

EXPERIMENTAL INVESTIGATION OF STRENGTH AND TEMPERATURE EFFECT OF RUBBERIZED CONCRETE

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I, SAROJ KANTI BISWAS, Master of Engineering in Civil Engineering (Structural Engineering), Jadavpur University, Faculty of Engineering and Technology, hereby declare that the work being presented in the thesis work entitled, “**EXPERIMENTAL INVESTIGATION OF STRENGTH AND TEMPERATURE EFFECT OF RUBBERIZED CONCRETE**”, is an authentic record of work that has been carried out in the Department of Civil Engineering, Jadavpur University, Kolkata under **Mr SANTOSH KUMAR DAS**, Assistant Professor, Department of Civil Engineering, Jadavpur University. The work contained in this thesis has not yet been submitted in parts or full to any other university or institute or professional body for award of any degree or diploma or any fellowship.

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ABSTRACT

Concrete is weak in tension and it has very limited ductility. Plain cement concrete performs very poorly when it is exposed to repetitive load and impact load. Crumb rubber obtained from rubber wastes of transportation and engineering sector can be added to concrete to improve the ductility and crack-resisting property of concrete, although there is known to be some reduction in compressive and flexural strength of concrete.

Based on this background, an experimental investigation on the effect of crumb rubber in plain cement concrete has been made. The study includes the effect of addition of crumb rubber in different percentage of fine aggregate on the workability and mechanical properties of concrete. Initially the particle size distribution of crumb rubber, fine aggregate and coarse aggregate are analysed. The mechanical properties like compressive strength, flexural strength, split tensile strength, strength under thermal exposure, stress-strain behaviour of rubberized concrete have been studied.

Nominal size of 10mm coarse aggregates and nominal size of 2.36mm crumb rubber chips are used along with sand of Zone-II to prepare the rubberized concrete mixes. Superplasticizer has also been used to improve the workability. Ordinary Portland cement (OPC) has been used and as a result, initial strength gain of 7 days has been found to be noteworthy. The crumb rubber chips are used in surface-dry condition without any surface treatment. Four different mixes have been prepared with M25 and M35 grades each, having 0%, 5%, 10% and 15% crumb rubber chips. Workability and compressive strength tests have been performed with both M25 and M35 grade mixes while split tensile strength, flexural strength, stress-strain study and study of temperature tests have been performed with M25 grade mixes.

It is noted that the strength of rubberized concrete has been reduced but its toughness increases in proportion to the increasing rubber content which means the rubberized concrete has more strain energy storing capacity in comparison to the controlled mix concrete. Under thermal exposure, rubberized concrete has shown desired results which have established the fact that the crumb rubber induced in concrete is able to sustain high temperature exposure.

CHAPTER-1

INTRODUCTION

Concrete is an important building material that is widely used in the construction industry. Cement, fine aggregate, coarse aggregate, and water are the main constituents of concrete, but chemical admixtures including plasticizer, superplasticizer, accelerator, and retarders are now also necessary ingredients. But in addition to this, it has been discovered that some industrial by-products can be combined with concrete to improve its properties and reduce the environmental hazard. These are referred to as mineral admixtures and include rice husk ash, fly ash, silica fumes, GGBFS, and others. Utilisation of these environmental wastes has been proven to be cost-effective, environmentally responsible, and advantageous for improving the mechanical and chemical properties of concrete. Rubber waste from scrapped tyres is another type of industrial waste material that has lately been discovered to be useful in concrete application. Over 160 billion new tyres are produced each year, along with over 100 billion discarded tyres. Only 7% of waste tyres were locally recycled in 2011, 11% were burned for fuel, and 5% were exported for processing abroad. The remaining 77%, or over 76.5 crore tyres annually wasted, were disposed of in landfills, stored, or illegally discarded. About 6-7% of the world's waste tyres come from India, and there is no effective framework in place to manage this garbage. Investigations have revealed that used rubber tyres contain elements that are harmful and do not breakdown in the environment. Burning is one method of decomposition, but it would also produce toxic pollution. Tyres can be utilised as aggregates in concrete based on these issues. Concrete can use rubber in the form of crumb rubber and rubber chips to replace 5–15% of the aggregates.

It has been discovered that rubberized concrete has a low compressive strength compared to regular concrete but is more durable and has improved crack resistance. By adding some silica to rubberized concrete, its compressive strength can be raised. Rubber has been used previously as a replacement of coarse aggregate and the mechanical properties of that rubberized concrete has been tested. It has been found that with the partnership of GGBS and microsilica, rubberized concrete performs satisfactorily. Microsilica reduces the normal size of pores in cement paste and thus the rubberized concrete achieves almost equal strength to that of conventional concrete. Anti-carbonation property has also been seen to improve in rubberized concrete at a later age, although initially it decreases, and the optimum rubber content for anti-carbonation property is approximately 10%. Abrasion resistance and frost resistance are also some beneficial properties which are found to improve in rubberized concrete. Pre-treated rubber when used in concrete, reduces slump and compressive strength but increases abrasion resistance linearly. Rubberized concrete has also been made to undergo freeze-thaw cycles and it has been observed that frost resistance has improved at an optimum rubber content of 10%. Through temperature study also it has been observed that rubberized concrete can withstand heat of 150°C for 3 hours and can perform equally well as conventional concrete.

In this present study, the major focus of investigation will be to study the overall behaviour in terms of the workability, compressive strength, flexural strength, split tensile strength, performance under heat application, and stress-strain performance of rubberized concrete in which crumb rubber particles is used to replace fine aggregate up to 15%. The study has been made for M25 and M35 grades of concrete.

CHAPTER-2
LITERATURE REVIEW

2.1 General

Rubber wastes used as additives in concrete can be subdivided into 2 types – crumb rubber chips of size less than 4.75 mm and coarse rubber particles of size greater than 4.75 mm. Some research papers have been reviewed in the following section where experiments have been performed with both of these types of rubber wastes used in concrete along with different other admixtures like silica fumes, fly ash, sodium hydroxide and many other mineral and chemical admixtures. Some critical observation has been made based on the literature survey and objective and scope have been given at the end of this chapter.

2.2 Review of Literatures

H. A. Toutanji (1996) studied the change in compressive strength, flexural strength and toughness in concrete made using rubber tire aggregate by volume percentages of 25%, 50%, 75% and 100%. The reduction in compressive strength was observed to be approximately twice the reduction of flexural strength. For compressive strength test, cylindrical test specimens of 100x200mm were used in Universal Testing Machine. For flexural tensile test, specimens of 100x100x350mm were used in Instron testing machine for four-point bend test. Toughness was observed to be higher in rubber concrete specimens and those specimens underwent ductile failure. It was observed the compressive strength fell gradually from 33% reduction at 25% rubber content to 75% reduction at 100% rubber content. Within 50-100% rubber content, there was no considerable increase in toughness but compressive and flexural strength fell by up to 75% and up to 30% respectively. The research data has been tabulated in the table 2.1.

Table 2.1 Compressive and flexural strength test results with different rubber content

Volume of chip rubber aggregate (%)	Compressive Strength (MPa)	Flexural Strength (MPa)
0	31.9	3.8
25	19.6	3.5
50	13.8	3.1
75	9.9	2.8
100	7.5	2.4

N. Segre, I. Joekes (2000) studied on how to improve the surface of tyre rubber powder to promote adherence to cement paste. The surface of one type of rubber particle was left untreated, while the surface of the other type was treated with a NaOH solution. 10% of each type of rubber was utilised, and test specimens were used to quantify things like density, water absorption, flexural strength, compressive strength, abrasion resistance,

modulus of elasticity, and fracture energy. Test specimens for cement paste were created with 10% by mass of rubber either as received or 10% by mass of rubber that had been treated with NaOH (water/cement ratio = 0.36). When sodium silicate was added, a 10% volume aqueous solution of this reagent was used in place of the water. The specimens were made with Type I cement and allowed to cure for 28 days at 50°C and 100% relative humidity for the studies on water absorption through capillarity, flexural strength, modulus of elasticity, scanning electron microscopy (S.E.M.), and fracture energy. The specimens were made with Type I cement and cured for 28 days at 20°C and 100% relative humidity for the compressive strength experiments. The specimens were constructed with Type I cement and allowed to cure for 28 days in a controlled environment at 20°C and 60% relative humidity to test their resistance to abrasion. Prismatic test specimens with measurements for flexural strength, fracture energy, and modulus of elasticity were employed. They were 49 x 10 x 9 mm in size. It underwent a three-point bend test. Through all of these tests, it was shown that the amount of water absorbed decreased as the amount of rubber component increased since rubber particles do not absorb water. In terms of flexural strength, the specimens containing rubber that had been treated with NaOH and rubber that had been supplied as-is displayed higher values than the control specimens. Tyre rubber was added, and this resulted in a fourfold increase in fracture energy, showing that the rubber-containing specimens are more robust than the control. The modulus of elasticity showed no variations. The results of the abrasion resistance tests indicated that the specimen with surface-treated rubber had greater adhesion than those with rubber that was received untreated. Additionally, the specimens' compressive strength was lowered by 33% as a result of the addition of rubber particles.

F. Hernandez-Olivares, G. Barluenga, M. Bollati, B. Witoszek (2002) observed the mechanical behaviour of concrete specimens loaded with tiny volumetric fractions of crushed tyre rubber and short polypropylene fibres at 7 and 28 days under static and dynamic loads. Cement, water, sand, coarse aggregate, superplasticizer, retarder, polypropylene meshed fibre, and rubber (0, 3.5, and 5% by volume) were used to prepare the samples. In order to conduct compression and indirect tension testing, cylindrical specimens (15x30 cm) were produced. Bending tests were conducted on two different specimen types: standard 15x15x60 cm and 10x10x40 cm. According to the test results, plain concrete had a characteristic compressive strength of 36 MPa while short rubber fiber-filled concrete had a compressive strength of 23 MPa. Both 29 and 40 MPa were the average compression values. Standard specimens (15x30 cm) with rubber fibre concentrations of 3.5% and 5% recycled truck tyres were used for experimental dynamic measurements at 7 and 28 days. In theory, it should be evident that the concrete matrix's endurance process, which increases the stiffness of the material, is the reason why the dynamic modulus was lower at 7 days than at 28 days. In every instance, concrete with 5% rubber by weight exhibited a lower dynamic modulus than concrete with 3.5% rubber fibre. At 7 and 28 days, it was discovered that this effect held true with increasing age. Last but not least, Young dynamic modulus was responsive to the frequency of load application. With an increase in frequency, it somewhat grew. Finally,

it was found that the elastic modulus of concrete under static or dynamic load increased with age and decreased as the fibre content or temperature increased. The addition of crumpled tyre rubber volume fractions up to 5% in a cement matrix did not imply a significant variation of the concrete's mechanical features, either maximum stresses or elastic modulus.

A. Benazzouk, K. Mezreb, G. Doyen, A. Goullieux, M. Que´neudec (2003) studied the influence of alveolar structure of rubber aggregates in cement-rubber composite. Among the two types of rubber aggregates used, compact rubber aggregate (CRA) and expanded rubber aggregate (ERA), ERA had alveolar texture on the surface, more water absorption due to more porosity and twice the capacity of strain before failure. The deformability of the cement-rubber composite was done by measuring Brittleness Index with rubber contents of 10%, 20%, 30% and 40% by volume. The dry unit weight was observed to reduce by 22% and 35% respectively for CRA and ERA composites. The compressive strength was also observed to reduce with increase of rubber aggregate, but the strength values were higher with CRA and finer size of rubber particles, although keeping the unit weight constant the ERA proved to be more efficient. Flexural strength was found to be optimum at rubber volume content of about 20%, and beyond 35%, flexural strength decreased significantly. From the loading, unloading and reloading test for determining fracture strain and ductility, it was found that optimal rubber content was 10% and ERA cement composite had more ductility/deformability due to alveolar structure.

A. Benazzouk, O. Douzane, K. Mezreb and M. Que´neudec (2006) studied the properties of aerated cement composites comprising of rubber waste particles. They observed that the fresh composite showed some interesting properties like improvement in workability and high stability of air bubbles in the matrix. Here the mix used comprised of rubber particles of 1mm diameter, polypropylene fibres and proteinic air-entraining agent. It was used to replace cement from 0% to 50%. From the workability test it was observed that slump was efficiently increased by the addition of air-entraining agent and rubber chips also added to the air content due to its texture and greater specific area. The research data has been tabulated in the table 2.2.

Table 2.2 Loss in mechanical properties of concrete with increasing rubber content

Volume of rubber (%)	W/C	Air entrainment	Loss in fresh unit wt (%)	Loss in hardened unit wt (%)	Loss in Comp Strength (%)	Loss in Flexural Strength (%)
10	0.32	12.7	8.03	14.12	35.08	6.25
20	0.35	16.5	15.02	23.33	54.97	15.63
30	0.39	20	21.23	28.76	69.6	25
40	0.44	23.6	27.06	38.24	81.49	43.75
50	0.52	28.2	36.2	48.7	89.5	56.25

The authors observed the enhanced sound insulation properties of this aerated cement rubber composite and also indicated that if w/c ratio is reduced alongwith increasing unit weight, then the compressive and flexural strengths would increase significantly.

A. Benazzouk, O. Douzane, T. Langlet, K. Mezreb, J.M. Roucoult and M. Que´neudec (2007) studied the physico-mechanical properties and water absorption of cement composite comprising of shredded rubber wastes. The rubber wastes were used as partial replacement of fine aggregate for inducing lightweight properties in the composite concrete. The analyses included dry unit weight, elastic dynamic modulus, compressive and flexural strengths, strain capacity, and water absorption. With addition of every 10% of rubber content, it was observed that entrapped air increased by 3% and dry unit weight decreased by about 200 kg/m³. Naturally the modulus of elasticity also decreased with increase in rubber content. Compressive strength decreased by 20-30% for every 10% increase in rubber content. Flexural strength increased upto 20-25% rubber content but then it decreased. It was also observed in the composite characteristics that both capillary water absorption and water absorption speed decreased with increase in rubber content. The study of the stress-strain curve showed that toughness improved in this rubber composite and insulation properties also improved due to entrapped air. The authors also observed satisfactory durability properties and the resistance to acid and sulphate attacks in aggressive environment.

Mehmet Gesog˘lu, Erhan Gu˘neyisi (2007) performed the study on properties of rubberized concrete with and without silica fume. For this purpose, crumb rubber was used to replace fine aggregate and tyre chips were used to replace coarse aggregate. 150mm cubes were used for compressive strength and UPV test, and 100x100x150mm specimen were used for chloride ion permeability test. Silica fume was found to be effective in strength development and improvement of chloride penetration resistance. At 90 days, the rate of strength increase due to the inclusion of silica fume was in the range of 8–20% and 9–34% for the plain and rubberized concretes, respectively. With increasing the rubber content to 25% by total aggregate volume, reductions of up to 26, 21, and 19% in the 7-, 28- and 90-day UPV of the concrete, depending on silica fume content and w/c ratio, were observed, respectively. When the curing period was extended in steps of 3–7 days and 7–28 days, the reduction in the magnitude of chloride penetration depth was significantly higher for both plain and rubberized concretes, even at a rubber content of as high as 25%.

Malek K. Batayneh, Iqbal Marie, Ibrahim Asi (2008) conducted a thorough investigation on the advantages of crumb rubber concrete. Slit tyres (slit into two halves), shredded/chipped tyres (particle size is 300-400 mm long by 100-230 mm wide), ground rubber (19-0.15 mm) and crumb rubber (4.75-0.075 mm) are the four categories into which scrap tyre particles have been divided. According to reports, the nominal size of the crumb rubber ranged from 4.75 mm to 0.075 mm. The crumb rubber waste tyre particles employed in this

investigation ranged in size from 4.75 to 0.15 mm. Crumb rubber was incorporated into the concrete mix in varied percentages of 20%, 40%, 60%, 80%, and 100% to partially replace fine particles (sand). The Type I Ordinary Portland Cement, natural silica sand, coarse aggregates made of crushed limestone, tap water, additives, and crumb rubber were the main ingredients utilised to prepare the concrete mix. Fine aggregates were swapped out for waste crumb rubber in various proportions (20%, 40%, 60%, 80%, and 100%) in various concrete mixes to create the recycled crumb rubber concrete examples. 100 mm cubes, 150 x 300 mm cylinders, and small beams of 100 x 100 x 400 mm each were made for each mix. Each specimen was created, and after 28 days, it was placed in water to cure. Slump tests were conducted for each concrete mix and recorded at the time the specimens were cast. Following curing, specimens underwent compressive, split tensile, and flexural strength tests in accordance with ASTM guidelines. The slump test revealed that as the amount of crumb rubber in the combination increased, both the slump and the unit weight of the mixtures decreased. However, observation while mixing and casting revealed that adding more crumb content to the mix still generated a workable mix in comparison to the control mix, despite the fact that the measured slump had decreased. The usage of crumb rubber decreased all types of evaluated strength, according to the compressive strength, split tensile strength, and flexural strength tests. As was to be expected, the drop in compressive, tensile, and flexural strengths increased with the amount of rubber in the mixture. A linear relationship between the rise in crumb rubber and the compressive strength was maintained up to a limit of 40%, with a loss of around 50% of compressive strength at that point. When the rubber concentration was greater than 40%, the tendency decreased. However, rubber content between 40% and 100% kept weakening the material until a maximum strength loss of up to 90% was reached. According to the stress-strain observations, specimens containing up to 40% rubber exhibited stress-strain behaviour that was similar to that of the control specimen but with a smaller peak. For the other two specimens, which contained 60% and 80% rubber respectively, nonlinear behaviour was seen. Here, the specimen continued to give even after the peak tension was attained. These findings led to the conclusion that concrete with a larger crumb rubber content had high toughness because the energy generated was primarily plastic. Although adding more rubber to modified concrete decreased its strength, it might still meet the requirements for light concrete due to its lower unit weight.

L.-J. Li, Z.-Z. Chen, W.-F. Xie and F. Liu (2009) studied the compressive strength, splitting strength, flexural strength, elastic modulus, stress-strain relationship and permeability of chloride ion of rubber high strength concrete with different rubber content (0-3 %) and different particle size (0.25-1 mm). There was no noticeable change in slump of concrete with different rubber content. Compressive strength, splitting tensile strength and flexural strength of RHSC decreased with increase in content of the rubber. It was observed that the lack of interface bonding between rubber-aggregate and rubber-cement was not strong. For cube

compressive strength and split tensile strength tests, 100x100x100mm blocks were used. For flexural strength test, 100x100x400mm specimen were used. The research data has been tabulated in the table 2.3.

