

EFFECTS OF PRE-TREATED WASTE TIRE RUBBER ON PROPERTIES OF CONCRETE

*A Thesis Submitted in Fulfilment of the
Requirement for the Award of Degree of*

MASTER OF ENGINEERING IN STRUCTURAL ENGINEERING

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ACKNOWLEDGMENT

DECLARATION

I, Amandeep Singh Sidhu hereby declare that the work which is presented in this thesis report entitled “Effects of pre –treated waste tire rubber on properties of concrete “in fulfilment of requirement for the award of degree of **Master of Engineering in Structures**, submitted at **Civil Engineering Department, Thapar Institute of Engineering & Technology(Deemed to be University), Patiala**, is an authentic record of the work carried out under the guidance of **Dr.Rafat Siddique, Senior Professor, Department of Civil Engineering, Thapar Institute of Engineering & Technology(Deemed to be University), Patiala** and **Dr. Malkit Singh, Additional Superintending Engineer, Punjab State Power Corporation Ltd., Patiala** from January 2018 to June 2018.

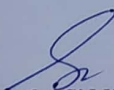
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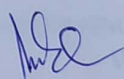
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I feel utterly delighted to put forward my project report on “**Effects of pre-treated waste tire rubber on properties of concrete**”. I feel privileged for having helpful people who have been of great assistance to me in bringing this work to its fruitful conclusion. The successful finalisation of this thesis is sheer result of extensive labour and determination put in by myself with the help of my project guide. I hereby take this opportunity to add special note of thanks for **Dr. Rafat Siddique , Senior Professor, Department of Civil Engineering, TIET, Patiala** and **Dr.Malkit Singh Additional Superintending Engineer, Punjab State Power Corporation Ltd., Patiala** who undertook to act as a mentor to myself despite their many other professional commitments. Their knowledge, wisdom and patience to highest standards has motivated and has been inspiration to reach for my goals. Without their vision, encouragement and uncanny guidance this thesis would not have reached its fruitfulness.

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ABSTRACT

In present day scenario with increase in environmental protection awareness there is need to induce 3R (recycle, reuse, reduce) principle into the construction field. One such example can be use of discarded materials such as used tire rubber into building industry. The application of discarded rubber by incorporating it in concrete mixtures helps in creating landfill prevention and minimize the use of virgin raw materials. According to an estimate almost 1000 million tires are discarded after their service life every year which maybe effectively used in building industry as a partial replacement of aggregates.

Tire burning, which extends as the simplest and cost effective method of used tire disposal, poses grave fire risks. Waste rubber has been tested for lending its use as a part of fine aggregate, coarse aggregate or both in manufacturing of concrete. This paper tries to build up on foregoing and earlier work researches carried out on the use of waste rubber as partially natural sand replacement with pre-treatment in conventional concrete mixtures.

Pre-treatment with KMnO_4 and NaOH were adopted to increase the hydrophilic nature of rubber (due to presence of silica) and hence be able to perform better bonding with cement at the interface. Various tests such as slump test, hardened density, compressive strength test, split tensile strength and RCPT (Rapid chloride penetration test) were performed on concrete incorporating pre-treated rubber as fine aggregate. The rubber particles were used as a partial replacement material for sand by weight and replacement level were kept at 5, 10,15 and 20 percent (by weight). The size of crumb rubber used was combination of 30mesh and 60mesh.

The experiment results showed that workability as well as strength properties of concrete decrease with addition of rubber. However, part of compressive strength lost can be regained by treating rubber with NaOH before its use in concrete. The hardened density also decreased reason being the lower specific gravity of rubber particles as opposed to sand.

Based on the observation of the experiments it can be recommended that tire rubber cannot be used in structural concrete but rather find its usage in non-structural applications mainly such as light weight concrete blocks, floor ribs, road side walks, partitions

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LIST OF ABBREVIATIONS

CCSR20	Concrete consisting of combined-size rubber, 20% of fine aggregate by vol.
CRA20	Concrete consisting rubber sample A(3mm), 20% of fine aggregate by vol.
CRB20	Concrete consisting rubber sample B(0.5mm), 20% of fine aggregate by vol.
CRC20	Concrete consisting rubber sample C(0.3mm), 20% of fine aggregate by vol.
CSR	Combined-size rubber
C1	0% replacement of Coarse aggregate by rubber
RA1	25% replacement of Coarse aggregate by rubber
RB1	50% replacement of Coarse aggregate by rubber
RC1	75% replacement of Coarse aggregate by rubber
C2	0% replacement of Fine aggregate by rubber
RA2	15% replacement of Fine aggregate by rubber
RB2	30% replacement of Fine aggregate by rubber
RC2	50% replacement of Fine aggregate by rubber
RD2	75% replacement of Fine aggregate by rubber
C3	Control mix
RA3	25% replacement of Fine aggregate by rubber
RB3	50% replacement of Fine aggregate by rubber
RC3	75% replacement of Fine aggregate by rubber
ELTs	End of life tires
w/c	Water cement ratio
SSD -	Saturated surface density
T0	Reference Concrete Mix with 0% rubber
T5	Rubber concrete with 5% sand replacement with tire crumb rubber
T10	Rubber concrete with 10% sand replacement with tire crumb rubber
T15	Rubber concrete with 15% sand replacement with tire crumb rubber
T20	Rubber concrete with 20% sand replacement with crumb rubber

- T5N** Rubber concrete with 5% sand replacement with crumb rubber (NaOH treated)
- T10N** Rubber concrete with 10% sand replacement with crumb rubber (NaOH treated)
- T15N** Rubber concrete with 15% sand replacement with crumb rubber (NaOH treated)
- T20N** Rubber concrete with 20% sand replacement with crumb rubber (NaOH treated)
- T5K** Rubber concrete with 5% sand replacement with crumb rubber (KMnO₄ treated)
- T10K** Rubber concrete with 10% sand replacement with crumb rubber (KMnO₄ treated)
- T15K** Rubber concrete with 15% sand replacement with crumb rubber (KMnO₄ treated)
- T20K** Rubber concrete with 20% sand replacement with crumb rubber (KMnO₄ treated)

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In recent years environmental degradation has been on the rise due to many human activities. The waste disposal and recycling is a colossal problem which lend its roots to the industrial revolution due to which large number of products are manufactured by machines in fairly short span of time and after the products complete their life span they increment to the waste disposal problem. One of the serious problems which is encountered the disposal of vehicle tires.

A large amount of discarded tires is produced on yearly basis. An estimated amount of discarded tires is about 10 billion worldwide(*Nole et. al.,2011*). According to United Nation Environmental protection agency about 251 million tons of trash was generated by American population of which only 82 million tons was recycled or reused. The waste tires recycling is only 34.9%(*US EPA, 2014*). In Europe each year about 355 million tires are manufactured in 90 plants, which represents about 24% of world production(*Presti, 2013*).The Figure 1.1 shows the recovery trend of end life of tires (ELTS) in Europe in recent decade

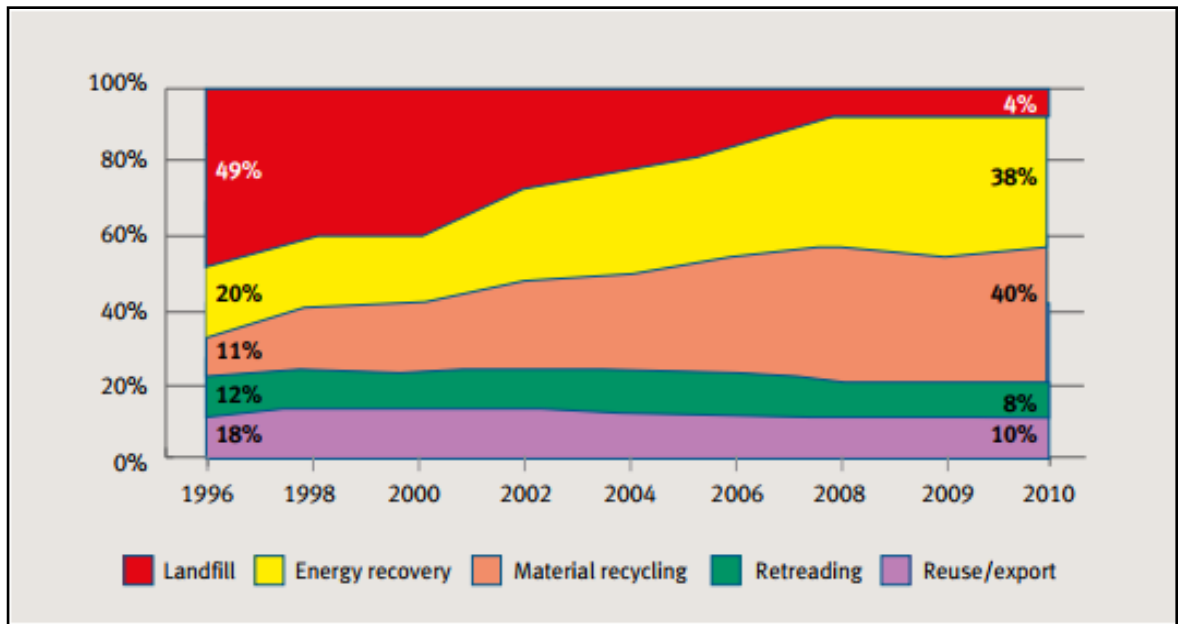


Figure1.1 Recovery trend of ELTS in Europe in recent decade (ETRMA, 2011)

The rest of discarded tires are used as landfills or are stockpiled which give rise to various environmental degrading factors and sometimes also serves as haven for disease causing elements. Figure 1.2 shows the disposal site of waste rubber tires.



