STUDY OF STRENGTH AND DURABILITY OF RUBBERIZED CONCRETE

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This is to certify that SUCHAYAN DINDA (Exam Roll. No. M4CIV24007, Registration No. 163461 of 2022-23) has carried out the thesis work entitled **"STUDY OF STRENGTH AND DURABILITY OF RUBBERIZED CONCRETE"** under my direct supervision and guidance. He has carried out this work independently. I hereby recommend that the thesis be accepted in partial fulfilment of the requirements for awarding the degree of **"MASTER OF ENGINEERING IN CIVIL ENGINEERING (STRUCTURAL ENGINEERING)".**

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This foregoing thesis is hereby approved as a creditable study of an engineering subject carried out and presented in a manner satisfactory to warrant it's acceptable as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made, opinion expressed, or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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DECLARATION

I, SUCHAYAN DINDA, 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, **"STUDY OF STRENGTH AND DURABILITY OF RUBBERIZED CONCRETE"**, is an authentic record of work that has been carried out in the Department of Civil Engineering, Jadavpur University, Kolkata under **Dr. 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

Rubberized concrete (RC) is an innovative, user and environmentally friendly invention in building materials that require less energy to manufacture and have a lower carbon footprint than cement-based systems, alleviating global warming concerns. It has the potential of reducing the dilemma of disposal of the huge rubber tire wastes by including them in production as a partial substitute for natural aggregate. This hereby avoids the depletion of natural mineral aggregates and protects the nature against air, water, and soil pollution. The present work shows the feasibility of incorporating waste rubber in concrete to solve the environmental issue and also improving the properties of concrete. For strength characterization, this work analysed the flexural, split tensile, and compressive strengths of rubberized concrete. To study the durability characterization of rubberized concrete, water absorption, acid resistance, chloride diffusion, temperature study, impact strength study, stress-strain behaviour study, and sorptivity study were evaluated. Finally, the outcome of this work concludes that rubberized concrete has distinct, tangible benefits compared with OPC concrete regarding environment protection, durability, and strength properties. Furthermore, rubberized concrete is recommended for producing lightweight concrete and civil engineering structures when compressive strength is not the main property.

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CHAPTER -1

INTRODUCTION

The nonbiodegradable wastes generated from industrial, domestic, and mining activities are challenging to recycle. It has been reported that a total 12 billion tons of waste is generated annually, whereas 11 billion tons of waste is from industries and 1.6 billion tons of solid waste is from municipal. This amount will reach 19 billion tons by 2025. Among all the industrial wastes, vehicle tires from the automotive industry are major concern in the present world. It was reported that about 2.7 billion tons of tires are generated annually, and the number is expected to keep increasing at a rate of 3.5 % with the increased population and vehicle demand. The existing disposal practices for discarded tires are stockpiling, landfilling, and burning. The accumulation of waste tyres causes serious damage to the environment such as soil and air contamination, deforestation, scarcity of agricultural lands, spreading of deadly diseases and toxic gas emissions etc. On the other hand, the increasing consumption of natural resources is one of several problems facing human communities all around the world. The ever-growing need for infrastructure development necessitates the construction of reinforced concrete structures consuming concrete on a massive scale.

One possible application for waste tyre rubber is as a partial replacement for natural aggregate in concrete. By using industrial waste, rubberized concrete can support construction sustainability and help the development of the civil engineering field by reducing the consumption of natural resources and producing a more efficient material. The addition of flexible rubber to rigid concrete changes its overall performance, brittleness and ductility Rubberized concrete is a form of concrete in which discarded tyre rubber particles are used instead of natural aggregates. This sort of concrete provides an environmental alternative to the millions of discarded tyres. Many successful achievements were reported by researchers around the world.

Waste tyres have been studied widely for the last twenty years on several applications such as asphalt pavements, water proofing systems and concrete pedestrian block etc. There are several properties of the rubber could be used usefully in this application such as low density and water proofing property etc.

CR (crumb rubber) is a ductile material as more than 50% of its composition is rubber. The CR (crumb rubber) particles are angular in shape with a smooth surface texture and specific gravity of 1.10 ± 0.05. These particles are highly hydrophobic in nature.

Previous studies used waste tire rubber crumbs and chips to replace partially natural aggregates in concrete. However, in terms of mechanical properties, partially replacing FA (fine aggregates) with rubber crumb produces better results than replacing CA (coarse aggregate) with rubber chips. The adhesive properties of rubber particles and cement paste are the main issues, and another is the strength decrement in RC (rubberized concrete). The inclusion of rubber particles in concrete increases the flexibility, ductility, impact, and toughness resistance. RC (rubberized concrete) enhances sound insulation and can be used in seismic applications because it absorbs the impact energy due to external forces. Many studies have found that surface treatment of rubber crumbs and adding pozzolanic material enhance bonding at the interfacial transition zone between rubber and cement and improve RC's (rubberized concrete) mechanical and durability properties.

Most earlier studies investigated only the mechanical properties of CRC (crumb rubber concrete) and a limited number of studies investigated some durability aspects of CRC (crumb rubber concrete). Thus, further investigations are needed to assess the effect of CR (crumb rubber) treatment techniques on the durability of CRC (crumb rubber concrete). Our present study aims to investigate the durability properties and the optimal use of waste tire rubber as a partial replacement of fine aggregate in concrete and their sensitivity to different conditions such as water absorption and water permeability, sulphate attack, chloride attack, impact resistance, fire resistance are investigated.

CHAPTER -2

LITARATURE REVIEW

2.1 GENERAL:

Several researchers examined rubberized concrete in different conditions and with different test procedures. Where most of the researchers examined on strength of rubberized concrete and very few of them performed experiment on durability conditions. In this chapter we reviewed some available literature and some critical observations have been made at the end of this chapter.

2.2 REVIEW OF LITARATURE:

Yasser et al. did an experiment on concrete with recycled rubber aggregates to replace natural fine aggregate, where crumb rubber was used to partially replace the fine aggregate by 0%, 10%, 15%, and 20% by volume of sand. They found as the rubber content increased, the compressive strength decreased. Up to 20% replacement, the reduction of compressive strength was within accepted ranges. Up to 20% rubber replacement, workability, and water absorption were not affected significantly. For concrete exposed to elevated temperature, significant reductions in the compressive strength occurred, especially at 600° C. After being exposed to sulphuric acid and high temperatures, rubberized concrete showed more ductile performance than traditional concrete. Minimal spalling was observed for rubberized concrete at sulphuric acid attack tests.

Ul Islam et al. investigated rubberized concrete with the complete replacement of traditional coarse aggregates by waste tire rubber particles. They found that the durability of compressed Rubberized concrete samples increased by reducing the entrapped air inside the rubber particles. Rubberized concrete with larger rubber particle sizes exhibited higher slump values compared to smaller ones. The inclusion of 100 % coarser rubber increased the voids in Rubberized concrete significantly, resulting in higher permeability. Compression of rubber aggregates reduced the permeability and improved the water absorption. For 100 % rubber content in Rubberized concrete, the capillary water absorption was significantly reduced for the compressed samples than the normal samples. The sulphate attack on normal Rubberized concrete caused mass and strength loss and reduced the durability of the concrete. However, the compression technique enhanced the resistance of Rubberized concrete toward sulphate attack. All the compressed samples showed better resistance to chloride ion penetration than the normal Rubberized concrete samples.

Islam et al. experimented with 100 % waste coarser tire rubber and set an inaugurating move in identifying its durability properties. They found that the durability of compressed RC (Rubberized concrete) samples was improved by reducing the entrapped air inside the rubber particles. The compaction of fresh RC (Rubberized concrete) also enhanced the internal packing of RC (Rubberized concrete) samples. Significantly, resulting in higher permeability. However, compression of rubber aggregates reduced the permeability and improved the water absorption by immersion. For 100 % rubber content in RC (Rubberized concrete), the capillary water absorption was significantly reduced for the compressed samples than the normal samples. Compressed RAs with better compaction in RC (Rubberized concrete) assisted in encountering the capillary pressure for water suction. Drying shrinkage was higher than the autogenous shrinkage for all RC (Rubberized concrete) samples. The total shrinkage rate stabilized at 180 days and was significantly influenced by the drying process and existing water in the concrete voids. All the compressed samples depicted lower shrinkage strains compared to the normal RC (Rubberized concrete) samples. The sulphate attack on normal RC (Rubberized concrete) was severe and caused mass and strength loss, threatening the durability of the concrete. However, the compression technique enhanced the resistance of RC (Rubberized concrete) toward sulphate ingression and protected it from mass and strength loss. All the compressed samples exhibited better resistance to chloride ion penetration by improving the internal pack of concrete than the normal RC (Rubberized concrete) samples.

Singh et al. investigated recycled concrete of silica fume and waste glass powder and a partial replacement of fine aggregate with crumb rubber (5%, 10%, and 15%). Where the workability of the concrete decreased with an increased proportion of CR (crumb rubber) in all kinds of mixes. The compressive strength of concrete containing CR (crumb rubber) decreased due to the softness and poor bonding of the cement and rubber particles. However, the 10% substitution of SF (silica fume) as cement in the rubber concrete increased strength by 21%. The tensile strength of the rubber concrete was also reduced. Incorporating 10% SF (silica fume) and 10% WGP (waste glass powder) as cement in the rubberized concrete increased tensile strength compared to rubberized concrete without SF (silica fume) and WGP (waste glass powder). The density of concrete decreased by 3% for 5% CR up to a 5.7% decrease for 15% CR used in the rubber concrete without SF (silica fume) and WGP (waste glass powder). The dynamic modulus of elasticity of CR (crumb rubber) concrete dropped by 24.8% for 5%

CR (crumb rubber) and 60% for 15% CR (crumb rubber) replacement as compared to the reference mix.

Alsaif and Alharbi did an experimental study on the properties of rubberized concrete made by replacing up to 40% of the conventional aggregate with waste tire rubber (WTR) and internally reinforced by a combination of waste tire steel Fibers (WTSF) and industrial steel Fibers (ISF) and found that the workability and unit weight decreased, and the air content increased. The addition of steel Fibers to rubberized concrete further reduced the workability and air content but did not affect the unit weight. The combination of steel Fibers and rubber considerably increased the flexural strain capacity and post-peak energy. Steel Fibers had no significant effect on the porosity of concrete, whereas the presence of rubber hurt permeability. The addition of rubber particles increased the shrinkage of concrete. High content of flexible rubber and/or steel Fibers prevented the initiation and development of cracks in all concrete ring specimens subjected to restrained shrinkage testing.

Kumar et al. experimented on rubberized concrete to see the influence of chloride and sulphate solution and they found that when conventional and rubberized concrete were submerged in a 5% NaCl solution, conventional concrete gained 40% of its compressive strength at 12 weeks but loosed 1.86% at 24 weeks, while rubberized concrete gained 50% of its compressive strength at 12 weeks but loosed 1.67% at 24 weeks. When specimens were immersed in Na_2SO^4 solution for 24 weeks, conventional concrete lost 3.57%, while rubberized concrete lost 2.79% of its compressive strength. While specimens were immersed in $MgSO^4$ solution for 24 weeks, conventional concrete loosed 4.82%, while rubberized concrete loosed 3.16% of its compressive strength. So, we can say rubberized concrete showed better resistance to sulphate attack than conventional concrete.

Beiram and Al-Mutairee experimented on rubberized concrete by partial replacement of coarse aggregate with different volumes of west tire rubber, where they found that the impact resistance of concrete increased by 35.6% because of the replacement of 30% of the coarse aggregate with rubber chips. Concrete's thermal conductivity can be decreased by 20.6% by replacing 30% of the coarse aggregate with rubber chips. The workability of concrete is reduced by 37.04% when the percentage of chip rubber in the concrete mix is increased to 30%. When 30% of coarse aggregate is replaced with chip rubber, the density of rubberized concrete mixtures is 9.08% smaller than that of reference mixtures. Where at 30% replacement, compressive strength, splitting tensile strength, and modulus of rupture are all reduced by 47.64%, 35.34%, and 44.75%, respectively. By substituting 30% of coarse particles with chip rubber in concrete, the modulus of elasticity is reduced to 50.49%.

Khaled and Al-Sodani did an experimental review on rubberized geopolymer concrete, and they found that a significant reduction in compressive strength of
Rubberized geopolymer concrete (RGPC) with increasing rubber content from 0% to 30%. A 5% replacement of rubber resulted in an increase in the flexural strength of rubberized geopolymer concrete (RGPC) compared to Normal geopolymer concrete (GPC). However, flexural strength reduced as the replacement ratio of rubber was increased. Splitting tensile strength decreased by following the same pattern as the compressive strength decreased. The tensile strength was reduced by 34.6%, 23%, and 35.5% with increasing CR (crumb rubber) content from 0% to 10%, 20% and 30% compared to control specimen, respectively. Water absorption increased significantly with increasing curing temperature.

Saleh et al. experimented with the effect of waste rubber on self-compacting concrete where they found that in the fresh state, the evolution of the density of concrete was inversely proportional to the substitution rate of rubber. The flexural tensile strength of rubberized concrete decreased with increasing rubber substitution rate. The flexural tensile strength of the concrete was much better when powder grains of waste rubber were incorporated into the concrete. The compressive strength was reduced in rubberized concrete. This was inversely proportional to the substitution rate of rubber grains. Thermal conductivity evolution was inversely proportional to the substitution rates and the rubber grain sizes of the cement-based matrix. Porosity increased proportionally with the substitution rate of the rubber grains in the self-compacting rubberized concrete as well as with the size of the rubber grains.

Assaggaf et al. did research on the effect of NaOH, $KMnO^4$, and cement treatment of crumb rubber (CR) on the durability characteristics of crumb rubber concrete (CRC). They found that the water absorption of NaOH-, $KMnO^4$, and cement-treated CRC was less than that of untreated CRC. The decrease in the water absorption of CRC with 40% NaOH-, $KMnO^4$-, and cement-treated CR was 4.4, 3.5, and 7%, respectively, compared to the untreated-CRC. The weight- and strength loss upon exposure to sulfuric acid were the highest in conventional concrete specimens as compared to CRC (crumb rubber concrete) specimens. The weight loss and loss in strength in the conventional concrete were 16.6 and 54%, 31.4, and 70.9%, after 90 and 180 days, respectively. The NaOH-treated CRC (crumb rubber concrete) with up to 8% CR exhibited significant improvement in acid resistance compared to the untreated- CRC (crumb rubber concrete) specimens. The cement-treated CRC (crumb rubber concrete) specimens, with as high as 40% CR, exhibited 119 and 114% increase in compressive strength after 90 and 180 days of acid exposure, respectively. All the treated- CRC (crumb rubber concrete) specimens showed a significant improvement in electrical resistivity and chloride permeability compared to the untreated ones.

Ahmad et al. did an experiment where waste glass was substituted in the proportion of 10%, 20%, and 30% by weight of binder while 20% waste rubber as coarse aggregate was kept constant throughout the study. They found that the Flowability of rubberized concrete decreased with the substitution of waste glass due to the larger surface area and rough texture which enhance the internal friction between concrete ingredients. Isothermal conductivity analysis showed a decrease in heat of hydration with the substitution of waste glass. Maximum compressive strength was observed at 20% substitution of waste rubber which is 24% more than reference concrete at 28 days of curing. At the same dose of waste glass (20%), split tensile strength is 30% more than reference concrete. Increased acid resistance and decreased dry shrinkage cracks of rubberized concrete were also observed with the substitution of waste glass. Minimum acid resistance was observed at 20% substitution of waste glass which is 25% less than reference concrete.

Li et al. did an experimental review on the durability property of rubberized concrete, and they reached some conclusions that Rubber particles reduced the abrasion resistance of concrete. A rubber content of 5–10% has a slightly negative impact on abrasion resistance. When the rubber content is less than 10%, the increase in water absorption is small or even decreased. When the rubber content is too large (greater than 15%), the water absorption increases significantly. Rubber with a small particle size (0–1 mm) can effectively fill the pores and water seepage channels, which can effectively reduce water absorption and enhance the RC (rubberized concrete) impermeability. The pores created by the rubber into the concrete enhanced the freeze-thaw resistance of concrete. The best freeze-thaw resistance is achieved when the rubber content is 25–30%. Rubber particles decreased concrete strength. The addition of an appropriate amount of rubber (5–20%) to concrete can effectively improve the resistance to chloride permeability. The addition of rubber particles to concrete increased carbonation depth.

Pre-treatment increased the adhesion of the rubber and increased the density of the RC (rubberized concrete).

Ataria and Wang investigated the performance of concrete made with 100% recycled aggregates and crumb rubber at different replacement levels (5%, 10%, 15%, and 20%). Where The results clearly show that the addition of crumb rubber reduced the compressive strength of the recycled aggregate concrete moderately when its concentration is limited to 5%. The study also observed that the resistivity of chloride ions for recycled aggregate concrete with 5% crumb rubber concentration is moderate. The results of the surface resistivity tests showed that the resistivity of the recycled aggregate concrete to chloride ion penetration is moderate under the air-dried curing technique. The ductility of recycled concrete with crumb rubber is found to be greater than that of recycled concrete without crumb rubber.