Table 2.3 Fall in strength and workability with different size of rubber particles

Size of rubber particles (mm)	Fall in slump (%)	Fall in cube compressive strength (%)	Fall in split tensile strength (%)	Fall in flexural strength (%)
0.25	12.2	22.8	9.2	14
0.4	14.6	14.7	12.9	22
1	7.3	23.4	20.4	19

The authors performed Ultrasonic Pulse Velocity tests on 100x100x100mm specimen and found that the pulse velocity increased with age-growth and strength of concrete. And they observed that rubber particles of 0.4 mm showed better pulse velocity results due to its better gradation which meant stronger rubber-cement interface and less pulse velocity loss. Chloride penetrability was also tested by staining method and it was found that depth of chloride ion penetration was zero, indicating good resistance against chloride penetration.

Lingqiang Yang, Liwei Zhang and rui Gao (2011) conducted a number of studies to investigate the thermal capacity of rubber concrete by measuring the adiabatic temperature rise and the temperature change associated with hydration. It was then cast in steel moulds and stored in an adiabatic temperature rise machine. The rubber concrete was created in several mixes with various amounts of rubber particles replacing coarse aggregate by 20%, 40%, 60%, and 80%. Every 30 minutes, a thermometer was used to record temperature changes. It was discovered that the rubber content of rubber concrete had no impact on the heat hydration adiabatic temperature value. Additionally, the same rubber concrete mixes containing 20%, 40%, 60%, and 80% rubber were used for a pouring block hydration temperature test. Temperature and strain sensors were used in this test to detect the temperature and strain that developed in the concrete during the hydration phase. With increasing rubber content, it was found that the peak hydration temperature rose, with a maximum difference of 6°C. As a result, it was possible to draw the conclusion that the addition of rubber particles to concrete changed the material's heat conductivity. Due to the increased size of the voids, these trials demonstrated that coarse rubber particle concrete had a better ability to insulate than fine rubber particle concrete. Higher rubber particle content was found to improve insulating capacity.

Alireza Ahangar-Asr, Asaad Faramarzi and Akbar A. Javadi (2011) used evolutionary polynomial regression (EPR) to describe the mechanical behaviour of rubber concrete. EPR is a data-driven evolutionary computing technique designed to look for polynomial structures that reflect a system. The evolutionary algorithm and the least squares approach are combined in this method to find workable structures and the proper constants for those structures. One of the most important benefits of EPR was its ability to represent the relationship between the parameters as a polynomial expression. This allowed parametric studies to be carried out to determine the role of the various parameters involved and to determine whether the developed model had been successful in capturing the physical relationships between the system's various parameters. This also provided insight into the extent to which various additives may affect the behaviour of the final mixture in the current investigation. To accomplish this, a parametric research was conducted, with the exception of one parameter, which was adjusted between its minimum and maximum values in the training and testing sets. All other parameters were set to their mean values. The findings indicated that while adding more tyre chips and fine-grained aggregate decreased the mixture's compressive strength, adding more coarse-grained aggregate increased the compressive strength of the rubber concrete. The resistance to failure and cracking as well as the shear strength of concrete were both improved by adding more coarse particles. However, adding more fine particles lessened this impact and hence reduced the strength of the concrete.

Bian Libo, Song Shaomin (2011) studied the workability, apparent density, compressive strength, flexural strength, brittleness index, anti-crack performance, wear resistance, and anti-fatigue performance of crumb rubber concrete. Crushed stone with a maximum size of 25 mm was used as the coarse aggregate, along with coarse natural sand with a fineness modulus of 3.1, second-class fly ash, cement, tyre crumb rubber and a highly effective superplasticizer made of naphthalene with a 20% water-reduction ratio. According to the slump test, the degree of concrete slump clearly decreased as the amount of crumb rubber rose. Compared to the slump of the crumb rubber concrete with 10%, which was just 130mm, the control mix's slump was 190mm. Additionally, the compressive strength tests showed that the strength decreased compared to control mix concrete due to the addition of more crumb rubber. The reason for this outcome may be because rubber particles have a microporous structure and low strength, thus when fine aggregate was replaced in the concrete with these rubber particles, the rubber particles generated weak joints that caused the concrete to lose strength and workability. Additionally, when the amount of crumb rubber in concrete rose, the air content increased as well, which led to a reduction in the apparent density of rubber concrete as compared to control mix concrete. With the addition of rubber to concrete, it was also discovered that the flexural strength decreased. The approach of a slab test of early-age shrinking and cracking of HPC was employed on two concrete slabs (400mm x 600mm x 80mm) in the anti-crack test for performance of crumb rubber concrete. Conclusion: The CRC had better cracking resistance than control mix concrete. Up to a rubber content of 56.70 kg/m³, the CRC had only a few very small cracks, whereas the control mix concrete had much more cracks. Because the

blended rubber could absorb the energy of the load cycle of tension and compression, CRC's anti-fatigue performance was superior than that of control mix concrete. However, CRC's anti-fatigue performance was subpar because its compressive strength was inferior to that of control mix concrete.

Wei Wu, Chao Zhang and Yong Li (2012) studied the variables that affected the compressive strength of rubber concrete. Cement of grade 42.5 MPa, river sand with a maximum size of 5 mm and a fineness modulus of 2.45, coarse aggregate 5–20 mm gravel, regular tap water, water reducing agent as an admixture, and fine powder rubber with an apparent density of 1.03 g/cm³ and available in four different mesh sizes, 20 mesh, 40 mesh, 60 mesh, and 80 mesh, were the raw materials used for the experiment. Waste tyres were combined in three different ways: solely replacing sand, only replacing gravel, and replacing both at a ratio of 1:1.97. Waste tyres were combined in four different forms according to four different mesh sizes. Then, cube pieces for 7d and 28d strength gains were created. According to the findings of the compressive strength test, the compressive strength of rubber concrete dropped as the dosage of powder increased. The greatest reduction in compressive strength was 64% for specimens 7D and 28D where 20 mesh powder was used in place of sand and gravel, respectively. The surface of the specimens had a few minor cracks, but they continued to hold up for some time after the load limit. It demonstrated that rubber concrete has greater toughness and crack resistance than regular concrete. Additionally, it was observed that the compressive strength of rubber concrete fell less noticeably when the rubber dose exceeded 100 L/m³. When the rubber dosage was the same and the powder size was less than 40 microns, the compressive strength of the rubber concrete that used powder to replace the sand was greater than that of the rubber concrete that used powder to replace the gravel. Compressive strength of rubber concrete added into 20 mesh powder was greater than that mixed into other mesh powders when replacement method and rubber dosage were the same. These findings led to the conclusion that the compressive strength of rubber concrete decreased as rubber dosage increased. The slower the compressive strength of rubber concrete decreased, the smaller the rubber granules became. Rubber concrete has much greater tenacity, cracking resistance, and failure properties than regular concrete.

XU Jin-Hua, FENG Xia-Ting, CHEN Si-Li, Shi Chen-Yang (2012) studied the basic mechanical properties of rubber concrete using crumb rubber particles in two grain sizes—50-mesh and 3–4 mm—in place of fine aggregates. The replacement levels for the fine aggregates were 0, 5, 10, 15, and 20% by volume. Crushed stone that complied with aggregate specifications made up the coarse aggregate. The sand had a fineness modulus of 2.6 and was unprocessed river sand. The cementitious materials utilised had a 28-day compressive strength of 42.5MPa and were made of Portland cement. These rubber concrete mixtures were used to construct 100mm cubes and 100x100x400mm beams. Compressive strength of rubberized concrete was measured using cube specimens, whereas flexural strength and dynamically elastic modulus were measured using prism specimens with dimensions of 100x100x400mm. At 28 days of concrete age, all of the hardened

concrete's qualities were acquired. Slump testing was done for the workability study, and it was found that the slump value dropped as the rubber content in the concrete increased. Additionally, it was found that rubber powder-infused concrete had generally higher slump values than rubber grain-infused concrete. Additionally, it was discovered that unit weight decreased as the proportion of rubber component rose, while the sort of rubber used had less of an impact. Compressive strength dropped as rubber content rose, and a rubber replacement level of 5–15% was found to be ideal for satisfying the basic engineering requirement of compressive strength. The bond between rubber and cement paste, which was weaker than the bond between aggregate and cement paste, was the cause of the decrease in compressive strength. When the dynamic modulus of elasticity of rubber concrete was measured using a dynamic elastic modulus instrument, it was discovered that the dynamic modulus of elasticity reduced up to 31.3% for rubber powder and up to 40.6% for rubber grain with an increase in rubber content of up to 20%.

Ren-Jwo Tsay and Huynh Nguyen Nhat L-Am (2012) observed the rubber concrete-made RC slab's dynamic response. Rubber material has excellent elasticity and energy absorption capabilities; thus, it can be utilised to increase the RC slab's absorption capabilities and lessen vibration in RC floors. For the RC slab, 4 different types of concrete mixes were created, each of which included 0%, 2.5%, 5%, and 7.5% rubber replacement by weight of sand. Non-destruction test methodology was used to obtain the material properties and to comprehend the actual behaviour under dynamic stress. Additionally, three cycles of the walking load were applied to the RC slab to imitate the dynamic loads brought on by people. Three distinct body weight scenarios of humans were used to assess the dynamic response in order to better understand how various persons of different weights reacted to the rubber concrete RC slab. The experiment revealed that the measure slab Eigen frequency exceeded that predicted by the thesis. It may have been caused by the combined behaviour of steel and concrete, which increased the system rigidity under dynamic stress. The walking load microtremor research revealed that the 5% rubber concrete slab's Eigen frequency was concentrated at 7.2 Hz. The mass increase of moving loads made the effect of the slab structure frequency discount more apparent.

Wei Li, Xiaochu Wang, Junwei Wang, Chuanji Wang (2013) investigated the mechanical characteristics of concrete that substituted scrap rubber tyre crumbs for some of the fine particles. Cement with a model number of PO 32.5R, medium-coarse river sand, coarse aggregates measuring 5 to 25 mm, a high-effect water reducer, and two types of rubber—colloidal particles and crumb rubber—were the ingredients utilised. In order to create rubber concrete, both types of rubber were utilised in substitution of fine aggregate in amounts of 20%, 40%, 60%, 80%, and 100%. The cube compressive strength test, the splitting tensile strength test, the flexural strength test, the axial compressive strength test, the modulus of elasticity test, and the ultimate compressive strain test were all conducted on this rubber-modified concrete. According to the compressive strength tests, the compressive strength of rubber cement concrete aged 7 and 28 days decreased as the rubber

content increased, but the strength of concrete mixed with powder was significantly lower than that of concrete mixed with colloidal rubber, indicating that the latter performed better. According to the results of the split tensile strength test, the splitting tensile strength of rubber cement concrete decreased with an increase in rubber dosage. The basic splitting tensile strength also decreased linearly after mixing rubber powder and colloidal particles, but in the 28th day and when the rubber ratio was between 40 and 60%, the strength of the concrete underwent a mutation. After being destroyed, the specimens kept their original shape, and there were hardly ever surface fractures. The flexural strength test experiment made use of the one-third point of loading mode. This test revealed that, when the proportion of rubber powder was between 0% and 20%, the strength of rubber cement concrete rapidly decreased. The strength of rubber powder decreased more slowly when the ratio was between 40% and 60%. Additionally, with increasing dosage, the rubber cement concrete's modulus of elasticity decreased linearly.

Qun Yu, Wen-Chao Ye (2013) did an experimental study on the compressive strength and frost resistance of rubber concrete. The results showed that the concrete compressive strength reduced with addition of rubber particles but at the same time the frost resistance increased. It was observed that around 5-10% of rubber dosage, the compressive strength decreased by about 15-20% but beyond that rubber content, there was further and steep decrease in compressive strength. With age, the cube compressive strengths showed varying degrees of growth, but the increase was observed indeed. More the rubber content, more the rate of increase of compressive strength with age. Frost resistance was measured by maximum number of freeze-thaw cycles, and rubber concrete with optimum rubber concrete content of 10% showed much improved frost resistance about 50% than conventional concrete. So, the authors concluded that in mixed conditions, the 50% increased frost resistance would be more beneficial, overshadowing the 20% decrease in compressive strength.

Feng Liu, Wanhu Zheng, Lijuan Li, Wenxian Feng, and Guofang Ning (2013) analysed the fatigue performance and mechanical performance of rubber concrete, in which fine aggregates have been replaced by 0%, 5%, 10% and 15% recycled rubber tyre contents. The authors studied the mechanism of fatigue damage and found the fatigue life, dynamic strain and fatigue performance to be better than Ordinary Concrete. It was observed that the anti-cracking property improved with increasing rubber content due to improvement in toughness. Fatigue strength was found to be 45-47% of static strength. The research data has been tabulated in the table 2.4.

Table 2.4 Weight and strength test results for concrete with different crumb rubber content

Crumb Rubber Content (%)	Weight of specimen (kg)	Cube strength (MPa)	Axial compressive strength (MPa)	Flexural strength (MPa)
0	8.3	57.8	43.4	5.6
5	8.18	50.6	38.2	5.3
10	8.02	45.3	32.6	5.1
15	7.87	37.7	26.9	4.6

Tung-Chai Ling, Hasanan Md. Nor, Mohd. Rosli Hainin and Abdul Aziz Chik (2013) studied the laboratory performance of crumb rubber concrete block pavement (CBP) subjected to 10,000 cycles of load repetition under a single truck wheel via a tyre inflated to 600 kPa. The concrete blocks used were 210*105*60 mm, compressive strength between 23-64 MPa, with rubber content of 0-30%. Mix proportion 1:1.87:3.77 by weight, target 28d compressive strength 30 MPa. Crumb rubber sizes were 1-5 mm. It was observed that the sample blocks with lesser rubber content showed lesser transverse, mean and longitudinal rut depth. Toughness also improved to a large extent by adding crumb rubber to brittle concrete paved blocks, which meant higher capability of absorbing dynamic load and resisting crack propagation. Skid resistance was measured in terms of British Pendulum Number and it also improved in crumb rubber concrete blocks. BPN value of the blocks ranged between 65 and 73. The concrete blocks with more rubber showed lesser shear resistance to pull-out force due to weaker interlocking of the components.

Osama Youssf, Mohamed A. ElGawady, Julie E. Mills, Xing Ma (2014) looked into how well crumb rubber concrete performed when contained in fiber-reinforced polymer tubes for potential usage in structural columns. In order to partially replace fine aggregates in concrete mixtures, crumbed scrap tyre rubber was added in amounts of 0%, 5%, 10% and 20%. The workability, compressive strength, tensile strength, elastic modulus, and Poisson's ratio of 101 typical concrete cylinders were tested to determine the effects of rubber content, rubber pre-treatment, and silica fume (SF) additions. Additionally, 18 concrete cylinders enclosed in FRP tubes of varying thicknesses were compressed uniaxially to see if there was any difference in behaviour between the confined CRC and regular concrete. All but one rubber-containing mix used pre-treatment of the rubber particles with NaOH. To start the process, the rubber particles were rinsed in tap water to get rid of any dirt and impurities. They were then placed in a container and left in a 10% NaOH solution for 30 minutes. The rubber particles were then cleaned once more by swirling water until its pH reached 7, after which they were allowed to dry by air. Any residual NaOH solution must be removed during the final washing to prevent any harm to the concrete's durability. The following factors were examined in this study: rubber content (0%, 5%, 10%, and 20% as a replacement for sand volume), rubber particle pre-treatment (with and without NaOH), SF

content (0% and 10% by weight of cement), and number of confinement FRP layers (1, 2 and 3 layers). From each mixture, eight 100x200 mm cylinders were made: three for testing the compressive strength after seven days, three for testing it after twenty-eight days, and two for testing the elastic modulus, the Poisson's ratio, and the stress-strain behaviour after twenty-eight days. Due to the high Poisson's ratio of tyre rubber and its capacity to bend under stress, tests revealed that Poisson's ratio rose with increasing rubber content. The concrete slump was reduced by about 25% as a result of the pre-treatment of rubber particles, and the compressive strength rose as a result by about 6% and 15% at 7 and 28 days, respectively. Finally, it was determined that producing viable CRC mixes for CFFT columns would involve substituting small (or badly graded) pieces of rubber (1.18–2.36 mm) for sand while yet having a workable consistency. The compressive strength of the confined specimens significantly increased as compared to the unconfined ones after confining both conventional concrete and CRC with FRP layers, and the larger the FRP thickness, the greater the gain in strength. All CRC mixes had greater ductility than their control mixes. Concrete's ductility improved as rubber volume increased, especially at increasing densities of confinement. Therefore, it was determined that confined CRC application in structures vulnerable to seismic loads was a viable area for further research.

Qun Yu, Jing Wang (2014) studied the carbonation resistance performance of waste rubber concrete with rubber particles mainly of coarse size. Different particle size and percentage of content of rubber had different influence on carbonation resistance or anti-carbonation property of rubber. It was found that the optimum rubber content for carbonation resistance was 10%. It was also found that the smaller particle size improves better anti-carbonation property. This experiment was done in anti-carbonation testing machine using specimens of size 100x100x400 mm. It was observed that with gradually increasing carbonation time from 3d to 28d, the carbonation depth increased from 3mm to 10mm. The authors also noted that at initial stage the anti-carbonation property decreased but then increased at late stage.

Iman Mohammadi, Hadi Khabbaz, Kirk Vessalas (2014) investigated the properties of Crumb Rubber Concrete prepared by water-soaking treatment method. The water-soaking treatment was performed to reduce the hydrophobic property of rubber and its attached air-bubbles so that rubber-cement bond developed better. As a result, chances of segregation were reduced and unit weight of concrete was also improved. The improvement in compressive and flexural strengths due to the use of water-soaked rubber was 22% and 8% respectively in comparison to that of untreated rubber.

The compressive strength tests showed that beyond rubber content of 5%, strength fell with increase in rubber and fell sharply at higher rubber content although rubber addition was uniform. At 2-4% rubber content for every 1% addition of rubber, strength fell by 4-8%. The research data has been tabulated in the table 2.5.

Table 2.5 Loss in strength of concrete for different rubber content and different w/c ratio

Rubber %	W/C Ratio	Compressive Strength Loss (%)		Flexural Strength Loss %		W/C Ratio	Compressive Strength Loss (%)		Flexural Strength Loss %	
		7-d	28-d	7-d	28-d		7-d	28-d	7-d	28-d
		10	0.4	11.29	14.12		11.48	6.94	0.45	21.85
20	35.05	29.68		21.31	19.44	39.07	37.23	22.22		16.67
30	44.95	50.95		29.51	22.22	51.88	57.19	33.33		31.67
40	58.81	63.65		36.07	36.11	63.57	67.27	44.44		40

The flexural to compressive strength ratio was found to increase with increasing rubber content. In cyclic loading test also, the fatigue behaviour improved.