Figure1.2: Waste rubber tire piles(Beston (Henan) Machinery Co., 2016)

1.2 COMPONENTS OF TIRE

The tire is highly composite material consisting of many compounds which are required for manufacturing, these components are as follows:

- a) Synthetic Rubber
- b) Natural Rubber
- c) Sulphur and Sulphur Compounds
- d) Silica
- e) Phenolic Resin
- f) Oil: Aromatic, Naphthenic, Paraffin
- g) Fabric: Polyester, Nylon etc.
- h) Petroleum Waxes
- i) Pigments: Zinc Oxide, Titanium Dioxide
- j) Carbon Black
- k) Fatty Acids
- l) Inert Materials
- m) Steel Wires

The tire construction involves many layers which have different materials involved as well as each layer perform its function for the overall satisfactory functioning of the tire. The typical cross section of a newly manufactured tire is shown in Figure 1.3

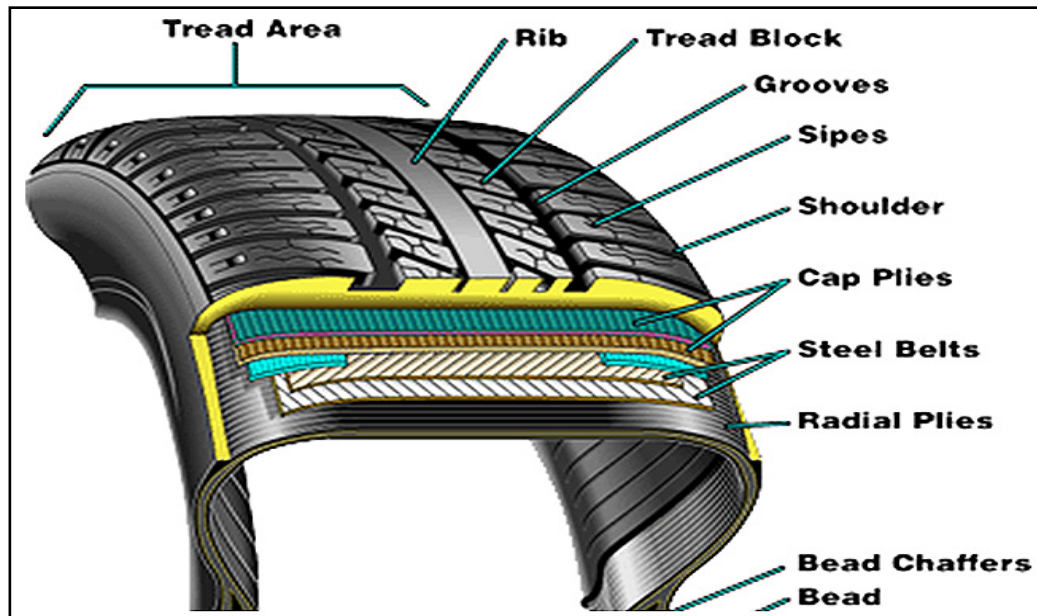


Figure 1.3 Typical cross section of new tire

1.3 RISK ASSOCIATED WITH TIRE DISPOSAL

Fire hazard- When heated, tires can be used as a fuel source. In fact, approximately 50 % of recycled scrap/waste tires find a subsequent life in fuel generation. Fires fuelled by tires are challenging to control and extinguish. Additionally, the smoke constitutes hazardous elements and particulate matter that poses risk to human health, such as a worsening of prevailing respiratory conditions. (*Federal Emergency Management Agency and United States Fire Administration, 1998*)

Breeding place for rodents or other pests like as mosquitoes- stockpiles of tires can allow standing water which serves as breeding ground for mosquitoes, also it provides shelter to rodents(*Kankakee County Health Department, 2017*).

Toxin Release -When the chemicals contained by the tires are released into the environment by the breakdown of tires it causes the entry of hazardous wastes into the surrounding environment. Tires comprises of oils that may be poisonous for the soil; they also consist of heavy metals such as lead that can persevere in the environment and accumulate over time (*US Environmental Protection Agency, 2010*).

Previously most countries used to rely on land filling to dispose of waste tires but the space crunch and their prospective for reuse has led to many countries to ban the use and import of such waste tires. One such recent example can be of India where Union Ministry of Environment, Government of India, replaced its older version made in 2008 with the new rule, which states that import of waste tires for direct reuse purpose is totally banned. However, the rules permits import of waste tires for pyrolysis and reprocessing (*Firstpost, 2015*).

Tire rubber may be used as fuel but the economy aspect of it is very non sustainable. The carbon black procured from tires is very expensive and is of minimal quality as compared to that manufactured from petroleum products. Tire rubber can be used in innovative ways pertaining to various non-civil and civil engineering applications such as in road construction, construction of railway sleepers, onshore and offshore breakwaters, retaining walls, estuaries and harbours to mitigate the impact of ships, artificial reefs to create and enhance marine life, as a fuel in cement kilns, subgrade fill and as an aggregate in concrete

products. Still, an enormous amount of tires are being just buried underground, stockpiled or burnt all over the world (*Bravo and de Brito, 2012 and Segre and Joekes, 2000*).

1.4 SCRAP TIRE CLASSIFICATION

Scrap tires can be divided in main three categories chip, crumb and ground rubber (*Ganjiane et. al., 2009*)

1.4.1 Shredded or Chipped Rubber

It is a dual stage process. In first phase, the rubber pieces are torn to 300–440 mm length and 100 to 230 mm breadth. In latter stages of shredding, the dimensions are reduced to 100–140 mm, and then further reduced to 13–75 mm and are named as ‘shredded particles’, which can be added as replacement for coarse aggregates.

1.4.2 Crumb Rubber as Replacement of Fine Aggregates:

It is manufactured with crushers that can grind the tire rubber to crumbs of size ranging from 0.425–4.75 mm. Variable sizes of rubber particles size could be produced depending on the temperature generated and type of mill.

1.4.3 Ground Rubber that can Partially Replace Cement:

The size of ground rubber varies according on the machinery used for size reduction. If the micro-milling mode is undertaken, the rubber bits can be grinded to 0.075 to 0.475 mm. Various sizes of rubber are shown in Figure 1.4. A two-stage process of magnetic separation for removal of metal wires and screening would be implemented in the process of making ground rubber.



Crumb Tire Rubber



Chipped Tire Rubber

Figure 1.4 Sizes of rubber scrap

1.5 TIRE RECYCLING PROCESS

1.5.1 Whole Tire Processing

The tires are collected at processing plant, initial treatment basically starts with shredding the tires into smaller fraction. This is an important step that helps in easy handling of the tires by transforming them into small easy workable pieces. The tire shredders basically shred or cut tires using two counter rotary shafts which produces size upto 2 inches. The finish product of this step can be of usage as a raw material for tire derived fuel. Tire processing engages one of these two systems:

1.5.1.1 *Mechanical Systems*

A closed process is used in mechanical system to grind tires in smaller chips. In a usual ambient method, the rubber shreds are placed into large granulator provided with screens that aid in determination of the finishing product size.

1.5.1.2 *Cryogenic Systems*

Extremely low temperature are employed by cryogenic systems resulting in a tire freeze. It causes tires to become brittle and hence they shatter causing uneven size pieces, later the tire chips are treated with liquid nitrogen. The fragile, cold rubber is then crushed into small particles by allowing them to pass through a hammer mill. From these minute particles,

steel is forcefully removed using powerful magnets and fibres are extracted with help of air classifiers. To end with, clean recycled rubber is gained and may be used in other applications.

1.5.2 Steel Liberation Stage

The tire scraps achieved from step 1 are processed further and made ready for the removal and separation of the steel wire contained from the rubber. Fibre separation and course screening are vital steps involved. Tires contain steel wires for flexibility, resilience and strength. The steel wires are removed, recovered and reprocessed and then transported to steel rolling grinders for the production of new steel. The leftover rubber may serve as rubber covering or may find its way to be used in schoolyard or field turf or used as raw material for other applications.

1.5.3 Milling and Screening Stage

After wire separation from the rubber, the next stage is screening. A strict quality check is required to ensure non availability of any kind of leftover wire or any other contaminants. The screening process involves separation of great number of varied sized rubber particles that are free from any wires sorting them into different sizes.

1.5.4 Cleaning Stage

At the end of screening process, the next process involves cleaning. Here, the rubber attained from the milling and screening stage is thoroughly cleaned. This process involves the use of cleaning agents and water extensively to clean the rubber. Once the clean rubber is achieved, it is packed and moved to other factories that uses rubber as a raw material in their respective processing plants. For example, shoes manufacturers, running turf manufacturers and other rubber product dependent factories.

The waste tire recycling program involves many output materials having different uses ,the Figure 1.5 shows the various applications of waste recycle tire.

