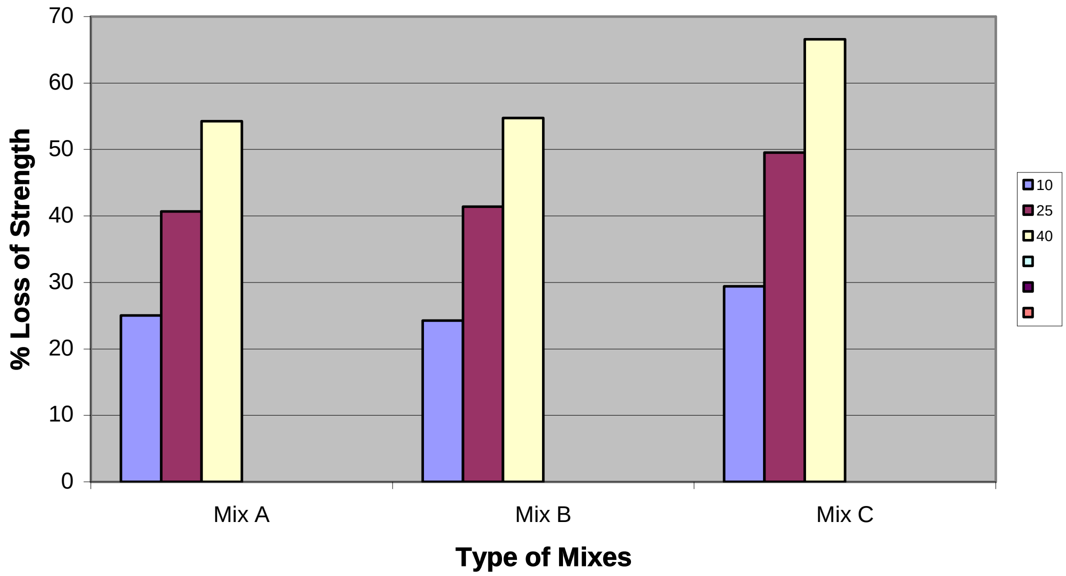


Figure 4.4: Percentage Loss of Compressive Strength with different content of plain rubber aggregate

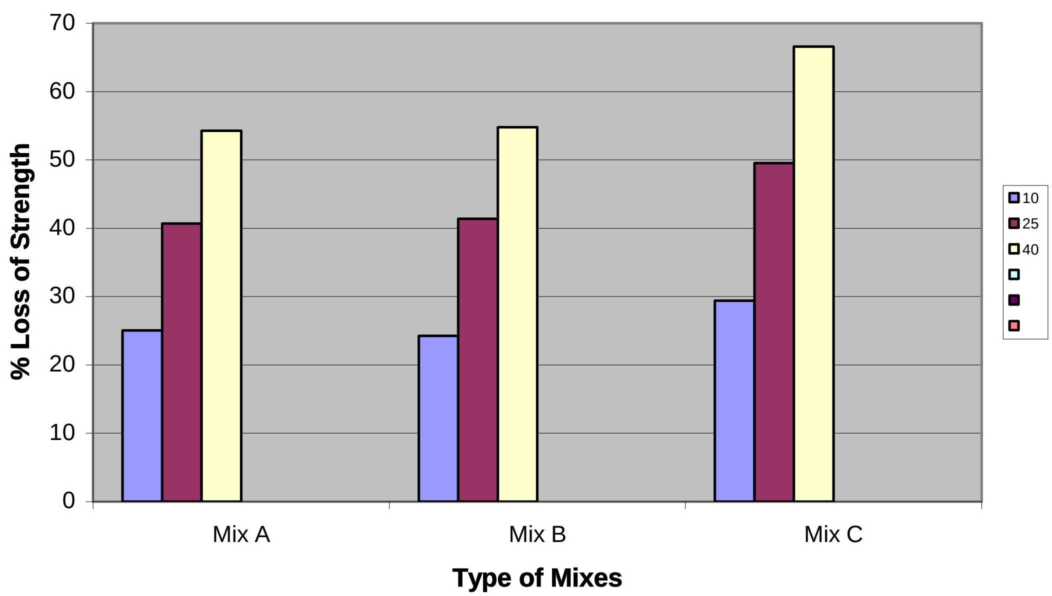


Figure 4.5: Variation of Compressive Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate, Mix A