Kumar and Dev did an Investigation on the effect of acids and freeze-thaw on pozzolanic cement-based rubberized concrete. Where they found Surface-treated rubber crumbs with a 15% H_2SO^4 solution reduced rubberized concrete's strength loss and improved interfacial bonding between the rubber crumbs and cement paste. After surface treatment of rubber crumbs, it may be used as a partial substitute for FA (fine aggregate) up to 15% without causing substantial compressive strength loss. After boiling, the water absorption value was higher in the rubberized concrete mix than in conventional concrete. When exposed to H_2SO^4, the rubberized concrete mix specimens showed moderate spalling, but it showed only minor spalling of cement paste, rubber crumbs, and aggregates when exposed to HCl. It was discovered that with the same time of immersion and concentrations of H_2SO^4 and HCl, the rubberized concrete experienced less surface degradation, weight loss, and compressive strength loss due to HCl. There were no apparent microcracks on the surfaces of the samples exposed to freeze-thaw cycles. Rubberized concrete design strength remains unaffected after 45 freeze-thaw cycles.

Ahmad et al. did an experiment where the waste glass was used as a pozzolanic material in the proportion of 10–30% in increments of 10% by weight of cement while 20% rubber tires as coarse aggregate were kept constant. Fresh properties were evaluated through slump cone test while mechanical performance was evaluated through compressive and split tensile strength. Water absorption, dry shrinkage, and acid resistance tests were performed to assess the durability aspects of rubberized concrete. Results indicated that waste glass can be successfully used to enhance the mechanical performance of rubberized concrete by up to 20% substitution. Compressive and split tensile strength was 24% and 30% more than reference concrete at 20% substitution of waste glass respectively. It also indicates that durability aspects such as water absorption, dry shrinkage, and acid resistance were considerably improved with the substation of waste glass. However, at higher doses of waste glass (30%), a decrease in mechanical and durability performance was observed due to a lack of workability. The overall study demonstrates that waste glass of up to 20% can be safely used as a binding material in rubberized concrete without negative effects on the mechanical and durability performance of concrete.

Khaled And Al-Sodani researched on Rubberized geopolymer concrete, (RGPC) as an innovative, user, and environmentally friendly invention in building materials that require less energy to manufacture and have a lower carbon footprint than cement-based systems, alleviating global warming concerns. They included waste rubber Fibers in geopolymer concrete (GPC), which emits 90% less carbon dioxide when compared with ordinary Portland cement (OPC). They found that the Compressive strength of RGPC is affected by CR (crumb rubber) content and size. The effect of CR content is much higher than that of CR size and the recommended rubber particle size is 0–2 mm. A 5% replacement of CR resulted in an increase in the flexural strength of RGPC compared to the GPC, however, flexural strength was reduced as the replacement ratio of CR was increased to 10%, 15%, 20%, and 30%. The optimum replacement levels for CR and steel Fibers are 5% and 1%, respectively. Furthermore, GPM with 100% CR revealed a reduction of 74% in flexural strength compared to control specimens (with 0% CR). Splitting tensile strength decrease follows the same pattern as the compressive strength decrease. The tensile strength was reduced by 34.6%, 23%, and 35.5% with increasing CR content from 0% to 10%, 20% and 30% compared to control specimen, respectively. Water absorption increased significantly with increasing curing temperature to 90 ◦C. Finally, it can be stated that GPC and RGPC have distinct, measurable benefits over OPCC in terms of durability and strength properties.

Kelechi et al. did an experimental investigation on the Durability Performance of Self-Compacting Concrete (SCC) Containing Crumb Rubber, Fly Ash, and Calcium Carbide Waste (CCW). The resistance of the SCC against acid attack, as measured by immersion in H_2SO^4, and the resistance against salt medium, as measured by immersion in $MgSO^4$, all improved with the use of fly ash and CCW as supplementary cementitious materials (SCM). The partial

replacement of fine aggregate with CR in SCC mixes significantly reduced its resistance against acid and salt attacks. This negative effect was more severe in the SCC mixes without fly ash and CCW. The resistance of the SCC mixes against heat decreased the replacement of 40% cement with fly ash beyond a temperature of 200 0C. Furthermore, the heat resistance of the SCC mixes decreased with the increase in the partial replacement of fine aggregate with CR, and the use of CCW as SCM.
The optimum temperature for the blends was found to be 400 ^{0}C; however, the water absorption was decreased with the increase of the fly ash content and was increased with the increase of the CR content.

Pham et al. investigated the durability characteristics of rubberized concrete up to 30% rubber content. Where The inclusion of rubber aggregates led to a reduction of the compressive strength of rubberized concrete. Rubberized concrete absorbs more water than that of the conventional concrete. The water absorption of rubberized concrete increased with the rubber content. The carbonation depth of rubberized concrete was higher than that of the conventional concrete. In addition, the carbonation depth increased with the rubber contents. Rubberized concrete leads to a reduction of the service life.

Luhar et al. did an experiment on rubberized geopolymer concrete where the depth of water penetration rises with enhanced rubber Fiber. No physical modifications in the geopolymer samples were noted after exposure to sodium sulphate for up to a year. These specimens did not show any change in shape, and no cracking or spalling. The damage to the concrete surface increases as the sulfuric acid becomes stronger. It was found that higher concentrations of sulfuric acid result in greater deterioration, resulting in greater loss of strength. With the increase in the rubber Fiber content and an increase in time for both cases, the drying shrinking has increased. Carbonation depth decreased with an increase in rubber content. For geopolymer concrete with 30% fine aggregate replacement levels, a peak carbonation depth of 8.0 mm has been noted.

Toma et al. did an Experimental Investigation on the Long-Term Material
Properties of Rubberized Portland Cement Concrete. where they found that a significant drop in the values of density after 5 years is observed for specimens
made with rubberized concrete, whereas the density of the reference mix changes by a very small amount. The values of the static modulus of elasticity decreased after 5 years compared

to the standard value obtained at 28 days, Since the dynamic modulus of elasticity was influenced both by the mass of the specimen and by its fundamental longitudinal frequency of vibration, any trend observed for the two parameters is reflected in the evolution in time for this material property. The voids inside the RC (rubberized concrete) specimens lead to lighter concrete and lower values for the frequency of vibration. The conversion equations from dynamic modulus to static modulus of elasticity cannot be directly applied to rubberized concrete. Further investigations are deemed necessary in this direction. Material damping is strongly influenced by the rubber content in concrete. A 40% replacement of sand by rubber aggregates leads to a three-fold increase in the value of the material damping. However, a further increase in the replacement percentage has the opposite effect on the damping properties due to the occurrence of voids at the ITZ level between rubber particles and the cement matrix. Both compressive and tensile splitting strength are adversely affected by the presence of rubber aggregates.

Amiri et al. Evaluated the synergic effect of waste rubber powder (WRP) and recycled concrete aggregate (RCA) on the mechanical properties and durability of concrete. Concrete specimens containing the WRP with the replacement ratios of 0 %, 2.5 %, and 5 % by weight of cement, and the RCA with the replacement levels of 0 %, 25 %, and 50 % of coarse aggregate were prepared. Where they found that the mechanical properties of the concrete containing WRP and RCA were lower than those of the reference concrete. For the concrete containing the WRP, larger capillary pores and higher porosity of the paste were formed because of the hydrophobic characteristics of WRP. The concrete specimens with the WRP had lower migration rates of chloride ions compared to the reference specimens because of the better blockage capacity of WRP as the electric insulator. Increasing the WRP rate by 5% improved the penetration resistance of concrete. The use of only RCA in concrete increased the penetration of the chloride ions because of the weaker ITZ of the produced concrete and the existence of the weak old ITZ in the aged concrete. The penetration rate was increased significantly by increasing the RCA from 25 % to 50 %. There were no remarkable differences between the durability performances of the concrete specimens containing the (WRP, and RCA) rates of (2.5 %, 25 %), (5%, 25 %) and their reference concretes. It showed that the positive effects of WRP neutralized the negative effects of the RCA on the durability performance.

Gupta et al. investigated the durability properties of reinforced concrete fabricated by incorporating Fiber-type rubber shreds as fine aggregate in concrete and silica fume as a supplementary cementitious material. Concrete designs were produced to replace natural fine aggregate and cement with rubber shreds and silica fume respectively. The concrete mixes were studied for compressive strength for up to 365 days, abrasion resistance, and water absorption for up to 28 days. The carbonation and acid resistance (H_2SO^4 and HCl) properties were studied for up to 90 and 180 days, respectively. Corrosion samples were tested for up to 18 months for both macro-cell current and half-cell potential. The incorporation of rubber shreds lowered the compressive strength of concrete and resistance to water absorption, carbonation, and corrosion. For 28 days of standard curing, a decrease of 51.8% was observed in the replacement of 25% natural sand by rubber shreds. It was found that up to 10% rubber shreds could be used as fine aggregate in silica fume concrete without significantly affecting the compressive strength. However, the resistance to abrasion and acid attack was enhanced by the utilization of rubber shreds in concrete. For 25% rubber content, the depth of wear decreased by 33% due to the incorporation of flexible rubber shreds which resist the abrasion force by acting as a brush between cement paste and abrasive powder. The presence of silica fume considerably enhanced the mechanical and durability properties of rubber shreds concrete and lowered the probability of corrosion. It increased the compactness of the concrete structure, which refined the interfacial bonding and achieved good abrasion resistance. The water absorption of concrete mixes increased upon adding 5% of rubber shreds and then reduced for higher doses of rubber shreds (10, 15, 20, and 25%) in concrete mixes. The authors also observed the durable, stable, and hydrophobic nature of rubber shreds favouring durability against acidic solutions, and the addition of silica fume densified the concrete matrix resisting the penetration of aggressive acid.

Dong et al. studied the strength, durability, carbonation resistance, and water absorption properties of rubberized geopolymer concrete and compared them to those of rubberized conventional cement concrete. Results showed that the compressive strength of rubberized geopolymer concrete had a strong correlation with bulk density, elastic modulus, ductility, splitting tensile strength, and water absorption. The recycled crumb rubber particles (2–5 mm) were primarily used to replace up to 30% of the coarse aggregates, which were 4 mm ungraded aggregates and 7 mm graded aggregates. A low calcium Class F fly ash, commercially available GGBS (Ground granulated blast furnace slag), densified silica fume was used in the geopolymer concrete mix. It was observed that a low dosage of rubber improved the workability, but a high dosage at 30% replacement ratio resulted in reductions in the slump and spread values. All the mixes were seen to have satisfactory workability, with the lowest being 140 mm and the highest reaching 230 mm. A high compressive strength of 61.4 MPa was achieved at 56 days by the control mix with no rubber. The strength reduced as the rubber content increased. A sorptivity test, Water Absorption test & Initial Rate of Absorption test were performed which showed that water absorption increased by about 40-50% for every 15% increase in rubber content.

Geethavani and Narendra investigated to use of waste tire rubber chips as a partial replacement of coarse aggregate to produce rubberise concrete in M30 grade. They found that the workability has increased in the nominal mix, and it is adversely affected by the replacement of coarse aggregates with rubber tyres. Replacing 5% volume of plain (or) reinforced rubber in 20mm coarse aggregates and 30% mass of GGBS (ground granulated blast furnace slag) in cement gave more strength for M30 grade concrete compared to control mix results. Compressive strength, split tensile & flexural strength of concrete reduced with an increase in percentages of both plain and reinforced tyre rubber chips. The durability studies showed that HCl curing has more effect than H_2SO^4 curing. The elasticity also decreased with the increase of percentages in rubber content.

Shivaji et al. experimented on concrete by partial replacement of coarse aggregate with waste rubber. They found that by adding the rubber chips in concrete the property of concrete enhanced. As the quantity and size of rubber increased, the compressive strength of concrete decreased. That decreasing strength can be increased by adding glass Fiber to the weight of cement. Waste tire rubber chips filled RC block specimens give better ductility than normal RC block specimens. It is suitable for the members subjected to seismic forces. The rubberized concrete became crack resistant.

Mehdipour et al. investigated the effects of metakaolin (MK), as a replacement for Portland cement, in the ratios of 0%, 10%, and 20% by cement weight and steel Fiber (SF) dosages of 0%, 0.25%, 0.5%, and 1% by concrete volume in rubberized concrete. Where they found that by increasing the temperature from 25^{o} C to 600° C the mass loss rate of the specimens increased while adding the MK content of 0%, 10%, and 20% to the mixes reduced the mass loss rate by 10.46%, 9.73% and 10.01%, respectively. At ambient temperature, increasing the MK content by 10% and 20% led to an increase in compressive strength by 18.91% and 18.08%, which also increased by 12.71%, 22.25%, and 18.91% with the addition of 0.25%, 0.5% and 1% of SF steel Fiber respectively. By increasing the MK content by 10 and 20%, the tensile strength first increased by 9.30%, and then decreased by 1.16%, respectively. As the temperature increased, the porosity of the mixes also increased. In general, the ductility index gradually increased with raising the temperature.

Fawzy et al. did investigation on the optimal use of waste tire rubber as a fine aggregate in concrete and its sensitivity to high-temperature effects. Five different concrete compositions were prepared: a reference concrete (RC) made with natural fine aggregate (sand) and coarse aggregate (dolomite) and four concrete mixes with replacement rates of 4%, 8%, 12%, and 16% of sand by crumb rubber from waste tires. For the effect of elevated temperature: Similar specimens were exposed for 4 hours to a temperature of 70°C, to study the effect of high daily temperature, and 2 hours for both temperatures 200 °C and 400° C to study the effect of fire. After cooling down to ambient temperature, the compressive strength, flexural strength, and the splitting tensile strength were measured and compared with the values that obtained before fire exposure. The in-hand study indicated that the workability of crumb rubber concrete decreased with an increase in crumb rubber content. Partial substitution of crumb rubber aggregate in concrete caused a gradual decrease in the compressive and tensile strengths of concrete. The reduction in the compressive strength was around 9.6%, while the reduction in the tensile strength was around 7.75% for a concrete mix containing 16% crumb rubber. The highest loss in compressive strength in concrete was noticed at the temperature between 200° C and 400° C, because of the decomposition of calcium silicate hydrate (C-S-H). When the concrete was subjected to elevated temperature, splitting strength was reduced by (6.4 - 16%) at 70°C, (17 - 27%) at 200° C and (28.4 - 32.9%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%). The reduction in flexural strengths is up to 8.2% at 16% crumb rubber for unheated specimens. However, when concrete was subjected to elevated temperature, flexural strength was reduced by (4% - 15.6%) at 70° C, (19.8% - 37.3%) at 200° C, and (36.7% - 43.45%) at 400° C compared with normal concrete, for concrete containing rubber (0%-16%).

Grinys et al. investigated the durability properties of rubberized and glass powder-modified concrete, and they found that When rubber content increased, the workability decreased due to its irregular shape and fineness. From experiments, we can see that when crumb rubber content increased, fresh concrete density decreased, and air content increased due to its low specific gravity nature. When rubber amounts increase, compressive strength decreases due to rises of air voids and cracks. The flexural strength of rubberized concrete with small amounts of crumb rubber was increased by 3.4–15.8% compared with a control mix. Due to its non-polar nature, rubber entraps air in concrete, which provides space for pressure release during water freezing thawing. From all results, we can state that 2 kg/m3 of prefabricated air bubbles can be successfully replaced by 10 kg/m3 of fine crumb rubber to get similar mechanical and durability properties.

Luhar et al. investigated the durability property of rubberized concrete where the percentage of waste rubber Fibers increased, the compressive strength decreased at all ages. The tension properties of rubberized geopolymer concrete, such as flexural and tensile strength, are increased as the percentage of rubber Fibers increases. The maximum Flexural strength was observed in the 30% replacement of sand by Fiber rubber. The modulus of elasticity of the geopolymer concrete and OPC concrete decreased by 36.34% and 34.54%, respectively, as the rubber Fiber content increased from 0 to 30%. The pull-off strength decreases when rubber Fibers are introduced to the mix.

Kechkar et al. investigated the durability properties of rubberized concrete with a partial replacement of the sand at 0%, 10%, 17.5%, and 25% of the volume. Where The incorporation of rubber granules decreased compressive strength and flexural tensile strength. The rubber content plays an important role in the resistance to chemical attacks by sulfuric acid, sodium sulphate, and seawater. Concrete drying shrinkage decreased with increasing percentage of rubber granules in concrete. Rubberized concrete has a greater expansion than ordinary concrete.

Ahmed et al. investigated the combined effect of RCA (Recycled concrete aggregate) and CR (Crumb rubber) on the properties of concrete where the rubberized recycled aggregate concrete showed a reduction in compressive strength concerning the control mixture. Treatment of CR with 20% Sodium Hydroxide solution resulted in better interlocking of CR in the matrix. The addition of steel Fibers has increased the mechanical properties of rubberized concrete as well as freeze-thaw resistance.