Jun Cai (2014) conducted a number of tests to examine the mechanical characteristics of crumb rubber concrete (CRC). Investigations were done on the CRC's flexural toughness, splitting tensile strength, and compressive strength. Experimental analysis was done on the impact of crumb rubber proportion on mechanical characteristics. Ordinary portland cement, coarse aggregate measuring 5 to 20 mm, sand measuring no more than 5 mm, fly ash as a mineral addition, polycarboxylic superplasticizer as an additive, and crumb rubber in proportion to the total volume of concrete were the elements utilised to produce the concrete mix. Compressive and splitting tensile strengths of cubes (100 x 100 x 100 mm) were measured, and four-point loading flexural tests on beams (100 100 400 mm) were performed. The test findings revealed that when crumb rubber content increased, compressive strength and splitting tensile strength declined. The increase in porosity brought on by the introduction of crumb rubber is what caused the drop in compressive strength and splitting tensile strength. On the other hand, the flexural properties of CRC were significantly impacted by the crumb rubber. The increased crumb rubber content improved the post-peak behaviour of the beams. CRC's ability to carry more weight increased dramatically. The amount of rubber in CRC rose along with its flexural toughness factor. The inclusion of crumb rubber greatly increased the ductility and flexural toughness of CRC.

Wei Li1, Zhen Huang, Xiaochu Wang, Zisheng Zang (2014) studied the mechanical characteristics of silane coupling agent-modified crumb rubber concrete. It was based on the idea that silane coupling agent could bind organic and inorganic molecules, and that rubber's modified surface could increase the cementitiousness of cement-based materials, improving the mechanical properties of crumb rubber concrete. The materials included coarse aggregate measuring between 5 and 25 mm, KH-560 silane coupling agent, water reducer with a 20% reduction rate, and two different forms of rubber: colloidal particles and crumb rubber. The mix proportion was: cement : water : sand : stone : silane coupling agent : Water reducer = 1 : 0.35 : 1.289 : 2.742

: 0.005 : 0.075. Compressive strength tests revealed that silane coupling agent concrete exhibited a clear improvement compared to datum concrete at 28 days, with an amplification of 24.0%, in the absence of rubber blending. The largest increase in compressive strength under the 20% rubber blending condition occurred at 28 days, or roughly 25.8%, and was affected by the silane coupling agent. The rate at which compressive strength decreased changed from being rapid to being sluggish as rubber content increased. Concrete's splitting tensile strength fell when the rubber content rose as a result of rubber blending. Because silane coupling agent was blended, the splitting tensile strength of concrete was much increased. In the case of 20% rubber blended, the silane coupling agent-modified splitting tensile strength reached its peak at 28 days, or roughly 32.0%. Because of rubber blending, concrete's flexural strength reduced, and the more rubber was mixed, the more concrete strength was lost. The flexural strength of concrete mixed with rubber colloids was higher than that of concrete mixed with rubber crumb at the same rubber content. In comparison to the same concrete with rubber crumb under the condition of 10% rubber content, the non-modified rubber concrete with rubber colloids had increased flexural strength by 5.7%. Because of silane coupling agent, the flexural strength of concrete also increased significantly. It was determined that concrete blended with rubber colloids had higher compressive strength, splitting tensile strength, and flexural strength than concrete blended with rubber crumb did for the same rubber content.

F. Liu, L.-Y. Meng, G.-X. Chen and L.-J. Li (2015) used a split Hopkinson pressure bar with crumb rubber concentrations varying from 0% to 20% to evaluate the dynamic mechanical behaviour of crumb rubber-concrete composites subjected to repeated impacts. Investigated was how the rubber content affected the dynamic properties of crumb rubber concrete that were subjected to repeated impacts. The specimens for the experiments were made using crushed stone aggregates with a maximum size of 15 mm (2.685 specific gravity), regular Portland cement with a 28-day compressive strength of 42.5 MPa, river sand with a fineness modulus of 26, a water-reducing admixture with a 30% water-reducing rate, and water for mixing and curing. The crumb rubber was made by mechanically grinding the external surfaces of used tyre fragments. The size of the rubber granules ranged from 2 mm to 1.06 g/cm³. The same volume of fine particles (sand) in the control concrete were swapped out for rubber contents of 5%, 10%, 15%, and 20%. An input bar, an output bar, a stopper (damper), velocity measuring tools, and a data collection system made comprised the SHPB test setup. A gas pistol was used to press the striker bar. The SHPB method is based on the theory of one-dimensional wave propagation in an elastic bar. According to the theory of one-dimensional wave propagation, if a long bar is made of an ideal elastic material, any disturbance at the bar end will move along the bar with an elastic wave velocity without deforming, with the exception of high-frequency waves. In the SHPB tests, CRC with crumb rubber contents ranging from 0% to 20% was repeatedly struck at the same pressure (the gas cannon was fixed at 0–20 MPa), and its strain rate ranged from 18.3 to 30.6 s⁻¹. From the failure modes, it was clear that the micro-cracks started at the cylindrical specimens' edges before gradually spreading to the centre. The

concrete may not crumble and the spread of microcracks may be restricted by the randomly placed crumb rubber. These showed that under repeated impact, CRC has a substantially greater capacity to absorb energy than NC. The results showed that as the amount of crumb rubber was increased, the cubic compressive strength values of CRC declined. The strength of CRC was drastically reduced by 43.5% at a rubber concentration of 20%. When more crumb rubber was used in the SHPB testing, the peak stress dropped. The peak and ultimate strains, however, grew.

Ishtiaq Alam, Umer Ammar Mahmood, Nouman Khattak (2015) studied the compressive strength, ductility, crack resistance of rubberized concrete. It was found that rubberized concrete is durable, less ductile, has greater crack resistance but has a low compressive strength when compared with ordinary concrete. The authors also observed that concrete made of crumb rubber as fine aggregate showed much strength when compared with concrete made of chipped rubber as coarse aggregate. For complementing the reduction in compressive strength, silica fume was found to be the best mineral admixture. The research data has been tabulated in the table 2.6.

Table 2.6 Strength values of rubberized concrete for different rubber content

Crumb rubber Content (%)	Flexural strength (MPa)	Splitting tensile strength (MPa)	Compressive strength, f_c (MPa)
0	3.68	2.82	25.33
20	2.55	1.84	18.96
40	2.04	1.47	12.27
60	1.38	0.94	8.07
80	0.77	0.533	4.47
100	0.64	0.22	2.5

Iman Mohammadi, Hadi Khabbaz (2015) studied the shrinkage properties of concrete pavement made using rubberized concrete. Their analysis revealed that concrete strength decreased upon increasing crumb rubber content and the optimum rubber content was found to be 20% and 25% for w/c ratio of 0.45 and 0.4 respectively. The increase in rubber content decreased the maximum failure load but the toughness index also increased, although insignificantly. From the plastic shrinkage test, it was observed that the average crack dimensions reduced, crack reducing ratio or CRR index improved and the free drying shrinkage strain increased. The research data has been tabulated in the table 2.7.

Table 2.7 Change in shrinkage and compressive strength for different rubber content and w/c ratio

W/C Ratio	Optimum rubber %	CCR (%)	Drying Shrinkage (μ s)	Change in Compressive Strength
0.45	20	+56%	445	+12.5%
0.4	25	+4%	380	+9.38%

Blessen Skariah Thomas, Ramesh Chandra Gupta (2015) studied the properties of high strength concrete containing scrap tire rubber by performing compressive strength, flexural tensile strength, pull-off strength, abrasion resistance, water absorption and water penetration tests. The concrete samples and their microstructures were observed using Scanning Electron Microscopy (SEM). Rubber content was 0-20% and 6% silica fumes by weight of cement was also added to the concrete due to its ability to add strength in concrete and also fill the pores. The research data has been tabulated in the table 2.8.

Table 2.8 Strength, water absorption and abrasion resistance for different rubber content

Rubber %	Comp Strength	Flexural Strength	Pull-off strength	Water absorption	Abrasion Resistance
5	-3.1%	-4.17%	-6.25%	-4.55%	+19.72%
10	-13.66%	-8.33%	-12.5%	-3.03%	+19.72%
15	-33.1%	-20.83%	-25%	+3.03%	+27.46%
20	-57.3	-23.61%	-31.25%	+12.12%	+32.4%

It was observed that all the concrete mixes with 0-12.5% crumb rubber, crossed the compressive strength limit of 60 MPa. Observations of Scanning Electron Microscopy revealed that there were cracks and cavities between crumb rubber and cement paste, which was the reason behind weak bond between the crumb rubber and cement mortar leading to reduced compressive strength of concrete. Water penetration increased in the rubberized concrete but abrasion resistance also increased. It was observed that for high strength concrete, the optimum rubber content was upto 12.5% for better strength, abrasion and water penetration resistance.

Dong Lanqi, Liang Chaofeng, Wang Xiaogang, Zhou Zechenglong and Chen Yanli (2015) studied the interfacial bond property by split tensile strength test and shear strength test. It was observed that split tensile strength and shear strength decreased with increase in rubber content and increase in rubber particle size. The bond strength and properties were found to improve with increase in surface roughness. Shear strength was found to reduce with increasing rubber content and decreasing size of rubber particles. So optimum rubber

content for durability and economic efficiency was found to be less than 20%. The research data has been tabulated in the table 2.9.

Table 2.9 Change in split tensile strength and shear strength with increasing rubber content

Rubber Content %	Change in Split Tensile Strength	Change in Shear Strength
10%	-38.57%	+18.38%
20%	-44.73%	+17.4%
30%	-76.43%	+103.17%

Treatment of surface with 10% concentration HCl resulted in better bond property.

Mohammed Mudabheer Ahmed Siddiqui (2016) performed an experimental investigation on the compressive strength and workability of rubcrete made by replacing upto 15% coarse aggregates with rubber tyre particles. M20 concrete was chosen as the reference concrete and the ingredients included OPC 53 cement, Zone-II Sand, 20mm coarse aggregates and tyre chips below 20mm.

To improve surface roughness of rubber and to make good attachment with cement paste, tyre aggregates were surface-treated with Carbon Tetrachloride, and this resulted in 57% improvement in compressive strength. The research data has been tabulated in the table 2.10.

Table 2.10 Change in workability and strength for different percentage of rubber

% of rubber particles	Fall in slump (%)	Fall in unit weight (%)	Fall in 7d compressive strength (%)	Fall in 28d compressive strength (%)
5	34.8	2.3	7.8	28.9
10	68.5	6.6	22.1	42.9
15	94.5	14.3	40.7	55.2

Agampodi S.M. Mendis, Safat Al-Deen, Mahmud Ashraf (2017) studied the flexural behaviour of reinforced beams made of Crumb Rubber Concrete (CRC) mixes of similar compressive strengths. Crumb rubber of 1-3mm and 2-4mm were used replacing sand. Similar ultimate flexural capacities were observed in reinforced beams made of similar strength CRCs, regardless of rubber content and other mix proportion of CRC. The research data has been tabulated in the table 2.11.

Table 2.11 Change in strength and flexural capacity for different rubber content and different grades of concrete

Concrete Mix	Rubber %	Compressive Strength, MPa	Split Tensile Strength, MPa	Flexural Strength, MPa	Ultimate Flexural Capacity, KN-m
M40	5%	46.4	4.05	4.46	15.6
M40	21%	41.1	3.95	4.95	14.85
M30	5%	35.3	3.29	4.57	14.85
M30	16%	32.55	2.87	3.99	14.25

It was concluded that reinforced concrete beams made from similar strength CRCs behave similarly under flexural loads.

Osama Youssf, Reza Hassanli, Julie E. Mills (2017) studied the mechanical properties of high-rubber-content concrete that was both contained and unconfined by FRP. Experimental research was done to determine the mechanical performance of concrete mixes including fine aggregates and crumbed scrap tyre rubber in amounts of 0, 10, 20, 30, 40 and 50%. 102 typical concrete cylinders were tested to determine the effects of rubber content on the concrete's compressive strength at various elevated temperatures, tensile strength, elastic modulus, unit weight, impact resistance, water absorption, and stress-strain behaviour. Additionally, 12 concrete cylinders that had been contained using various numbers of layers of carbon FRP were compressed uniaxially to examine any differences in behaviour between the confined CRC and regular concrete. The binder material was a general-purpose cement type with a specific gravity of 3.15; the coarse aggregate was dolomite stone with nominal maximum aggregate sizes of 10 mm and 20 mm; the river sand had a maximum aggregate size of 5 mm; and crumb rubber with particle sizes of 1.18 and 2.36 mm was used in part place of sand. For all mixes comprising rubber particles in the current study, pre-treating the rubber particles with NaOH was used. To start the process, the rubber particles were rinsed in tap water to get rid of any dirt and impurities. They were then placed in a container and left in a 10% NaOH solution for 30 minutes. The rubber particles were then cleaned once more by swirling water until its pH reached 7, after which they were allowed to dry by air. Twelve 100 x 200 mm cylinders of each mix were made: two for testing the strength after seven days, six for testing the strength after two weeks at various elevated temperatures, two for testing the elasticity and stress-strain behaviour after two weeks, and two for testing the water absorption. Through experimentation, it was discovered that rubber had no discernible impact on concrete unit weight up to 10% rubber content. Beyond that, the unit weight declined almost linearly as the rubber content increased as anticipated since the rubber particles have a lower unit weight than the sand they replaced. The weight of

the concrete unit was reduced by 0.4, 2.1, 3.6, 4.6, and 6.9%, respectively, by using 10, 20, 30, 40, and 50% rubber content. Additionally, both at 7 and 28 days, the concrete's compressive strength declined as the rubber component increased. Using 10, 20, 30, 40, and 50% rubber content reduced the concrete's compressive strength by 17.7, 39.9, 54.1, 62.0, and 72.2% at 7 days and by 21.3, 37.9, 54.3, 62.5, and 66.4% at 28 days, respectively, compared to ordinary concrete. The concrete's tensile strength was reduced by 15.0, 40.1, 44.1, 48.9, and 58.5%, respectively, by using rubber contents of 10, 20, 30, 40, and 50%. With an increase in rubber content, the measured modulus of elasticity (E) decreased. E was reduced by 4.8, 16.4, 30.1, 34.8, and 51.5%, respectively, when rubber content was 10, 20, 30, 40, and 50%. Additionally, employing rubber content up to 10% had only a minor impact on concrete's water absorption—down to about 3.2%—and not much of an impact at all. Additionally, compared to normal concrete, crumb rubber concrete had a better concrete ductility.

Mohamed K. Ismail, Assem A. A. Hassan and Amgad A. Hussein (2017) investigated the strength and cracking properties of enhanced self-consolidating and vibrated rubberized concrete mixtures with/without steel fibers (SFs) using substantial reinforced concrete beams. Different amounts of crumb rubber (CR) (0 to 35%), SF volume fractions (0, 0.35 and 1%), and SF lengths (35 and 60 mm) were used to cast the test beams. All of the created mixes were bound with type GU Canadian Portland cement, which is comparable to type 1 ASTM C150 cement, metakaolin (MK), which complies with ASTM C618 class N, and type F fly ash. For the coarse and fine aggregates, respectively, natural crushed stone with a maximum particle size of 10 mm and natural sand with a specific gravity of 2.6 and water absorption of 1% were employed. In this investigation, CR aggregate—which had a maximum size of 4.75 mm, a specific gravity of 0.95, and minimal water absorption—partially replaced the fine aggregate. There were two different kinds of SFs with hooked ends: the first type had dimensions of 35 mm long by 0.55 mm in diameter and a 65 aspect ratio, and the second variety measured 60 mm long by 0.9 mm in diameter and a 65 aspect ratio as well. Each variety of SF had a density of 7.85 kg/m³, a Young's modulus of 210 GPa, and a tensile strength of 1050 MPa. They employed a polycarboxylate-based high-range water-reducing admixture (HRWRA) with a specific gravity of 1.2, a volatile weight of 62%, and a pH of 9.5, which is comparable to ASTM C494 type F. To cast the 12 reinforced concrete beams, a total of 12 concrete combinations were created. The findings of this study suggested that, in order to get satisfactory slump flow and no visible signs of segregation, a total binder content of at least 550 kg/m³ and a minimum water/binder (w/b) ratio of 0.4 should be utilized. It was discovered that replacing cement with 30% fly ash and 20% MK was the best option for altering the mixes' viscosity, resulting in an excellent particle suspension with reasonable flowability. The deformability of the tested beams was increased at a given load by using lightweight crumb rubber (CR) aggregate with low stiffness, which also helped to decrease the weight of the beams themselves. However, self-consolidating rubberized concrete (SCRC) beams' normalized shear strength declined by 91% as CR percentage (0 to

25%) increased. The normalised shear strength of SCRC beams with up to 15% CR rose by 23% (on average) with the inclusion of 0–35% steel fibres (SFs) (35 mm length), while this increase reached 57–5% in vibrated rubberised concrete (VRC) beams with a higher percentage of CR (35%). The failure mode of beams with up to 35% CR was comparable to that of a beam with no CR (shear failure), but it was characterized by more cracks and narrower crack widths. Steel-fibre-reinforced SCRC and VRC (SFSCRC and SFVRC) beams with 0–35% SFs (35 or 60 mm) and up to 35% CR continued to have smaller fracture widths, but the failure pattern remained same.

Mayank Bharadwaj, Prof. Shailendra Singh (2017) conducted an investigation of the material after adding crumb rubber as fine aggregate to concrete. By substituting crumb tyre rubber for aggregate, they aimed to determine the various qualities required for the construction of concrete mix. The reference concrete specimen was made of M20 grade concrete. In place of traditional fine aggregate, recycled tire rubber powder was used as fine aggregate. OPC (ultra-tech cement), Fine Crumb Rubber, Natural Coarse Aggregate (Sedimentary Rock Source), Natural Fine Aggregate (Sand), and Water (Fresh Drinkable Water) were the essential components of rubberized concrete used in this research. Concrete that had been rubberized was utilized to prepare test samples utilizing locally accessible coarse particles. Used was graded coarse aggregate, which is defined by its nominal size, such as 40mm, 20mm, 16mm, or 12.5mm. In this investigation, coarse aggregate with a nominal size of 20 mm was used. For this project, beam samples of 50 x 10 x 10 cm and cube samples measuring 15 x 15 x 15 cm were prepared. For the preparation of the samples, concrete grade M20 was taken into consideration. Using volumetric ratios for M20, or 1:1.5:3, the mix was created. Materials were combined before being put into the cube mould. To test the compressive strength of rubberized concrete, the compressive strength test was done on cubes with dimensions of 15 cm x 15 cm x 15 cm. To assess the flexural strength of the rubberized concrete, a flexural test on beams measuring 50 x 10 x 10 cm was conducted. In this investigation, a progressive decline in compressive strength was seen as the proportion of crumb rubber in the fine aggregate increased. According to this study, crumb rubber can be added to concrete mixtures up to 10% of the weight of fine aggregate without significantly reducing the compressive strength. The workability of concrete deteriorated as the proportion of crumb rubber increased in concrete that had a larger crumb rubber content. If 15% of the sand were substituted with crumb rubber, the concrete's flexural strength would have fallen by around 56%. When 15% of the sand was substituted with crumb rubber, the compressive strength of the concrete reduced by around 25%. The loss of strength was inevitable with the inclusion of the crumb rubber.