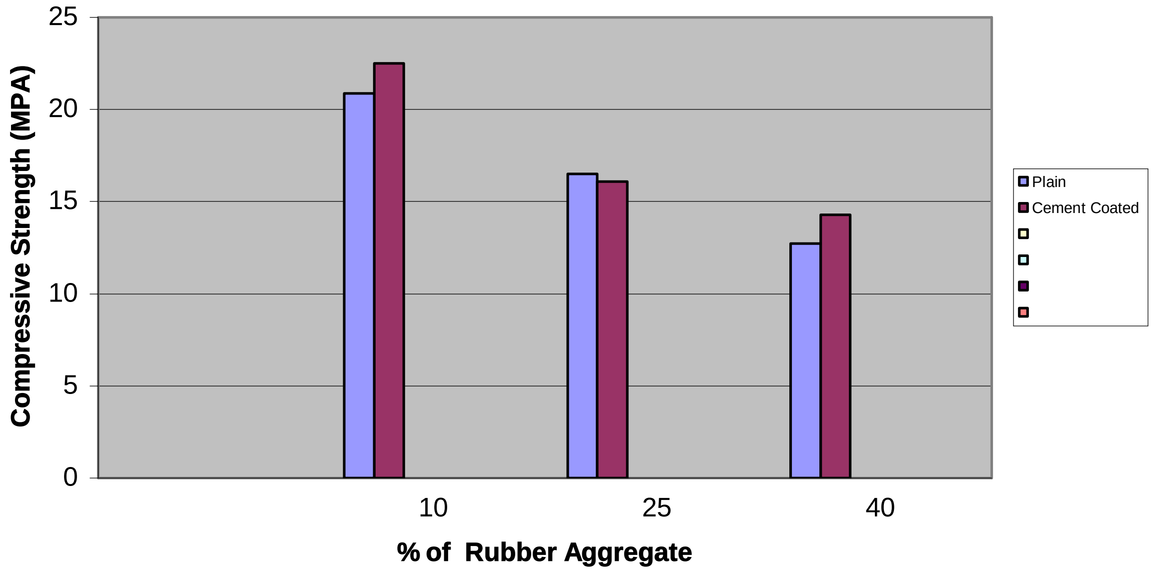


Figure 4.6: Variation of Compressive Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate , Mix C

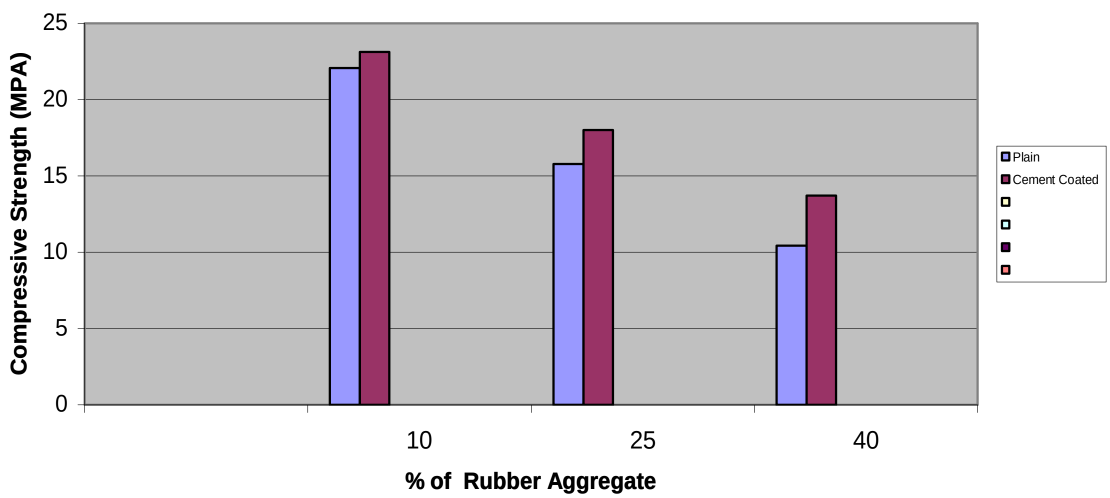


Figure 4.8: Variation of Splitting Tensile Strength with different content of plain rubber aggregate