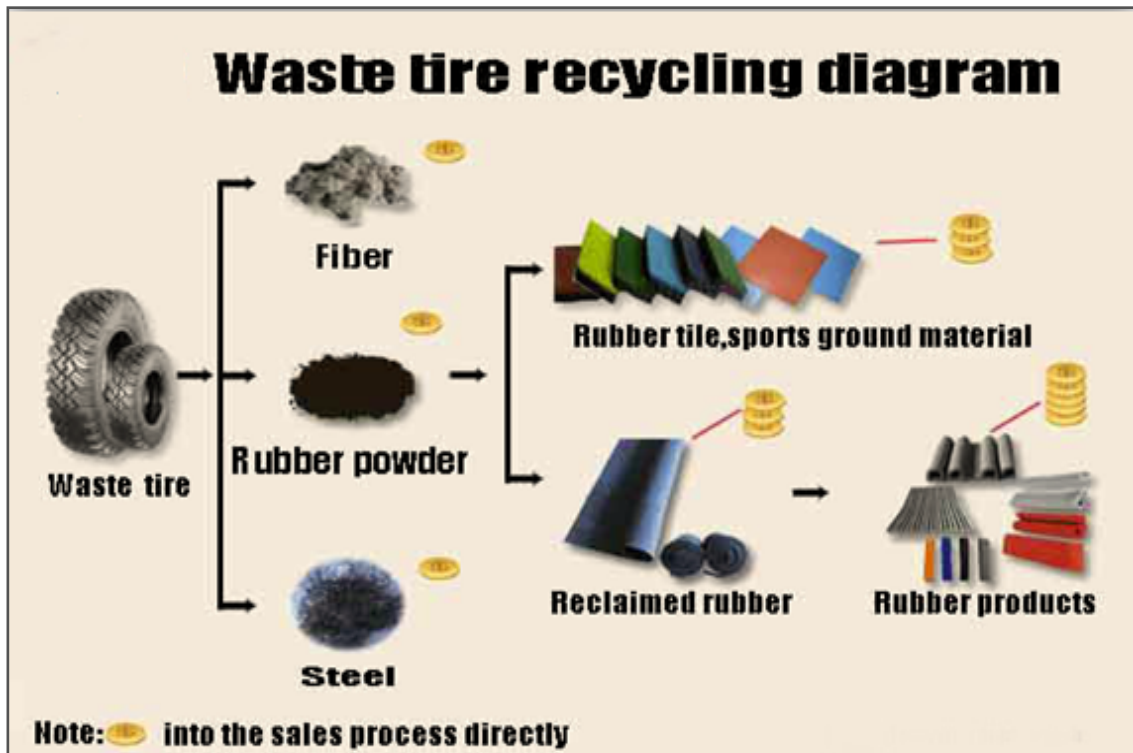


Figure 1.5: Waste tire recycling applications diagram (www.bestonpyrolysisplant.com)

1.6 GENERAL FEATURES AND CONSTITUENTS OF CONCRETE MIX

Concrete is a combination of number of materials of which basic constituents include coarse granular material (fine and coarse aggregates), sand and cement which act as binder to all the constituents along with water. To put forward simply concrete is mix of cement paste and aggregates coated in that paste. The hydration reaction is responsible for imparting the concrete with hard rock like mass. The feature of concrete that it can be moulded into any desired form or shape is an important aspect in construction industry which compensate for its shortcomings concrete mix carefully designed for service life and properly placed and compacted is highly durable and generally maintenance free thought its designed lifetime. Various advantages offered by concrete include

- Easy availability of raw materials at most of the places.
- Concrete is relatively free from defects and flaws compared to natural stones
- High durability including its in situ casting
- High in fire resistance

Concrete also have shortcomings which are listed below

- Very less tensile strength compared to other construction materials\
- Less ductility
- Compared to its strength weight is high
- May contain some amount of soluble salts which can cause efflorescence

In recent decades' tremendous advancement in concrete technology have been achieved in areas of materials, mix proportion, durability requirement, testing methods recycling etc.

1.7 OBJECTIVE AND SCOPE OF WORK

This report is summation of experiments performed and results derived from study of introduction of pre-treated tire rubber crumb in non-structural concrete applications. Various objectives that are included in study are:

- Test the feasibility of usage of waste materials(tires) in concrete manufacturing
- Comparison of properties of substituent material (tire crumb rubber) with sand
- Determining whether the use of pre-treatment techniques can be applied to cause any appreciable improvement in required properties
- Determining an optimum amount of tire replacement which give satisfactory results for its application in concrete manufacture

The tire crumbs used in this study are procured from a tire rubber recycling plant whose sizes are pre-determined during the recycling process. Comparison is made based on the results of the experimented performed.

The concrete strength invariably depends on porosity, ITZ and interfacial bonding. It is known that cement has a hydrophilic nature opposed to tire rubber which possess a hydrophobic nature, so to improve the strength of concrete involving use of tire rubber there are following ways that have been previously employed to enhance the mechanical properties which are negatively affected due to addition of rubber in concrete include for instance, washing and cleaning rubber particles with water before use, altering the rubber surface with chemical etching or giving plasma treatment, and utilizing coupling agents to

improve bonding between particles or using chemical treatment to counteract the hydrophobic nature of tire rubber .

The method used in study involves use of method 1 i.e. to make tire rubber more hydrophilic for better bonding in cement matrix.

1.8 METHODOLOGY

The process of addition of rubber in concrete as a partial replacement of sand involved firstly obtaining the tire rubber of specified size. The rubber size of mesh 60 and mesh 30 were selected for replacement as they fall within the size range of sand. The rubber was then used as combination of two sizes in equal ratio. The rubber was procured from the RS rubber industry, Ludhiana. The physical properties of rubber were measured. Then the rubber was treated with NaOH(0.4N) and KMnO₄ (4% solution).The rubber washed and dried after treatment was then used in concrete as sand partial replacement.

1.9 OUTLINE OF THE THESIS

The thesis is covered in four main sections which include the following:

Chapter-1 Provides the introduction about the Waste tire rubber problems, composition and classification.

Chapter-2 Presents the literature review of the previously done research work by different researchers in field of use of waste tire in concrete.

Chapter-3 Provides the detailed procedure of experimentation involved, material used along with their properties including any other variables. Concrete mix, chemicals used, treatment procedure, casting of samples, curing of samples and testing of samples.

Chapter-4 Gives the results and finding of the experiments on fresh properties like workability, strength property which included compressive and splitting tensile strength and durability property i.e. rapid chloride penetration resistance showing the variation and comparing them to the reference mix.

Chapter- 5 Presents the final concluding remarks along with summary of the findings

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

Waste management is very complicated problems in present day scenario as large quantity of materials are disposed off. An innovative approach to tackle this problem is required. One such idea is to use waste rubber disposed of after life cycle completion of tire in concrete as replacement of fine and coarse aggregate. Some previous studies and their results are presented below.

2.1 WORKABILITY

The ease with which the concrete mix can be mixed by certain method , transported to the application site, placed at required area, fully compaction achieved is defined as its workability. The observations of different researches regarding the workability are presented below.

Sukontasukkul and Chaikaew (2006) studied the effect of use of crumb rubber of sizes 3.35 mm and 850 micron separately and mixture of both as replacement of coarse and fine aggregates on consistency of concrete.. An increase in water requirement in comparison to control concrete mix was reported on inclusion of crumb rubber as replacement of both fine and coarse aggregates. The maximum w/c ratio of 0.47 was observed in 850 micron size crumb rubber at replacement level of 20% to maintain same Vebe time whereas minimum w/c of 0.35 was reported in usage of 3.35 mm size crumb rubber at 10% replacement level for similar Vebe time.

Mendis et al.(2017) experimented with mixes of Group 30(compressive strength of 30-35 MPa) and of Group 40(compressive strength of 40-46 MPa)and The waste tire was used in various sizes consisting of 30 mesh, 1-3 mm, 2-4mm as replacement of sand .It was observed that slump decreased with the addition of rubber as compared to reference mix. The research also suggested that use of an admixture can improve the workability despite having high portion of rubber in concrete.

Bisht and Ramana(2017) performed experiment with usage of crumb rubber of size 0.600 mm with replacement 0%, 4%, 4.5%, 5% and 5.5% by weight basis. Coarse aggregate used have nominal size of 10 and 20 mm. It was observed that the admixture content increased with increase in rubber to maintain same level of workability which concludes that the workability of concrete with rubber content decrease as replacement percentage increase. The highest value for admixture usage was found at 5.5% replacement which was about 2.4%

Batayneh et al.(2008) reported that by increasing content of crumb rubber for a replacement of aggregate in the concrete mix may result in a lower value for both the slump(workability) and the unit weight of the mixes. Observation during operation of mixing and then casting samples confirmed that even if increasing the crumb content negatively affect the slump value in the mix but it still produced a workable mix which did not show any sign of segregation as compared to the control mixture. The slump values were 75.33mm,60.7mm,35.7mm,17.7mm,10.3 mm and 4.7mm for replacement of 0%, 20%, 40%,60%,80% and 100% of sand with crumb rubber.

Su et al.(2015) observed by visual inspection the mix was cohesive showing neither segregation nor any sign of bleeding through the mix process, placement and compacting process. The highest slump value of 95 mm was provided by Reference mix. The designated mixes CRA20 showed values of slump 16.8% (16 mm), CRB20 23.2% (22 mm), CRC20 25.2% (24 mm) and CCSR20 mixes showed values of slump to be 13.7% (13 mm) lesser than that of Reference mix. It can be understood from above results that there was a reduction trend in slump values when rubber particles were used as replacement of sand particles, regardless of any size of tire rubber particle size. This trend can be attributed to reason that rubber particles have greater water absorb capacity in contrast to that of sand which reduces availability of the free water, thus leaving the concrete mixture less workable. Loss of slump also increased with usage smaller size of rubber particles. The slump of CRA20 mix with the greatest rubber crumb size was at 79 mm. Further when the rubber particle size reduced from 3 mm (RA) to 0.5 mm (RB), the CRB20 mix was less workable due to lower value i.e. 73mm. When the rubber particle size was further reduced to 0.3 mm (RC), the slump of CRC20 dipped to value of 71 mm, giving

out the lowest workable mix among all samples. This phenomenon can be attributed to the higher surficial area and water absorption capacity of the finer rubber particles.