Sofi et al. studied the properties of rubberized concrete and found that the compressive and flexural strength gradually decreased with an increase in the amount of crumb rubber in concrete. The reduction in compressive strength at 28 days was about 10–23% for aggregates and 20–40% for cement replacement. The rubberized concrete exhibited better resistance to abrasion than the control mix. The water penetration of rubberized concrete was higher than the control mix. The reduction in modulus of elasticity was 17–25% in the case of 5–10% aggregate replacement by chipped rubber. Replacement of rubber for aggregate or cement in concrete caused a reduction in its flexural strength and tensile strength. The depth of chloride penetration of the mixes with crumb rubber up to 7.5% was lower than that of the control mix in the case of w/c 0.4. According to this study, it is possible to design high-strength concrete in which waste tyre rubber may be utilized as a partial substitute for fine aggregate up to 12.5% by weight.

Guo et al. did an experimental study on the mechanical and thermal insulation properties of rubberized concrete. Where they found the compressive strength of rubberized concrete was remarkably reduced after introducing rubber particles into concrete, which was negatively correlated with rubber content and positively correlated with rubber particle size. In addition, by increasing rubber content or decreasing rubber particle size, the peak strain corresponding to the uniaxial compressive strength gradually increased. By adding rubber particles into plain concrete, the number and size of surface cracks and penetrating cracks decreased as rubber content increased. Increasing the rubber content or reducing the rubber particle size contributed to an increase in the thermal insulation performance of the specimens. Additionally, the rubber particle size was positively correlated with heat flux, and negatively correlated with heat resistivity, while the rubber content was the opposite. When the rubber content was less than 30%, the thermal insulation performance of the specimens increased at a high rate as the rubber content increased. Conversely, the increasing rate was gradually slowed down. Thus, when rubber particles of 40 mesh and 50% content were mixed into concrete, the best thermal insulation was obtained. The SEM analysis revealed that rubberized concrete specimens contained many voids, and rubber, as a hydrophobic material, weakened the bond between rubber particles and other aggregates, which can explain the reduction of compressive strength of rubber-modified specimens.

Gerges et al. explore the effect of using recycled rubber powder as an alternate fine aggregate in concrete mixes. Natural sand in the concrete mixes was partially replaced by 5%, 10%, 15%, and 20%. Physical properties such as density, compressive strength, fresh concrete properties, split tension, and impact load capacity were examined. Partial fine aggregate replacement in the concrete mix by powdered rubber leads to a reduction in the density of the final product because the specific gravity of the rubber used was less than that of fine aggregates. Decreasing in the rubberized concrete strength (compressive and tensile strength) was observed with the increasing powdered rubber content in the mixture. The reduction in strength was an average of 30, 35, 50, and 63% against a powdered rubber replacement of fine aggregates at 5, 10, 15, and 20%, respectively. The addition of powdered rubber to the concrete mix resulted in a negative effect on the modulus of elasticity. The decrease in elasticity is reflected in the capability of rubberized concrete to behave elastically when loaded in tension, thus improving the failure manners of typical concrete. Rubberized concrete exhibits enhanced energy absorption since the concrete did not undergo a typical brittle failure yet it encountered a ductile, plastic failure mode.

Medine et al. did an experimental investigation on the durability properties of five years aged lightweight concretes containing rubber aggregates, incorporating rubber aggregates as partial replacement of 5%, 7.5%, and 10% of fine and coarse aggregates. Where they found that the percentage of water absorption decreased when rubber content was < 7.5%. The biggest percentage of water absorption of 5.13% was recorded in the case of the control mix. The highest percentage of water absorption of 4.68% and 4.81% was observed in the case of the mixes containing 10% of rubber aggregates. The percentage of water absorption decreased when the rubber content ranged between 5% and 7.5%. The biggest mass loss of 3.1% was recorded in the case of the control mix exposed to freeze-thaw cycles. The exposure of lightweight concretes to elevated temperatures of 200°C, 400°C, 600°C, 800°C and 1000°C, has demonstrated that mass loss increased with the decrease of rubber content and the increase of the temperature heating. The mass losses due to the Na_2SO^4 immersion increased slightly with the increase of the duration of immersion. The test has also revealed that the biggest mass loss of about 0.26% was observed on the specimens containing 5% rubber aggregates. The relationship between HCl concentration and aggressiveness has been demonstrated. The results have indicated that the mass losses of rubberized mixes are less significant as compared to those recorded in the case of the control mix. This proved that these mixtures resist more to this acid.

Mendis et al. did an experimental review on the properties of rubberized concrete, From the experiments this study found that by changing other mixing parameters, similar compressive strength can be achieved from different crumb rubber content. Similarly, rubberized concrete of similar rubber content can have very different compressive strength due to different proportions of other constituents of the mix. Also regardless of rubber content, similar strength, splitting tensile strength, modulus of rupture, modulus of elasticity, and stress. Strain behaviour can be achieved. The variations of these properties between one mix to another mix of similar strength are well within the range of variation observed for normal concrete. The experiments also showed that after 14 days of concrete casting, the strength developments of different mixes of similar strengths are very similar. This is true for both compressive and splitting tensile strength of the crumb rubber concrete tested.

Noor et al. experimented on the abrasion resistance of rubberized concrete, where crumb rubber replacement was 10%, 15%, and 20% of sand by volume. The depth loss of the concrete surface decreased with the increase of crumb rubber volume which indicates that abrasion resistance was improved with the presence of crumb rubber in the mix, However, in the case of rubberized concrete with silica fume, abrasion resistance was found to be slightly decreased with compressive strength more than 50N/mm2 due to the lack of low elastic modulus of crumb rubber particles to accommodate with denser cement matrix. Crumb rubber with 20% replacement gave much higher resistance against abrasion.

Thomas and Gupta did an experiment on rubberized concrete where they replaced natural fine aggregate from 0% to 20% in multiples of 2.5%. by crumb rubber. Tests were performed to determine the compressive strength, flexural tensile strength, pull-off strength, abrasion resistance, water absorption, and water penetration of these concrete samples and their microstructures were observed using Scanning Electron Microscopy (SEM). It was observed that the compressive strength, flexural tensile strength, pull-off strength, and depth of water penetration of the rubberized concrete were less than that of the control mix, while the abrasion resistance and water absorption (up to 10% substitution) exhibited better results than that of the control mix concrete. Rubberized concrete may be used in structures where there are chances of brittle failure. Crumb rubber may be utilized in high-strength concrete as a partial substitute for fine aggregate up to 12.5% by weight for obtaining strength above 60 MPa.

Gupta et al. did an experimental investigation on concrete with rubber Fibers (obtained by grinding waste rubber tyres) as partial replacement of fine aggregates, to evaluate the compressive strength, density, water permeability, static modulus of elasticity, dynamic modulus of elasticity, and chloride diffusion. Rubber Fibers were used with three different water-cement ratios (0.35, 0.45, and 0.55). Six levels of rubber Fiber contents (0, 5, 10, 15, 20, and 25%) as partial replacement of sand and three levels of silica fume (0, 5, and 10%) as partial replacement of cement have been considered. They found that the Workability of concrete is not affected significantly by adding rubber Fibers. The compressive strength of waste rubber tyre Fiber concrete decreased. with the increase in the replacement level of fine aggregates by rubber Fibers. The strength increased on partial replacement of cement by silica fume. The reduction in static and dynamic modulus of elasticity on partial replacement of the fine aggregate by rubber Fiber indicates higher flexibility. The rubberized concrete can be therefore used in buildings as an earthquake shock-wave absorber, foundation pad of machinery, and construction of highway pavement, airport runways, and crash barriers. Rubberized concrete shows medium water permeability which increased with an increase in rubber Fiber content for all three w/c ratios (0.35, 0.45, and 0.55 w/c ratios). The permeability of rubberized concrete is reduced on partial replacement of cement by silica fume. No trend is observed for the change in chloride ion resistance with the replacement level of rubber Fibers. The chloride-ion penetration increases on partial replacement of cement by silica fume. Microstructural analysis shows that gaps are present between the rubber Fiber and cement paste indicating weak interfaces leading to the reduced strength of rubberized concrete.

Kamaruddin et al. investigated on durability performance of polymeric waste crumb rubber as partial fine aggregate replacement in concrete grade M30. They Found that Concrete workability in terms of slump value increased with the increase of crumb rubber percentages. Water absorption of concrete increased with the increase of crumb rubber percentages in rubberized concrete. The water permeability of concrete increased with the increase of crumb rubber percentages in rubberized concrete. According to this study, we can say the durability performance in terms of water absorption and water permeability of concrete decreases with the increase of crumb rubber percentages in rubberized concrete.

Ghedan and Hamza did an experiment on rubberized concrete where they found Mechanical properties of concrete such as compressive strength decreased with the addition of rubber content resulting from the weak bond between rubber particles and concrete compared with the bond between concrete and concrete and this confirm the results from previous research. The average decrease in the compressive strength when added 15% rubber particles is about 49.8% from traditional concrete. The thermal conductivity of the concrete is decreased by the addition of rubber particles by about 26.7% from traditional concrete. The results showed that the bond between rubber particles and concrete can be enhanced by increasing electrostatic interactions and facilitating chemical bonding.

Guneyisi et al. experimented on rubberized concrete to study the durability-related properties of rubberized concrete. Two types of waste scrap tire rubber were used as fine and coarse aggregate, respectively. The rubber was replaced with aggregate by three crumb rubber and tire chips of 5, 15, and 25% for the rubberized concrete productions. The water absorption of rubberized concrete was observed to be decreased by the utilization of silica fume. However, at 25% rubber content level, silica fume tended to lose its effectiveness. The gas permeability coefficients of rubberized concrete were also reduced by silica fume addition. Moreover, after 5% rubber content, the gas permeability test failed due to a high amount of porosity. The water permeability of rubberized concrete reached 150 mm, which is the dimension of the test specimen, in both concrete with and without silica fume at 25% rubber content. After a nine-week NaCl exposure period, the corrosion current density values started to decrease with some fluctuations. There was a continuous rise in the corrosion current density when the whole chloride exposure period was considered. The rate of corrosion was adversely affected by increasing the rubber content. Utilization of tyres in concrete production increases pores in concrete. These pores in the concrete are ways for penetration of water and oxygen into concrete. When the number of pores increases, the penetration of water and oxygen to concrete also increases.

Grdic et al. experimented on the Hydro-abrasive resistance of rubberized concrete. Where they found that the concrete with 10 % replacement of fine river aggregate with recycled rubber granulate has a slightly better hydro-abrasive resistance when compared to the reference concrete with no rubber added, even though its compressive and flexural strength values are lower than those of the reference concrete. The hydro-abrasive resistance of concrete is reduced if the recycled granulated rubber in concrete is increased beyond 10 %. The replacement of fine river aggregate by recycled granulated rubber caused a reduction of compressive strength, flexural strength, bond strength by "pull-off", and static modulus of elasticity. For example, at 28 days, the compressive strength decreased by 36 to 70 %, flexural strength by 20 to 55 %, bond strength by "Pull-off" by 15 to 51 %, and static modulus of elasticity by 16 to 54 %, depending on the granulated rubber content. The ultrasonic wave propagation through concrete, and the rebound number of sclerometers, decreased with an increase in the quantity of recycled rubber granulate in concrete. Based on the results obtained in this research, the best hydro-abrasive resistance should be expected in concrete produced by using about 5 % granulated rubber instead of fine river stone aggregate.

Li et al. studied the compressive strength, splitting strength, flexural strength, elastic modulus, stress-strain relationship, and permeability of chloride ion of rubber high-strength concrete (RHSC) with different rubber content (0-3 %) & different particle size (0.25-1 mm). There was no noticeable change in a slump of concrete with different rubber content. The compressive strength, splitting tensile strength, and flexural strength of RHSC decreased with an increase in the content of the rubber. It was observed that the lack of interface bonding between rubber aggregate & rubber cement was not strong. For cube compressive strength & split tensile strength tests, 100x100x100mm blocks were used. For the flexural strength test, 100x100x400mm specimens were used.
For rubber content of 3%, in comparison to concrete with no rubber,

Table 1: Experimental results.

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 specimens & found that the pulse velocity increased with age growth & strength of concrete. They observed that rubber particles of 0.4 mm showed better pulse velocity results due to their better gradation which meant a stronger rubber-cement interface & less pulse velocity loss. Chloride penetrability was also tested by the staining method & it was found that the depth of chloride ion penetration was zero, indicating good resistance against chloride penetration.

Benazzouk et al. studied the physico-mechanical properties & water absorption of cement composite comprising of shredded rubber wastes. The rubber wastes were used as a partial replacement for fine aggregate to induce 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 the addition of every 10% of rubber content, it was observed that entrapped air increased by 3% & dry unit weight decreased by about 200 kg/m3. Naturally, the modulus of elasticity also decreased with an increase in rubber content. Compressive strength decreased by 20-30% for every 10% increase in rubber content. Flexural strength increased up to 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 an increase in rubber content. The study of the stress-strain curve showed that toughness improved in this rubber composite & insulation properties also improved due to entrapped air. The authors also observed satisfactory durability properties & resistance to acid & sulphate attacks in aggressive environments.

2.3 OBSERVATION:

Few observations have been made on the basis of past literature.

- Concrete is a brittle material. By addition of rubber chips, we can improve its ductility and toughness.

- Rubber particle has a negative impact on strength of concrete. But adding pozzolanic materials, silica fume, metakaolin (MK) and other polymer we can recover this strength loss.

- By adding crumb rubber, the durability properties of concrete can be improved.

- Very few studies have been done on the durability properties of rubberized concrete.

2.4 OBJECTIVE OF THE WORK:

Study on strength, durability, and temperature effect on concrete by replacing the coarse aggregate with crumb rubber.

2.5 SCOPE OF WORK:

1. Mix design of concrete as per IS code.
2. Study on strength of concrete by replacing the fine aggregate with crumbed rubber.
3. Study on durability of concrete using crumbed rubber.
4. Study on temperature effect on concrete using crumbed rubber.
5. Study on the impact resistance and stress strain behaviour of rubberized concrete.

CHAPTER -3
EXPERIMENTAL INVESTIGATION

3.1 GENERAL:

First, we collect the materials which are needed to cast rubberized concrete like rubber chips, cement, fine aggregate, coarse aggregate, admixture etc. By trial mixing procedure we have reached our final mix design proportion as per IS 456:2000 and IS 10262:2019. According to the standard test procedure given in the code we have done all the tests.

3.2 MATERIALS:

The details of materials used for our experiments are given below.

Cement: Portland Pozzolana Cement (Fly Ash based) complying with IS:1489-2015 (Part 1)

Table 2: Details of materials.

CHEMICAL REQUIREMENTS	Test Results	Requirements of IS:1489-2015(Part 1)
Insoluble Residue (% by mass)	25.48	X+4*(100-X)/100 (Max) 0.60 X (Min) X = declared % of fly ash
Magnesia (% by mass)	1.04	6.00 (Max)
Sulphuric Anhydride (% by mass)	2.43	3.50 (Max)
Loss on Ignition (% by mass)	1.66	5.00 (Max)
Total Chlorides (% by mass)	0.009	0.10 (Max)
PHYSICAL REQUIREMENTS		
Fineness (m2/kg)	350	300 (Min)
Standard Consistency (%)	30.5	
Initial Setting Time (minutes)	180	30 (Min)
Final Setting Time (minutes)	240	600 (Max)
Soundness: Le-Chatelier exp (mm)	1.0	10.0 (Max)
Soundness: Autoclave exp	0.080	0.8 (Max)
3-d Compressive strength	22	16 (Min)
7-d Compressive strength	34	22 (Min)
28-d Compressive strength	54	33 (Min)
% of fly ash addition	28	15.0 (Min), 35.0 (Max)

Fine Aggregate: Typical river sand was utilized as a fine aggregate (F.A) which had a fineness modulus (F.M) of 2.32, which is belongs to zone III sand (500gm of sample taken), Particle Size Distribution of is given in Table 3.

Table 3: Particle Size Distribution of fine aggregate.

Sieve (mm)	Weight retained (gm)	Cumulative wt. retained (gm)	Cumulative % wt. retained	percentage wt. passing	% passing of Zone-III Sand
4.75	10	10	2	98	90-100
2.36	15	25	5	95	85-100
1.18	25	50	10	90	75-100
0.6	135	185	37	63	60-79
0.3	210	395	79	21	12-40
0.15	100	495	99	1	0-10
Pan	5	500			
	500		232		

Fineness Modulus = 232/100 = 2.32. So, Fine Sand as per IS 383:2016.