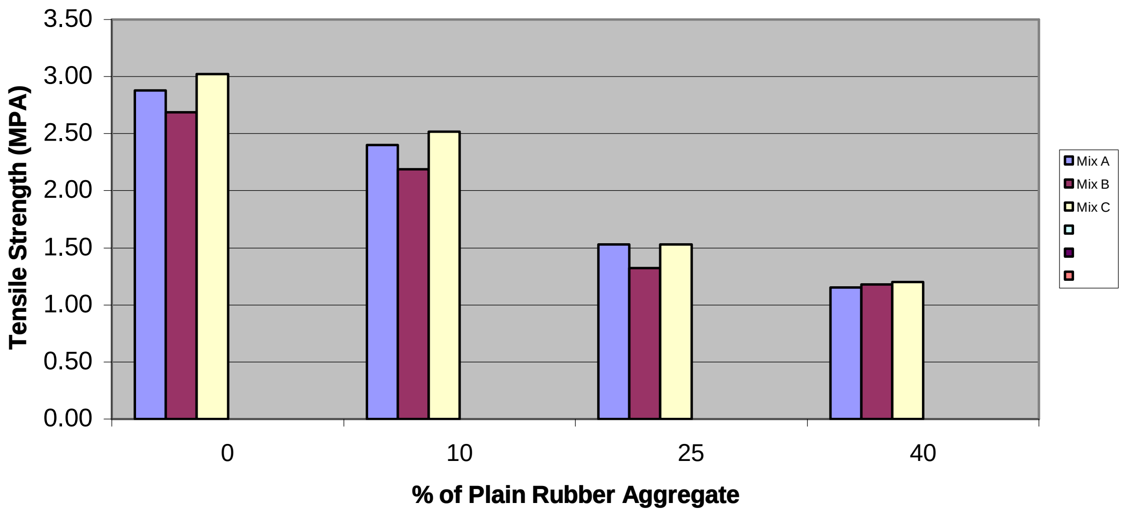


Figure 4.9: Variation of Splitting Tensile Strength with different content of rubber aggregate Coated with Cement

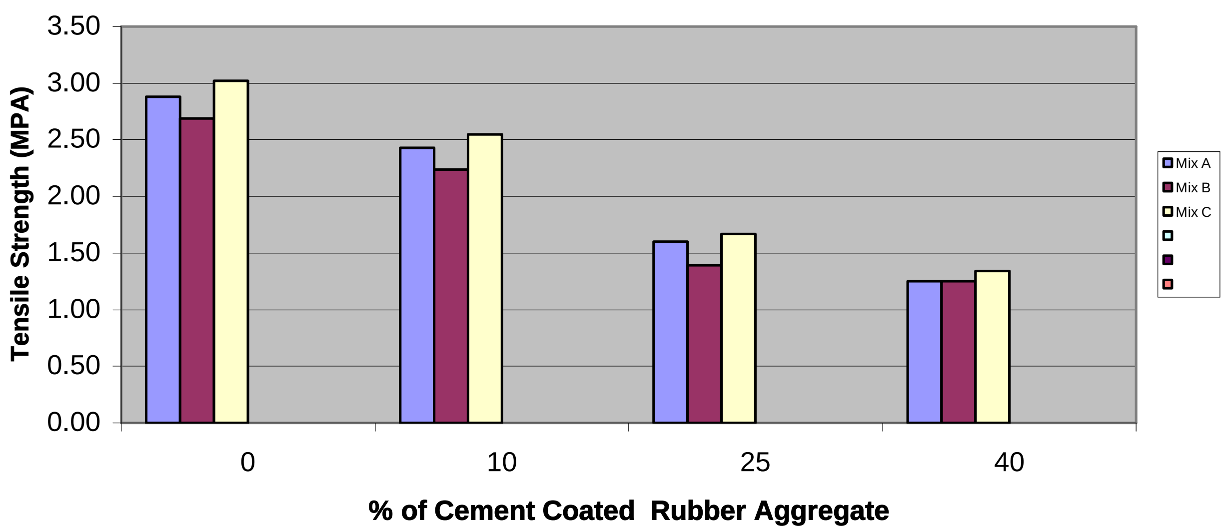


Figure 4.10: Percentage Loss of Tensile Strength with different content of plain rubber aggregate