Han Zhu, Bin Rong, Rong Xie and Ziheng Yang (2018) observed the floating property of rubber particles in crumb rubber concrete. Fresh crumb rubber concrete is vibrated and compacted, and as a result, rubber

particles tend to float, which causes voids and affects the homogeneity of the mix. Materials such as OPC of Chinese Grade 42.5, medium sand as fine aggregates, crushed stone as coarse aggregates, and naphthalene superplasticizer with water-reducing capability of 25% were used to create prismatic specimens of 100*100*300 mm for this investigation. Compressive strength and rubber particle distribution percentage were used to calculate the degree of floating of the rubber particles. It was discovered that the compressive strength and density fluctuation was minimal for low slump range. But as the slump rose, so did the compressive strength and density variation. The density variation and floating impact were found to be substantial at slump values greater than 180 mm. Additionally, it was observed that as the vibrating time increased. Due to the fact that fine aggregates prefer to float to the top and coarse aggregates tend to settle at the bottom, the density difference ratio also rose.

A.E. Polikutin, A.V. Levchenko, D.N. Korotkih (2018) studied the resistance of reinforced rubber concrete's standard section with fibre bending components. Additionally, they manufactured and evaluated cross-bending samples of beams with dimensions of 60 mm, 120 mm, and 1400 mm. The benefits of rubber concrete included its great adherence to metal surfaces, deformation-strength features, and good insulating and damping qualities. However, rubcon's high level of chemical and water resistance was what set it apart. The percentage of longitudinal reinforcement was a variable parameter used in the construction and testing of armofiberrubcon beams. The parameters of the experimentally determined and theoretically predicted armofiberrubcon and reinforced concrete beams were visually displayed and contrasted in order to evaluate the performance of the examined constructions with reinforced concrete. According to experimental findings and SP 63.13330.2012, reinforced concrete beams with the same geometrical parameters and percentage of reinforcement built of controlled mix concrete experienced a breaking moment that was three times lower than that of the fiberrubcon testing samples. According to the graph in fig. 2.1, in order to perceive a same destructive load, it was necessary to increase the cross section of the bending elements constructed of conventional reinforced concrete, which would increase the structure's weight and material usage. As floor beams and flooring, lintels of a door, window, or other openings of buildings and structures, where the presence of aggressive environments of industrial or other origin, as bending structural elements of bridges and Railways, elements of foundations (in particular, foundation beams) exploitation under aggressive groundwater are just a few examples, bending elements of rectangular cross-section with the addition of fibres and reinforced with non-stressed reinforcement. The research data has been expressed graphically in the fig. 2.1.

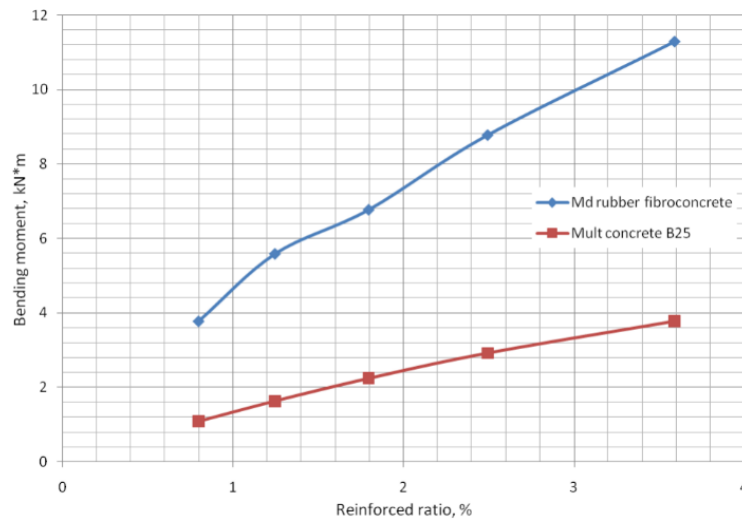


Fig. 2.1 Graphical representation of bending moment vs rubber reinforcement percentage

Trilok Gupta, Salman Siddique, Ravi K. Sharma, Sandeep Chaudhary (2019) studied the mechanical and durability capabilities of hybrid rubber concrete and waste rubber powder in harsh environments. Rubber fibres (shredded tyres) and rubber powder (incinerated tyres) are two distinct aggregate types that need comparable durability-based assessments for structural applications. As a result, in this investigation, the resistance to adverse environmental conditions of waste rubber powder and hybrid (rubber powder and rubber fibres) concrete was observed. In this study, ordinary Portland cement of grade 43 with a specific gravity of 3.12 was used. As coarse aggregate, crushed stone aggregates that were readily available were used. The coarse aggregate's maximum size was 12 mm, and its specific gravity was 2.59. As a fine aggregate, natural river sand with a specific gravity of 2.56 was used. Superplasticizer with a high range of water reduction was utilised to preserve the desired workability. Waste rubber tyres that had been discarded were shred into fibres that ranged in size from 2 to 20 mm in length and width. Such rubber fiber's (RF) specific gravity was determined to be 1.07. Waste rubber tyres were burned at 850°C for 72 hours to produce rubber powder (RP) particles. Rubber powder particles ranged in size from 0.15 millimetres to 1.9 millimetres. In order to recreate an acidic environment for the acid attack test, 100 mm cubic concrete specimens were immersed in 3% acidic solutions. Hydrochloric acid (HCl) and sulfuric acid (H₂SO₄) solutions were applied to concrete sample. A steady state chloride diffusion test was used to assess the resistance to chloride ion penetration. Concrete samples that were 65 mm in diameter and 50 mm in thickness were used. 3% sodium chloride and distilled water, respectively, were placed in the upstream (Anode) and downstream (Cathode) cells. After 72 hours, the specimen's chloride ion penetration was assessed at a 30 V DC potential. Three 12 mm dia TMT steel rebars were cast in specimens measuring 115 mm x 275 mm x 225 mm to conduct corrosion studies. After the initial 28 days of curing, the specimens were pounded for 14 days with a 3% NaCl solution. An electrochemical macrocell develops in concrete when there is moisture, chloride ions, and oxygen present. As a result, the top bar serves as an anode and the bottom bars as a cathode. Between the anode and the cathode, a 100 resistor was used to measure the macrocell corrosion. After pondering for seven days, the potential difference was

noted. Corrosion readings were tracked for a full 18 months. For concrete samples containing 20% rubber powder, it was shown that the greatest mass loss occurred 180 days after exposure. Rubber powder can boost resistance to sulfuric acid attack by up to 15% when added. At longer ages of exposure, the results of mass loss in hybrid concrete samples were comparable to those of control concrete. In comparison to sulphuric acid, hydrochloric acid attacked the bulk of concrete samples less forcefully. When 20% rubber powder was used as fine aggregate, the mass loss decreased from 8.8% for control concrete to 7.1%. Compared to control concrete, which saw an 8.7% mass loss, hybrid concrete mix experienced an 8.6% loss. It was observed that the resistance to acid attack decreased with increasing the amount of waste rubber in the concrete mix and immersion time, resulting in a drop in compressive strength. On 180 days of sulphuric acid immersion, the compressive strength of control concrete decreased by 56.1%. The rate of deterioration in hydrochloric acid was less rapid than it was for sulfuric acid. With the addition of rubber aggregate to concrete, the diffusion of chloride ions was reduced. In particular, it was found that rubber fibres offered the three advantages of tortuosity, hydrophobicity, and big size, acting as a barrier to control the influx of chloride ions into the cement matrix. Additionally, the addition of rubber aggregate enhanced the likelihood of corrosion in concrete. In the case of rubber aggregate, the increased durability against chloride ions did not guarantee durability against corrosion. Rebar corroded because of the poor link between rubber aggregate and cement paste, which allowed oxygen to enter.

Sulagno Banerjee, Aritra Mandal, Jessy Rooby (2019) performed compressive strength test, tensile strength test, flexural strength test and heat study of concrete with 5-20% coarse aggregate replaced by chipped rubber, 40% cement replaced by GGBS and extra added microsilica at 5% by weight of cement. Along with these, 0.5% superplasticizer was also used. They observed that 5% replacement of coarse aggregate with rubber is the optimum content for strength. The rubber aggregates were Tyre Derived Aggregates (TDA) of 40mm size. The final design mix for M25 grade concrete was found out to be 1:2.20:2.72.

The authors found from the strength tests that deficit of strength due to rubber content was satisfied by the addition of microsilica and GGBS, and target strength was achieved in 56 days. After 56 days, concrete with 5% replaced rubber aggregate shows only 5.9% decrease in compressive strength, 5.8% decrease in split tensile strength and 1.9% decrease in flexural strength. They also found from heat study that exposure of rubber concrete in higher temperature around 150°C didn't cause any significant reduction in strength.

M Záleská, M Pavlíková, D Čítek and Z Pavlík (2019) assessed the impact of waste tyre rubber particle size on the characteristics of light rubber concrete. Cement, water, and both coarse and fine natural and rubber aggregates were employed to prepare test specimens. As a binder, Portland slag cement was used. Rubber

fragments between 0 and 4 mm in size were produced by mechanically crushing used tyre rubber. Silica sand in fractions of 0/4 mm and 4/8 mm was used as a natural aggregate. To investigate the impact of rubber size, four concrete combinations were created. For all studied mixes, the water to cement ratio (w/c) was 0.5. There were prepared prismatic samples with dimension of $40 \times 40 \times 160$ mm and cubic samples with side dimension of 100 mm, which were after casting left at highly humidity environment ($RH \geq 98\%$) and temperature (23 ± 2) °C. Samples were demoulded after 24 hours and cured in water for the following 27 days. Concrete samples that had been hardened for 28 days were used for testing. In the experiments that were run, structural, mechanical, thermal transport, and storage qualities were evaluated using optical microscopy. On cubic specimens with a side size of 100 mm, the thermal transport and storage characteristics of rubber concrete were examined. Since one of the primary elements affecting concrete's thermal performance is the degree of saturation, the volumetric heat capacity and thermal conductivity were calculated in relation to the moisture content. It was found that rubber had much lower thermal conductivity and volumetric heat capacity than silica sand. This result validated the hypotheses regarding enhanced thermal insulation capabilities of rubber-containing concrete. The air spaces between the aggregate grains were closed during compaction, increasing the thermal conductivity and volumetric heat capacity. Based on the test results, it was determined that adding crushed tyre rubber to concrete reduced its mechanical resistance, unit weight, thermal conductivity, and volumetric heat capacity. Additionally, even in the presence of moisture, the rubberized samples shown better thermal insulating qualities. Concrete with better thermal insulation performance was produced by 10% replacement of the fine, coarse, or both fractions of natural aggregate with crushed rubber particles of the suitable size.

Jing Lv, Tianhua Zhou, Qiang Du, Kunlun Li (2020) studied the impact of rubber particles on the self-compacting rubber lightweight aggregate concrete's (SCRLC) uniaxial compressive fatigue parameters. When the number of cycles in uniaxial compressive fatigue testing was increased, the stresses of SCRLC at maximum loading and minimum loading initially increased quickly, then gradually, and finally dramatically. The SCRLC's fatigue stresses and fatigue lifetimes increased as the fraction of rubber particles replacement increased. The ability of rubber particles to absorb the deformation and energy of SCRLC under fatigue loading was primarily responsible for this. However, the stress level corresponding to fatigue limit strength increased initially before decreasing as the rubber particle substitution percentage in SCRLC increased. When rubber particles were substituted at a 30% substitution rate, the peak stress level at fatigue life of 2×10^6 was 0.68. In general, when rubber particles substitution percentage ranged from 0 to 50%, superior fatigue properties of SCRLC would be attained at a rubber particles substitution percentage of 30%. Internal flaws brought on by the integration of rubber particles in SCRLC were still at a low level and had a minimal impact on the fatigue limit strength when the rubber particles substitution percentage was under 30%. Moreover, the flowability of fresh SCRLC decreased noticeably when more than 30% of rubber particles were substituted.

Trilok Gupta, Salman Siddique, Ravi K. Sharma, Sandeep Chaudhary (2020) investigated the durability of reinforced concrete that had fiber-type rubber shreds added as fine aggregate and silica fume added as an additional cementitious element. Rubber shreds and silica fume were used in place of cement and natural fine aggregate in concrete projects. The concrete mixtures' compressive strength up to 365 days, resistance to abrasion, and water absorption up to 28 days were all examined. Up to 90 and 180 days, respectively, of carbonation and acid resistance (H_2SO_4 and HCl) studies were conducted. Up to 18 months of corrosion samples were evaluated for both half-cell potential and macrocell current. Concrete's compressive strength and resistance to corrosion, carbonation, and water absorption were decreased by the addition of rubber shreds. A reduction of 51.8% was seen when 25% of the natural sand was replaced with rubber shreds during the typical 28-day drying period. It was discovered that the compressive strength of silica fume concrete may be made stronger by adding up to 10% rubber shreds as fine aggregate. However, using rubber shreds in concrete increased its resistance to acid and abrasion attack. Due to the use of flexible rubber shreds that resist abrasion force by serving as a brush between cement paste and abrasive powder, the depth of wear decreased by 33% for 25% rubber content. Silica fume significantly improved the mechanical and durability characteristics of rubber shreds concrete and decreased the likelihood of corrosion. It improved the interfacial bonding and increased the compactness of the concrete structure, which led to improved abrasion resistance. When rubber shreds were added in doses of 5%, 10%, 15%, and 25%, the water absorption of concrete mixtures first increased and subsequently decreased. The durability, stability, and hydrophobic character of rubber shreds favouring resilience against acidic solutions were also noted by the scientists. In addition, silica fume was added to the concrete matrix to densify it and prevent aggressive acid from penetrating it.

Minhao Dong, Mohamed Elchalakani, Ali Karrech, Bo Yang (2020) studied the strength, durability, carbonation resistance, water absorption properties of rubberised geopolymer concrete and compared to those of rubberised conventional cement concrete. The results demonstrated a good association between bulk density, elastic modulus, ductility, splitting tensile strength, and water absorption and the compressive strength of rubberized geopolymer concrete. In order to replace up to 30% of the coarse aggregates, which were 4 mm ungraded aggregates and a 7 mm graded aggregate, recycled crumb rubber particles (2–5 mm) were largely utilised. The geopolymer concrete mix contained low calcium Class F fly ash, commercially available GGBS, and densified silica fume. It was shown that adding less rubber enhanced workability, however adding more rubber at a 30% replacement ratio decreased the slump and spread values. The lowest blend measured 140 mm and the maximum mix measured 230 mm; all mixtures were deemed to be satisfactorily workable. The control mix without rubber was able to reach a high compressive strength of 61.4 MPa after 56 days. As the rubber content grew, the strength decreased. Testing for sorptivity, water absorption, and initial rate of absorption revealed that for every 15% increase in rubber content, water absorption rose by roughly 40–50%.

Hesham S. Ahmad, Raed M. Abende and Yasser M. Hunaiti (2020) evaluated how concrete-filled steel tubes (CFST) held together when waste chipped rubber from recycled tyres was used in place of some of the natural coarse aggregate. 112 square and circular CFST specimens were subjected to a series of push-out tests, with the following key factors taken into account: (i) cross-sectional type (circular and square); (ii) cross-sectional dimension; (iii) concrete type (normal and rubberized concretes, i.e. RuC); (iv) replacement ratio of recycled chipped rubber; and (v) concrete age (28-365 days). There were four replacement ratios for rubber chips (0%, 10%, 20%, and 30% by volume of coarse aggregate). By combining the compounds in the appropriate amounts (kg/m³), the concrete core of the CFST was created in accordance with the requirements of ACI 318. The concrete control mixture (containing 0% chipped rubber) was intended to have a compressive strength of 25 MPa after 28 days. By partially substituting 10%, 20%, and 30% of the coarse aggregate with an equivalent volume of chipped rubber, the rubberized concrete mixtures were created. After the mixing was completed, an ASTM C143/C143M-20 slump test was performed to assess the mixtures' workability at room temperature and 54% relative humidity. In order to test the compressive strength at 28 days and one year, six 150-mm standard cubic specimens of each of the four mixture types (0%, 10%, 20%, and 30% of rubber chip) were cast. To investigate and measure the interfacial bond strength between the steel inner surface and concrete infill at concrete age of 28 days, four specimens for each circular and square CFST shape with chipped rubber content (0, 10, 20 and 30%) were tested, and three specimens for each shape were tested at one year. Without segregation or floating in the specimens, concrete mixtures demonstrated an even distribution of the mix's constituent parts and good dispersion of chipped rubber in the cement matrix. A slump test showed that adding chipped rubber particles to concrete mixtures improved their workability. The soft and flexible nature of rubber particles as well as their weak adhesion to cement paste may be responsible for the rise in slump. Because the cement paste and the rubber had little adhesion, adding chipped rubber had a negative impact on the compressive strength. All specimens with chipped rubber had compressive strength much less than those containing crumb rubber, which had the highest loss in strength (40%) at 30% crumb rubber replacement ratio. At 30% chipped rubber replacement ratio, the compressive strength recorded the lowest reduction of 62%. To assess the bond behaviour between the inner surface of steel tubes and the concrete infill, a push-out test was performed on 112 RuCFST specimens. In comparison to both the small circle sections (CS2) and the other square sections (SS1 and SS2), the larger circular specimens (CS1) showed greater interfacial binding strength (τ_u). The enhanced ductility of RuC had no beneficial effects on the bond behaviour of CFST specimens. RuCFSTs generally exhibited interface bond behaviour comparable to that of traditional CFSTs. Additionally, compared to square RuCFST specimens, circular RuCFST sections displayed significantly higher core slip.

Ling-Yun Feng, Ai-Jiu Chen and Han-Dong Liu (2021) studied the abrasion resistance of rubber concrete with the help of underwater steel ball method. The authors found that the abrasion resistance is directly proportional to the fine rubber content whereas the compressive strength is inversely proportional and it decreases linearly. 2 types of rubber particles were used based on size, 1-3mm and 3-5mm, to replace fine aggregate content by a small percentage. The authors observed that slump initially increased but then started decreasing with respect to increasing rubber content. For rubber content = 15%, the slump of the mixture increased by 13.3% (1–3 mm) and 9.3% (3–5 mm). Compressive strength and split tensile strength decreased linearly while abrasion resistance increased with respect to increasing rubber content. Reason behind decrease in strength was that rubber is weak compared to sand and bond quality of rubber and cement is not as good as that of sand and cement, and innate micro-cracks have appeared between rubber particles and cement bonding surface. Rubber particles were pretreated by various processes like water processing, NaOH solution processing, NaOH+KH570 processing among which the NaOH+KH570 processed rubber showed better effect with 6-12% increased compressive strength and 11-17% increased split tensile strength and 10-30% increased abrasion resistance.