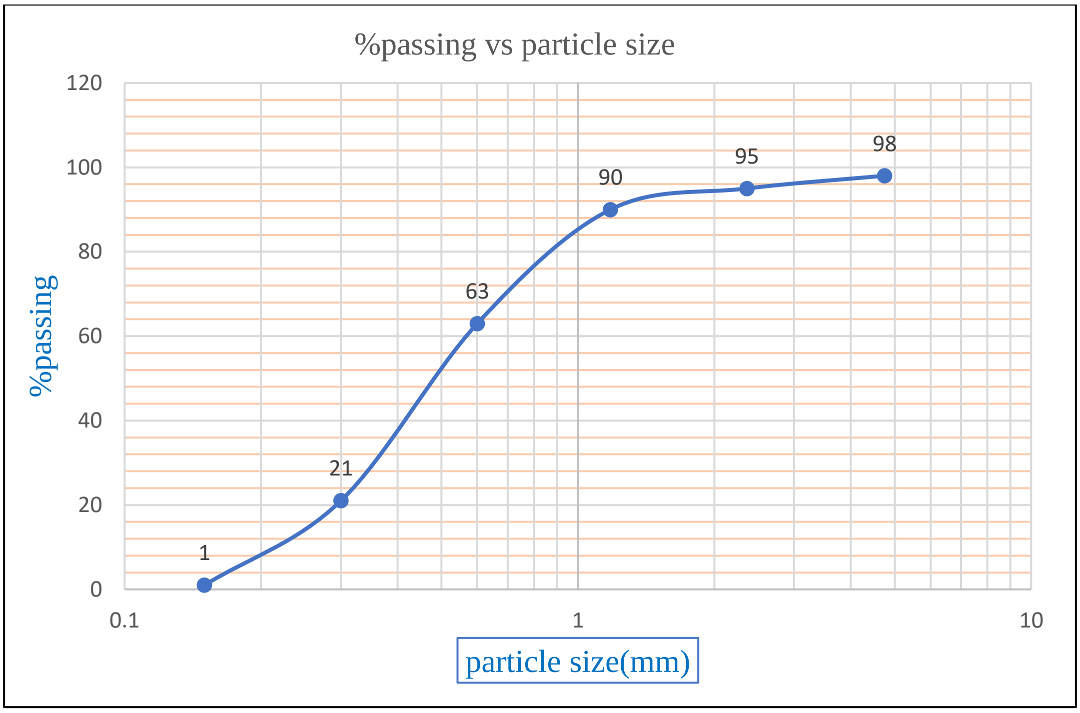

Fig. 1: Particle size distribution curve of fine aggregate curve.

Coarse Aggregate: Coarse aggregates of maximum nominal size 20 mm as per IS 383:2016 and specific gravity 2.87 was used. Sieve analysis of 2000 gm of coarse aggregate was performed using sieve size of 40mm, 20mm, 10mm and 4.75mm, 2.36mm and 1.18 mm. And the following data was obtained.

Table 4: Particle Size Distribution of coarse aggregate.

Sieve (mm)	Weight retained (gm)	Cumulative wt retained (gm)	Cumulative % wt retained	percentage wt. passing	percentage passing of 20mm nominal size
40	0	0	0	100	100
20	185	185	9.25	90.75	90-100
10	1120	1305	65.25	34.75	25-55
4.75	580	1885	94.25	5.75	0-10
2.36	100	1985	99.25	0.75	
1.18	10	1995	99.75	0.25	
Pan	5	2000	100	0	

Rubber chips: Crumbed Rubber particles of average particle size below 4.75 mm, specific gravity 1.25. 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:

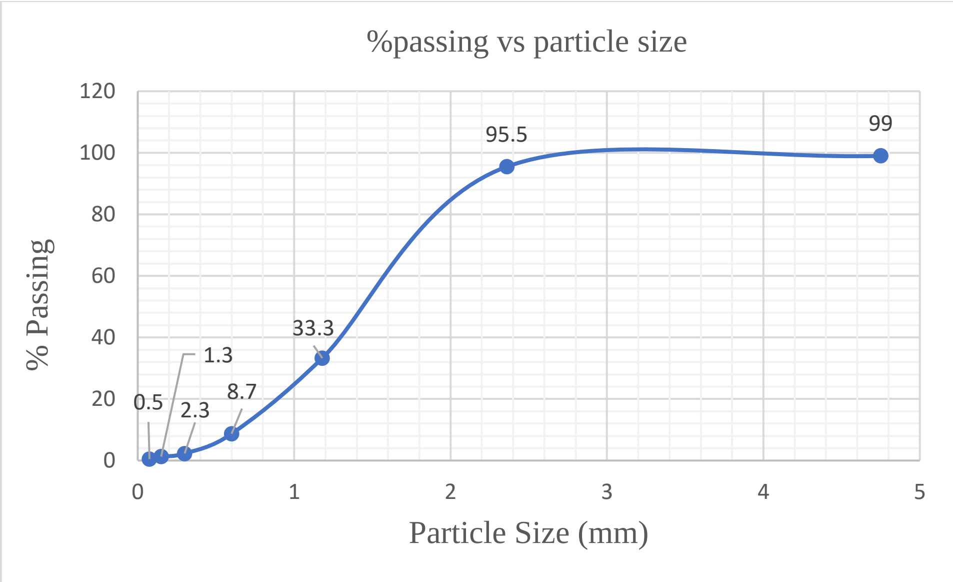

Fig. 2: Particle size distribution curve of crumbed rubber

Table 5: Particle Size Distribution of crumb rubber.

Sieve Size (mm)	Wt retained (gm)	Cumulative wt retained (gm)	Cumulative % wt retained	percentage wt. passing
4.75	10	10	1	99
2.36	35	45	4.5	95.5
1.18	622	667	66.7	33.3
0.6	246	913	91.3	8.7
0.3	64	977	97.7	2.3
0.15	10	987	98.7	1.3
0.075	8	995	99.5	0.5
Pan	5	1000	100	0
	1000			

So as per IS 383: 2016, specification this crumb rubber particles are falling corresponding to grading zone-I.

Fig. 3: Crumb rubber.

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

Dosage – 0.8% by weight of cement.

3.3 SPECIMENS:

In this study, four different concrete mixes, such as 0% (control mix), 5%, 10% and 15%, were prepared following the mix designs as per IS 10262:2019, and IS 456:2000, where conventional fine aggregates were partially replaced by waste tire rubber aggregates as 0%, 5%, 10%, and 15% by weight for all concrete mixes. Tests for harden strength and durability was performed for each mix proportion after 28 days and 90 days to check the performance of the material with respect to time duration. The details of the specimens were casted is given bellow.

Table 6: Details of specimens.

Name of test	**No. of specimens for each mix.**	**Dimension of each specimen**
Compressive Strength Test	6	Cube of 100x100x100mm
Flexural Strength Test	3	Beam of 100x100x500mm
Splitting Tensile Strength Test	3	Cylinder of 150x300mm
Acid test	6	Cube of 100x100x100mm
Temperature effect study	6	Cube of 100x100x100mm
Rapid Chloride Permeability Test	3	Cylinder of 100x200mm
Sorptivity Test	3	Cylinder of 100x200mm
Water absorption	6	Cube of 100x100x100mm
Impact test	3	Cylinder of 100x200mm
Stress strain behaviour study	3	Cylinder of 100x200mm

Fig. 4: Specimens.

3.4 DETAIL MIX DESIGN OF CONCRETE:

Mix Design as per IS 10262:2019 & IS 456:2000:

Type of cement	:	PPC
Maximum Nominal Size of Aggregate:	:	20 mm
Maximum Cement Content:	:	As per IS-456:2000
Maximum W/C Ratio:	:	As per IS-456:2000
Workability:	:	75 mm Slump
Exposure Condition:	:	Moderate
Specific Gravity of Cement:	:	2.90
Specific Gravity of Coarse Aggregate	:	2.75
Specific Gravity of Fine Aggregate	:	2.65
Fine aggregate zone	:	II

Concrete Mix Design (M 25)

- **Target Strength for Mix Proportion:**

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

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

Hence, (i) f'ck = 25 + 1.65 x 4.0 = 31.6

(ii) f'ck= 25 + 5.5 = 30.5

So, f'ck = 31.6 MPa (N / mm2) is adopted.

- **Selection of Water Cement Ratio (W/C):**

From fig. 1 of IS-10262-2019, for Target Strength 31.6 MPa & PPC Cement using Curve 2 the W/C Ratio required: 0.47.

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 0.47

- **Selection of Water Content (W.C):**

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

As per Table 4 of IS 10262-2019 for 20 mm Nominal Maximum Size of aggregate & 50 mm Slump, the Water Content per Cum of Concrete = 186 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 = 186+(75-50)/25*3/100*186 =192 kg of water per Cum of Cement.

As admixture is used water can be reduced by 10%

So, actual water required = 173 kg/m^3.

- **Selection of Cement Content:**

For, W/C Ratio = 0.47, Water Content = 173 kg / Cum

Cement Content = 173 / 0.47 = 368 kg of Cement

Check:

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

Calculated Cement Content (368) > Required Cement Content (300)
Cement Content of 368 kg / Cum of Concrete is adopted.

- **Determination of Air Content:**

As per Cl. 5.2, Table 3 of IS-10262-2019, Entrapped Air Content for 20 mm Nominal Maximum Size of aggregate is = 1% of Volume of Concrete

- **Estimation of Proportion of Volume of Coarse & Fine Aggregate (CA & FA):**

From Table 5 of IS-10262-2019 for W/C Ratio 0.5 and 20mm Nominal Maximum Size of Aggregate and Zone-II Sand, Volume of Coarse aggregate per Total Volume of Aggregate = 0.62

But the adopted W/C Ratio is 0.47

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 x (0.50-0.47)/0.05 = 0.626

Hence Adopted Ratio of CA = 0.626.

- **Mix Calculation:**

Volume of Concrete (M 25) = 1 Cum

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

(ii) Volume of Cement in Wet Concrete (b) = (Mass of Cement) / (Sp. Gr. Of Cement) x 1/1000 = 368 /2.90 x 1/1000 = 0.1269 Cum

(iii) Volume of Water in Wet Concrete (c) = (Mass of Water) / (Sp. Gr. Of Water) x 1/1000 = 173 /1 x 1/1000 = 0.173 Cum

(iv) Volume of Aggregate in Wet Concrete (d) = (a-b-c) = (1-0.01-0.1269-0.173) Cum = 0.6875 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 = 0.6875 x 0.626 x 2.75 x 1000 kg = 1184 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 = 0.6875 x (1-0.626) x 2.65 x 1000 kg = 681.48 kg

- **Mix Proportion:**

Cement: FA: CA = 368: 681.48: 1184 = 1: 1.85: 3.22 and the W/C = 0.47

Table 7: Mix proportion

Materials	**Mix proportion per $1m^3$ (in kg)**
Cement	368
Water	173
FA	681.48
CA	1184

9. Compressive Strength Results:

Table 8: Compressive strength test results

7 days compressive strength (MPa)	**28 days compressive strength (MPa)**
19	29.8
20.5	32.4
22.7	31.1

3.5 SUMMARY OF MIX PROPORTIONS FOR RUBBERIZED CONCRETE:

Per 1 m^3 of concrete.

Table 9: Final mix design.

CONTROL MIX NAME	Cement (kg)	Water (kg)	FA (kg)	CA (kg)	Rubber Chip Coarse (kg)
M25	368	173	681.48	1184	0
M25 + 5% RUBBER	368	173	647.41	1184	34.074
M25 + 10% RUBBER	368	173	613.33	1184	68.148
M25 + 15% RUBBER	368	173	579.26	1184	102.22

3.6 EXPERIMENTAL PROGRAMME:

Tests to be performed:

- Compressive strength test as per IS 516-1959
- Split tensile strength test as per IS 5816-1959
- Flexural tensile strength test as per IS 516-1959
- Impact test according to ACI Committee 544.
- Stress strain behaviour study as per ASTM C469.
- water absorption and sorptivity test as per ASTM C1585:200
- Sulphate attack test as per ASTM C1898
- Rapid chloride penetration test as per ASTM C1202
- Study on Temperature effect.

3.6.1 Compressive Strength Test:

About: One of the important properties of concrete is its strength in compression. The strength in compression has a definite relationship with all other properties of concrete i.e. these properties improved with the improvement in compressive strength. Thus, with this single test one judge that whether Concreting has been done properly or not. In India cubical moulds of size 15 cm × 15 cm × 15 cm are commonly used. But in our case, we take 10cm × 10cm × 10 cm moulds (as per IS 516 :1959).

Objective: To determine the cube strength of the concrete of given properties.

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

Apparatus: Moulds for the test cubes, tamping rod, metallic sheet, compressive testing machine.

Material: Cement, sand, aggregate and water, grease.

Procedure:

1. Calculate the material required for preparing the concrete of given proportions.
2. Mix them thoroughly in mechanical mixer until uniform colour of concrete is obtained.
3. Pour concrete in the lightly greased cube moulds.
4. Fill concrete in two layers each of approximately 75 mm and ramming each layer with 35 blows evenly distributed over the surface of layer.
5. Struck off concrete flush with the top of the moulds.
6. Level the concrete at the top of the mould by means of trowel and give proper identification mark of the specimen.
7. Immediately after being made, they should be covered with wet mats.
8. Specimens are removed from the moulds after 24hrs and cured in water. Keep it for curing up to 28 days.
9. Take the cube out of water at the end of 28 days with dry cloth. Measure the dimensions of the surface in which the load is to be applied. Let be 'L' and 'B' respectively.
10. Place the cube in compressive testing machine and apply the load uniformly at the rate of 35N/mm2.
11. Note the load at which the cube fails. Let it be 'P'. Also note the type of failure and appearance of cracks.

12. Calculate the compressive strength of the cube by using formula P/A. Where A is the area of loaded surface (i.e. L×B).
13. Repeat the same procedure (steps 9 to 12) for other two cubes.
14. Repeat the whole procedure (Step 9 to 13) to find the compressive strength of the cube at the end of 7 days and 28 days.

Compressive Strength (N/mm^2) = P/A

Where,

P = Failure load of cube (N). A = Area of cube (100 *100) (mm^2).

Fig.5: Compression testing machine.

3.6.2 Flexural Tensile Strength Test:

About: Flexural strength is a measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam to resist failure in bending. It is measured by loading 150 x 150 mm concrete beams with a span length of 700 mm. This test is performed by three-point loading experiment. The Third point loading test applies the forces at the 1/3 and 2/3 points equally from the top side by distributing a single centred force through a steel beam to two points rather than one. The beam is supported at two points from below near the ends. The bending moment is lower in a third point test than in a centre point test. in our case mould is 100mm × 100mm × 500mm.

Objective: To determine flexural strength of cubic concrete specimens.

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

Apparatus: Flexural testing beam moulds, tamping rod, metallic sheet, universal testing machine.

Material: Cement, sand, aggregate and water, grease.

Procedure:

1. Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.

2. The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.

3. The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.

4. The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.

5. The standard size shall be 15 × 15 × 70 cm. Alternatively, if the largest nominal size of the aggregate does not exceed 19 mm, specimens 10 × 10 × 50 cm may be used.

6. The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.

7. The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients. Then immersed in water for 28 days.

8. The bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are at contact with the rollers.

9. The specimen shall then be placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mould, along two lines spaced 20.0 or 13.3 cm apart.

10. The axis of the specimen shall be carefully aligned with the axis of the loading device. No packing shall be used between the bearing surfaces of the specimen and the rollers.

11. The load shall be applied without shock and increasing continuously at a rate such that the extreme fibre stress increases at approximately 7 kg/ cm^2/min, that is, at a rate of loading of 400 kg/min for the 15.0 cm specimens and at a rate of 180 kg/min for the 10.0 cm specimens.

12. The load shall be increased until the specimen fails, and the maximum load applied to the specimen during the test shall be recorded. The appearance of the fractured faces of concrete and any unusual features in the type of failure shall be noted.

Flexural Strength (N/mm^2) = $PL/(B*D^2)$

where,

P = Failure Load of Beam(N). L = Clear Span of Beam (400 mm)

b = Width of Beam (100 mm) d = Depth of Specimen (100 mm)

Fig.6: Flexural strength testing.

3.6.3 Split Tensile Strength Test:

About: Splitting tensile strength is generally greater than the direct tensile strength and lower than the flexural strength (modulus of rupture). Splitting tensile strength is used in the design of structural light weight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of the reinforcement.

Objective: To determine splitting tensile strength of cylindrical concrete specimens.
Reference: IS: 5816 - 1999, IS: 1199-1959, SP: 23-1982, IS: 10086-1982.

Apparatus: Cylindrical mould confirming to IS: 10086-1982 for splitting tensile strength, tamping rod, metallic sheet, universal testing machine.

Material: Cement, sand, aggregate and water, grease.

Procedure:

1. Samples of aggregates for each batch of concrete shall be of the desired grading and shall be in an air-dried condition. The cement samples, on arrival at the laboratory, shall be thoroughly mixed dry either by hand or in a suitable mixer in such a manner as to ensure the greatest possible blending and uniformity in the material.
2. The proportions of the materials, including water, in concrete mixes used for determining the suitability of the materials available, shall be similar in all respects to those to be employed in the work.
3. The quantities of cement, each size of aggregate, and water for each batch shall be determined by weight, to an accuracy of 0.1 percent of the total weight of the batch.
4. The concrete shall be mixed by hand, or preferably, in a laboratory batch mixer, in such a manner as to avoid loss of water or other materials. Each batch of concrete shall be of such a size as to leave about 10 percent excess after moulding the desired number of test specimens.
5. The cylindrical mould shall be of 150 mm diameter and 300 mm height conforming to IS: 10086-1982.
6. The test specimens shall be made as soon as practicable after mixing, and in such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance.
7. The test specimens shall be stored in a place, free from vibration, in moist air of at least 90 percent relative humidity and at a temperature of 27° ± 2°C for 24 hours ± ½ hour from the time of addition of water to the dry ingredients. Then immersed in water for 28 days.
8. The bearing surfaces of the supporting and loading rollers shall be wiped clean, and any loose sand or other material removed from the surfaces of the specimen where they are to make contact with the rollers.