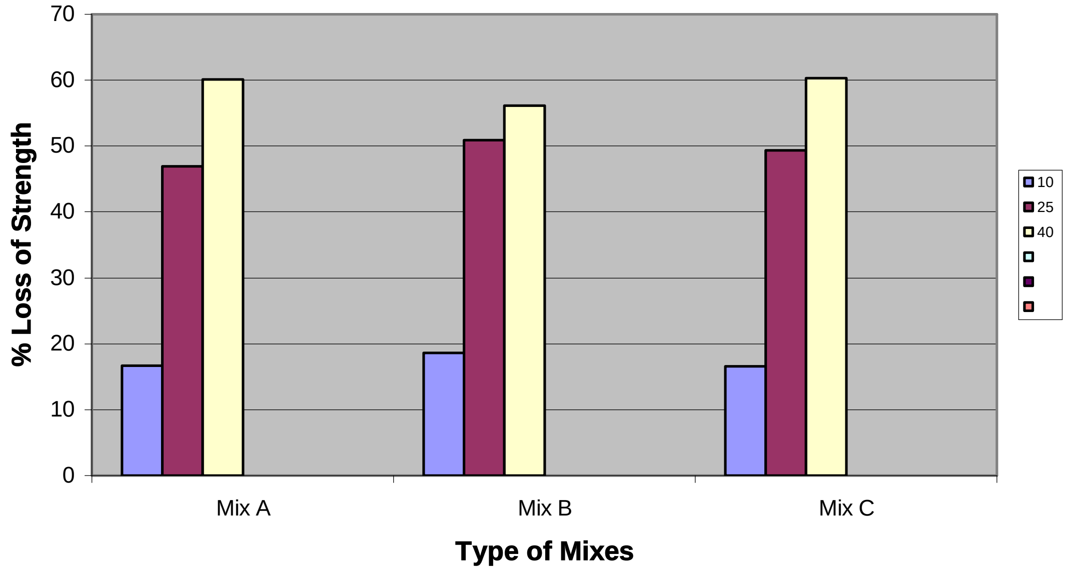


Figure 4.11: Percentage Loss of Tensile Strength with different content of Cement Coated rubber aggregate

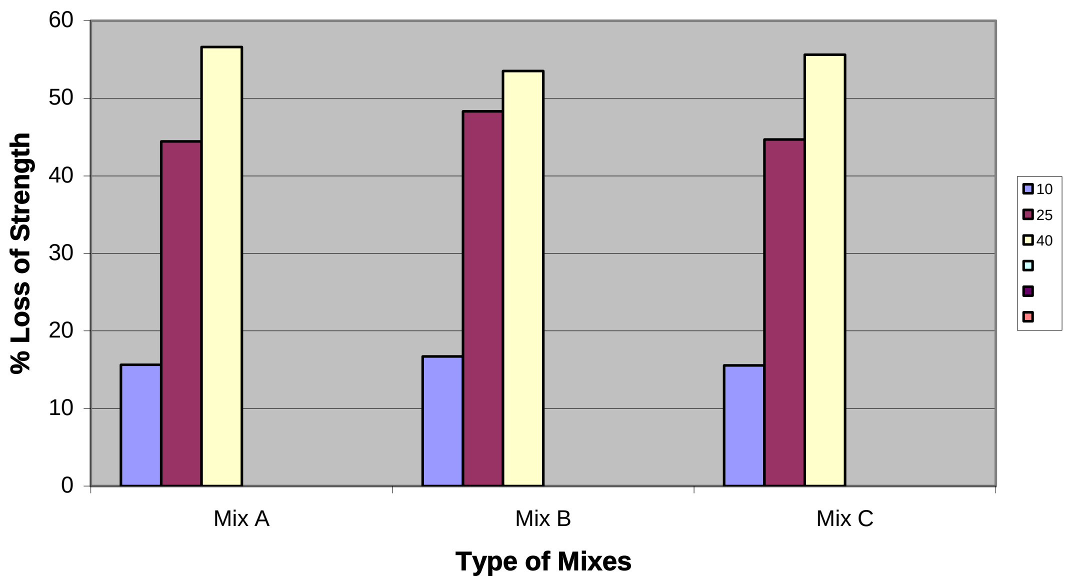


Figure 4.12: Variation of Tensile Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate, Mix A