Ling-Yun Feng, Ai-Jiu Chen and Han-Dong Liu (2022) studied the characteristics and bonding mechanisms of rubberized concrete and regular concrete. On the one hand, it could be said that rubber particles (RP) could lessen concrete's tendency to shrink, which would lower shear and tensile stress close to the bonding border. On the other hand, RPs reduced the overall strength of concrete, which had a negative impact on the interface transition layer's mechanical performance. In this study, Portland cement 42.5 was employed. Limestone gravel was used as the coarse aggregate, and natural river sand and two different types of RPs, measuring 1-3 mm and 3-5 mm in diameter, were used as the fine aggregate. The RPs had a smooth, angular surface and were constructed from crushed automobile tyres. As interfacial agents, a commercial cement paste and a modified epoxy were chosen. To ensure a stronger binding at the interface, the water-cement ratio of the cement paste should be lower than that of the RC. So, in this investigation, the water-cement ratio of cement paste was established at 0.4. Epoxy makes up the majority of the modified epoxy. First, a batch of NC specimens with dimensions of 150 mm 150 mm 150 mm were made and stored for 28 days in the typical curing environment. The specimens were then aged for 60 days in a natural setting before being divided in half to create two concrete specimens that were around 75 mm 150 mm 150 mm in size. These specimens were used as ancient concrete specimens in the subsequent bonding experiments. The bonding splitting tensile strength between the new and the old concrete was seen to increase and subsequently decrease as the PC concentration in RPs rose. The RC with 5% of RPs and the old NC had a lower bonded splitting tensile strength than the RC with 0% of RPs (new NC) and the old NC. The bonding splitting tensile strength between the old NC and the RC mixed with 3-5 mm RPs was higher than that between the old NC and the RC mixed with 1-3 mm RPs because the body strength (compressive strength and splitting tensile strength) of the RC mixed

with 3-5 mm RPs was greater than that of the RC mixed with 1-3 mm RPs. The body strength of the RC was enhanced when combined with the modified RPs, and this directly contributed to an increase in the bonding splitting tensile strength.

2.3 Observations

Depending on the above literature survey some critical observations have been made as follows.

- Rubberized concrete is found to be typically lightweight and slightly weaker in compressive strength and workability has also reduced to some extent with rubber content more than 15%, but with less rubber content, workability is unaffected.
- It has been seen that use of pozzolanic material and water-reducing admixtures improved the strength as well as workability of rubberized concrete.
- It has been found that addition of rubber chips improves the ductility, crack resistance, toughness & abrasion resistance of concrete
- It has also been found that addition of rubber chips improves the durability of concrete.
- Rubberized concrete is thermally capable up to 150° C without losing strength.
- Surface treatment of rubber additives improves the strength of concrete.

2.4 Objective

Study on strength and effect of temperature of sustainable concrete with partial replacement of fine aggregate by recycled rubber chips.

2.5 Scope

- 1) Determination of properties of materials to be used for the proposed experimental study
- 2) Mix design calculation for controlled mix & mix using recycled rubber chips.
- 3) Casting of samples as per proposed experimental programme.
- 4) Testing the samples as per proposed experimental programme.
- 5) Study on temperature effect on rubberized concrete.

CHAPTER-3
EXPERIMENTAL INVESTIGATION

3.1 Materials –

Cement: The cement used was OPC 53 grade i.e. Ordinary Pozzolana Cement of 28 days compressive strength 53 MPa, conforming to BIS specification IS:12269-1987.

Table 3.1 Chemical composition of OPC 53 cement

Chemical Composition	Values adhering to IS 12269-1987
CaO-0.7SiO ₃ / (2.8SiO ₂ + 1.2Al ₂ O ₃ + 0.65Fe ₂ O ₃)	0.8-1.02
Al ₂ O ₃ / Fe ₂ O ₃	>0.66
Insoluble residue (% by mass)	<5.00
Magnesia (% by mass)	<6.00
Sulphuric Anhydride (% by mass)	<3.00
Total loss on ignition (% by mass)	<4.00
Total chlorides (% by mass)	<0.10

Table 3.2 Physical composition of OPC 53 cement

Physical Composition	Values adhering to IS 12269-1987
Fineness (m ² /kg)	>225
Standard consistency (%)	
Initial setting time (minutes)	>30
Final setting time (minutes)	<600
Soundness (Le Chatelier expansion in mm)	<10.0
Soundness (Autoclave expansion in mm)	<0.8
Compressive strength (3d) in MPa	>27
Compressive strength (7d) in MPa	>37
Compressive strength (28d) in MPa	>53
Performance Improver (%) - Limestone	<5.0
Performance Improver (%) – Fly ash	
Performance Improver (%) – Granulated slag	

Sand: Zone-II Sand (IS 383: 2016) of specific gravity 2.66 was used.

Table 3.3 Particle Size Distribution of Sand

Sieve (mm)	Weight retained (gm)	% wt retained	Cumulative % wt retained	% wt passing	% passing of Zone-II Sand
4.75	0	0	0	100	90-100
2.36	60	5.56	5.56	94.44	75-100
1.18	115	10.65	16.21	83.79	55-90
0.6	515	47.69	63.9	36.1	35-59
0.3	300	27.78	91.68	8.32	8-30
0.15	80	7.41	99.09	0.91	0-10
Pan	10	0.93			
	1080		276.44		

Fineness Modulus = $276.44/100 = 2.7644$. So, Medium Sand as per IS 383:2016.

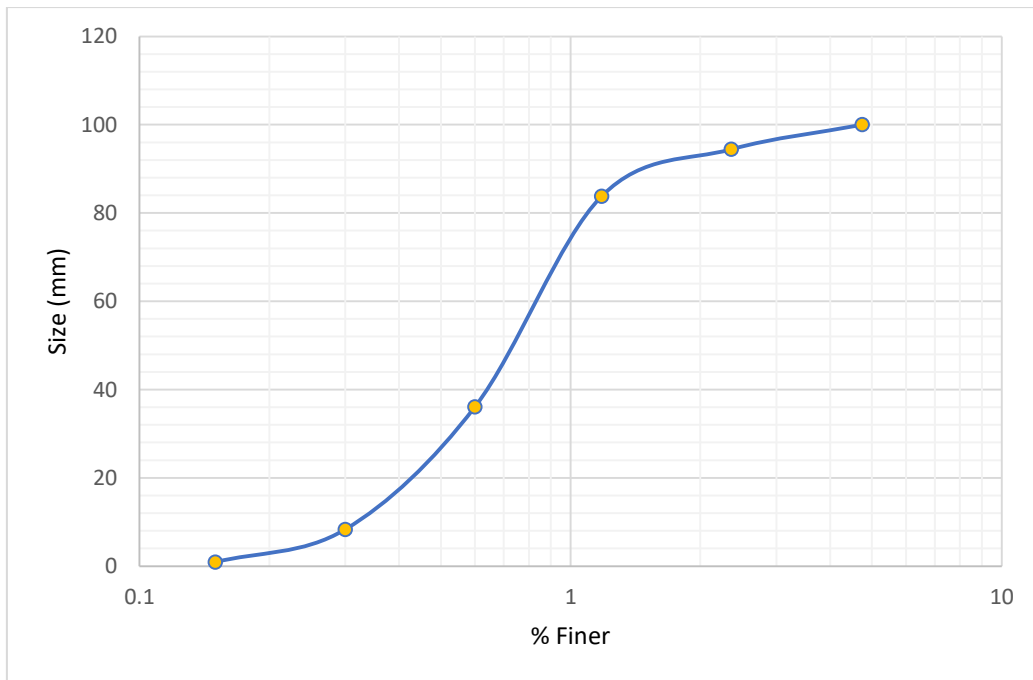


Fig. 3.1 Particle size distribution graph of Sand

Coarse Aggregate: Coarse aggregates of maximum nominal size 10 mm (IS 383: 2016) and specific gravity 2.87 was used. Sieve analysis of 2000 gm of coarse aggregate stones performed using sieves of 20mm, 10mm and 4.75mm gives the following data:

Table 3.4 Sieve analysis data of coarse aggregate

Sieve Size (mm)	Wt retained (gm)	% wt retained	Cumulative % wt retained	% wt passing
40	0	0	0	100
20	260	13	13	87
10	340	17	30	70
4.75	1385	69.25	99.25	0.75
Pan	15	0.75	100	0

Rubber chips: Rubber crumb particles of average particle size below 2.36 mm, specific gravity 1.15. Sieve analysis of 1000 gm of crumb rubber particles performed using sieves of 75 µm, 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm and 4.75 mm gives the following data:

Table 3.5 Sieve analysis data of rubber chips

Sieve Size (mm)	Wt retained (gm)	% wt retained	Cumulative % wt retained	% wt passing
4.75	10	1	1	99
2.36	35	3.5	4.5	95.5
1.18	622	62.2	66.7	33.3
0.6	246	24.6	91.3	8.7
0.3	64	6.4	97.7	2.3
0.15	10	1	98.7	1.3
0.075	8	0.8	99.5	0.5
Pan	5	0.5	100	0

Admixture: Auramix 450 superplastizer complying to IS 9103 - 1999 (2013) and ASTM C 494 Type F and G was used. Following are its properties:

- Appearance: Light yellow coloured liquid
- pH: 6.0-6.5
- Volumetric mass @20°C: 1.09-1.11
- Chloride content: Nil

3.2 Specimens –

Four types of mixes are used for every mix grade of concrete in which only rubber content is varied keeping the other parameters constant. The mixes are formed as per mix design prepared according to IS 10262:2019 and standardized. The four mixes have 0% (control mix), 5%, 10% and 15% rubber content by replacement of fine aggregate. These mixes are used to manufacture the following specimens. Standard cube specimens of 100 mm x 100 mm x 100 mm are prepared for compressive strength test. Prisms of 100 mm x 100 mm x 500 mm are prepared for flexural strength tests and cylinder-shaped concrete specimens of 150 mm diameter and 300 mm height are prepared for split tensile strength tests. Standard cube specimens of 100 mm x 100 mm x 100 mm are prepared for temperature study and stress-strain behaviour study.



Fig. 3.2 100mm cube specimens

3.3 Experimental Programme - The following tests were conducted at the Concrete Laboratory of Civil Engineering Department, Jadavpur University, Kolkata.

- 1) Workability test: Slump Cone Test as per IS 1199-1959
- 2) Strength tests:
 - i. Compressive Strength Test as per IS 516-1959
 - ii. Flexural Strength Test as per IS 516-1959
 - iii. Splitting Tensile Strength Test as per IS 5816-1959
 - iv. Temperature Study at 200°C for 24 hrs
 - v. Stress-Strain Behaviour Study

a. Slump Cone Test

Principle - In accordance with IS 1199-1959, the workability property of freshly-poured concrete is measured using the concrete slump test. It is an empirical test that gauges how easily new concrete can be worked. It measures the consistency of the concrete between batches more precisely. Due to the

straightforward gear and straightforward process, the test is well-liked. The outcome of the slump test serves as an indicator of how a compacted, inverted cone of concrete would behave when subjected to gravity. It gauges the consistency or wetness of the concrete, which provides information on the mix's workability.

Apparatus required – Slump cone, Scale for measurement, Steel tamping rod

Procedure - The mould for the concrete slump test is a cone-shaped frustum with a height of 300 mm (12 in). The hole at the top is narrower, measuring 100 mm (4 in), while the base is 200 mm (8 in) in diameter. A smooth surface is chosen for the foundation, and the container is filled with three layers of concrete whose workability will be evaluated. A typical steel rod with a diameter of 16 mm (5/8 in) and a rounded end is used to heat each layer 25 times. The top surface is struck off (leveled with the mould top aperture) once the mould has been entirely filled with concrete using screening and a rolling motion of the temping rod. Using handles or foot rests that have been brazed to the mould, the mould must be securely held against its base throughout the whole process to prevent movement caused by the concrete pour. The cone is gently and carefully raised vertically once the concrete has been filled and leveled because unsupported concrete will now sink. The term "slump" refers to the reduction in height in the center of the slumped concrete. The tamping rod is positioned over the cone such that it should also cover the area of slumped concrete, and the cone is placed just next to the slumped concrete to measure the slump. The height difference between mould and concrete is noted with scale. (often approximated to the closest 5 mm (1/4 in)).

Precautions - The inside of the mould and its base should be moistened at the start of every test to lessen the impact of variations in surface friction on slump, and before lifting the mould, the area immediately surrounding the base of the cone should be cleared of any concrete that may have fallen there accidentally.

Types of slump - Collapse Slump, Shear Slump and True Slump.

The concrete fully falls during a collapse slump. A collapsing slump will typically indicate that the mixture is either too wet or highly workable, in which case the slump test is inappropriate. It denotes an excessively high water-to-cement ratio, or a high workability mix for which a slump test is inappropriate.

The top part of the concrete shears off and slides sideways in a shear slump. Shear slump is the term used to describe a slump in which one-half of the cone slips down an inclined plane. Concrete must be retested in order to obtain accurate results because the shear slump shows that the result is insufficient. A new sample should be taken, and the test should be repeated if a shear or collapse slump is attained. If the shear slump continues, as it sometimes does with severe mixes, this is a sign that the mix is not cohesive.

The concrete just subsides and maintains its shape in a real slump. Only this slump is utilized in numerous examinations. Since mixtures with a stiff consistency have zero droop, it is impossible to distinguish between them in the rather dry range regardless of their workability. A real slump can quickly transform into a shear

slump type or even collapse in a lean mix with a predisposition toward harshness, and samples from the same mix can yield wildly varied slump values.

Applications –

- The slump test is used to determine the effects of plasticizers on their introduction and to assure uniformity for various batches of comparable concrete in field settings.
- This test can be used on-site to check for variations in the materials being put into the mixer from day to day or hour to hour. For instance, a rise in slump could indicate an unexpected rise in the moisture content of the aggregate.
- Another reason can be a change in the aggregate's grade, like a sand shortage.
- A slump that is too high or low provides an immediate alert and helps the mixer operator to correct the condition.
- The widespread usage of the slump test is due to both its application and its ease of use.



Fig. 3.3 Slump Cone

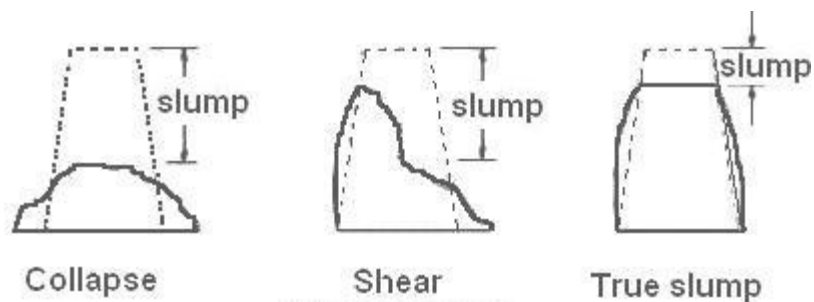


Fig. 3.4 Types of slump

b. Compressive Strength Test

Principle - Depending on the size of the aggregate, either 15 cm x 15 cm x 15 cm or 10 cm x 10 cm cubes are employed as specimens for the cube test. Cubical moulds with dimensions of 15 cm x 15 cm x 15 cm are frequently utilized for the majority of works. This concrete is properly tempered after being put into the mould to prevent voids. Moulds are removed after 24 hours, and test specimens are then submerged in water to cure. These specimens' top surfaces ought to be level and smooth. To accomplish this, apply cement paste evenly throughout the whole surface of the specimen. After seven or 28 days of curing, these specimens are evaluated using a compression testing equipment. Compressive strength tests were performed using standard 100mm cubes (dimensions 100mm x 100mm x 100mm) in order to investigate the impact of rubber chips' inclusion on the mechanical characteristics of concrete. The compressive strength of concrete with and without rubber

particles was investigated using cube specimens at 7 and 28 days after casting and water curing. With the use of a compressive strength testing machine, the maximum load was calculated. According to the recommendations of IS 516-1959, loading was applied at a constant rate of 2.2 KN/sec. In a compression test, compressive strength is estimated by dividing the maximum load by the initial cross-sectional area of the specimen. Until the specimens fail, a load should be applied gradually at a rate of 140 kg/cm² per minute. Concrete's compressive strength is calculated by dividing the load at failure by the specimen's surface area.

Apparatus required - Compression testing machine

Preparation of specimen – The proportion and material for making these test specimens are from the same concrete used in the field. 6 cubes of 15 cm size Mix M15 or above are used.

For manual mixing, we must first thoroughly blend the cement and fine aggregate on a watertight, non-absorbent platform until the mixture is a uniform colour, then add the coarse aggregate and mix until it is evenly distributed throughout the batch. Finally, we must add water and continue mixing until the concrete appears homogeneous and has the desired consistency.

For making the cubes, we must clean the moulds, apply oil, fill the moulds with layers of concrete that are about 5 cm thick, compact each layer with a tamping rod (a steel bar with a 16 mm diameter and 60 cm length, bullet-pointed at the lower end), and level and smooth the top surface with a trowel. The test specimens are kept in moist air for 24 hours, after which they are marked, taken out of the moulds, and kept submerged in freshwater until the test is performed. Every seven days, the curing water should be examined, and it needs to be 27 ± 2 °C in temperature.

Procedure - After the allotted curing period, remove the specimen from the water, and wipe off any extra moisture from the surface. Calculate the specimen's size to the nearest 0.2m. The testing device's bearing surface should be cleaned. Place the specimen in the device so that the load is distributed across the cube's opposing sides. Place the specimen in the center of the machine's base plate. Gently turn the movable part by hand so that it touches the specimen's top surface. Till the specimen fails, continue apply the load at a rate of 140 kg/cm²/minute without jarring it. Record the maximum load and make a note of any peculiar characteristics of the failure type. At each chosen age of 3 days, 7 days and 28 days, a minimum of three specimens should be tested. The results of such specimens should be disregarded if the strength of any specimen differs by more than 15% of the average strength. Concrete's crushing strength is determined by taking the average of three specimens.



Fig. 3.5 Compression Testing Machine

c. Flexural Strength Test

Objective - To ascertain the concrete's flexural strength, which may be affected by wheel loads and/or volume variations brought on by temperature fluctuations or shrinking on a road slab with insufficient sub-grade support.

Reference Standards - IS: 516-1959 – Methods of tests for strength of concrete

Equipment and Apparatus –

- Beam mould of size 15 x 15x 70 cm (when size of aggregate is less than 38 mm) or of size 10 x 10 x 50 cm (when size of aggregate is less than 19 mm)
- Tamping bar (40 cm long, weighing 2 kg and tamping section having size of 25 mm x 25 mm)
- Flexural test apparatus: The testing apparatus's bed must have two 38 mm-diameter steel rollers that will support the specimen. These rollers must be mounted so that, for specimens measuring 15.0 cm or 10 cm, the distance between them is 60 cm or 40 cm, respectively. Two comparable rollers positioned at the third places of the supporting span, which are spaced at 20 or 13.3 cm center to center, are where the load will be applied. The load must be distributed equally among the two loading rollers, and each roller must be positioned so that the load is applied axially and without placing any torsional strains or constraints on the specimen.