Aiello and Leuzzi (2010) performed slump test in order to examine the impact of waste tire rubber particles as a viable option for replacement for mineral aggregate, on workability of fresh rubberized concrete.

Slump tests were carried out in two steps: In the first step rubcrete mixtures were prepared using rubber shreds involving a maximum size of 20 mm and replaced coarse aggregate. In the latter and final step the rubberized concretes were prepared by addition of rubber particles pertaining to a size range of 10 - 15 mm. It was stated that workability of fresh concrete was so slightly improved by the replacement of coarse or fine aggregate by rubber shreds.

So the above studies shows that generally there is a decrease in workability with addition of tire particles to concrete and to achieve a desired workability we need to use a superplatisizer.

2.2 DENSITY

2.2.1 Fresh Density/Unit Weight

Atahan and Yücel(2012) made mixes with w/c ratio of 0.52. The rubber replacement of fine aggregate was done at increment of 20% till upto 100% rubber replacement. The unit weight of concrete decreases with increasing the quantity of rubber replacement percentage. The unit weight of reference mix was noted to be 2500 kg/m³, whereas the density values dropped to about 2080 (20% replacement), around 1900 kg/m³(40% replacement), around 1700 kg/m³ (60% replacement), 1459 kg/m³(80 % replacement)

Girskas and Nagrockienė (2017) reported that density was found to decrease with increase in rubber content. The density of batch 20(2/4 size) was found to be 2145 kg/m³as opposed to control mixture which displayed an average density of 2403 kg/m³. Concrete with bigger size granules showed higher density.

*Su et al.(2015)*carried out density test for fresh concrete in according to BS EN 12350-6. Mix design was 1:0.82:1.6. Regardless of the size of incorporated rubber in concrete, an appreciable reduction in the concrete fresh density was recorded with the incorporation/replacement by rubber aggregates. This is due to the differences in the density

of rubber aggregates as compared to natural aggregates. It was observed that the rubber particles of different sizes cause some different reductions in the value of concrete fresh density. The overall percentage reduction in density for CRA20, CRB20, CRC20 and CCSR20 were reported to be 3.1%, 3.9%, 3.8%, and 3.5%, as compared to Reference mix.

Aiello and Leuzzi(2010) compared the density value of two types of rubbercrete in which alike results were registered. In fact, mixes RB1 and RC2, both consisting of 50% by vol. of rubber bits, showed a density decay of 5.8% and 6.0% respectively. Continuing on the same trend, mixtures RC1 and RD2, obtained by including 75% by volume of rubber particles, offered correspondingly an 8.8% and 8.3% unit weight decrease. Because of the lower density value of tire rubber, a decrease in value of density was shown in both the mixes with increasing the replacement percentage of natural aggregate

2.2.2 Hardened Density

Sukontasukkul and Chaikaew(2006) showed a decreasing trend in dry density with increase of crumb rubber .reason for this was attributed to mainly lighter weight of rubber particles and flocculation process of rubber particles when mixed with concrete. it was reported that 20% replacement mix was severely affected by flocculation process.

Ling(2011) demonstrated the hardened density of rubber concrete with substitute of sand with rubber of size ranging from 1- 5 mm. The replacement was as 5, 10, 15, 20, 25, 30, 40, 50% .Different water to cement ratio were kept at 0.45, 0.50, 0.55 for comparison. It was observed that air dry density of concrete blocks reduced as the amount of rubber replaced was increased. The density reduced by 8% when replacement was 50% of sand by rubber. *Siddique and Naik(2004)* explained this decrease in value by mentioning the non -polar nature of rubber may lead to air entrapment at rough surfaces and reduce density of concrete mix. In terms of different w/c ratio density of rubbercrete increased as water content increased. The reason for this increase can be attributed to availability of water which provides better workability and good compaction.

Bisht and Ramana(2017) reported a decrease in hardened density of concrete with increase in inclusion ratio .with inclusion of 5.5% crumb rubber the bulk density value decreased by 10% as compared to control mix.

Grdić et al. (2014) experimented by replacing sand with rubber granules varying in size from 0.5 to 4mm at level of 10%, 20% and 30% by volume and reported a reduction in value hardened density with increase of rubber content. The reduction reported in hardened density was 4.64%, 9.49% and 13.2% with addition of rubber at 10%, 20% and 30% respectively.

2.3 COMPRESSIVE STRENGTH

Sukontasukkul and Chaikaew (2006) demonstrated a decreasing trend both in terms of stiffness and strength. Both mention properties suffered a decrease in value with increase in replacement ratio of rubber. The replacement of 10 and 20 % lead to a loss in compression by 44.84% and 47.85% with respect to reference mix.

Mendis et al. (2017) demonstrated from his experiment that mixing process of crumb rubber have very limited impact on compressive strength of rubcrete. The results showed that after 14 days of casting of concrete the normalized strength development rate were almost very similar for all considered mixes.

Atahan and Yücel (2012) concluded from their experiments the decreasing trend in compressive strength of concrete by increasing percentage replacement of rubber. The value of compressive strength crashed by 94% in comparison to control mix at 100% replacement. The factors attributed to such results were low strength and elastic modulus of rubber. The properties of concrete started to be controlled by properties of rubber especially when replacement went beyond 60%.

Girskas and Nagrockienė (2017) reported that concrete samples prepared with coarser rubber particles were more dense in comparison to samples that were made with finer rubber granules. The control mix reported quite a high value of compressive strength of 62.5 MPa but with the addition of 2/4 rubber size (5% wt. replacement) caused the strength to reduce to 43.6 MPa and 10% and 20% wt. replacement caused value to even reduce further to 33.7 MPa and 20 MPa respectively. It was also observed that larger rubber particles caused less reduction of compressive strength as compared to smaller size crumb rubber.

Ling (2011) experiments showed decreasing tendency of strength with increasing mix ratio of rubber. The drop in strength in case of w/c ratio of 0.55 was substantial, the strength

dropped from 42.5 to 12.4 for control and 50% replacement mix respectively. The negative effect of rubber on strength was more prominent at 28 days than 7 days.

Bisht and Ramana (2017) stated that incorporation of rubber at 4% and 5.5% as fine aggregate replacement caused a decrease in compressive strength by 3.79% and 17.8%. The strength decrease was explained due to loss of adhesion in-between rubber particles and cement paste, generation of voids due fine nature of rubber particle causes the compressive strength to decrease.

Guo et al.(2017) used NaOH-treated rubber crumb for the experimentation. Tests performed on samples with changing replacement ratio. It was witnessed that the rubber concrete with 25% replacement managed to fulfil the strength criteria for rigid pavement design. The results demonstrated that NaOH solution pre-treatment to rubber can improve the bonding among rubber aggregates and cement paste. The compressive strength of NaOH treated rubber used concrete presented a rise in value by 23.4% as opposed to the results of samples which were casted with addition of untreated rubber aggregate. The decrease in strength value of the samples involving 15% and 25% NaOH solution treatment to rubber aggregate were reported at 3.4% and 25.36% respectively, which can both still accomplish the least requirement for rigid pavement construction design.

*Batayneh et. al.(2008)*reported that the usage of crumb rubber in concrete reduced the tested compressive strength. As in agreement with previous researches, the higher replacement of rubber content in the mix gave more reduction in compressive strength. Increasing the crumb rubber to 40% retained a linear relationship trend among the increase of crumb rubber with compressive strength, showing a decrease of about 50% in the compressive strength at 40% replacement level of rubber content. The drop is reduced when rubber content is above 40%; however, rubber content between 40% and 100% continues to decrease the strength to a maximum 90% of the initial strength loss.

Su et. al.(2015) performed 28 days compressive strength of hardened concrete as per BS EN 12390-3. Replacing the natural sand with the comparatively softer rubber aggregate is expected to reduce the concrete compressive strength. The compressive strength of CRA20 decreased by 10.6%(54.6 MPa), CRB20 by 9.6%(55.2 MPa), CRC20 and CCSR20

decreased by approximately, 9.5% (55.3 MPa) and 9.8% (55.1 MPa) as compared to that of the Reference (61.1 MPa). This was attributed to the poor surface roughness and low stiffness of the rubber particles causing an inconsistent mixture of concrete, and the lack of bonding between the rubber particles with its neighbouring cement paste, hence a loss of compressive strength is observed

2.4 SPLIT TENSILE STRENGTH

Mendis et. al.(2017) conducted experiment by preparing mixes with comparable compressive strength by trial mixes. The mixes were categorized as Group 30(compressive strength 30-35 MPa) and Group 40(compressive strength 40-46 MPa). The average splitting tensile strength was found to be 3.9 and 3.1 MPa for Group 40 and Group 30 respectively. It was shown that irrespective of rubber content, the mixes of rubcrete with similar compressive strength exhibited comparable splitting tensile strength.

Su et. al.(2015) performed splitting tensile strength test for hardened concrete after casting and curing for 28 days following procedure according to BS EN 12390-6. Similar to case of compressive strength, the addition of rubber particles there was some noticeable decreases in the splitting tensile strength. The tensile-splitting strength reported reductions of about 11.1%, 8.3% and 6.9% for the CRA20, CRB20 and CRC20 respectively. It can be easily deduced for above results that the lesser the size of the crumb rubber particles, lesser is strength loss. The reason for above behaviour is similar to that of the compressive strength, as the smaller rubber particles may cause into a filler effect to increase the compactness of the concrete, and it reduces the stress singularity level produced at the internal voids, and henceforth reduce the likeliness of fracture.