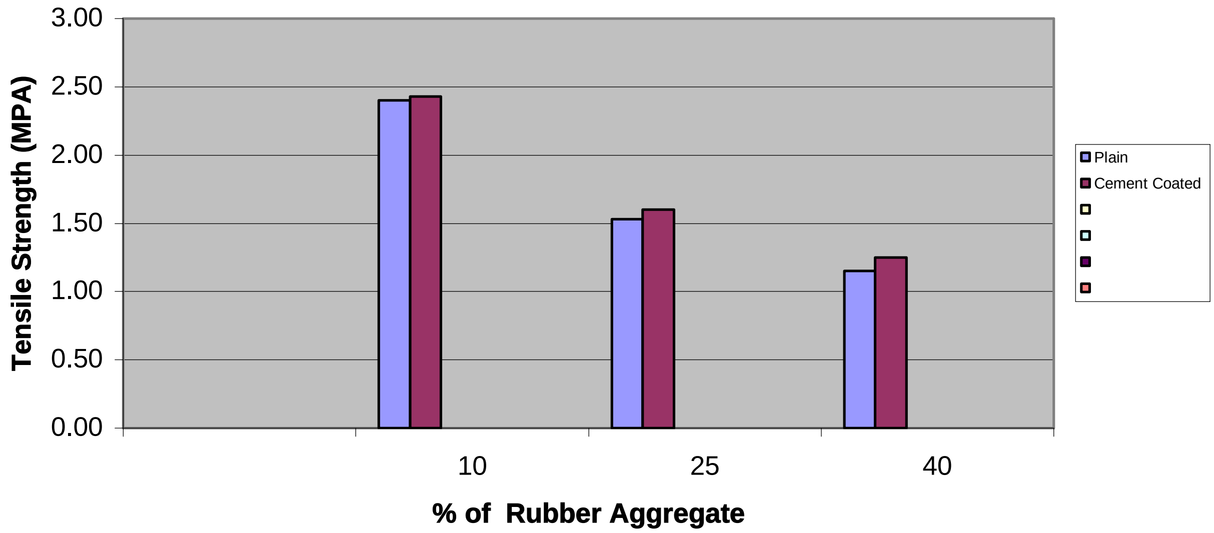


Figure 4.13: Variation of Tensile Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate, Mix B

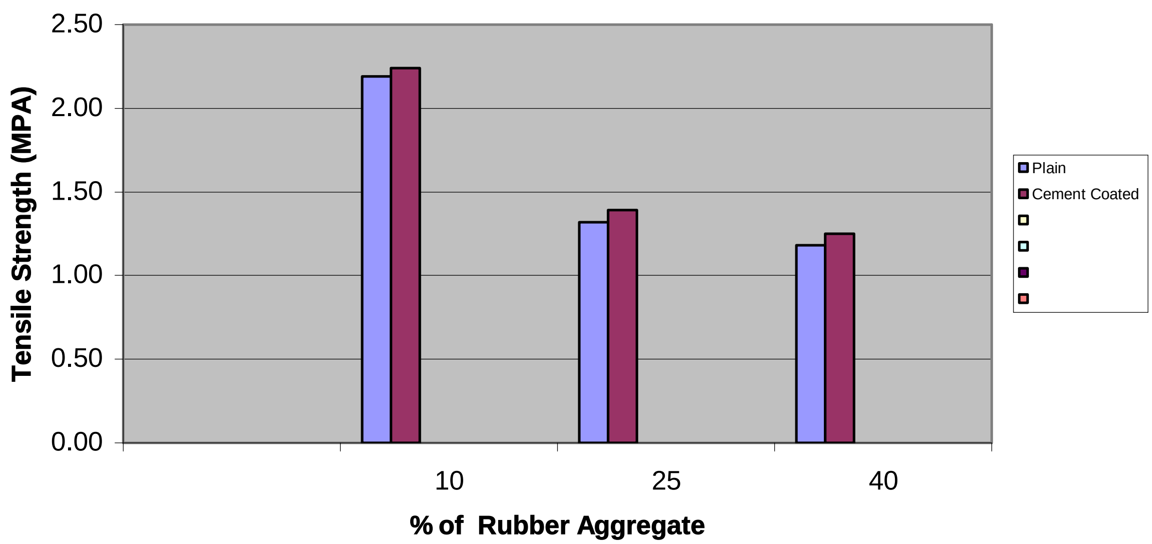


Figure 4.14: Variation of Tensile Strength with Same content of plain rubber aggregate & Cement Coated Rubber Aggregate, Mix C

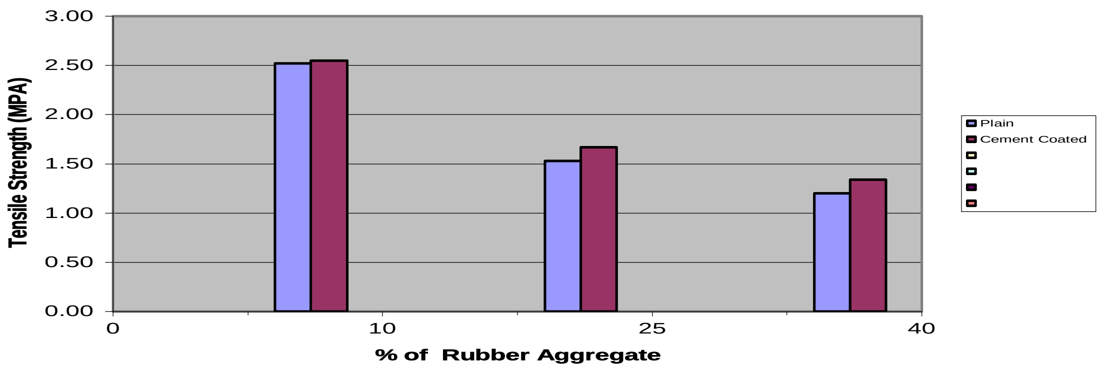


Figure 4.16: Variation of Flexural Strength with different content of rubber aggregate (7 days)