9. Two bearings strips of nominal (1/8 in i.e. 3.175mm) thick plywood, free of imperfections, approximately (25mm) wide, and of length equal to or slightly longer than that of the specimen should be provided for each specimen.

10. The bearing strips are placed between the specimen and both upper and lower bearing blocks of the testing machine or between the specimen and the supplemental bars or plates.

11. Draw diametric lines on each end of the specimen using a suitable device that will ensure that they are in the same axial plane. Canter one of the plywood strips along the centre of the lower bearing block.

12. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centred over the plywood strip.

13. Place a second plywood strip lengthwise on the cylinder, centred on the lines marked on the ends of the cylinder. Apply the load continuously and without shock, at a constant rate within, the range of 689 to 1380 kPa/min splitting tensile stress until failure of the specimen.

14. Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and appearance of fracture.

Split Tensile Strength (N/mm^2) = $2P/(\pi * L * d)$

Where

P = Failure load of cylinder (N)

L = Height of Specimen (300 mm)

d = Diameter of Specimen (150 mm)

Fig.7: Testing of split tensile strength.

3.6.4 Sorptivity Test:

About: This test method is used to determine the rate of absorption (sorptivity) of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water.

Apparatus:

- Pan, a watertight polyethylene, or other corrosion resistant pan large enough to accommodate the test specimens with the surfaces to be tested exposed to water.
- Support Device, rods, pins, or other devices, which are made of materials resistant to corrosion by water or alkaline solutions.
- Top-pan Balance, complying with Specification C 1005 and with sufficient capacity for the test specimens and accurate to at least 0.01 g.
- Timing Device, stopwatch, or other suitable timing device accurate to 1 s.
- Paper Towel or Cloth, for wiping excess water from specimen surfaces.

- Water-Cooled Saw, with diamond impregnated blade to cut test specimens from larger samples.
- Environmental Chamber, a chamber allowing for air circulation and able to maintain a temperature of 50 °C and a relative humidity at 80 %.
- Polyethylene Storage Containers, with sealable lids, large enough to contain at least one test specimen but not larger than 5 times the specimen volume.
- Calliper, to measure the specimen dimensions to the nearest 0.1 mm.

Procedure:

1. The standard test specimen is a 100 mm diameter disc, with a length of 50 mm. Specimens are obtained from either moulded cylinder according to Practices C 31/C 31M or C 192/C 192M or drilled cores according to Test Method C 42/C 42M. The cross-sectional area of a specimen shall not
   vary more than 1 % from the top to the bottom of the specimen.
2. Place test specimens in the environmental chamber at a temperature of 50 °C and RH (relative humidity) of 80 % for 3 days.
3. After the 3 days, place each specimen inside a sealable container. Use a separate container for each specimen.
4. Store the container at 23°C for at least 15 days before the start of the absorption procedure.
5. Remove the specimen from the storage container and record the mass of the conditioned specimen to the nearest 0.01 g before sealing of side surfaces.
6. Measure at least four diameters of the specimen at the surface to be exposed to water. Measure the diameters to the nearest 0.1 mm and calculate the average diameter to the nearest 0.1 mm.
7. Seal the side surface of each specimen with a suitable sealing material. Seal the end of the specimen that will not be exposed to water using a loosely attached plastic sheet. The plastic sheet can be secured using an elastic band or other equivalent system.
8. Use the procedure below to determine water absorption as a function of time. Conduct the absorption procedure at 23°C with tap water conditioned to the same temperature.
9. Measure the mass of the sealed specimen to the nearest 0.01 g and record it as the initial mass for water absorption calculations.

10. Place the support device at the bottom of the pan and fill the pan with tap water so that the water level is 1 to 3 mm above the top of the support device. Maintain the water level 1 to 3 mm above the top of the support device for the duration of the tests.
11. Start the timing device and immediately place the test surface of the specimen on the support device. Record the time and date of initial contact with water.
12. Record the mass at the intervals after first contact with water. The first point shall be at 1min and the second point at 5 min. Subsequent measurements shall be within 10 min, 20 min, 30 min, and 60 min. The actual time shall be recorded within 10 s. Continue the measurements every hour, up to 6 h, from the first contact of the specimen with water and record the time within 1 min. After the initial 6 h, take measurements once a day up to 3 days, followed by 3 measurements at least 24 h apart during days 4 to 7; take a final measurement that is at least 24 h after the measurement at 7 days. The actual time of measurements shall be recorded within 1 min.

The absorption, I, is the change in mass divided by the product of the cross-sectional area of the test specimen and the density of water. For this test, the temperature dependence of the density of water is neglected and a value of 0.001 g/mm^3 is used. The units of I are mm.

$I = m_t /(a*d)$

where:

I = the absorption,

m_t = the change in specimen mass in grams, at the time t,

a = the exposed area of the specimen, in mm^2, and

d = the density of the water in g/mm^3

The initial rate of water absorption ($mm/s^{1/2}$) is defined as the slope of the line that is the best fit to, I plotted against the square root of time ($s^{1/2}$).

Fig.8: Sorptivity test

3.6.5 Water Absorption:

The water absorption test was performed similarly by the concrete discs of 50 mm thickness and 100 mm diameter extracted from cylindrical specimens (100 mm diameter × 200 mm length) to determine the water absorption at 28, and 90 days. Initially, specimens were oven dried for 48 h at 100 ± 5 ◦C and left at room temperature for cooling. Then take the weight as dry weight, Afterward, concrete discs were immersed in water for 30 min and 72 h to determine the initial and final weight of the samples, respectively. The following equation (Eqn. 5) was used to calculate the water absorption rate, w_r

$$W_r = \frac{Sd - Od}{Sd} \text{ X } 100\%$$

where, S_d = mass of dry surface specimens in the saturated condition at 30 min and 72 h,

O_d = mass of the oven-dried specimens.

3.6.6 Sulphate Attack:

About: These test methods are intended to evaluate the chemical resistance of cement paste, mortar and concrete materials. These test methods provide for the determination of changes in the following properties of the test specimens and test medium after exposure of the specimens to the medium:

1 Mass of specimen,

2 Appearance of specimen,

3 Appearance of test medium, and

4 Strength of specimens.

Apparatus:

- Equipment, capable of weighing materials or specimens to 60.3 % accuracy.
- Equipment for Mixing, consisting of a container of suitable size, preferably made of corrosion-resistant metal, or a porcelain pan, and a strong, sturdy spatula or trowel.
- Micrometre, suitable for accurate measurement to 0.03 mm (0.001 in.).
- Containers: Wide-Mouth Glass Jars, of sufficient capacity, fitted with plastic or plastic-lined metal screw caps for low temperature tests involving media of low volatility.
- Testing Machine—compression testing machine.
- Equipment—A benchtop pH meter with an accuracy of 0.01.

Test sample:

- The standard test specimen of 10cm × 10cm × 10cm cubes are used.
- After 24 hours of casting the specimens are immersed in water for curing.
- After 28 days of curing the specimens are taken off and rest in room temperature for 24 hours.
- Then specimens are put into a solution of a sulfuric acid concentration resulting in a pH of 0.50. pH of the test Media shall be prepared to 0.03.

Procedure:

1. Immediately following the conditioning period, measure the cross-sectional dimensions of all test specimens to the nearest 250 μm (0.01 in.) using a micrometre. Take two measurements for each dimension at mid-height and perpendicular to the load axis and average them.

2. record the mass of all the specimens to the nearest 0.001 g on an analytical balance and record the values. Prior to immersion, record a brief description of the colour and surface appearance of the specimens and the colour and clarity of the test medium.
3. Then specimens are put into a solution of a sulfuric acid concentration resulting in a pH of 0.50. pH of the test Media shall be prepared to 0.03(N).
4. Examine the specimens after 1, 7, 14, 28, 56, and 84 days of immersion to determine the rate of attack. The solution shall be replaced every 7 days.
5. At specified interval the samples shall be removed from their respective containers and brushed with a stiff-bristle plastic brush to remove loose material.
6. Clean the specimens by three quick rinses in running cold tap water and quick dry by blotting with a paper towel between each rinse. For each test specimen prepared after final blotting, allow the specimen to dry for 1⁄2 h before massing. Mass all specimens to the nearest 0.001 g.
7. Measure the dimensions of the surface by micrometre in which the load is to be applied. Let be 'L' and 'B' respectively.
8. Place the cube in compressive testing machine and apply the load uniformly at the rate of 35N/mm2.
9. Note the load at which the cube fails. Let it be 'P'. Also note the type of failure and appearance of cracks.
10. Calculate the compressive strength of the cube by using formula P/A. Where A is the area of loaded surface (i.e. L×B).

Compressive Strength (N/mm^2) = P/A

Where,

P = Failure load of cube (N)

A = Area of cube (100 *100) (mm^2).

Fig.9: Sulphate resistance test

3.6.7 Rapid Chloride Penetration Test (RCPT):

About: This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test method consists of monitoring the amount of electrical current passed through 50-mm thick slices of 100-mm nominal diameter cores or cylinders during a 6-h period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

Apparatus: Vacuum Saturation Apparatus

- Separatory Funnel, or other sealable, bottom-draining container with a minimum capacity of 500 ml.
- Beaker (1000 mL or larger) or other container— Capable of holding concrete specimen(s) and water and of fitting into vacuum desiccator.

- Vacuum Desiccator—250-mm inside diameter or larger. Desiccator must allow two hose connections through a rubber stopper and sleeve or through a rubber stopper only. Each connection must be equipped with a stopcock.
- Coating—Rapid setting, electrically nonconductive, capable of sealing side surface of concrete cores.
- Balance or Scale, Paper Cups, Wooden Spatulas, and Disposable Brushes—For mixing and applying coating.
- Specimen Sizing Equipment (not required if samples are cast to final specimen size).
- Movable Bed Water-Cooled Diamond Saw or Silicon Carbide Saw.
- Sodium Chloride Solution—3.0 % by mass (reagent grade) in distilled water. Sodium Hydroxide Solution—0.3 N (reagent grade) in distilled water.

Test sample:

- Sample preparation and selection depends on the purpose of the test. For evaluation of materials or their proportions, samples may be (*a*) cores from test slabs or from large diameter cylinders or (*b*) 100-mm diameter cast cylinders.
- Transport the cores to the laboratory in sealed (tied) plastic bags. If specimens be shipped, they should be packed to be properly protected from freezing and from damage in transit or storage.
- Using the water-cooled diamond saw or silicon carbide saw, cut a 50mm slice from the top of the core or cylinder, with the cut parallel to the top of the core. This slice will be the test specimen. Use a belt sander to remove any burrs on the end of the specimen.
- Special processing is necessary for core samples where the surface has been modified, for example, by texturing or by applying curing compounds, sealers, or other surface treatments, and where the intent of the test is not to include the effect of the modifications. In those cases, the modified portion of the core shall be removed, and the adjacent 50 mm slice shall be used for the test.

Procedure:

1. Remove specimen from water, blot off excess water, and transfer specimen to a sealed can or other container which will maintain the specimen in 95 % or higher relative humidity.

2. Specimen mounting (rubber gasket alternative): Place a 100 mm outside diameter by 75 mm inside diameter by 6 mm thick circular vulcanized rubber gasket in each half of the test cell. Insert sample and clamp the two halves of the test cell together to seal.
3. Fill the side of the cell containing the top surface of the specimen with 3.0 % NaCl solution. (That side of the cell will be connected to the negative terminal of the power supply) Fill the other side of the cell (which will be connected to the positive terminal of the power supply) with 0.3 N NaOH solution.
4. Attach lead wires to cell banana posts. Make electrical connections to voltage application and data readout apparatus as appropriate; for example, connect as shown in Fig. 3.9. Turn power supply on, set to 60 V, and record initial current reading.
5. Temperatures of the specimen applied voltage cell, and solutions shall be 20 to 25 °C at the time the test is initiated, that is, when the power supply is turned on.
6. Read and record current at least every 30 min. If a voltmeter is being used in combination with a shunt resistor for the current reading (see Fig. 6), use appropriate scale factors to convert voltage reading to amperes. Each half of the test cell must remain filled with the appropriate solution for the entire period of the test. Terminate test after 6 h.
7. Remove specimen. Rinse cell thoroughly in tap water; strip out and discard residual sealant.

Calculation:

Plot current (in amperes) versus time (in seconds). Draw a smooth curve through the data and integrate the area underneath the curve in order to obtain the ampere-seconds, or coulombs, of charge passed during the 6-h test period.

Fig.10: Rapid chloride penetration test

3.6.8 Temperature Resistance:

According to the test procedure described by Nouran Yasser in his journal "Experimental investigation of durability properties of rubberized Concrete" we did this fire resistance study. For performing the fire tests, an electric oven with a thermostat which can attain a maximum temperature of 400° C and a control switch, was used. The used furnace could achieve a high heating rate speed that is somewhat like actual fire conditions. The dimensions of the oven hole were 520*520*300 mm, provided with insulator material and the outer body is stiff steel. To examine the sensitivity of studied mixes to temperatures effect, we exposed 100*100*100 cubes to a temperature of 200° C. We avoided going beyond 200° C because the portlandite starts to decompose at about 450° C, the sand aggregates at about 570° C and $Ca(OH)_2$ at about 600°C. In this case, we have 4 materials decompose at the same time, so it is very difficult to separate the rubber aggregates effect alone beyond 400° C. 12 specimens (3 for without rubber,3of 5% rubber replacement,3 of 10% rubber replacement, 3of 15% rubber replacement) were divided into 4 groups and subjected to 2 temperature exposure conditions after 28 days (200° C for 24 hours and 200° C for 48 hours) in an electrical furnace. In the furnace, the specimens were heated from the room temperature to the prescribed temperatures. The specimens were carefully cooled inside the oven until temperatures dropped to roughly 50^0 C.

The oven door was then opened, and all specimens were transferred to the lab until the compressive strength test was performed.

Fig. 11: Temperature effect study

3.6.9 Impact Resistance by Drop-Weight Test:

According to ACI Committee 544, the drop-weight test is done to evaluate the potential energy absorption for concrete cylinder samples (152 mm and 65 mm) diameter and depth respectively, three samples were evaluated for each blend. The number of blows was calculated after a fall of steel hammer sphere was repeatedly dropped on the sample from a given height to obtain the appropriate grade of failure (as well as first and failure crack). Fig. 3.11 depicts the test unit, which consists of a 3.5 kg hammer sphere dropping from a height of 730 mm onto a heavy steel sphere with a diameter of 65 mm. The following Eqn. (i) and (j) in joule (J) were used to compute the impact resistance at the first crack (Ei) and the final crack (Eu).

$$Ei = N1mgh \quad \text{i.}$$

$$Eu = N2mgh \quad \text{j.}$$

Where (m) is the fall hammer's mass in (kg), (g) is the gravitational acceleration (9.81 m/s2), and (h) is the releasing height of the fall hammer in (m), (N1) the number of impacts on first visible crack, (N2) blows amount that caused cracks to be visible and large.

Fig.12: Impact test by drop hammer.

3.6.10 Determination of Stress strain behaviour:

About: This test method provides a stress to strain ratio value and a ratio of lateral to longitudinal strain for hardened concrete at whatever age and curing conditions may be designated.

Apparatus:

- Testing Machine—Use a testing machine capable of imposing a load at the rate and of the magnitude prescribed.
- Compressometer—For determining the modulus of elasticity use a bonded or unbonded sensing device that measures to the nearest 5 millionths the average deformation of two diametrically opposite gage lines, each parallel to the axis, and each cantered about mid height of the specimen. The effective length of each gage line shall be not less than

three times the maximum size of the aggregate in the concrete nor more than two thirds the height of the specimen; the preferred length of the gage line is one half the height of the specimen. Either use gage points embedded in or cemented to the specimen and read deformation of the two lines independently.

- Balance or Scale, accurate to 0.1 lb (0.045 kg) shall be used if necessary.

Test specimen:

- Moulded Cylindrical Specimens—Mold test cylinders in accordance with the requirements for compression test specimens in Practice C 192/C 192M, or in Practice C 31/C 31M. Subject specimens to the specified curing conditions and test at the age for which the elasticity information is desired.
- Test specimens within 1 h after removal from the curing or storage room. Specimens removed from a moist room for test shall be kept moist by a wet cloth covering during the interval between removal and test.
- Measure the diameter of the test specimen by calliper to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other near the centre of the length of the specimen. Use this average diameter to calculate the cross-sectional area.
- Measure and report the length of a moulded specimen, including caps, to the nearest 0.1 in. (2.54 mm). Measure the length of a drilled specimen in accordance with Test Method C 174/C 174M; report the length, including caps, to the nearest 0.1 in. (2.54 mm).