Kardos& Durham,(2015) used crumb rubber as replacement of fine aggregate and performed the splitting tensile strength . the results showed a decrease in value of split tensile strength as the addition of rubber increased from 10% to 50% with increment of 10% at each step

2.5 FLEXURAL STRENGTH

According to *Sukontasukkul and Chaikaew(2006)* flexure strength was found lower than the control mix but the responses showed a greater flexibility and toughness with longer post peak response and larger deflections at peak load.

Su et. al.(2015) tested the impact of adding rubber particles on the flexure strength property of concrete, indicating that as the replacement level was kept about 25% (rubber aggregate replaced naturally obtained aggregates) there was a decrease of about 7.9% in the flexural strength with the addition of 25% rubber aggregate as the natural aggregate replacement. The mix design taken was 1:1.5:1.5. The experiments showed that when 20% of the fine aggregates were replaced with the rubber crumb, there was a downfall in flexural strength of almost 12.8%, 11.3% and 10.9% for different designated CRA20, CRB20 and CRC20 mixes. Thus it was inferred that introduction of well-graded rubber particles into the concrete mixture do not change the flexural strength in any significant way.

Aiello and Leuzzi(2010) conducted dual stage of flexural tests, following the guidelines of UNI 12390 (2003), to check the influence variation of coarse as well as fine aggregate substitution with unused waste tire rubber shreds on flexural strength of concrete. In the first stage, samples were prepared using rubcrete mixtures acquired by adding 25% to 75% rubber particles as a replacement of coarse aggregates|(by volume)for plain concrete specimens. In the consecutive phase, rubberized concrete mixtures were prepared incorporating 25%, to 75% waste rubber shreds of fine aggregate(by volume) used for the plain concrete. As in accordance with previous studies a heavier reduction of flexural strength was seen when the coarse aggregate rather than fine aggregate was switched by rubber particles.

2.6 RAPID CHLORIDE PENETRATION TEST

Oikonomou and Mavridou(2009) performed study on chloride ion resistance in mixes of cement mortar which had rubber tires. The sand was replaced with rubber crumb which had similar gradation as of sand. The replacement was from 2.5 % to 15% with 2.5% increment

at each step. The results presented showed that addition of rubber had advantageous effects as it caused decrease in value of charged passed. The value of charge decreased as 14.22% and dropped to 35.85% for 2.5 % replacement and 15% replacement respectively.

Onuaguluchi and Panesar (2014) performed experiment on rubber concrete with rubber as a partial replacement for sand with particle size falling mostly below 2.3mm. The replacement percentage followed from a pattern of decrease in value than reference mix at 5 and 10 percent of replacement but the value showed an increase at 15% replacement. The reason for such behaviour was attributed to less conductive nature of rubber upto 10 percent replacement but after that the value increased as other factors like moisture content and microstructure started to play the dominant role.

CHAPTER 3

EXPERIMENTAL MODEL

3.0 EXPERIMENTAL MODEL

This chapter includes the experimental steps and the materials which were used in the study. The results of use of crumb rubber and henceforth using the crumb rubber with pre-treatment on fresh and hardened properties are presented.

The design mix chosen for this study was with compressive value of 25 MPa. Several mixes were prepared and finally the mix ratio of **1 :1.82 :2.25** was adopted. After finalization of mix proportion many mixes with varying percentage of rubber crumb were made and its properties were compared to that of reference original mix. Two methods were used for pre-treatment were NaOH and KMnO₄.

Materials used for concrete included cement, sand (zone 2), fine aggregate (4.75 -10mm), coarse aggregate (10- 20 mm), waste tire rubber crumb (Mesh size 30 and Mesh size 60), NaOH, KMnO₄ and water.

The testing of samples included fresh, hardened and durability properties. Slump test was performed for fresh property, compressive strength, split tensile strength, unit weight. RCPT was performed for durability check.

Various properties of other material constituents performed included water absorption, consistency test, grain size distribution, setting time, unit weight, specific gravity.

The experimental methods, the process followed and equipment used for the purpose of this study are put forward in the following sections.

The tire rubber crumb was procured from **RS Rubber Industry, Ludhiana**. The tests were performed at Thapar Institute of engineering and technology lab, Patiala in accordance to IS code provision and ASTM C 1202 .

3.1 EXPERIMENTAL PROGRAM

Various mixes were prepared for the experiment which were as follows:

1. Control mix without any replacement called reference mix (R0), for the purpose of comparative analysis.
2. Four mixes with 5% ,10%, 15%, 20% of sand replacement by crumb rubber by weight
3. The tire rubber was first treated with NaOH by stirring it for 20 min and then allowed to be remained in solution for 40 minutes. rubber was the rinsed with water to remove any excess solution of NaOH.
4. The tire rubber was first treated with KMnO_4 by stirring it for 20 min and then allowed to be remained in solution for 40 minutes. rubber was the rinsed with water to remove any excess solution of KMnO_4 .
5. The rubber was then allowed to be dried in open air under sun for 48 hours.
6. Four mixes were prepared with 5%,10%,15%,20% replacement of sand by crumb rubber(dried for 48 hours) by weight using the pre-treated rubber in the ways mentioned below:
 - Pre-treated rubber with 0.4N NaOH solution called Rubber concrete(RCN)
 - Pre-treated rubber with 4% KMnO_4 solution called Rubber concrete(RCK)
7. It is to be noted that due to time and resource constraints the rubber may not have been adequately rinsed .

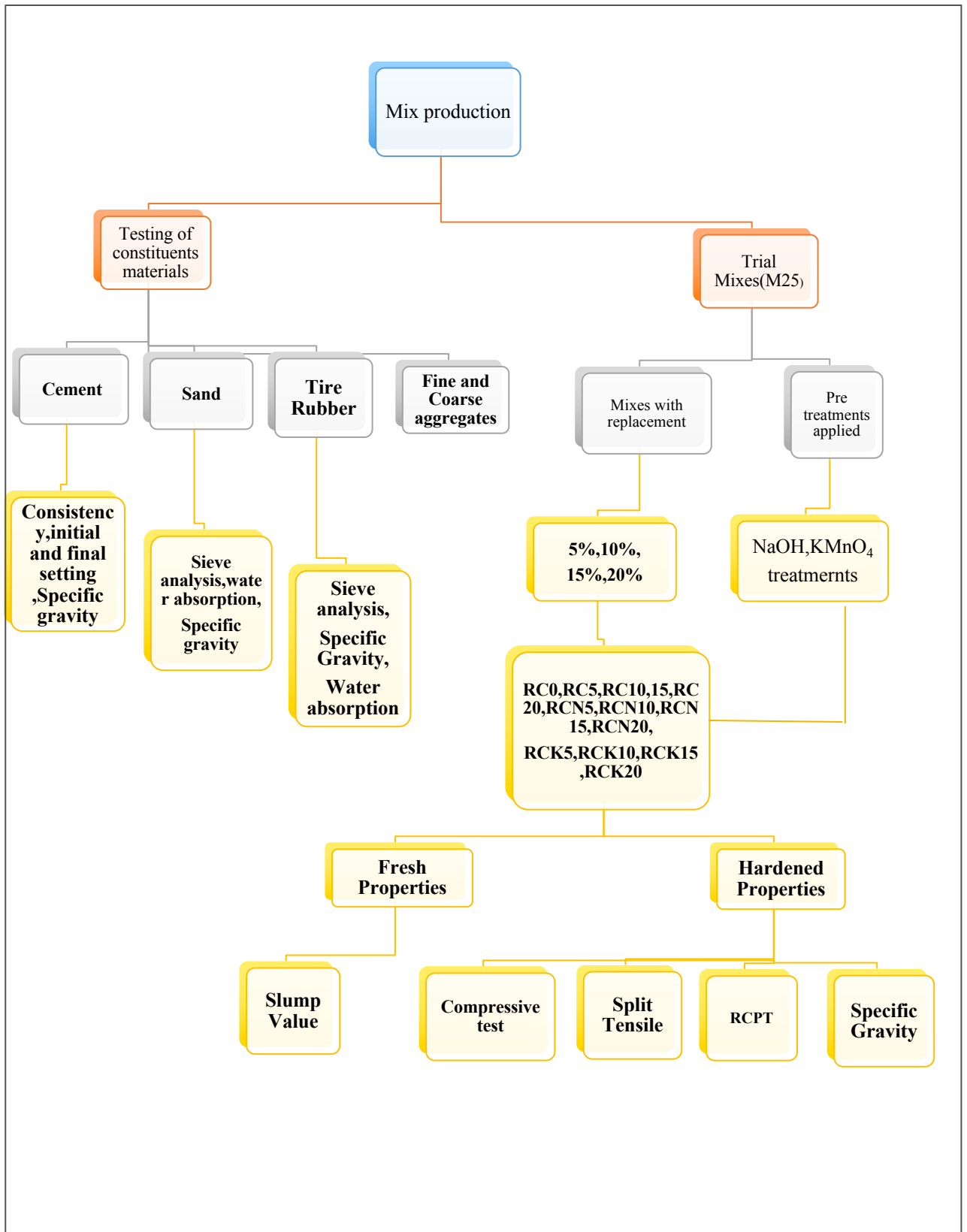


Figure 3.1 Experimental program represented in hierarchy diagram

3.2 CHARACTERIZATIONS OF CONSTITUENT MATERIALS

The rubberized concrete has materials which include OPC (Ordinary Portland Cement), Fine aggregate, coarse aggregate water, tire crumb rubber, Sodium Hydroxide(NaOH), Potassium Permanganate (KMnO₄)

Most of materials were obtained from local market, the detailed properties of each material is discussed below.