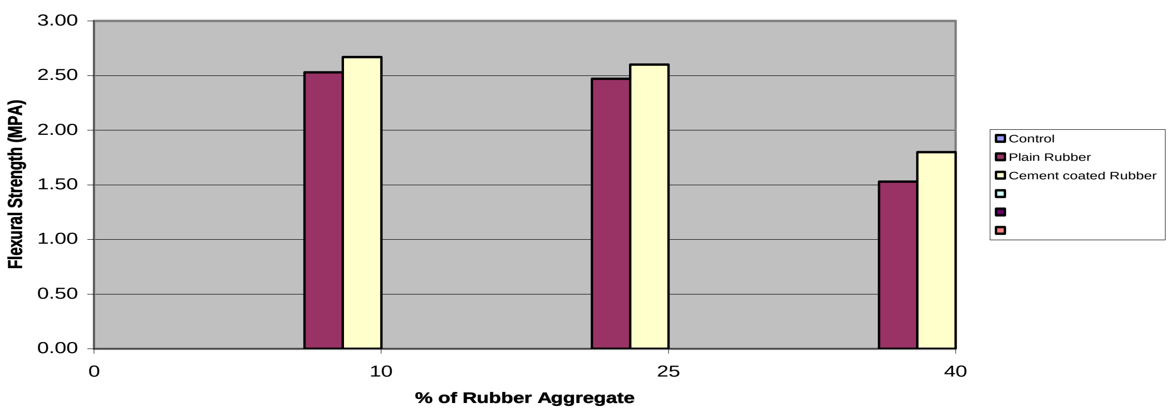
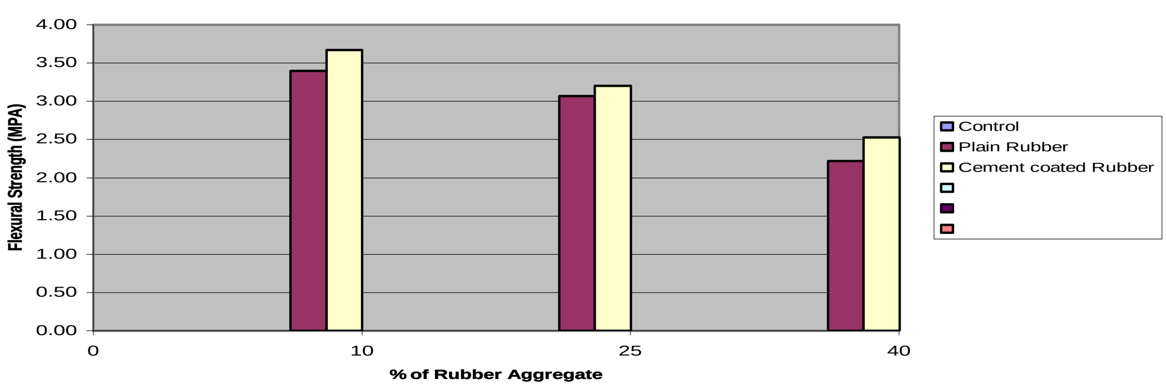


Figure 4.16: Variation of Flexural Strength with different content of rubber aggregate (28 days)



Annexes - III

Design for Concrete Mix Design (Mix A)

1) Design Stipulations

i) Characteristics compressive strength required in the field at 28 days --------- 20 MPA

ii) Maximum size of aggregate used (Round) .... 20 mm

iii) The degree of workability .... 0.9compacting factor

iv) The degree of quality control .... good

v) Type of exposure .... miled

2. Test Data for Materials

i. Specific gravity of cement 3.15

ii Strength of cement at 28 days.(Jaypee Buland) .... 38 MPA

iii Specific gravity of Sand. 2.72

iv Specific gravity of coarse aggregate 2.64

v) Water absorption of sand 1%

vi Water absorption of coarse aggregate 0.5%

3. Target Mean strength of Concrete

F_{ck} = f_{ck} +1.65 ∃ = 20+1.65x4 = 26.6 MPA

4 Water Cement Ratio = 0.48 (From Curve of cement strength vs. w/c ratio)

5 For 20 mm max. size of aggregate and sand conforming to grading zone IInd , water content per m^3 of concrete = 186 Kgs and sand content as percentage of total aggregate by absolute volume = 35%.

For change in value of w/c. ratio, compacting factor following adjustment is required.