Procedure:

1. Maintain the ambient temperature and humidity as constant as possible throughout the test. Record any unusual fluctuation in temperature or humidity in the report.
2. Use companion specimens to determine the compressive strength in accordance with Test Method C 39/C 39M prior to the test for modulus of elasticity.
3. Place the specimen, with the strain-measuring equipment attached, on the lower platen or bearing block of the testing machine. Carefully align the axis of the specimen with the centre of thrust of the spherically seated upper bearing block. Note the reading on the strain indicators. As the spherically seated block is brought slowly to bear upon the

specimen, rotate the movable portion of the block gently by hand so that uniform seating is obtained.

4. Load the specimen at least twice. Do not record any data during the first loading. Base calculations on the average of the results of the subsequent loadings During the first loading, which is primarily for the seating of the gages, observe the performance of the gages and correct any unusual behaviour prior to the second loading.
5. Obtain each set of readings as follows: Apply the load continuously and without shock. Set testing machines of the screw type so that the moving head travels at a rate of about 0.05 in. (1.25 mm)/min when the machine is running idle. In hydraulically operated machines, apply the load at a constant rate within the range 35 psi (241 kPa)/s. Record, without interruption of loading, the applied load and longitudinal strain at the point (*1*) when the longitudinal strain is 50 millionths and (*2*) when the applied load is equal to 40 % of the ultimate load.
6. Longitudinal strain is defined as the total longitudinal deformation divided by the effective gage length. If a stress-strain curve is to be determined, take readings at two or more intermediate points without interruption of loading; or use an instrument that makes a continuous record. Immediately upon reaching the maximum load, except on the final loading, reduce the load to zero at the same rate at which it was applied.
7. If intermediate readings are taken, plot the results of each of the three tests with the longitudinal strain as the abscissa and the compressive stress as the ordinate.

CHAPTER -4

RESULT AND DISCUSSION

4.1 GENERAL:

All tests were conducted at the concrete laboratory of civil engineering department, Jadavpur university, Kolkata.

4.2 TEST RESULTS AND DISCUSSIONS:

In the present section of work, all the experimental results on the behaviour of rubberized concrete are presented.

4.2.1 Compressive Strength Test:

The compressive strength values after 28 and 90 days of curing for different concrete mixes are shown in Fig. 14. Rubberized concrete specimens exhibited a gradual loss in the compressive strength with increase in the rubber percentage. The 28-day compressive strength for control mix was 31.1 MPa. Adding rubber with 5%, 10%, and 15% in the mixture reduced 28-day compressive strength by 0.32%, 26%, and 37.62%. The 90-day compressive strength for control mix was 35.4 MPa, with reductions of 0.57%, 12.43%, and 32.97% of strength for rubber replacements ratio of 5%, 10%, and 15%, respectively. So, we can see almost negligible loss of compressive strength up to 5% replacement of rubber.

A variety of reasons might contribute to the decline in compressive strength. The fast formation of cracks around rubber particles could be due to the elastically deformable nature of rubber particles. During loading process, quick failure happens because the rubber particles are much softer and elastic than the hard cement paste. Moreover, the smooth surface of rubber results in poor adhesion with cement paste. Yasser et al**.** (2023) and Grdic et al. (2013) found that at 28 days, the compressive strength decreased by 36 to 70 % depending on the granulated rubber content.

Fig.13: Compression test on cube specimen

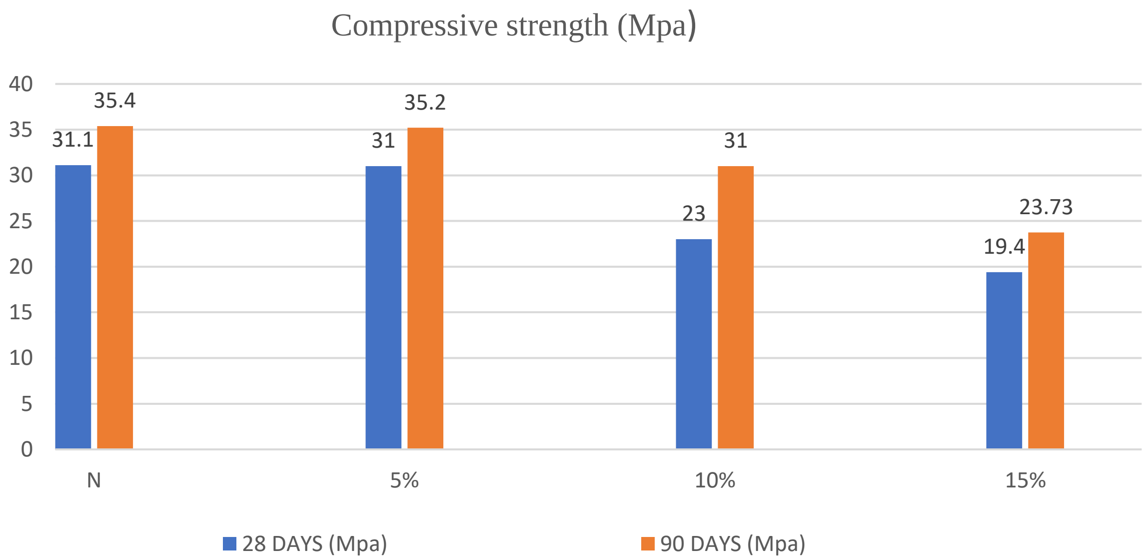

Fig.14: Compressive strength values of different mixes

4.2.2 Flexural Tensile Strength:

The flexural strength values after 28 days of curing for different concrete mixes are shown in Fig. 15. Rubberized concrete specimens exhibited a gradual loss in the flexural strength with increase in the rubber percentage. Adding rubber with 5%, 10%, and 15% in the mixture reduced 28-day flexural strength by 3.32%, 20.35%, and 24.78% as compared to control mix. Where the control mix showed a flexural strength of 4.52 Mpa after 28 days. Many researchers are found the similar trend of reduction in flexural strength by adding rubber particle. Grdic et al. (2011) Li et. al(2009) found that the tensile strength was reduced by 34.6%, 23%, and 35.5% with increasing CR (crumb rubber) content from 0% to 10%, 20% and 30% which can be rectified up to some extent by adding steel fibre, metakaolin and other such fibres with rubber chips. The reduction in flexural strength is due to poor bonding between paste and CR particles and the lower modulus of elasticity of the rubber particles as compared to conventional mineral aggregates. The rubber mortar had its mechanical strength reduced, but still meets the strength requirement for light concrete of moderate strength. It was also noted that replacement of sand with rubber changed the failure mode from brittle to ductile and is suitable for brick/block manufacturing.

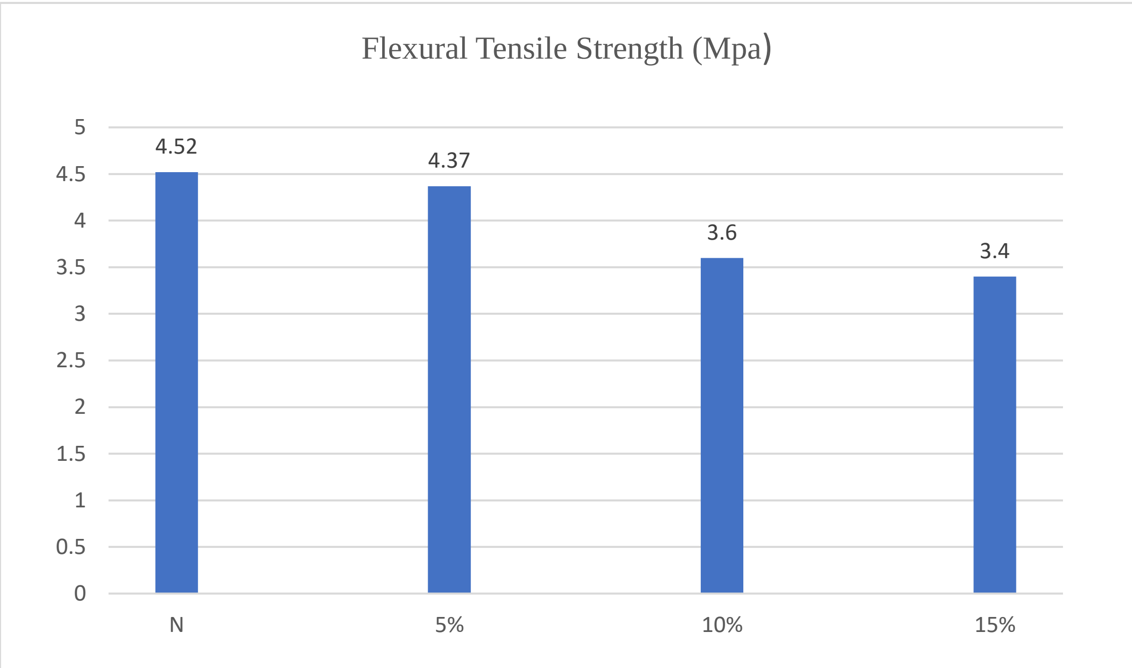

Fig.15: Flexural strength values of different concrete mixes

Fig.16: Flexural tensile test on beam specimen

4.2.3 Split Tensile Strength:

The split tensile strength values after 28 days of curing for different concrete mixes are shown in Fig. 18. As compressive and flexural strength Rubberized concrete specimens exhibited a gradual loss in the split tensile strength with increase in the rubber percentage. Adding rubber with 5%, 10%, and 15% in the mixture reduced 28-day split tensile strength by 8.56%, 14.26%, and 42.83% as compared to control mix Where the control mix showed a split tensile strength of 2.475 Mpa after 28 days. Many researchers are found the similar trend of reduction in split tensile strength by adding rubber particle**.** Beiram and Al-Mutairee (2022) and Khaled and Al-Sodani (2022) found that at 30% replacement splitting tensile strength reduced by 35.34% which can be rectified up to some extent by adding steel fibre, metakaolin and other such fibres with rubber chips. The reduction in split strength is due to poor bonding between paste and CR particles and the lower modulus of elasticity of the rubber particles as compared to conventional mineral aggregates. The rubber mortar had its mechanical strength reduced, but still meets the strength requirement for light concrete of moderate strength. It was also noted that replacement of sand with rubber changed the failure mode from brittle to ductile and is suitable for brick/block manufacturing.

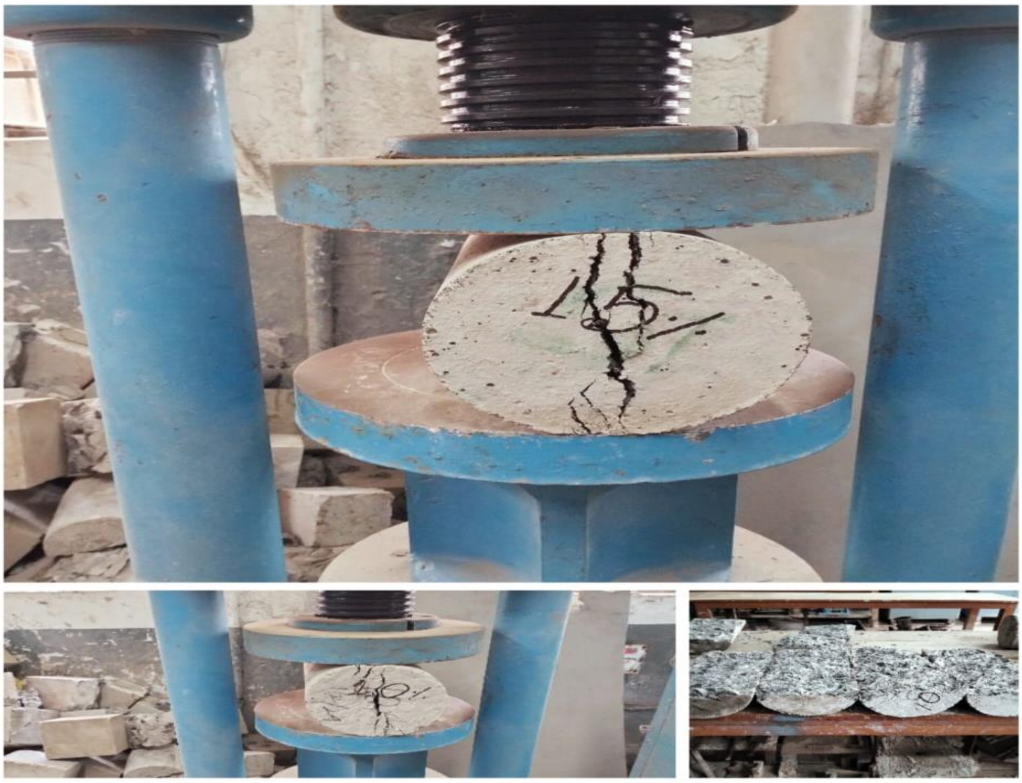

Fig.17: Split tensile test on cylinder.

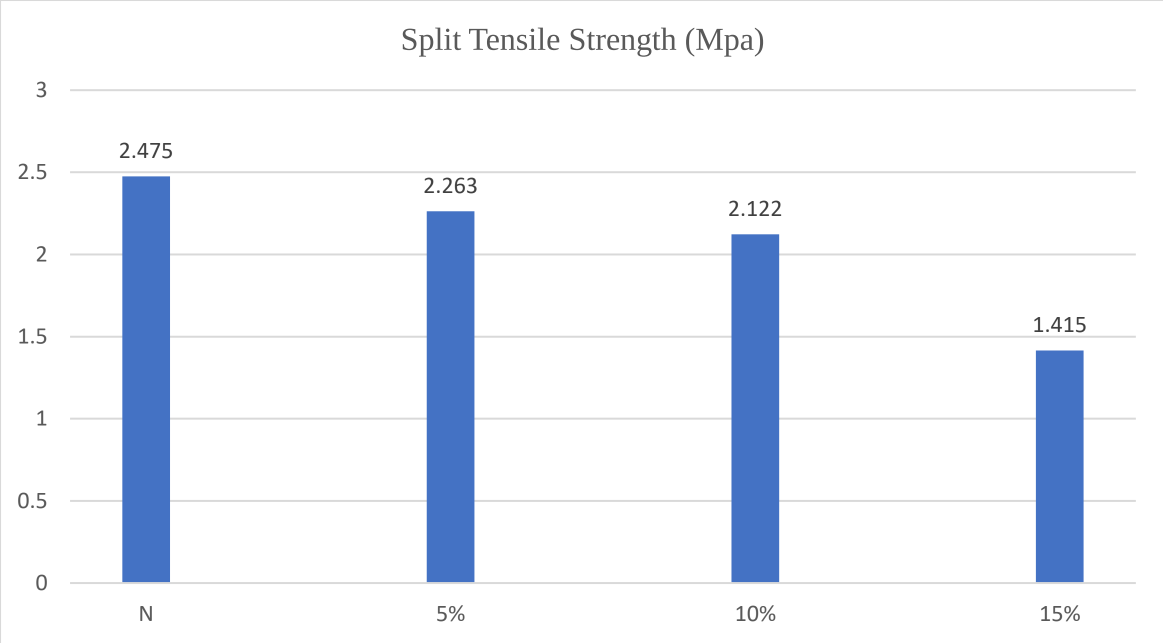

Fig.18: Split tensile strength values of different concrete mixes.

4.2.4 Water Absorption:

Water absorption is considered a major aspect of quantifying the durability properties of concrete. In fact, the durability of concrete materials crucially depends on transport properties, and water absorption is one of the foremost mechanisms controlling transport properties. In this study, water absorption was measured by immersion to interpret the porosity and permeability of normal and RC (Rubberized Concrete) samples. Replacing natural fine aggregates with rubber aggregates has a minor influence on the water absorption percentage in concrete as shown in Fig. 19. After 28 days of curing the control specimen had a maximum water absorption of 1.68%, then it decreased to 1.52% at 5% rubber content, further it decreased to1.46% and 1.37% at 10% and 15% rubber content respectively. After 90daysthe specimen also shown a similar reduction in water absorption with increase in rubber percentage. The control specimen showed a maximum water absorption of 1.44%, then it decreased to 1.42% at 5% rubber content, further it decreased to1.33% and 1.18% at 10% and 15% rubber content respectively. The decrease in water absorption may be due to the nature Rubber from waste tires is water insolvable in nature (non-polar), and their low absorption and high hydrophobicity. Similar findings have been reported by other researchers**.** Gupta et al. (2016) and Medine et al. (2018) also find the similar trend of reduction in water absorption.