3.2.1 Cement

OPC 43 (Brand Ambuja) was used in this study for making of rubberized concrete. The cement was checked for any hard lumps and the cement bear a uniform grey colour .The cement met the requirements of BIS 8112:1989.Thephysical properties of cement are discussed below in Table 3.1 along with the standard specified by IS specification for the comparison.

Table 3.1 Physical properties of cement (OPC 43)

Physical Properties	Value	Standard Specifications(BIS8112:1989)
Consistency of Cement Paste(%)	30%	-
Initial Setting Time(min)	88	>30 min
Final Setting Time (min)	266	<600 min
Specific Gravity	3.11	-

3.2.2 Sand

Aggregate is relatively cheap and also an important component for strength achievement of concrete. The aggregate properties such as maximum size, strength, water absorption, gradation are of chief concern in obtaining a mix design. The sand was in conformation with IS :383-1970 specifications. The key observation to be made in sand is that it is free from silt or clay as their presence will reduce cement aggregate bond, also causing an increase in water demand. The nominal size of sand varies from 150 microns to 4.75 mm. The sieve analysis of sand is shown in Table 3.2

Table 3.2 Sieve analysis of sand

Sieve Size	Wt. Retained(gms)	%age wt. Retained	Cumulative %age of wt. Retained	%age Passing	IS 383-1970 (Zone 2 Specifications)
4.75	42.33	4.252	4.252	95.74	90-100
2.36	162	16.276	20.528	79.47	75-100
1.18	236.5	23.761	44.289	55.72	55-90
600	160.66	16.141	60.43	39.57	35-59
300	319.16	32.07	92.5	7.55	8-30
150	72	7.23	99.73	.27	0-10
pan	2.66	0.27	100	0	-

The specific gravity was calculated as it was required for mix proportion. the specific gravity is dimensionless quantity which directly links the density of aggregate as compared to water. The specific gravity was determined in dried out state.

Moisture content is the quantity of water present in percentage in the aggregate sample within pores and on surface. The final water absorption was found after retaining sand in water for 24 hrs then, the sand was dried at 110°C ±5in oven.

The Physical properties of sand are shown in Table 3.3

Table 3.3 Physical properties of sand

Specific Gravity	2.68
Size Range	0.15mm to 4.5 mm
Conforming Zone	Zone 2
Fineness Modulus	3.21
Water Absorption	0.97

3.2.3 Coarse Aggregate

Coarse aggregate used were of two sizes with max value of 20 mm. The aggregates were mix in ratio 60% (20mm) and 40 % (10mm) aggregate. The 200 mm aggregates are shown in Figure 3.2

Table 3.4 Physical properties of aggregates

Property	20 mm aggregates	10 mm aggregates
Specific Gravity	2.59	2.60
Water Absorption	1.01	0.94
Max. Size	20mm	10mm



Figure 3.2 Coarse aggregates (20mm)

3.2.4 Crumb Tire Rubber

Rubber crumb was the main focus of this study, the rubber procured for this study was of size 600microns and 250 microns which was obtained from RS rubber industry.

Table3.5 Chemical composition of tire rubber(SEM –EDS Analysis)

Constituents	% Weight
C	80.85
O	6.92
Fe	5.03
Zn	3.34
S	2.87
Ca	0.20
Ti	0.02
Na	0.75

The rubber was free from steel wires used in tires .The properties of tires rubber is presented in Table 3.6

Table 3.6 Physical properties of crumb rubber

Property	Values
Specific Gravity	0.47
Water Absorption	4.21%

The rubber used in the experiment was mix of 600microns and 250 microns in 50:50, which was used as a replacement of sand due to the size comparability.



Figure 3.3 Mesh 30 size crumb rubber.



Figure 3.4 Mesh 60 size crumb rubber

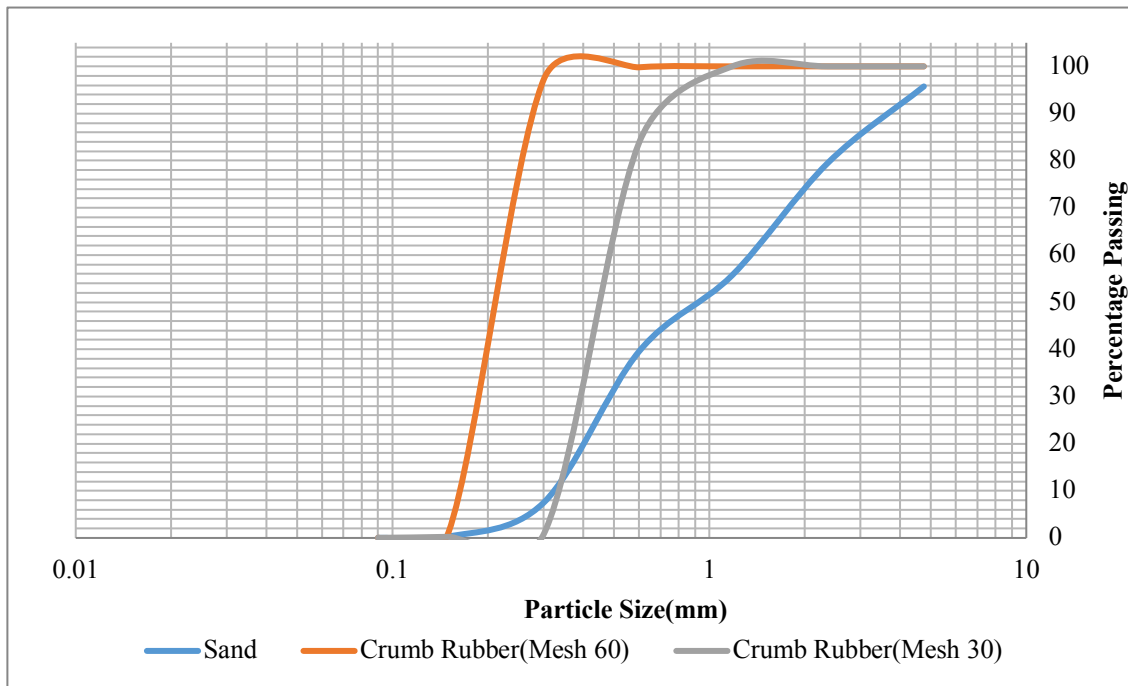


Figure 3.5 Sieve analysis of sand and crumb rubber

3.2.5 Sodium Hydroxide (NaOH)

The sodium hydroxide was used in experiment as an etchant to make the surface of tire rubber rough and hence increase its bonding with cement paste. It is slippery in nature and easily soluble in water. Sodium hydroxide is very alkaline in nature and its reaction with water is highly exothermic, hence it should be handled with care. NaOH pellets were used to make desired solution, see Figure 3.6

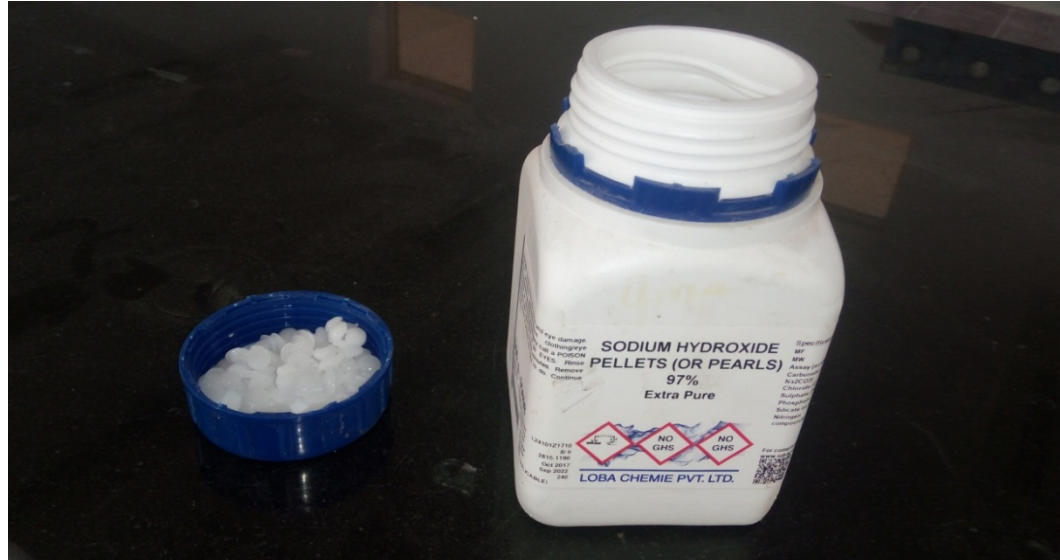


Figure 3.6 Bottle of Sodium Hydroxide

3.2.6 Potassium Permanganate (KMnO₄)

Potassium Permanganate is a powerful oxidising agent which gives purple colour when dissolved in water. It finds its use in many areas like bleaching agent, odour agent and water treatment etc.