Change in Condition	Percentage Adjustment Required	
	Water Content	**Sand in Total Aggregate**
For decrease in w/c ratio by (0.6-0.48) i.e.0.12	0.00	-2.40
For increase in compacting factor (0.9-0.8) i.e.0.10	+3.00	0..00
For rounded aggregate	-15 kg	-7
Total	**+3.00 & -15 kg**	**-9.4**

Required sand content as percentage of total aggregate by absolute volume = 35-9.4 = 26.6%

Required water content = 186+5.58-15 = 176.6 Ltr per m^3

6 Determination of cement content

w/c ratio = 0.48 i.e. cement = 367.917 kg per m^3

7 Determination of coarse & fine aggregate

For specified max. size of aggregate 20mm, the amount of entrapped air in the wet concrete is 2%.

Using formula,

$$V = \left[W + C/S_e + f_a /p\, S_{fa} \right] 1/1000$$

f_a = 496.77 Kg / m^3

Similarly, C_a = [1 - P] / P x f_a Ga / Gs = 1330.469 kgs / m^3

Mix proportion then becomes

Water :	Cement :	Fine aggregate :	Coarse aggregate
176.6 ltr	367.917 kg	496.77 kg	1330.469 kg
0.48	**1.00**	**1.35**	**3.61**

Annexes - IV

Table : Strength Calculation of concrete cubes

Mix A (w/c : 0.48)							
Specimen	Code	7 days			28 days		
		Loading	Strength	Avg. Strength	Loading	Strength	Avg. Strength
A	1	475	21.11	21.40	650	28.89	27.85
	2	490	21.77		640	28.44	
	3	480	21.33		590	26.22	
AP 10	1	320	14.22	14.52	480	21.33	20.88
	2	360	16.00		490	21.77	
	3	300	13.33		440	19.55	
AP 25	1	220	9.78	10.52	360	16.00	16.52
	2	240	10.67		390	17.33	
	3	250	11.11		365	16.22	
AP 40	1	235	10.44	9.85	300	13.33	12.74
	2	215	9.55		290	12.89	
	3	215	9.55		270	12.00	
AC 10	1	360	16.00	15.63	500	22.22	22.52
	2	340	15.11		520	23.11	
	3	355	15.78		500	22.22	
AC 25	1	280	12.44	11.63	400	17.78	16.08
	2	255	11.33		335	14.89	
	3	250	11.11		350	15.56	
AC 40	1	230	10.22	10.88	320	14.22	14.29
	2	250	11.11		305	13.55	
	3	255	11.33		340	15.11	

Mix B (w/c : 0.44)							
Specimen	**Code**	**7 days**			**28 days**		
		Loading	**Strength**	**Avg. Strength**	**Loading**	**Strength**	**Avg. Strength**
B	1	445	20.22	19.55	600	26.67	27.19
	2	440	19.55		625	27.78	
	3	425	18.89		610	27.11	
BP 10	1	280	12.44	13.03	450	20.00	20.59
	2	300	13.33		455	20.22	
	3	300	13.33		440	19.55	
BP 25	1	200	8.89	9.92	330	14.67	15.93
	2	240	10.67		390	17.33	
	3	230	10.22		355	15.78	
BP 40	1	195	8.67	9.18	270	12.00	12.30
	2	215	9.55		290	12.89	
	3	210	9.33		270	12.00	
BC 10	1	360	16.00	15.18	450	20.00	21.63
	2	325	14.44		510	22.67	
	3	340	15.11		500	22.22	
BC 25	1	255	11.33	11.26	330	14.67	14.74
	2	250	11.11		335	14.89	
	3	255	11.33		330	14.67	
BC 40	1	230	10.22	9.70	280	12.44	12.81
	2	220	9.78		295	13.11	
	3	205	9.11		290	12.88	

Mix C (w/c : 0.48)							
Specimen	**Code**	**7 days**			**28 days**		
		Loading	**Strength**	**Avg. Strength**	**Loading**	**Strength**	**Avg. Strength**
C	1	500	22.22	22.52	680	30.22	31.26
	2	520	23.11		700	31.11	
	3	500	22.22		730	32.44	
CP 10	1	360	16.00	15.33	520	23.11	22.07
	2	340	15.11		490	21.77	
	3	335	14.89		480	21.33	
CP 25	1	240	10.67	10.82	340	15.11	15.78
	2	240	10.67		360	16.00	
	3	250	11.11		365	16.22	
CP 40	1	200	8.88	9.03	240	10.67	10.44
	2	195	8.67		215	9.55	
	3	215	9.55		250	11.11	
CC 10	1	400	17.78	18.67	530	23.55	23.11
	2	480	21.33		520	23.11	
	3	380	16.89		510	22.67	
CC 25	1	280	12.44	11.63	440	19.55	18.00
	2	255	11.33		385	17.11	
	3	250	11.11		390	17.33	
CC 40	1	250	11.11	11.18	300	13.33	13.70
	2	280	12.44		305	13.55	
	3	225	10.00		320	14.22	