Procedure – Fill the mould with concrete in three layers that are roughly equal in thickness to create the test specimen. 35 times using the tamping bar as described above, tamp each layer. Tamping should be applied consistently across each layer's depth as well as over the whole cross section of the beam mould. Remove any loose sand or other material from the surfaces of the specimen where the bearing surfaces of the supporting and loading rollers will make contact. The specimens will be supported and loaded using circular rollers made

of steel with a cross section and diameter of 38 mm. The rollers' length must be at least 10 mm longer than the test specimen's width. There will be a total of four rollers employed, and three of them must be able to rotate around their respective axes. The space (or span) between the outer rollers and the inner rollers must be $3d$ and d , respectively. In order to ensure that the system as a whole is organized, the inner rollers must be equally spaced apart from the outer rollers. Immediately after being removed from the water and while they are still wet, the specimen placed in water must be analyzed. The test specimen must be properly oriented in the machine with its longitudinal axis at a right angle to the rollers. For specimens that have been moulded, the direction of the mould filling must match the direction of loading. For specimens measuring 15.0 cm, the load must be applied at a rate of 400 kg/min, and for specimens measuring 10.0 cm, the rate must be 180 kg/min.

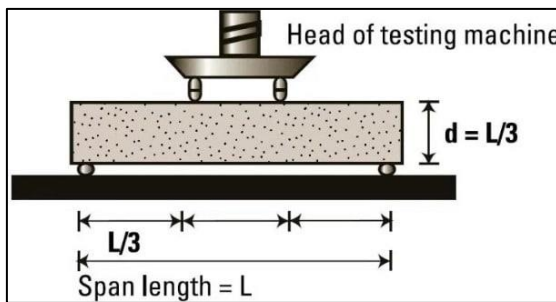


Fig. 3.6 Flexural strength test

The Flexural Strength or modulus of rupture (f_b) is given by:

$$f_b = pl/bd^2 \text{ (when } a > 20.0\text{cm for } 15.0\text{cm specimen or } > 13.0\text{cm for } 10\text{cm specimen)}$$

or

$$f_b = 3pa/bd^2 \text{ (when } a < 20.0\text{cm but } > 17.0 \text{ for } 15.0\text{cm specimen or } < 13.3 \text{ cm but } > 11.0\text{cm for } 10.0\text{cm specimen)}$$

Where,

a = the distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen

b, d = width and depth of specimen respectively

l = supported length/span

p = max. load

Precautions –

- When taking the test, wear safety shoes and hand gloves.
- Switch off the machine after the test.
- Maintain grease on all the exposed metal parts.
- Maintain a tight fit between the base and top plate for the guiding rods.
- Equipment should be fully cleaned both before and after testing.

d. Split Tensile Strength Test

Objective - This method covers the determination of the splitting tensile strength of cylindrical concrete specimens.

Reference Standards - IS: 516 – 1959, IS: 1199-1959, SP: 23-1982, IS: 10086-1982

Theory –

Age at Test - Tests must be performed on test specimens at known ages, with 7 and 28 days being the most common. The ages of 24 hours and 72 hours and two hours may be tested when it may be necessary to achieve the early strengths. The ages must be determined from the moment water was added to the dry components.

Number of Specimens - For testing at each chosen age, at least three specimens must be made, ideally from distinct batches.

Apparatus –

- **Testing Machine -** The testing machine may be of any dependable kind as long as it is capable of applying the load at the rate outlined in 5.5 and has sufficient capacity for the tests. The permitted mistake must not be higher than 2% of the maximum load.
- **Cylinders -** The cylindrical mould must adhere to IS: 10086-1982 and have dimensions of 150 mm in diameter and 300 mm in height.
- **Weighing scales and weights, tools and mixing vessels, (Square in cross section) Tamper, etc.**

Procedure –

- Material sampling - Aggregate samples for each batch of concrete must be of the desired grading and be in a dried-by-the-air state. To guarantee the greatest blending and consistency in the material, the cement samples must be well mixed dry upon arrival at the laboratory, either by hand or in an appropriate mixer.
- Proportioning - The proportions of the ingredients, including water, in concrete mixes used to assess the suitability of the materials on hand must be identical to those that will be used in the work in every way.
- Weighing - To an accuracy of 0.1 percent of the batch's total weight, the amounts of cement, each size of aggregate, and water for each batch shall be calculated by weight.
- Mixing Concrete - Concrete must be mixed by hand, or ideally in a laboratory batch mixer, in order to prevent the loss of water or other ingredients. After moulding the appropriate number of test specimens, each batch of concrete must be large enough to leave roughly 10% extra.
- Mould - The cylindrical mould must adhere to IS: 10086-1982 and have dimensions of 150 mm in diameter and 300 mm in height.
- Compacting - The test specimens must be created as quickly as possible after mixing and in a way that fully compacts the concrete without segregation or undue laitance.
- Curing - The test specimens must be kept for 24 hours and a half after the water has been added to the dry components in a place that is free from vibration, in moist air that is at least 90% relative humidity, and at a temperature of $27 \pm 2^{\circ}\text{C}$.
- Placing the Specimen in the Testing Machine - Any loose sand or other material that may come into contact with the bearing surfaces of the supporting and loading rollers must be removed before placing the specimen in the testing machine.
- For each specimen, there should be two bearing strips that are nominally (1/8 in, or 3.175 mm) thick, free of flaws, about 25 mm broad, and either the same length as the specimen or just a little longer.
- The bearing strips are positioned either between the specimen and the supplemental bars or plates or between the specimen and the upper and lower bearing blocks of the testing apparatus.
- Using a tool that will guarantee that they are in the same axial plane, draw diametric lines at the specimen's ends. One of the plywood strips should be positioned in the middle of the lower bearing block.
- The lines drawn on the specimen's ends should be vertical and cantered over the plywood strip when it is placed on the strip of plywood.
- Place a second longitudinal piece of plywood on the cylinder, aligning it with the lines drawn on its ends. until the specimen fails, apply the load continuously, without shock, and at a steady rate within the range of 689 to 1380 kPa/min splitting tensile stress.

- Note the maximum applied load that the testing device reported was reached at failure. Take note of the failure type and fracture appearance.

The splitting tensile strength of the specimen was calculated as follows:

$$T = 2P/\pi LD$$

Where

T = Splitting tensile strength

P = Maximum applied load

L, D = Length and Diameter respectively



Fig. 3.7 Split tensile strength test

e. Temperature Study at 200°C for 24 hrs

Three cubes (100 x 100 x 100 mm) of M25 mix proportion with (5%,10%,15% rubber content) and without rubber, are heated at 200°C for 24 hrs and then after cooling for some time at room temperature, compressive strength is measured using Universal Testing Machine.

f. Stress-Strain Behaviour Study

The stress-strain test for 100 mm cubes of different proportions M25 grade concrete has been done similar to the ASTM C469. Digital slide calipers are used for strain-measuring measurement.

Table 3.6 Number and dimensions of specimen for different tests of rubberized concrete

Name of test	No. of specimens per each mix	Dimension of each specimen
Slump Cone Test	3	Cone of 100*200*300mm
Compressive Strength Test	3 for 7-d, 3 for 28-d	Cube of 100*100*100mm
Flexural Strength Test	3	Beam of 100*100*500mm
Split Tensile Strength Test	3	Cylinder of 150*300mm
Temperature Effect Test	3	Cube of 100*100*100mm
Stress-Strain Behaviour Study	3	Cube of 100*100*100mm

CHAPTER-4
RESULTS AND DISCUSSION

4.1 General

To establish the mix proportion that gives desired workability and target strength, multiple trial mixes are needed to be done. So, several trials are performed to reach the M25 and M35 grade mix proportions with desired properties. After that, slump test as per IS 1199-1959, compressive strength test as per IS 516-1959, flexural strength test as per IS 516-1959, split tensile strength test as per IS 5816-1959, study on temperature test and stress-strain behaviour study are performed.

4.2 Details of Trial Mixes

Several trial mixes have been done for M25 and M35 grade of concrete as per IS 456:2000 and IS 10262:2019. Target strength for the first one (M25 grade) has been found 32 MPa. The details of the trials are given below.

Trial 1 for M25 grade concrete

First trial of M25 grade mix has been performed with the following ratio (Table 4.1(a)) and compressive strength for 7 days and 28 days has been given in Table 4.1(b). Here w/c ratio of 0.49 has been used. Volume of coarse aggregate has been taken as 50.6% of total aggregate volume.

Table 4.1(a) - Mix Proportions for first trial of M25 grade

Materials	Mix Proportions per 1m ³ (in kg)
Cement	349.78
Water	185.412
FA	911.503
CA	958.175

Table 4.1(b) – Compressive strength test results for first trial of M25 grade

7-d compressive strength of 100 mm cubes (MPa)	28-d compressive strength of 100 mm cubes (MPa)
10	15.1
10.8	13
8	13.8

Trial 2 for M25 grade concrete

Second trial of M25 grade mix has been performed with the following ratio (Table 4.2(a)) and compressive strength for 7 days and 28 days has been given in Table 4.2(b). W/c ratio of 0.47 has been used. To enhance strength, volume of coarse aggregate has been taken as 55% of total aggregate volume.

Table 4.2(a) - Mix Proportions for second trial of M25 grade

Materials	Mix Proportions per 1m ³ (in kg)
Cement	410.26
Water	205.793
FA	773.952
CA	1025.775

Table 4.2(b) – Compressive strength test results for second trial of M25 grade

7-d compressive strength of 100 mm cubes (MPa)	28-d compressive strength of 100 mm cubes (MPa)
12.6	18.5
12.5	15.9
14.8	19

Trial 3 for M25 grade concrete

Third trial of M25 grade mix has been performed with the following ratio (Table 4.3(a)) and compressive strength for 7 days and 28 days has been given in Table 4.3(b). W/c ratio of 0.45 has been used. Volume of coarse aggregate has been taken as 55% of total aggregate volume.

Table 4.3(a) - Mix Proportions for third trial of M25 grade

Final Mix Proportions per 1m ³ :	(in kg)
Cement	414.2
Water	199.563
FA	785.911
CA	1041.626

Table 4.3(b) – Compressive strength test results for third trial of M25 grade

7-d compressive strength of 100 mm cubes (MPa)	28-d compressive strength of 100mm cubes (MPa)
13.5	21.4
15.5	21.6
16.5	20.4

Trial 4 for M25 grade concrete

Fourth trial of M25 grade mix has been performed with the following ratio (Table 4.4(a)) and compressive strength for 7 days and 28 days has been given in Table 4.4(b). W/c ratio of 0.48 has been used and volume of coarse aggregate has been taken as 55% of total aggregate volume. Finally target strength of M25 concrete has been achieved with this trial mix.

Table 4.4(a) - Mix Proportions for fourth trial of M25 grade

Materials	Mix Proportions per 1m ³ (in kg)
Cement	388.31
Water	199.738
FA	796.316
CA	1055.416

Table 4.4(b) – Compressive strength test results for fourth trial of M25 grade

7-d compressive strength of 100 mm cubes (MPa)	28-d compressive strength of 100 mm cubes (MPa)
23.8	35.1
28.5	34.6
28.7	35.2

Target strength for the 2nd mix grade (M35 grade) has been found 43.25MPa. The details of the trials are given below.

Trial 1 for M35 grade concrete

First trial of M35 grade mix has been performed with the following ratio (Table 4.5(a)) and compressive strength for 7 days and 28 days has been given in Table 4.5(b). Target strength for M35 concrete is 43.25 MPa. This is not properly achieved in 1st trial mix for M35 where w/c ratio used is 0.42. Volume of coarse aggregate has been taken as 55% of total aggregate volume.

Table 4.5(a) - Mix Proportions for first trial of M35 grade

Materials	Mix Proportions per 1m ³ (in kg)
Cement	443.79
Water	199.363
FA	774.022
CA	1025.875

Table 4.5(b) – Compressive strength test results for first trial of M35 grade

7-d compressive strength of 100 mm cubes (MPa)	28-d compressive strength of 100 mm cubes (MPa)
30.3	46.1
34.2	41.8
34.1	40.8

Trial 2 for M35 grade concrete

Second trial of M35 grade mix has been performed with the following ratio (Table 4.6(a)) and compressive strength for 7 days and 28 days has been given in Table 4.6(b). Target strength has been achieved with this trial mix where w/c ratio used is 0.38 and volume of coarse aggregate has been taken as 55% of total aggregate volume.

Table 4.6(a) - Mix Proportions for second trial of M35 grade

Materials	Mix Proportions per 1m ³ (in kg)
Cement	490.5
Water	199.049
FA	755.271
CA	1001.01

Table 4.6(b) – Compressive strength test results for second trial of M35 grade

7-d compressive strength of 100 mm cubes (MPa)	28-d compressive strength of 100 mm cubes (MPa)
33.4	49.2
35.7	50.1
43.2	48.4

4.3 Final Mix Design calculation as per IS 10262:2019 and IS 456:2000:

- Type of Cement : OPC 53
- Maximum Nominal Size of Aggregate : 10 mm
- Maximum Cement Content : As per IS-456
- Maximum W/C Ratio : As per IS-456
- Workability : 75 mm Slump
- Exposure Condition : Moderate
- Specific Gravity of Cement : 2.95
- Specific Gravity of Coarse Aggregate : 2.87
- Specific Gravity of Fine Aggregate : 2.66
- Type of Concrete : RCC

4.3.1 Concrete Mix Design (M 25)

A) Target Strength for Mix Proportion

(i) $f'_{ck} = f_{ck} + 1.65 S$ or, (ii) $f_{ck} + X$, whichever is higher [As per Cl. 4.2 of IS-10262-2019]

As per Table 1 and 2, IS-10262-2019, $X = 5.5$ and $S = 4.0$

Hence, (i) $f'_{ck} = 25 + 1.65 \times 4.0 = 31.6$

(ii) $f'_{ck} = 25 + 5.5 = 30.5$

So, $f'_{ck} = 32 \text{ MPa (N / mm}^2\text{)}$ is adopted.

B) Selection of Water Cement Ratio (W/C)

From fig. 1 of IS-10262-2019, for Target Strength 32 MPa and OPC 53 Cement using Curve 2 the W/C Ratio required: 0.53

Check:

From Table 5, IS-456-2000, Maximum W/C Ratio for Moderate Exposure Condition and M 25 RCC is 0.5. Hence Adopted W/C Ratio is 0.48

C) Selection of Water Content (W.C)

As per Workability requirement of 75 mm Slump, Average Slump required = 75 mm

As per Table 4 of IS 10262-2019 for 10 mm Nominal Maximum Size of aggregate and 50 mm Slump, the Water Content per Cum of Concrete = 208 kg.

Now, as per Cl. 5.3 of IS-10262-2019, for every 25 mm increase in Slump above 50 mm, the Water Content is to be increased by 3%

Estimated Water Content for 75 mm Slump = $208 + (75 - 50) / 25 * 3 / 100 * 208 = 214.24 \text{ kg of water per Cum of Cement.}$

For addition of 0.8% Superplasticizer, water reduction = 13% of 214.24 = 27.85 kg of water per Cum of Cement.

Final Water Content for 75 mm Slump = $214.24 - 27.85 = 186.39 \text{ kg of water per Cum of Cement}$

D) Selection of Cement Content (C.C)

For, W/C Ratio = 0.48, Water Content = 186.39 kg / Cum

Cement Content = $186.39 / 0.48 = 388.31 \text{ kg of Cement}$

Check:

As per Table 5 of IS-456-2000, Minimum Cement Content for RCC in Moderate Exposure Condition and 20 mm Maximum Aggregate Size = 300 kg / Cum

Now, as per Table 6 of IS-456-2000, for 10 mm Nominal Maximum Size of Aggregate adjustment to minimum Cement Content = +40 kg / Cum

Hence, Minimum Cement Content required = 340 kg / Cum

Calculated Cement Content (388.31) > Required Cement Content (340)

Cement Content of 388.31 kg / Cum of Concrete is adopted

E) Determination of Air Content (A.C)

As per Cl. 5.2, Table 3 of IS-10262-2019, Entrapped Air Content for 10 mm Nominal Maximum Size of aggregate is = 1.5% of Volume of Concrete

F) Estimation of Proportion of Volume of Coarse and Fine Aggregate (CA and FA)

From Table 5 of IS-10262-2019 for W/C Ratio 0.5 and 10mm Nominal Maximum Size of Aggregate and Zone-II Sand, Volume of Coarse aggregate per Total Volume of Aggregate = 0.50

But, the adopted W/C Ratio is 0.48

Now, from Cl. 5.5.1 of IS-10262-2019, we know that the Volume of CA per Total Volume of Aggregate is increased by 0.01 for decrease in W/C Ratio by every 0.05

So, the Corrected Volume of CA per total Volume of Aggregate = $0.50 + 0.01 \times (0.50 - 0.48) / 0.05 = 0.504$

Hence Adopted Ratio of CA = 0.55.

G) Mix Calculation

Volume of Concrete (M 25) = 1 Cum

(i) Volume of Air in Wet Concrete (a) = 1.0% of 1 Cum = 0.01 Cum

(ii) Volume of Cement in Wet Concrete (b) = (Mass of Cement) / (Sp. Gr. Of Cement) x 1/1000 = $388.31 / 2.95 \times 1/1000 = 0.13163$ Cum

(iii) Volume of Water in Wet Concrete (c) = (Mass of Water) / (Sp. Gr. Of Water) x 1/1000 = $186.39 / 1 \times 1/1000 = 0.18639$ Cum

(iv) Volume of Aggregate in Wet Concrete (d) = (a-b-c) = $(1 - 0.01 - 0.13163 - 0.18639)$ Cum = 0.67198 Cum

(v) Mass of Coarse Aggregate (CA) = (d) x Proportion of Volume of CA per Total Volume of Aggregate) x (Sp. Gr. of CA x 1000 = $0.67198 \times 0.55 \times 2.87 \times 1000$ kg = 1060.72 kg

(vi) Mass of Fine Aggregate (CA) = (d) x (1 - Proportion of Volume of CA per Total Volume of Aggregate) x (Sp. Gr. of FA x 1000 = 0.67198 x (1-0.55) x 2.66 x 1000 kg = 804.36 kg

H) Mix Proportion

Cement : FA : CA = 388.31 : 804.36 : 1060.72 = 1: 2.07 : 2.73 and the W/C = 0.48

Water Correction applied to dry Aggregates:

For Sand (FA) = 804.36 x 1% = 8.0436 kg

For Stone Chips (CA) = 1060.72 x 0.5% = 5.3036 kg

Extra Water Requirement = 8.044 + 5.3036 = 13.348 kg

Final Mix Proportions per 1m³: (in kg)

Cement	388.31
Water	199.738
FA	796.32
CA	1055.416

4.3.2 Concrete Mix Design (M 35)

A) Target Strength for Mix Proportion

(i) $f'_{ck} = f_{ck} + 1.65 S$ or, (ii) $f_{ck} + X$, whichever is higher

As per Table 1 and 2, IS-10262-2019, X = 6.5 and S = 5.0

Hence, (i) $f'_{ck} = 35 + 1.65 \times 5.0 = 43.25$

(ii) $f'_{ck} = 35 + 6.5 = 41.5$

So, $f'_{ck} = 43.25$ MPa (N / mm²) is adopted.