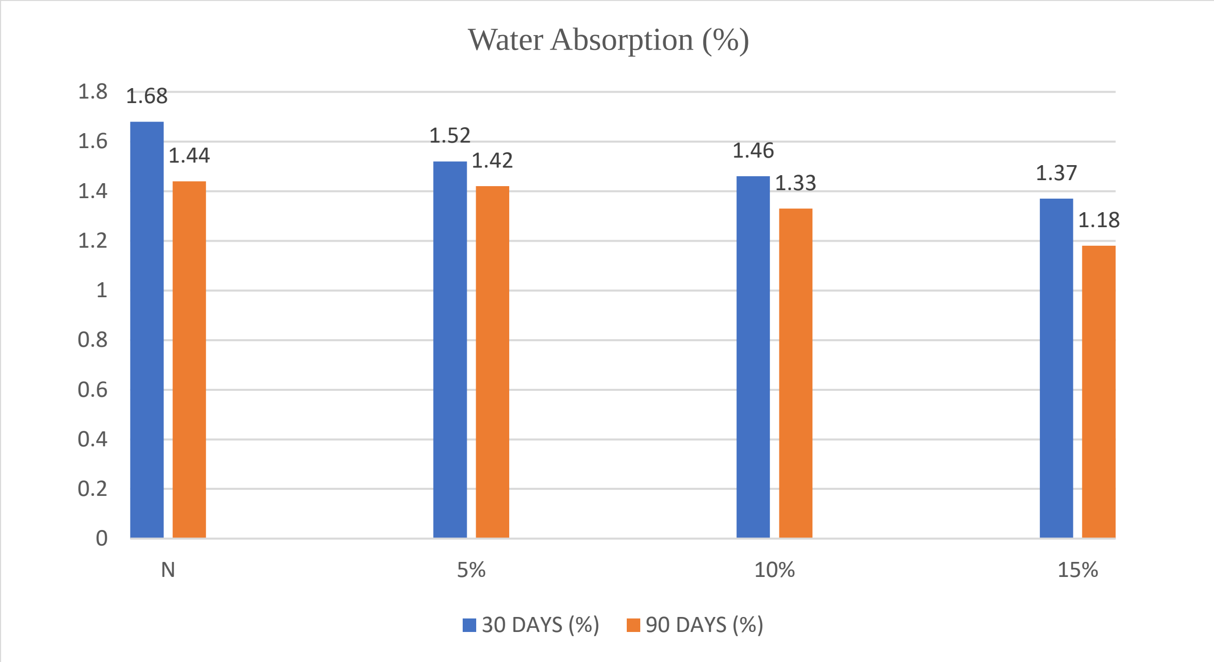

Fig.19: Water Absorption values of different concrete mixes

4.2.5 Sorptivity:

The Sorptivirty index, i.e., capillary water absorption, is calculated in terms of the square root of time and penetration depth. Water sorptivity on the concrete surface is influenced by several factors, such as mixing compositions, physical characteristics of aggregates, the existence of chemical admixtures, entrapped air content, curing period and types, presence of voids, hydration period, surface treatments, concrete moisture conditions while testing, and placement methods. Fig. 21a and Fig. 21b show the change in water absorption as a function of the square root of time. Sorptivity also shows the similar trend as water absorption, it decreased significantly with increasing rubber content. At 28 days the control specimen has the poorest performance, with initial absorption rate of 2.621 mm. Thereafter, as rubber content increased, an enhancement is found. The results for 5%, 10 % and 15 % of rubber aggregates were 2.421mm, 2.102mm, and 1.57mm with a reduction of 7.63%,19.8% and 40.1% respectively. The mix with 15% rubber aggregates content showed the best results. similarly for 90 days also give the similar trend where the control specimen shows the absorption rate of 2.69mm. and the results for 5%, 10 % and 15 % of rubber aggregates were 2.51mm, 2.16mm, and 1.37mm with a reduction of 6.7%,17.9% and 49% respectively. We can assume that the presence of discontinuous air entrainment voids in the specimen causes the blockage of water transmission. The non-sorptive material of rubber aggregates served to reduce the volume of water accessible and thus capillary porosity is reduced. Yasser et al. (2023) and Assaggaf et al. (2022) found the similar trend of reduction in sorptivity values.

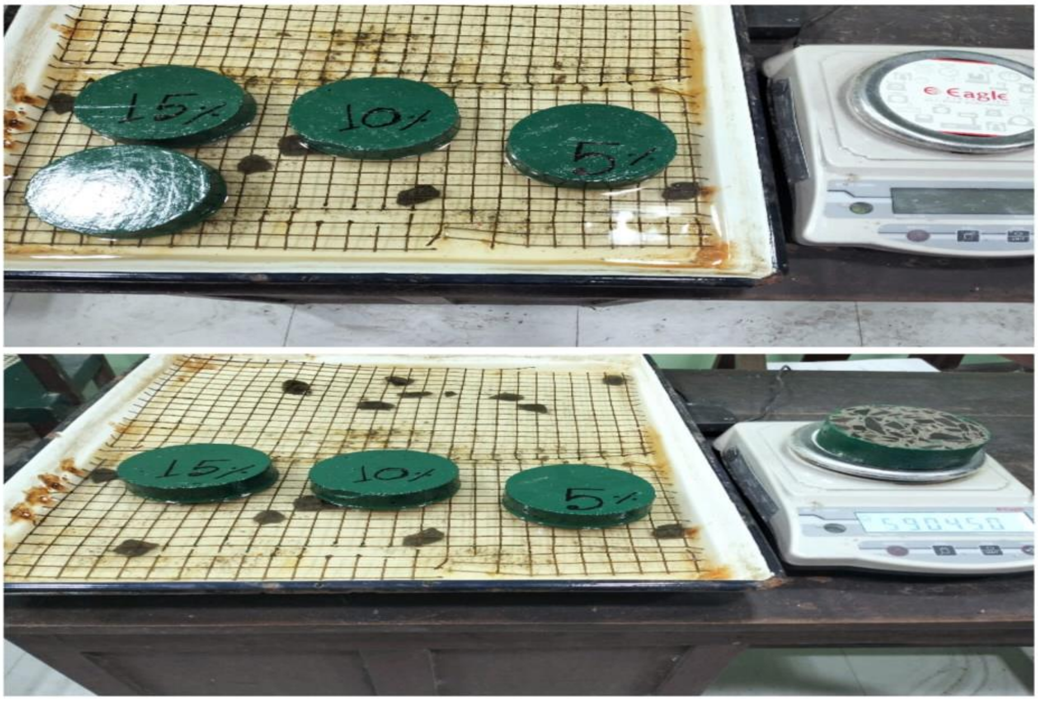

Fig.20: Sorptivity test on cylindrical specimen.

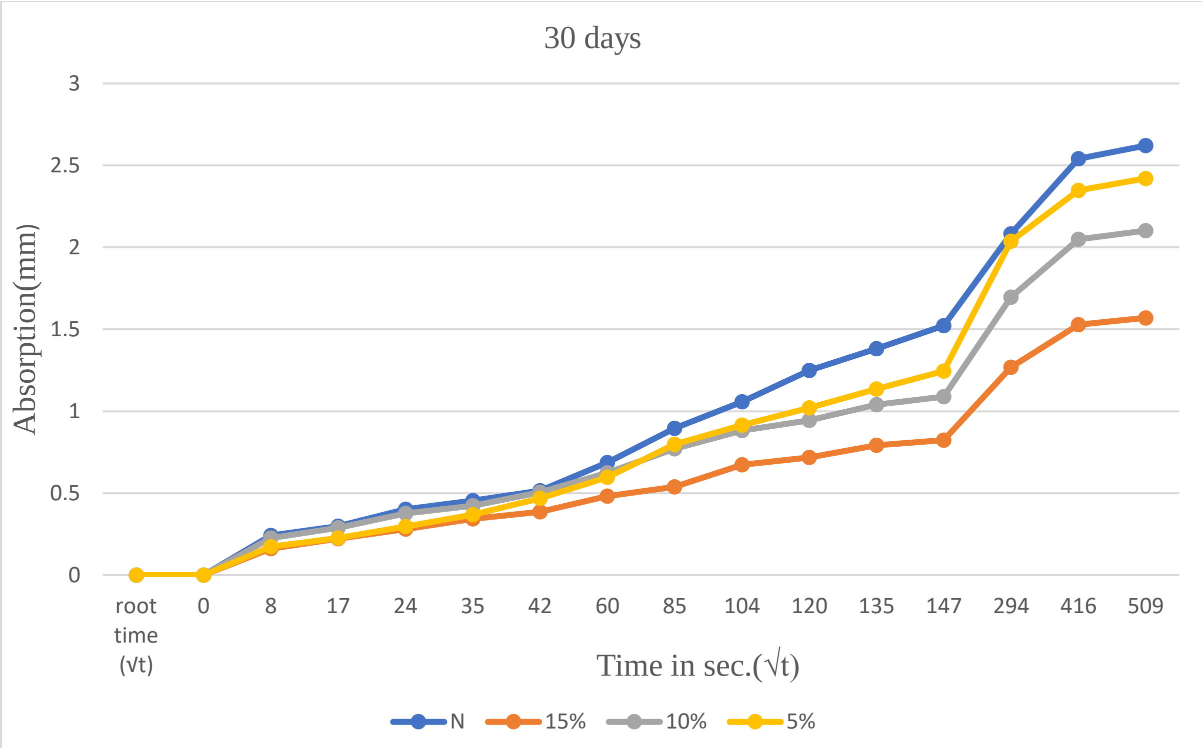

Fig.21a: Sorptivity test values of different concrete mixes

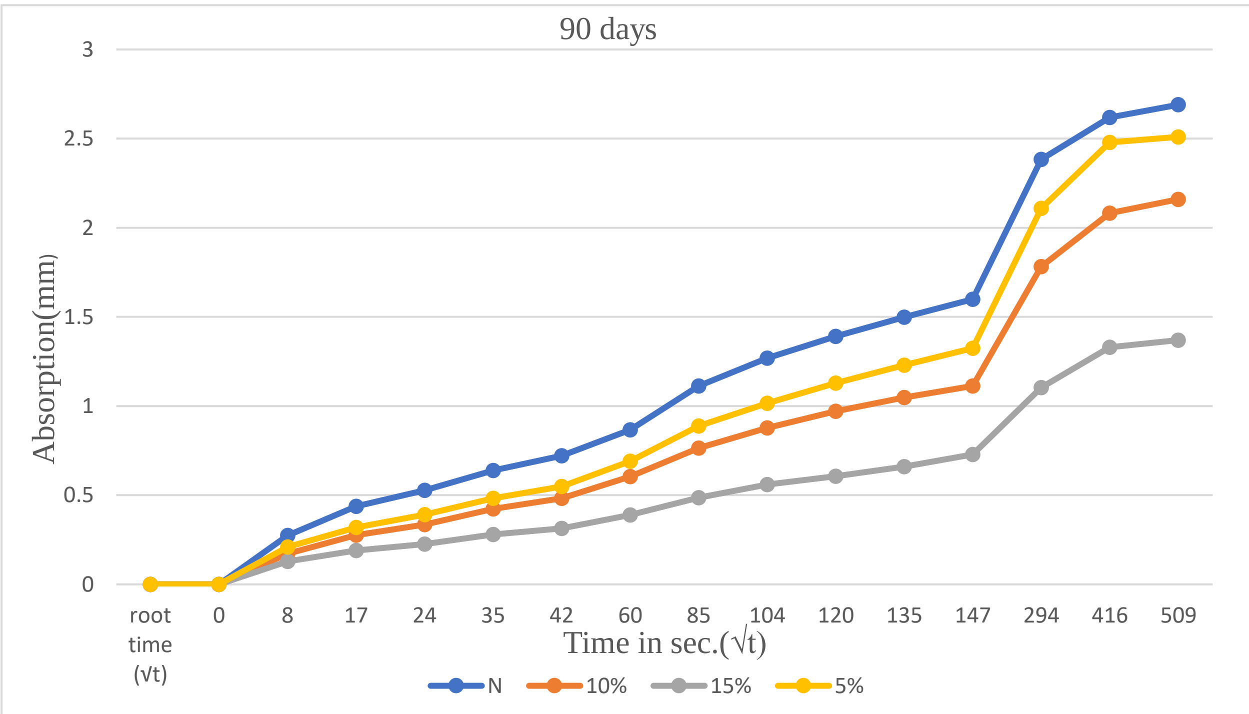

Fig.21b: Sorptivity test values of different concrete mixes

4.2.6 Acid Attack:

The compressive strength of the acid attacked specimen decreased with the increasing of rubber content, as presented in Fig. 22 compressive strength of control specimen after 28 days varied from 19.70MPa to 19.50 MPa, 15.4MPa and 13.26MPa for 5%,10% and 15% rubber replacement respectively. while for 90 days specimen the strength decreased from 14.27 MPa for control mix to 13.5MPa, 12.28MPa, and 9.47MPa for 5%, 10% and 15% rubber replacement respectively. On the other hand, when comparing the residual compressive strength percentages between the acid attacked and the non-acid attacked specimens, an improvement was noted with the increased percentage levels of rubber aggregates. The control specimen showed a residual strength of 63.02%, which was considered the lowest percentage. Afterwards, the percentage started to increase to 64.15%, 66.95% and 68.35% for 5%, 10% and 15% rubber replacement respectively. Similarly for 90 days also. Kumar and Dev (2022), and Kelechi et al (2022) found that the rubberized concrete experienced less surface degradation, weight loss, and compressive strength loss as compared to normal concrete. This is because of the formation of Sulphoaluminate, like ettringite, when sulphuric acid reacts with concrete hydration products. The massive amount of ettringite creates significant inner pressure in concrete, causing the formation of cracks that weaken the upper layer of the concrete, causing mass loss and strength loss. On the other hand, Mixes with rubber aggregates have voids in their microstructure, allowing a greater area for ettringite to grow without producing internal pressure in the concrete. Because rubber is an elastic material, it may absorb the energy of expansion induced by ettringite, preventing structural failure, and resulting superior compression loading performance.

Fig.22: Compressive test on acid exposed specimen.

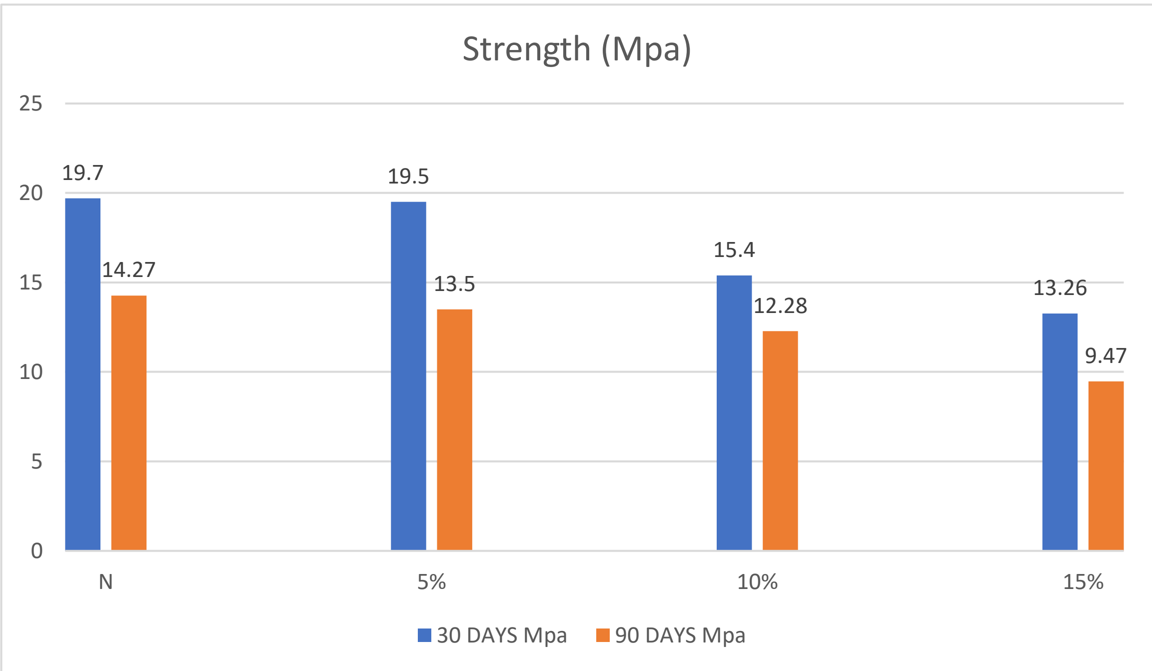

Fig.23: Compressive strength after acid exposure of different concrete mixes

4.2.7 RCPT Test:

RCPT test was performed to measure the conductivity of concrete, indicating the resistance to rapid chloride ion penetration. Fig 24 depicts the RCPT values for normal and compressed samples at 28, and 90-day. It is shown in Fig. 4.7 that the chloride penetration decreases in both concrete groups as the rubber percentage increases. For 28 days the specimen in the control mix had the highest number of coulomb charges, 2186 C. The increase in the replacement ratios of rubber aggregates by 5%, 10%, and 15% has resulted in a progressive reduction in the coulombs charges by 6.86%, 23.6%, and 30.46%, respectively, when compared to the control mix. Similarly for 90 days sample shows similar trend, where the control mix had the highest number of coulomb charges, 1842 C. The increase in the replacement ratios of rubber aggregates by 5%, 10%, and 15% has resulted in a progressive reduction in the coulombs charges by 13.7%, 36.6%, and 38.9%, respectively, when compared to the control mix.

Similar trend of restricting the passage of chloride ions was also found by other researchers. Ataria and Wang (2022) and Li et al (2022) conclude that the addition of an appropriate amount of rubber (5–20%) to concrete can effectively improve the resistance to chloride permeability. The reason for this restriction of chloride ion may be due to Rubber particles comparatively absorb less water and are impervious in nature, restricting the passage of chloride ions. Just like water sorptivity results, discontinuities in air voids could also result in enhancement of restricting the passage of chloride ions.