Annexes - V

Calculation Sheet : Average Tensile Strength (Cylinder)

Code	Mix A (w/c : 0.48)				Mix B (w/c : 0.44)				Mix C (w/c : 0.48)			
	Specimen	Loading	Strength	Avg. Strength	Specimen	Loading	Strength	Avg. Strength	Specimen	Loading	Strength	Avg. Strength
1	A	210	2.97	2.88	B	190	2.69	2.69	C	230	3.25	3.02
2		200	2.83			185	2.62			210	2.97	
3		200	2.83			195	2.76			200	2.83	
1	AP 10	165	2.33	2.40	BP 10	165	2.33	2.19	CP 10	175	2.47	2.52
2		175	2.47			150	2.12			185	2.62	
3		170	2.40			150	2.12			175	2.47	
1	AP 25	120	1.70	1.53	BP 25	85	1.20	1.32	CP 25	100	1.41	1.53
2		110	1.56			100	1.41			110	1.56	
3		95	1.34			95	1.34			115	1.63	
1	AP 40	90	1.27	1.15	BP 40	80	1.13	1.18	CP 40	90	1.27	1.20
2		80	1.13			80	1.13			75	1.06	
3		75	1.06			90	1.27			90	1.27	
1	AC 10	175	2.47	2.43	BC 10	165	2.33	2.24	CC 10	180	2.55	2.55
2		180	2.55			155	2.19			190	2.69	
3		160	2.26			155	2.19			170	2.40	
1	AC 25	110	1.56	1.60	BC 25	105	1.48	1.39	CC 25	130	1.84	1.67
2		110	1.56			95	1.34			115	1.63	
3		120	1.70			95	1.34			110	1.56	
1	AC 40	90	1.27	1.25	BC 40	100	1.41	1.25	CC 40	90	1.27	1.34
2		85	1.20			80	1.13			95	1.34	
3		90	1.27			85	1.20			100	1.41	

Annexes - VI

Calculation Sheet : Average Flexural Strength (beam)

Code	Mix C (w/c : 0.48)													
	Specimen	b cm	d cm	l cm	a cm		Loading p Kg		Strength a > 13.3 cm (p*l)/bd^2		Strength 13.3 cm > a >11 cm 3pa/bd^2		Avg. Strength	
					7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
1	C	10	10	40	19.2	18.6	55	70	2.2	2.8			2.53	3.27
2		10	10	40	17.4	19.5	70	90	2.8	3.6				
3		10	10	40	18.1	19.3	65	85	2.6	3.4				
1	CP 10	10	10	40	18.6	18.4	60	75	2.4	3			2.53	3.40
2		10	10	40	18.4	18.6	65	90	2.6	3.6				
3		10	10	40	19.2	19.2	65	90	2.6	3.6				
1	CP 25	10	10	40	12.4	18.4	65	75		3	2.60		2.47	3.07
2		10	10	40	17.6	18.2	55	80	2.2	3.2				
3		10	10	40	18.4	18.4	65	75	2.6	3				
1	CP 40	10	10	40	18.6	11.2	45	55	1.8			1.85	1.53	2.22
2		10	10	40	17.9	16.00	35	60	1.4	2.4				
3		10	10	40	16.8	18.6	35	60	1.4	2.4				
1	CC 10	10	10	40	19.4	19.6	70	85	2.8	3.4			2.67	3.67
2		10	10	40	18.6	19.2	70	95	2.8	3.8				
3		10	10	40	18.2	18.6	60	95	2.4	3.8				

Calculation Sheet : Average Flexural Strength (beam)

Code	**Mix C (w/c : 0.48)**													
	Specimen	**b cm**	**d cm**	**l cm**	**a cm**		**Loading p Kg**		**Strength a > 13.3 cm (p*l)/bd^2**		**Strength 13.3 cm > a >11 cm 3pa/bd^2**		**Avg. Strength**	
					7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
1	CC 25	10	10	40	18.3	18.3	60	85	2.4	3.4			2.60	3.20
2		10	10	40	17.9	18.6	70	85	2.8	3.4				
3		10	10	40	19.2	19.3	65	70	2.6	2.8				
1	CC 40	10	10	40	18.4	16.5	45	65	1.8	2.6			1.80	2.53
2		10	10	40	19.4	18.2	50	70	2	2.8				
3		10	10	40	19.4	14.8	40	55	1.6	2.2				