B) Selection of Water Cement Ratio (W/C)

From fig. 1 of IS-10262-2019, for Target Strength 43.25 MPa and PPC Cement using Curve 2 the W/C Ratio required: 0.43

Check:

From Table 5, IS-456-2000, Maximum W/C Ratio for Moderate Exposure Condition and M 35 RCC is 0.45.

Hence Adopted W/C Ratio is 0.38.

C) Selection of Water Content (W.C)

As per Workability requirement of 75 mm Slump, Average Slump required = 75 mm

As per Table 4 of IS 10262-2019 for 10 mm Nominal Maximum Size of aggregate and 50 mm Slump, the Water Content per Cum of Concrete = 208 kg.

Now, as per Cl. 5.3 of IS-10262-2019, for every 25 mm increase in Slump above 50 mm, the Water Content is to be increased by 3%

Estimated Water Content for 75 mm Slump = $208 + (75 - 50) / 25 * 3 / 100 * 208 = 214.24$ kg of water per Cum of Cement.

For addition of 0.6% Superplasticizer, water reduction = 13% of 214.24 = 27.85 kg of water per Cum of Cement.

Final Water Content for 75 mm Slump = $214.24 - 27.8512 = 186.39$ kg of water per Cum of Cement

D) Selection of Cement Content (C.C)

For, W/C Ratio = 0.38, Water Content = 186.39 kg / Cum

Cement Content = $186.39 / 0.38 = 490.5$ kg of Cement

Check:

As per Table 5 of IS-456-2000, Minimum Cement Content for RCC in Moderate Exposure Condition and 20 mm Maximum Aggregate Size = 300 kg / Cum

Now, as per Table 6 of IS-456-2000, for 10 mm Nominal Maximum Size of Aggregate adjustment to minimum Cement Content = +40 kg / Cum

Hence, Minimum Cement Content required = 340 kg / Cum

Calculated Cement Content (490.5) > Required Cement Content (340)

Cement Content of 490.5 kg / Cum of Concrete is adopted

E) Determination of Air Content (A.C)

As per Cl. 5.2, Table 3 of IS-10262-2019, Entrapped Air Content for 10 mm Nominal Maximum Size of aggregate is = 1.5% of Volume of Concrete

F) Estimation of Proportion of Volume of Coarse and Fine Aggregate (CA and FA)

From Table 5 of IS-10262-2019 for W/C Ratio 0.5 and 10mm Nominal Maximum Size of Aggregate and Zone-II Sand, Volume of Coarse aggregate per Total Volume of Aggregate = 0.50

But, the adopted W/C Ratio is 0.38

Now, from Cl. 5.5.1 of IS-10262-2019, we know that the Volume of CA per Total Volume of Aggregate is increased by 0.01 for decrease in W/C Ratio by every 0.05

So, the Corrected Volume of CA per total Volume of Aggregate = $0.50 + 0.01 \times (0.50 - 0.38) / 0.05 = 0.524$

Hence Adopted Ratio of CA = 0.55.

G) Mix Calculation

Volume of Concrete (M 35) = 1 Cum

(i) Volume of Air in Wet Concrete (a) = 1.0% of 1 Cum = 0.01 Cum

(ii) Volume of Cement in Wet Concrete (b) = (Mass of Cement) / (Sp. Gr. Of Cement) x 1/1000 = $490.5 / 2.95 \times 1/1000 = 0.16627$ Cum

(iii) Volume of Water in Wet Concrete (c) = (Mass of Water) / (Sp. Gr. Of Water) x 1/1000 = $186.39 / 1 \times 1/1000 = 0.18639$ Cum

(iv) Volume of Aggregate in Wet Concrete (d) = (a-b-c) = $(1 - 0.01 - 0.16627 - 0.18639)$ Cum = 0.63734 Cum

(v) Mass of Coarse Aggregate (CA) = (d) x Proportion of Volume of CA per Total Volume of Aggregate) x (Sp. Gr. of CA x 1000 = $0.63734 \times 0.55 \times 2.87 \times 1000$ kg = 1006.04 kg

(vi) Mass of Fine Aggregate (CA) = (d) x (1 - Proportion of Volume of CA per Total Volume of Aggregate) x (Sp. Gr. of FA x 1000 = $0.63734 \times (1 - 0.55) \times 2.66 \times 1000$ kg = 762.9 kg

H) Mix Proportion

Cement : FA : CA = 490.5 : 762.9 : 1006.04 = 1 : 1.56 : 2.05 and the W/C = 0.38

Water Correction applied to dry Aggregates:

For Sand (FA) = $762.9 \times 1\% = 7.629$ kg

For Stone Chips (CA) = $1006.04 \times 0.5\% = 5.0302$ kg

Extra Water Requirement = $7.629 + 5.03 = 12.659$ kg

Final Mix Proportions per 1m³: (in kg)

Cement	490.5
Water	199.049
FA	755.271
CA	1001.01

4.4. Summary of Mix Proportions for Rubberized Concrete

Table 4.7 Table of summary of mix proportions for rubberized concrete

MIX PROPORTIONS AS PER 1 M³ CONCRETE					
MIX NAME	Cement (kg)	Water (kg)	FA (kg)	CA (kg)	Crumb Rubber Particle (kg)
M25 (CONT. MIX)	388.31	199.738	796.316	1055.416	0
M25 + 5% RUBBER	388.31	199.738	756.5002	1055.416	39.8158
M25 + 10% RUBBER	388.31	199.738	716.6844	1055.416	79.6316
M25 + 15% RUBBER	388.31	199.738	676.8686	1055.416	119.4474
M35 (CONT. MIX)	490.5	199.049	755.271	1001.01	0
M35 + 5% RUBBER	490.5	199.049	717.50745	1001.01	37.76355
M35 + 10% RUBBER	490.5	199.049	679.7439	1001.01	75.5271
M35 + 15% RUBBER	490.5	199.049	641.98035	1001.01	113.29065

4.5 Test Results with Discussions

In the present section of work, all the experimental results on the behaviour of rubberized concrete are presented. The rubber chips are added as 5%, 10% and 15% by replacing the fine aggregate. Both workability, strength and temperature effects are observed and presented in the following sections.

4.5.1 Slump Test –

Fig. 4.1 shows the results of slump tests for M25 grade of concrete with different percentage of rubber chips (5%, 10% and 15%). Similarly, Fig. 4.2 shows the results of slump tests for M35 grade of concrete with different percentage of rubber chips. The results indicate that the workability of concrete decreases for addition of different percentage of crumb rubber chips with respect to the control specimen (without rubber chips). It is noted that for control mix of M25 grade the slump value is 105 mm. Whereas, the slump value for M25 grade of concrete with 5%, 10% and 15% rubber chips are 14.29%, 23.8% and 28.57% less than control mix respectively. Highest fall in slump value is observed when 5% rubber chips are added. In case of M35 grade mixes, the control mix have slump value of 95 mm. For M35 grade mixes with 5%, 10% and 15% rubber chips show the slump values 10.53%, 26.32% and 36.84% less than control the mix respectively. The possible reason for this reduction is that the rubber chips have much less specific gravity than fine aggregate. So, the volume of a certain weight of rubber chips will be higher than the volume of equal amount of fine aggregates. For this reason, the surface area of rubber chips will also be higher which consume more amount of water resulting reduction in workability.

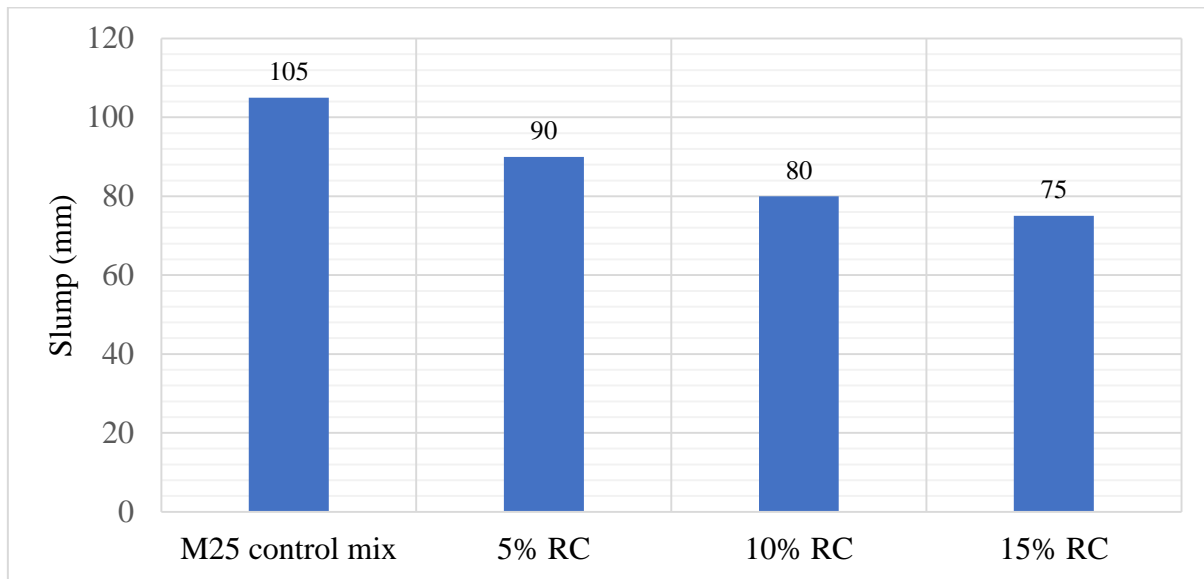


Fig. 4.1 Slump test values of M25 grade mixes

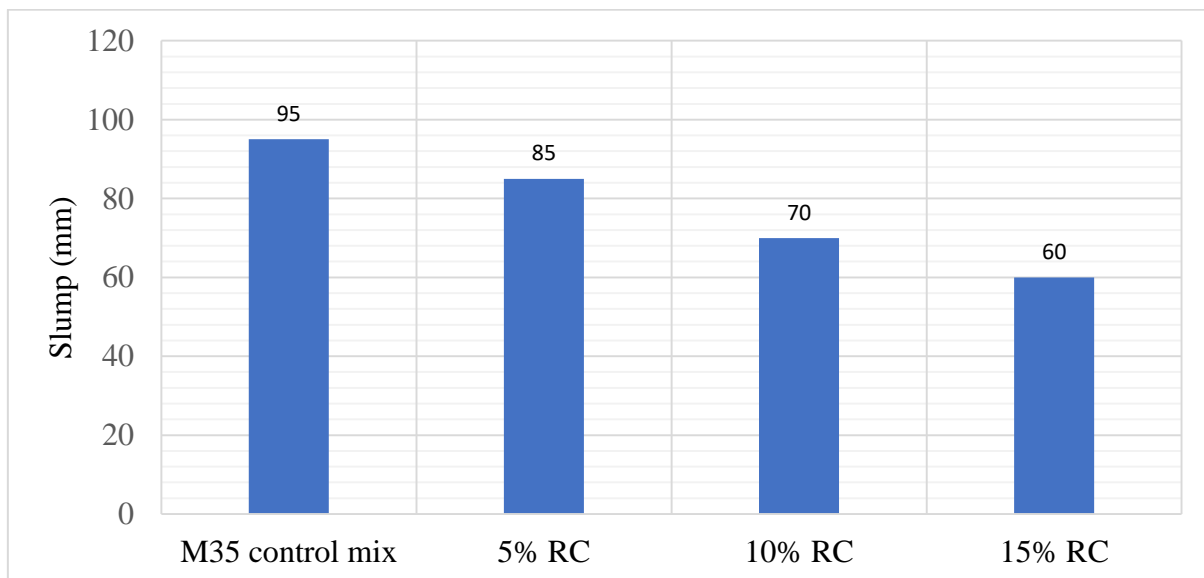


Fig. 4.2 Slump test values of M35 grade mixes

4.5.2 Compressive Strength Test –

The results of compressive strength of M25 and M35 mixes are presented in Fig. 4.3 and 4.4. It is noted that the compressive strength has been decreased with the increase in percentage of rubber chips. However, for higher grade of concrete, the compressive strength reduction due to addition of rubber chips has been seen lesser. In case of M25 grade, mixes with 5%, 10% and 15% rubber chips show reduction in strength as 23%, 36.67% and 54.7% respectively for the case of 7 days and that has been seen 28%, 36.6% and 55.29% less respectively for the case of 28 days strength. On the other hand, for M35 mixes with 5%, 10% and 15% addition of rubber chips, the strength reductions for 7 days are 9.35%, 17.9% and 39.7% respectively and that for 28 days are 4.47%, 21.12% and 34.53% respectively. It can be commented that for lower grades of

concrete, up to 5% replacement of rubber chips can be permitted and for higher grades of concrete (M35 and above), up to 10% replacement of rubber chips can be permitted.

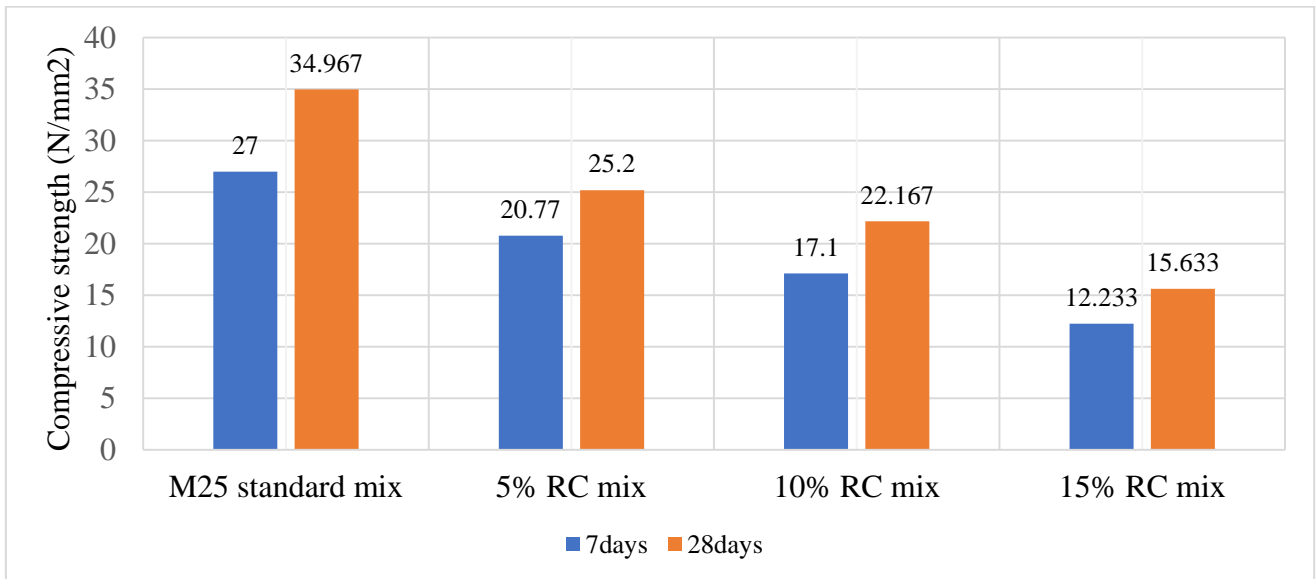


Fig. 4.3 Compressive strength test values of M25 grade mixes

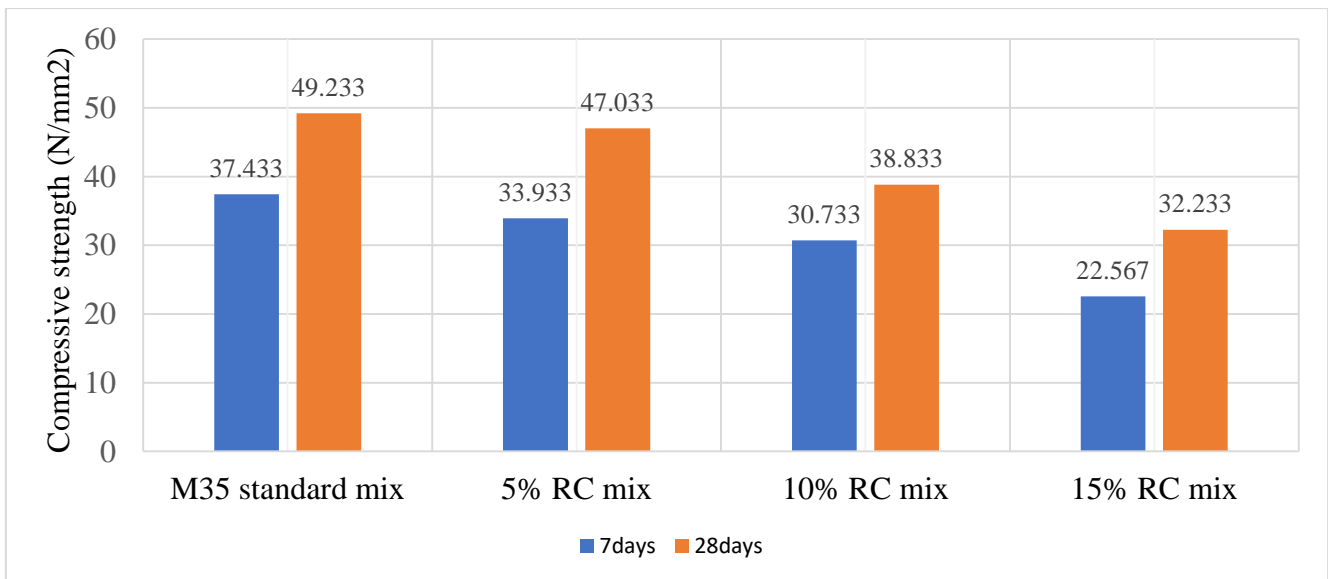


Fig. 4.4 Compressive strength test values of M35 grade mixes



Fig. 4.5 Specimens of M25 and M35 grade control mixes at 7 days



Fig. 4.6 Specimens of M25 control mix and mix with 15% rubber content at 7 days



Fig. 4.7 Specimens of M25 and M35 grade control mixes at 28 days

4.5.3 Split Tensile Strength Test –

The results of split tensile strengths of M25 mixes are presented in Fig. 4.8. It has been seen that the split tensile strengths of concrete mix with 5%, 10% and 15% rubber chips have decreased by 2.7%, 36.8% and 44.1% with respect to that of control mix. It is interesting to note that there is a drastic fall in split tensile strength when rubber content is increased from 5% to 10%. So, it can be commented that up to 5% replacement of fine aggregate can be permitted for getting better optimum result.