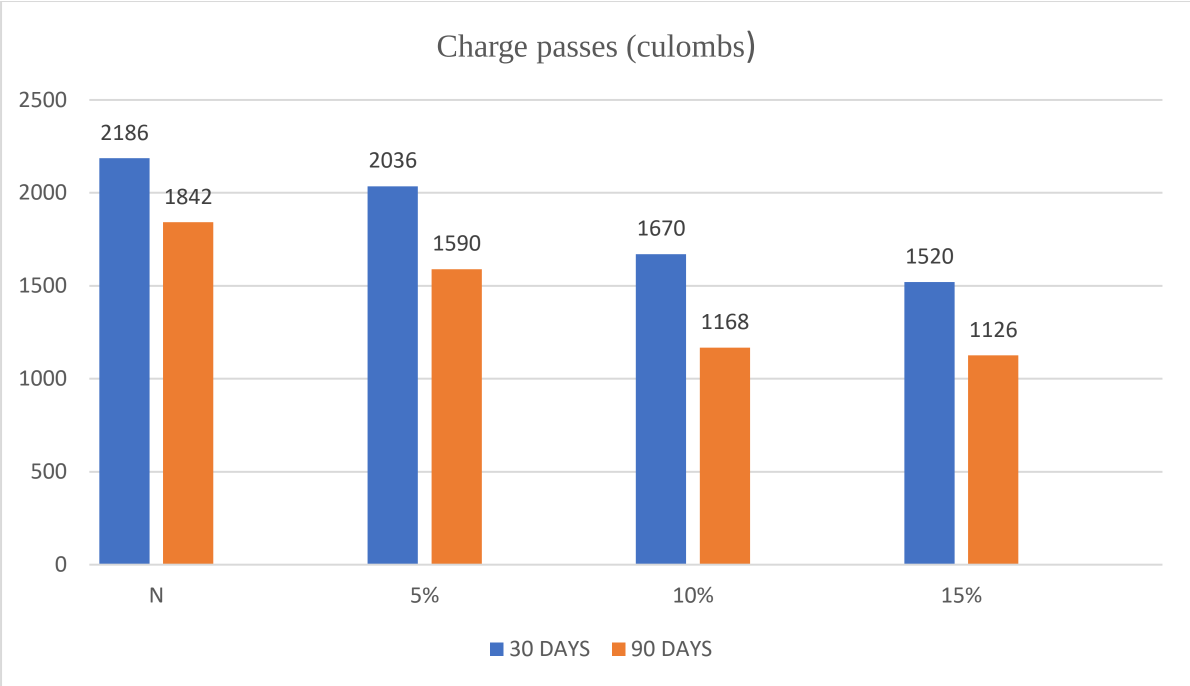

Fig.24: RCPT values of different concrete mixes

Fig.25: RCPT test on cylindrical specimen

4.2.8 Temperature Effect:

At the temperature of 200 ^{0}C, the compressive strength increased for all the mixes, at 24 hour and 48-hour exposure as shown in the Fig. 26. After 28 days the normal specimen showed an increase in the compressive strength at the temperature of 200 ^{0}C was 47.15Mpa which is a 51.6% increase as compared to unheated specimen. Similarly for 5%, 10% and 15% rubber replacement show an increase of 53.54%, 61.9% and 50.77% strength as compared to unheated specimen. Similarly in 48-hour heat exposure also showed increase in compressive strength, where normal specimen shows a 57.55% increase in strength and for 5%, 10%, and 15% rubber replacement given a 54.52%, 63.04% and 53.09% increase in compressive strength as compared to unheated specimen.

This is because of the hardening of the cement paste due to its free water evaporation in high temperature, which is owing to the increased surface forces among the gel particles (van der Waals forces) resulted from the removal of moisture content, Which faster the hydration process. Mehdipour et al. (2020) and Fawzy et al. (2020) found that when the concrete was subjected to elevated temperature, splitting strength was reduced by (6.4 - 16%) at 70°C, (17 - 27%) at 200° C and (28.4 - 32.9%) at 400° C compared with normal concrete.

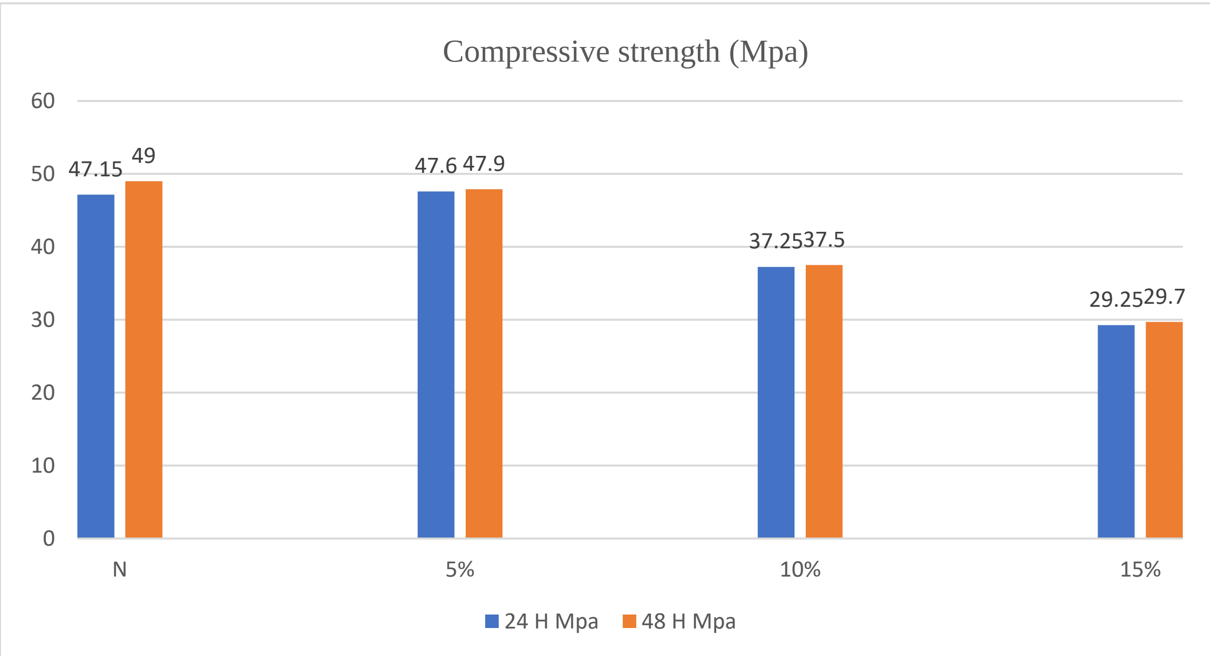

Fig.26: Compressive strength after fire exposure of different concrete mixes

Fig.27: Temperature effect on cube specimen

4.2.9 Impact Resistance:

The impact resistance of concrete specimen shows the absorption of energy due to the sudden applied load by drop hammer test. It is found that increasing the rubber content the impact resistance of concrete increases as compare to normal concrete. Fig.28 shows the energy absorption values in terms of initial and final crack. For normal concrete the initial absortion of energy was 125.33 N-m, this value increased by 20%, 40% and 120% with increase in rubber content of 5%, 10% and 15% respectively. Similarly upto final failure the energy absorption of normal specimen was 300.77 N-m, which increased by 75%, 125% and 158.4% with increase in rubber content of 5%, 10%, and 15% respectively. This increase in energy absorption was because of rubber is much softer than surrounding cement paste, loading cracks are initiated around the rubber particles due to this mismatch. The rubber particles acted as springs, delaying the widening of cracks and preventing early full disintegration of concrete mass. Gerges et al. (2018) found that Rubberized concrete exhibits enhanced energy absorption since the concrete did not undergo a typical brittle failure, yet it encountered a ductile, plastic failure mode.

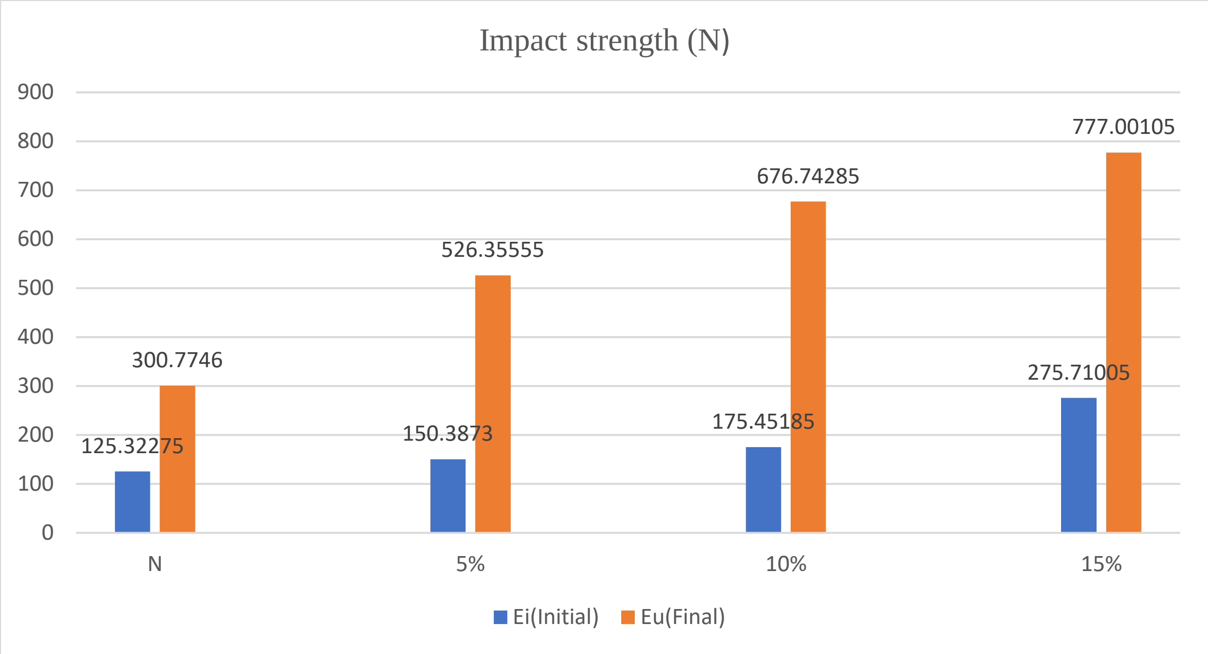

Fig.28: Impact strength values of different concrete mixes

Fig.29: Impact test on cylinder specimen

4.2.10 Stress- Strain Behaviour:

The stress strain behaviour study is done generaly to measure the young modulus and the toughness of the meterial, which indicates how much energy a material can take before faliour occures. Lateral elongtion of concrete cylinder was measured to calculate the stress strain behaviour of the material under uniaxial compression. Fig.30 shows the stress strain curve of the normal and rubberized concrete. It is found that with increasing the rubber content the strain of concrete increased up to the failure. But stress is reduced continuously. So the modulus of elastisity has decreased with increasing rubber content. It can also be observed that increase in rubber content results in increase the toughness of the material before failure, which is a indication of higher shock absorption capasity. Thus the rubberized concrete with higher rubber content can undergo higher value of strain before failure. As a result ductility of concrete is increased.

This behaviour of rubberized concrete can be attributed to the bridging of the cracks by the rubber fibers, which acts as internal confinement, increasing the load carrying capacity. Hence the ductility of concrete increased. Benazzouk et al. (2007) found that toughness improved in this rubber composite and insulation properties also improved due to entrapped air.

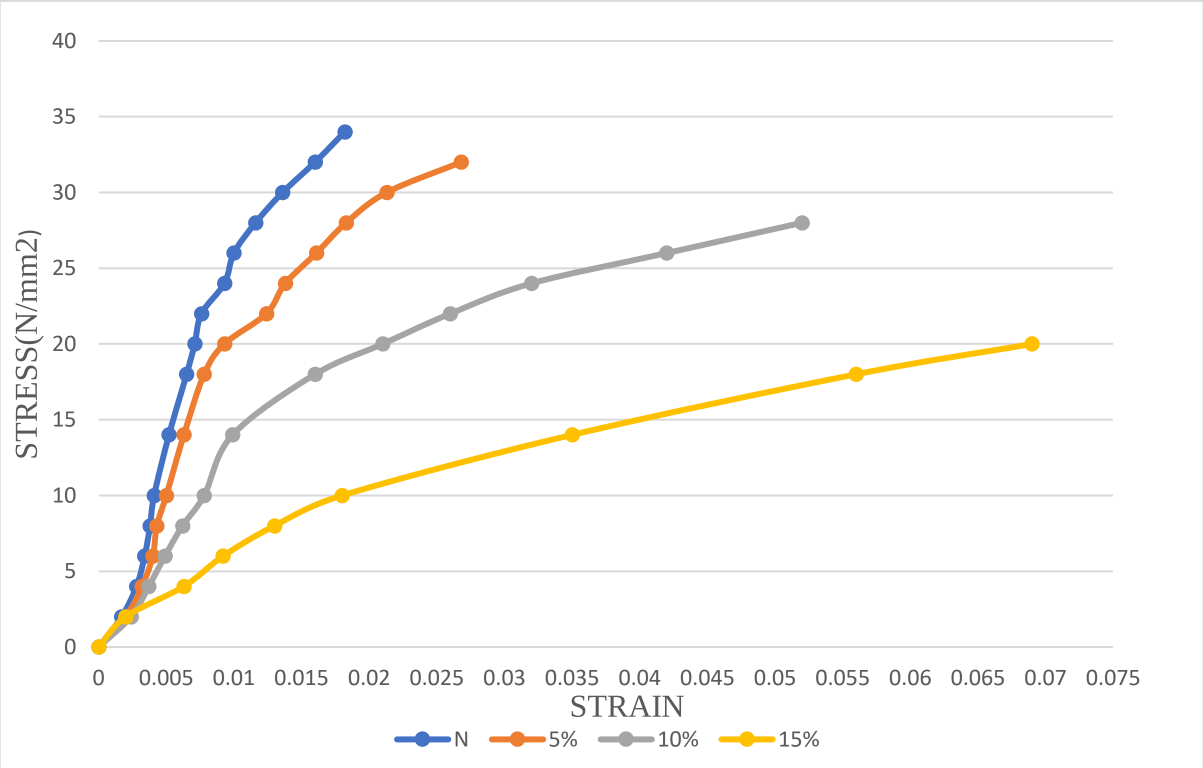

Fig.30: Stress vs Strain curve of different concrete mixes

CHAPTER 5

CONCLUSION AND FUTURE SCOPE OF STUDY

CONCLUSION:

This work presents the findings of an experimental study that was conducted to evaluate the strength and durability of concrete with rubber aggregates as a replacement of natural fine aggregate, where crumb rubber was used to partially replace the fine aggregate by 0%, 5%, 10%, and 15% by weight. The following findings were drawn from this experimental work:

1. Rubberized concrete shows a negative impact on strength. As the rubber content increases, the compressive strength, flexural tensile strength, and split tensile strength decreased slightly. Up to 10% replacement, the reduction of compressive strength, flexural tensile strength, and split tensile strength was within accepted ranges, which opens the possibilities of using rubberized concrete in construction field. The reduction of strength can be overcome by addition of pozzolanic material to the concrete.
2. On the other hand, the rubberized concrete shows a positive result on water absorption and sorptivity values. As we increase the rubber content from 0% to 15% the water absorption and sorptivity values decreases. This means the reduction of void is occurred to some extent by addition of crumbed rubber to the concrete mixes.
3. Rubberized concrete shows better resistance to chloride ion penetration. Where crumb rubber replacement of up to 15% reduce the chloride ion penetration by 30%.
4. When comparing the residual compressive strength percentages between the acid attacked and the non-acid attacked specimens, an improvement is noted with the increase percentage levels of rubber aggregates. The control specimen shows a residual compressive strength of 63.02%, which was considered the lowest percentage. Afterwards, the percentage started to increase to 64.15%, 66.95% and 68.35% for 5%, 10% and 15% rubber replacement respectively.
5. It is found that increasing the rubber content the impact resistance of concrete increases as compare to normal concrete. Incorporating crumb rubber in concrete the material can absorve more energy, so we can use rubberized concrete as pavement blocks.
6. The stress-strain study showes that as we increase rubber content behaviour of concrete becomes more ductile. The rubberized concrete with higher rubber content can undergo higher value of strain before failure. The insulation properties of concrete increased.
7. Temperature study showes that on elevated temperature (200 ^{0}c) rubberized concrete shows a reduction in compressive strength as we increase the crumb rubber replacement.

FUTURE SCOPE OF STUDY:

1. Replacing the coarse aggregate by rubber chips the effect on strength and durability of rubberized concrete can be done.
2. Addition of different pozzolanic materials with crumb rubber to improve the strength of concrete can be done.
3. Testing of rubberized concrete on different structural elements (beams, columns etc) is recommended.
4. Improving the rubberized concrete performance by employing different surface treatment and coating methods to local rubber aggregates is yet to be investigated.

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