KMnO₄ was used as cleaning agent for tire rubber and to make it more hydrophilic in nature which will help it in bonding with cement paste. The KMnO₄ used can be referred to Figure 3.7



Figure 3.7 Potassium Permanganate bottle

3.3 PROCEDURE FOR DESIGN OF NORMAL MIX

1. To determine the required strength for mix.
2. Selection of required constituents and investigating their properties
3. Mix design
4. Perform experiment to test mix design
5. If mix not perform according to needs, then adjusting proportions and verify again

3.4 PREPARING METHOD FOR NORMAL CONCRETE WITH RUBBER

The mix proportion is initial step toward the formation of concrete, a mix proportion should be carefully designed such that it provides good workability and also have the required strength. The mix proportion was carefully designed following the prescribed guidelines of BIS: 10262-1982.

After agreeing on needed mix proportions and selection of materials for mix, all materials are measured or weighed according to needs. Hand mixing of the material is done, firstly the dry mix is prepared with addition of rubber particles afterward the required water is

added and thoroughly mixed to create a homogenous mix. The Mix design requirement is presented below in Table 3.7

Table 3.7 Mix design requirements

Characteristic strength at 28 days	25 MPa
Max size of aggregates	20 mm
Type of exposure	Mild

The mix proportion selected for this study are shown in Table 3.8

Table 3.8 Mix Proportion (M25)

Water	Cement	Fine aggregate	Coarse aggregate (10mm)	Coarse aggregate (20mm)
0.48	1	1.82	0.9	1.35

The reference mix was prepared with cement, Fine aggregates(sand) and Coarse aggregates. The sand was replaced by crumb tire rubber by 5, 10, 15, and 20 percent. The proportions of all the mixes are presented in Table 3.9

Table 3.9 Concrete mix proportions

Mix	Cement (Kg/m³)	Water (Kg/m³)	Fine aggregate (Kg/m³)	Coarse aggregates (20mm) (Kg/m³)	Coarse aggregate (10mm) (Kg/m³)	Rubber (Kg/m³)	% Replacement
T0	420	205	765	567	378	0	0
T5	420	205	726.75	567	378	38.25	5
T10	420	205	688.5	567	378	76.5	10
T15	420	205	650.25	567	378	114.75	15
T20	420	205	612	567	378	153	20
T5N	420	205	726.75	567	378	38.25	5
T10N	420	205	688.5	567	378	76.5	10
T15N	420	205	650.25	567	378	114.75	15
T20N	420	205	612	567	378	153	20
T5K	420	205	726.75	567	378	38.25	5
T10K	420	205	688.5	567	378	76.5	10
T15K	420	205	650.25	567	378	114.75	15
T20K	420	205	612	567	378	153	20

3.5 METHODS OF PRE-TREATMENT

Concrete derives its strength from bonding between the constituents materials therefore when rubber particles do not form good bonding with the particles external treatment are provided to rubber particles to enhance its bonding. In regards to such methods 2 methods were followed in this study which are treatment with NaOH and treatment of rubber with KMnO₄. The procedure followed for the same are discussed below.

3.5.1 Treatment of Rubber with NaOH solution

A solution of 1N NaOH was prepared. Rubber particles were soaked in the solution and stirred for 10 minutes then rubber was allowed to remain dipped in solution for another 40 minutes. The next step involved washing of the rubber crumb with clean water to remove any chemical which may affect in some way in concrete properties. The cleaned rubber was then air dried in open for 48 hours. Figure 3.8 shows the tire rubber dipped in solution of NaOH.



Figure 3.8: Tire rubber treatment with NaOH

3.5.2 Treatment of Rubber with KMnO₄ solution

A solution of 4% of KMnO₄ was prepared in water. Crumb rubber was added to it and stirred for 10 min later on the tire was allowed to stay in solution for 40 min. Afterwards the mix was washed with fresh water to remove any traces of KMnO₄. The wet rubber was then allowed to air dry in open for 48 hours before use. The treatment of rubber with KMnO₄ can be seen in Figure 3.9



Figure 3.9: Treatment of rubber with KMnO_4

3.6 CURING PROCEDURE

For concrete to attain its required strength curing should be done with utmost care. If curing is not done properly then the concrete may lose moisture and ultimately will not be able to perform to the required standard.

All samples were immediately placed in curing tank after 24 hours of casting of sample by removing the mould. Samples were allowed to remain in curing basin until the time of testing. Curing tanks with samples submerged are shown in Figure 3.10

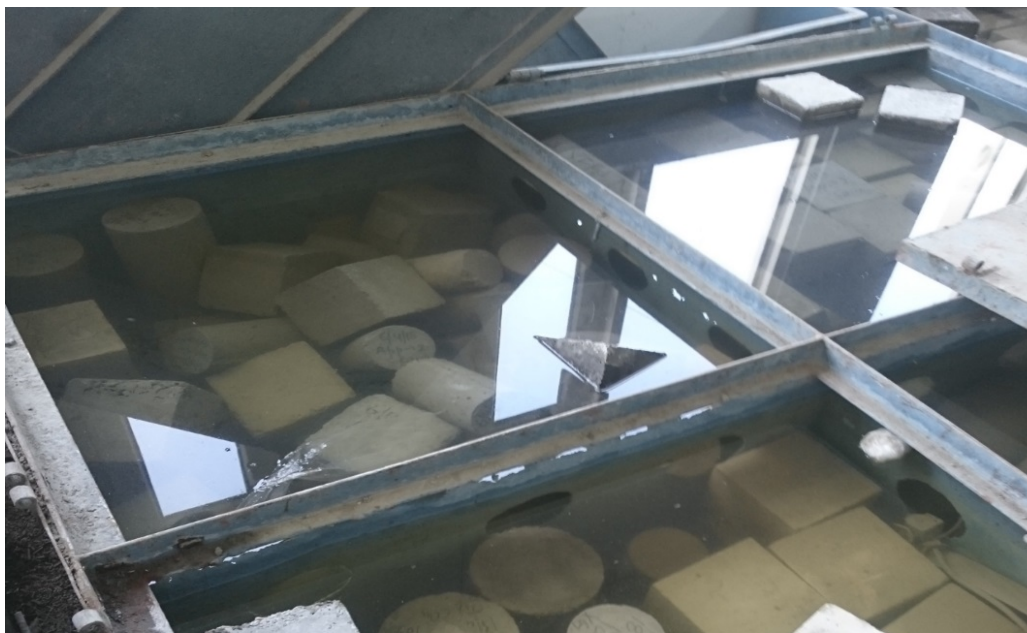


Figure 3.10 Curing of samples in water tub

3.7 SAMPLES TESTING PROCEDURE

The sample testing included the following properties:

3.7.1 Slump

To evaluate how the of fresh concrete will behave i.e. easy movement during placing of concrete slump test is performed that is a very easy and in situ test. The procedure followed for this test is in accordance with IS: 1199 – 1959.

Procedure

Place the slump cone on levelled surface. The slump cone should be firmly held during filling of concrete. The cone should be filled in 3 layers and tamping should be done 25 times after each layer uniformly across the whole cross section. Strike off any extra material from top of the cone with help of a trowel. Remove the cone carefully without any jerk to the mix. Measure the slump value, which is the difference in height of the cone and the height of the sample after subsidence has stopped.

3.7.2 Compression Test

Compression test gives us a value which corresponds its strength to withstand axial loads.

This test can be good indicator of whether the concreting is done as necessary. The codal provision of IS 516-1959 were followed for performing of this test.

Procedure for this test is rather easy, as the concrete is poured into cubical moulds of size 150mm in three layers with tamping 35 times between each layer. After 24 hours of casting the moulds are demoulded and the specimen is finally kept in water for curing.

The compressive strength is then calculated by the load sustained before failure divided by the surface area of the specimen over which load was applied axially.

For the purpose of this study a total of 111 cubes were casted which were of size 150mm each.

Procedure

Prepare the mould by lightly oiling the surface for easy removal of sample without sticking to mould. Fill the concrete in 3 layers in mould with 35 times tamping in-between each layer. The surface of cube should be levelled off with help of trowel for smooth finish. After 24 hours of casting remove the cubes from mould and place them in water for curing. After the required number of days(7 ,28 and 56) the cubes are removed from water .Now to test the compressive strength the cube is placed in CTM with keeping in mind to put that not to put that surface under load that we used to fill it. Machine is the set to a loading rate of 2.4KN/sec. Calculate the compressive strength by following formula

$$\text{Comp. Strength} = \text{Applied Force} / \text{Area}$$



Figure 3.11 Compressive strength test

3.7.3 Split Tensile Strength Test

Total no. of cylinders casted were 111 for the purpose of this study. The procedure followed was according to ASTM C496. 2004.

Procedure

Prepare the moulds by oiling the surface. Fill the material in 3 layer with tamping 30 times each time after filling. Bearing strips of normal plywood should be provided of width about 25 mm, with length slightly greater than the e specimen. Bearing stripes should be placed at upper and lower bearing block of machine. Specimen should have marked lined for to ensure load is applied on same plane. Application of load should be such that the rate of loading is in-between 689 to 1380 KPa till the peak load at which specimen fails. Note the peak value of load by the testing machine along with failure type and appearance for fracture.