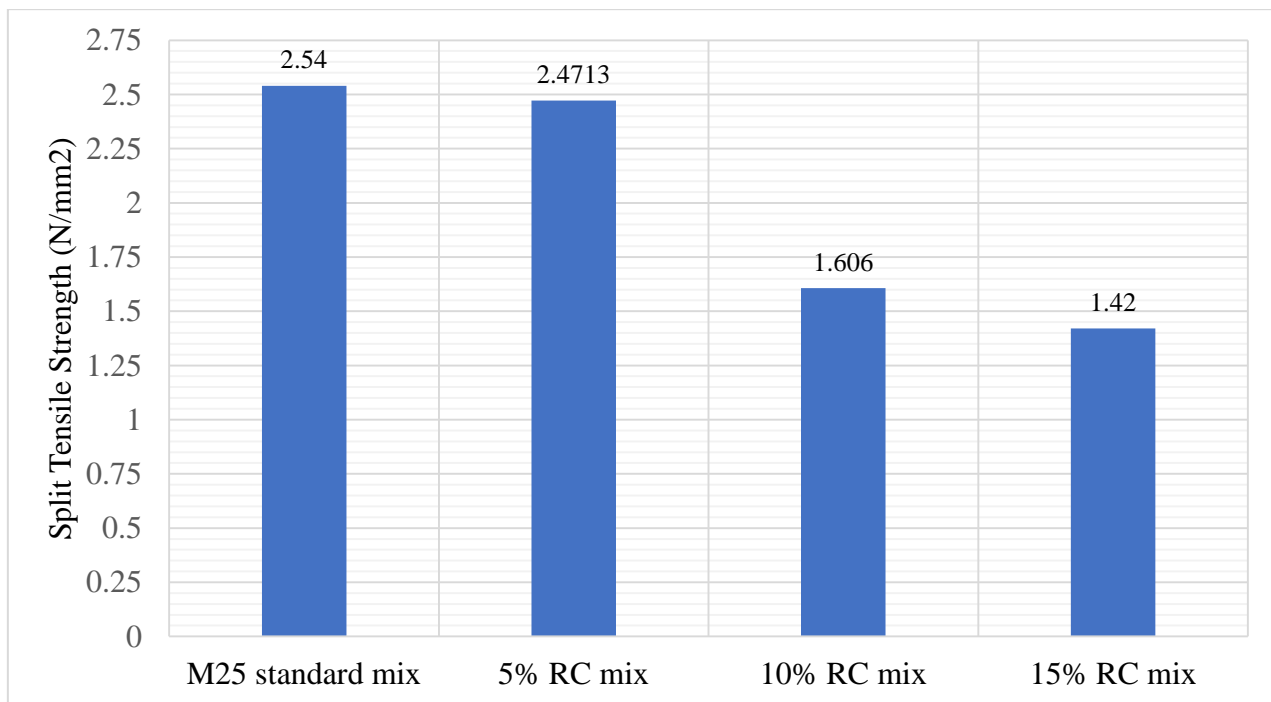


Fig. 4.8 Split tensile strength test values of M25 grade mixes



Fig. 4.9 Split tensile strength test specimens of M25 grade mixes with different rubber content

4.5.4 Flexural Strength Test –

From the results of test of flexural strength of M25 grade concrete, it is observed that there is a steady decrease in flexural strength on addition of rubber chips. The results have been presented in Fig. 4.10. On replacement of fine aggregates by 5%, 10% and 15% rubber chips, flexural strength reduction has been detected as 28.19%, 38.8% and 45.14% respectively.

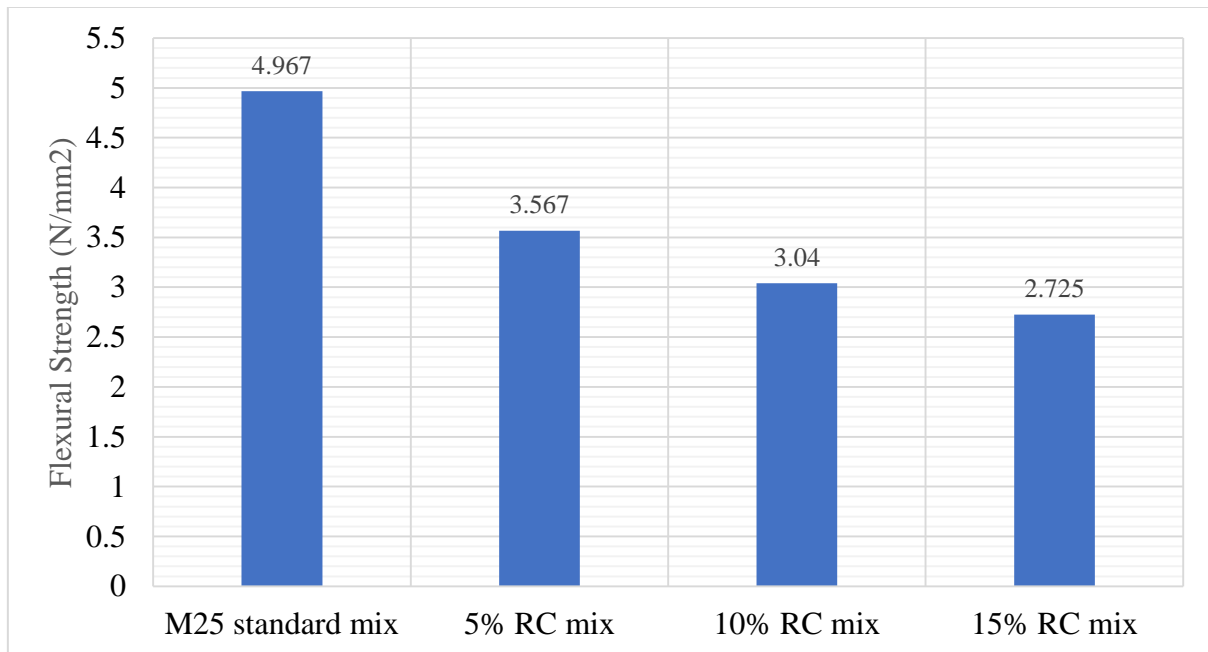


Fig. 4.10 Flexural strength test values of M25 grade mixes



Fig. 4.11 Failure surface of flexural strength test specimens after testing



Fig. 4.12 Flexural strength test specimens of M25 grade mixes with different rubber content

4.5.5 Test on Temperature Effect –

In case of temperature study, the compressive strength of concrete cubes are measured for different mixes of M25 grade after heating at 200°C for 24 hrs. Here, continuous decrease in strength has been observed with addition of rubber chips. The results are presented in Fig. 4.13. The strength reductions are 21.2%, 39.06% and 54.1% (w.r.t. control mix) for 5%, 10% and 15% rubber content respectively. This result complies with the results of compressive strength of control mix of M25 grade, which means the rubberized concrete is able to withstand temperature of up to 200°C without the rubber particles getting affected.

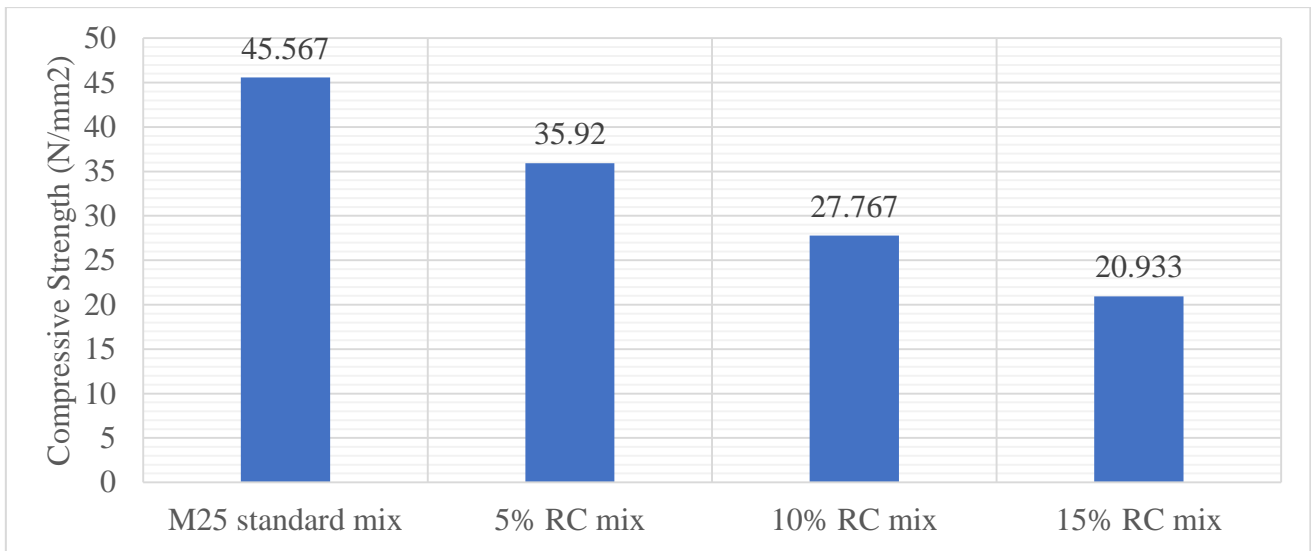


Fig. 4.13 Temperature effect test values of M25 grade mixes

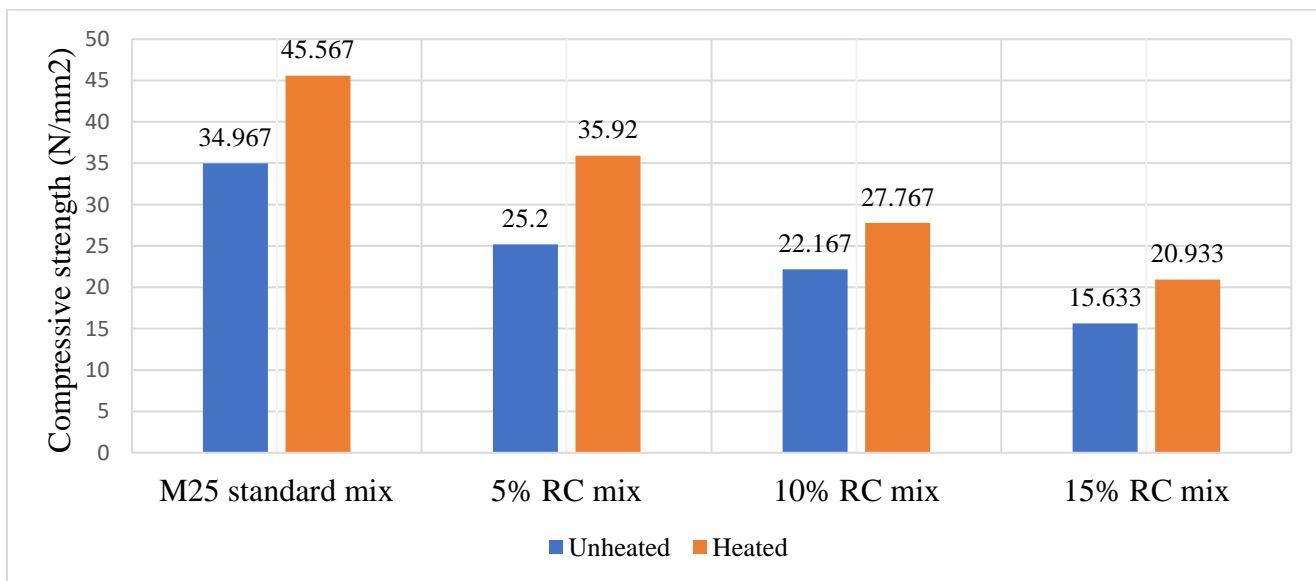


Fig. 4.14 Comparison of temperature effect result of M25 grade mixes with unheated M25 mixes



Fig. 4.15 Study of temperature test specimens of M25 grade mixes with 5%, 10% and 15% rubber content

4.5.6 Determination of Stress-Strain behaviour –

Lateral elongation of the concrete cubes under the uniaxial compressive stress is measured using Digital Slide Calipers. The stress versus strain results are presented in the Fig. 4.16. It is found that with increasing the rubber content, the strain of concrete cubes increased up to failure. But stress is reduced continuously. Hence, the modulus of elasticity has decreased with increasing rubber content. It can also be observed that increase in rubber content results increase in toughness of the material before failure. Thus, the rubberized concrete with higher rubber content can undergo higher strain before failure. As a result, ductility of concrete is increasing.

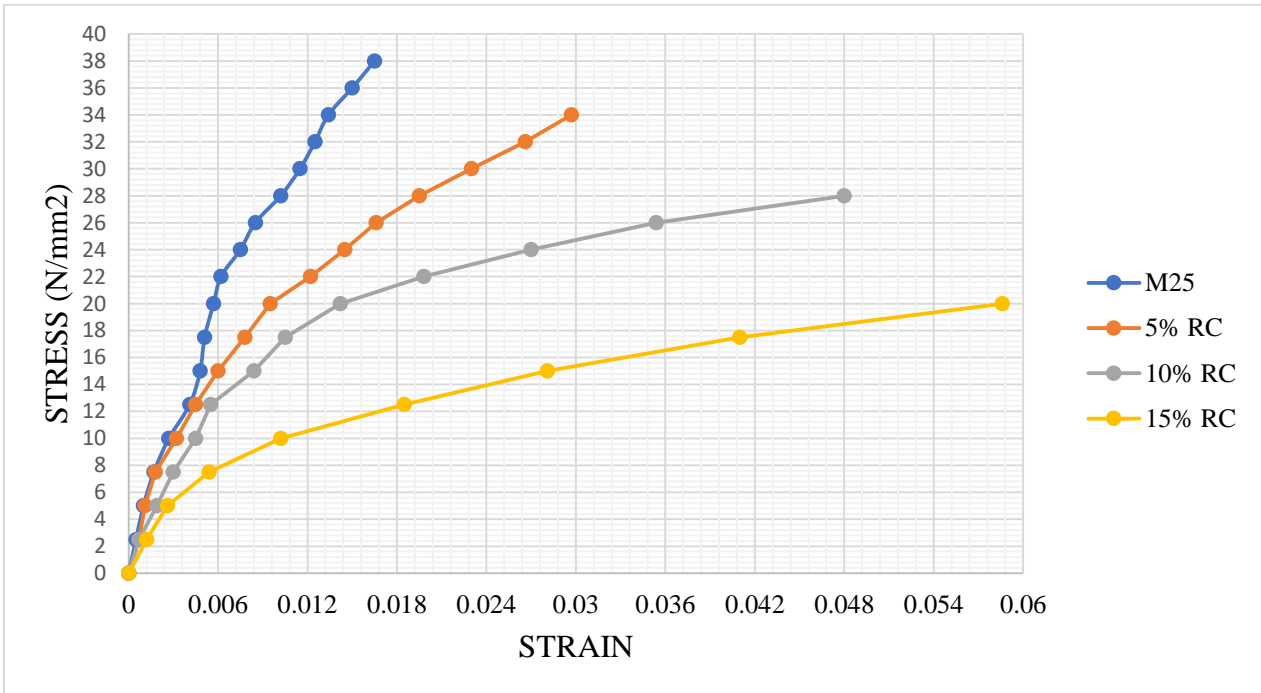


Fig. 4.16 Stress-strain behaviour of M25 grade mixes

CHAPTER-5
CONCLUSION AND FUTURE SCOPE OF STUDY

5.1 CONCLUSION

To improve the ductility and tensile strength of concrete, fine aggregates are replaced by 2.36 mm size rubber chips. Studies on strength, workability, temperature effect, stress-strain behaviour have been observed for different percentage of rubber chips. From the obtained results, some conclusions can be made as follows:

1. Workability reduces with the increase in rubber content. Rubber chips having low specific gravity and possess high surface area. It absorbs water from concrete which makes the concrete comparatively dry and less workable. The slump value for M25 grade of concrete with 5%, 10% and 15% rubber chips are 14.29%, 23.8% and 28.57% less than control mix respectively. Highest fall in slump value is observed when 5% rubber chips are added. For M35 grade mixes with 5%, 10% and 15% rubber chips show the slump values 10.53%, 26.32% and 36.84% less than control the mix respectively.
2. Compressive strength decreases with increase in rubber content as rubber chips are weaker than the replaced fine aggregate. For higher grade of concrete, the compressive strength reduction due to addition of rubber chips has been seen lesser. It is seen that in case of M25 grade of concrete, mixes with 5%, 10% and 15% rubber chips show reduction in strength as 23%, 36.67% and 54.7% respectively for the case of 7 days and that has been seen 28%, 36.6% and 55.29% less respectively for the case of 28 days strength. On the other hand, for M35 mixes with 5%, 10% and 15% addition of rubber chips, the strength reductions for 7 days are 9.35%, 17.9% and 39.7% respectively and that for 28 days are 4.47%, 21.12% and 34.53% respectively.
3. Split tensile strengths of concrete mix with 5%, 10% and 15% rubber chips have decreased by 2.7%, 36.8% and 44.1% with respect to the of control mix. It is interesting to note that there is a drastic fall in split tensile strength when rubber content is increased from 5% to 10%.
4. It is observed that there is a steady decrease in flexural strength on addition of rubber chips. On replacement of fine aggregates by 5%, 10% and 15% rubber chips, flexural strength reduction has been detected as 28.19%, 38.8% and 45.14% respectively.
5. It has been observed in the study of temperature effect that there has been improvement in strength under application of temperature and rubber particles have been able to withstand the temperature about 200°C. With increase in rubber content, there has been strength reductions of 21.2%, 39.06% and 54.1% (w.r.t. control mix) for 5%, 10% and 15% rubber content respectively.
6. Study of strain behaviour of concrete cubes under uniaxial compressive stress shows that concrete with increasing rubber content has increased ductility and toughness. The rubberized concrete with higher rubber content has experienced higher strain before failure.

Depending on the observations of the study, it can be concluded that up to 5% of fine aggregates can be replaced with rubber chips for up to M25 grade and up to 10% of fine aggregates can be replaced with rubber chips for M35 and above grade of concrete, sacrificing some percentage of strength for ductility properties.

5.2 FUTURE SCOPE OF STUDY

- 1) Replacement of both fine and coarse aggregates with rubber chips with appropriate proportion can be performed and the mechanical properties of this rubberized concrete can be studied.
- 2) Pozzolanic material can be added to rubberized concrete for improvement of strength.
- 3) Fibre can be added for improvement of tensile strength.
- 4) Abrasion and Impact properties of rubberized concrete can be also studied.
- 5) Durability of rubberized concrete can be observed.

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