As the compression takes place by 2 parallel plane faces in diametrically opposite planes. The result of the loading is that tensile stresses are developed in the opposite direction which ultimately causes the fracture failure and ASTM C496 code specify that the split tensile strength can be found out by following formula.

$$F_{\text{split}} = 2P / \pi DL$$

P = Max peak load

D = Cylinder Diameter

L = Length of cylinder



Figure 3.12 Split tensile strength test

3.7.4 Unit Weight Test

To find the unit weight of concrete weight of cube was divided by its volume. Values of different replacement levels were taken from same cube specimen which were originally casted for compressive strength

$$\text{Unit weight} = \text{Weight}/\text{Volume}$$



Figure3.13 Measuring weight of sample for hardened unit weight

3.7.5 Rapid Chloride Penetration Test

For structure to be able to take the environmental conditions and perform upto the expectations the durability test is performed. The permeability to chloride is an important aspect in durability considerations. The chloride is known damage the reinforcement and concrete also, one such example of adverse effect of chlorine is swelling of concrete which is about 2 to 2.5 times more than water penetration. So RCPT gives an electrical conduction value which is an indication of resistance of concrete against chloride ion penetration.

To perform this test a sample of cylinder of height 50 mm and diameter equal to 100 mm was made. The test involved the measuring of electrical current by applying a potential difference of 60 V Direct current at the ends of samples which consist of solution of 0.3 NaOH on one side (+)and 3% solution of NaCl on the side(-) for 6 hours. The charge passed (coulombs) is then find its relation to resistance to chloride ions penetration.

The Table 3.10 shows the values with relation of charge passed to chloride ion permeability

Table 3.10 Values of charge passed relation with Rapid Chloride Ion Permeability Test

Charge passed (Coulombs)	Chloride Ion Permeability)
> 4000	HIGH
2000 - 4000	MODERATE
1000- 2000	LOW
100 - 1000	VERY LOW
< 100	NEGLIGIBLE

3.7.5.1 *Sample Preparation of RCPT*

Cylindrical samples were made of ht. = 50mm and dia. =100 were prepared and curing was done for 7, 28 and 56 days. The replacement of sand was 5, 10, 15, 20 percent with tire crumb rubber. Figure 3.14 shows the sample setup for the experiment.

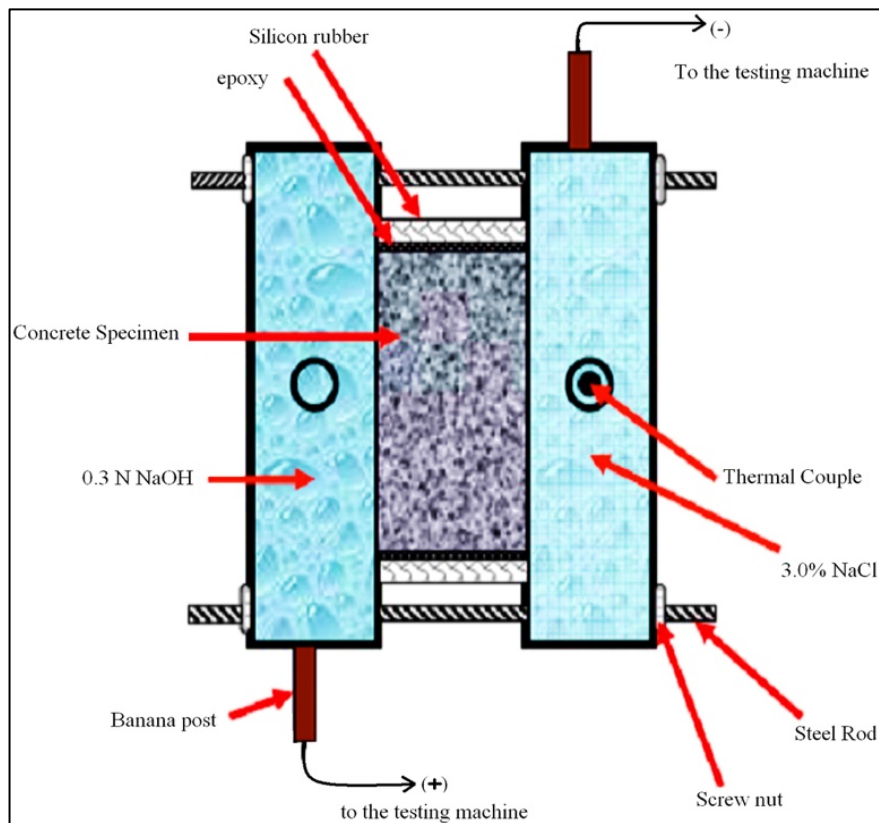


Figure 3.14 Rapid Chloride Penetration Test sample setup

3.7.5.2 Test Apparatus and Procedure

A desiccator bowl is taken and samples are vacuumed in the bowl for 3 hours. The sample is later vacuum saturated for about 1 hour and then samples are allowed to soak in for 18 hours in water. The samples were removed from desiccator and surface dried before they are mounted into gasket. The solution of 3% NaCl was filled on one side (-) and 0.3N NaOH was added to other cell (+). 60 Volt supply was set up and initial readings were observed. Temperature of all the apparatus, specimen and liquid were maintained at 20 to 25 °C. The final value was noted at end of experiment which was 6 hours.



Figure 3.15 Setup for Rapid Chloride Penetration test

3.8 SEM - EDS Analysis

Scanning Electron Microscopy is a powerful microscope which is capable of producing images with incredibly zoom and clarity of sample with help of focused beam of electrons. The sample exterior surface topography and composition are seen by use of focused beam consisting of electrons. SEM can help in providing information about morphology and chemical data of heterogeneous samples. For experimentation the sample are completely dried which is followed by 15 kV accelerating voltage. For sample testing emissive mode

is used as topographical info was required. Secondary electron acquiring low energy concentrates on topographical nature of sample.

3.9 X-Ray DIFFRACTION ANALYSIS

For non-destructive testing of sample XRD is a viable option to determine the minerals present in a sample/substance. The material's structural can be deeply studied in bulk form or thin sheet shapes. The sample preparation included crushing of sample carefully and then mount into glass fibre with help of tubular aerosol suspension chamber (TASC). The spectra was created using Cu anode with voltage rating of 40 kV and current value of 30mA, the scanning angle was 10 to 80°.

The basic principle on which XRD follows is that in a mix the value of intensity of diffraction peak is directly related to the amount of substance producing it.

The samples were obtained from inner core and were crushed into powdered form before the XRD test.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 INTRODUCTION

This chapter describes analyse of varies results performed on concrete incorporating crumb tire rubber as replacement of sand. Properties such as compressive strength, split tensile strength and rapid chloride penetration test of crumb tire rubber concrete have been evaluated. Microstructure of crumb tire rubber concrete by conducting scanning electron microscopy and XRD analysis have also been discussed in this chapter.

4.1 CHARACTERIZATION OF MATERIAL

4.1.1 Cement

Cement used was OPC 43 .Cement was checked before usage to be free from any lumps.

The properties of cement used in the study are shown in Table 4.1

Table 4.1 Physical properties of cement

Physical Properties	Value	Standard Specifications (IS:8112:1989)
Consistency of Cement Paste (%)	30%	-
Initial Setting Time(min)	88	>30 min
Final Setting Time (min)	266	<600 min
Specific Gravity	3.11	-
Fineness retained on 90 micron (%)	2.09	≤10
Compressive strength(MPa)		
7 days	29.8	>28.81
28 days	44.1	>43.00
Colour	Greyish	--

4.1.2 Coarse aggregate

Coarse aggregates having size equal to 10mm and 20 mm were used in 40:60 ratio. It was made sure that aggregates were free from any dust or dirt before their usage into concrete mix. The aggregated possessed angular shape along with greyish colour. Sieve analysis of the 10 mm and 20 mm aggregates are shown in Table 4.2 and Table 4.3

Table 4.2 Sieve analysis of size 10mm aggregates

Sieve Size(mm)	Wt. Retained(gms)	%age wt. Retained	Cumulative %age of wt. Retained	%age Passing
12.5	279	5.58	5.58	94.42
10	1347	26.94	32.52	79.47
4.75	2765	55.3	87.82	55.72
2.36	468	9.36	97.18	39.57
Pan	141	2.82	100	7.55
Total	5000	FM=6.231		

Table 4.3 Sieve analysis of size 20mm aggregates

Sieve Size(mm)	Wt. Retained(gms)	%age wt. Retained	Cumulative %age of wt. Retained	%age Passing
80	0	0	0	100
40	0	0	0	100
20	109	2.18	2.18	97.82
10	4681	93.62	95.8	6.38
4.75	201	4.02	99.82	0.18
Pan	9	0.18	100	0
Total	5000	FM=6.97		

The physical properties pertaining to the aggregates used are shown in Table 4.4

Table 4.4 Physical properties of aggregates

Property	20 mm aggregates	10 mm aggregates
Specific Gravity	2.59	2.60
Water Absorption	1.01	0.94
Fineness Modulus	6.97	6.23
Max. Size	20mm	10mm

4.1.3 Fine aggregate

The fine aggregates used were free from silt and clay. The nominal size of fine aggregate vary from 4.75mm to 150microns. The Physical properties and the Sieve analysis of the fine aggregates are shown in Table 4.5 and Table 4.6

Table 4.5 Physical properties of fine aggregates

Specific Gravity	2.68
Size Range	0.15mm to 4.5 mm
Conforming Zone	Zone 2
Fineness Modulus	3.21
Water Absorption	0.97

Table 4.6 Sieve analysis of fine aggregates

Sieve Size	Wt. Retained(gms)	%age wt. Retained	Cumulative %age of wt. Retained	%age Passing
4.75	42.33	4.252	4.252	95.74
2.36	162	16.276	20.528	79.47
1.18	236.5	23.761	44.289	55.72
600	160.66	16.141	60.43	39.57
300	319.16	32.07	92.5	7.55
150	72	7.23	99.73	.27
pan	2.66	0.27	100	0
		FM = 3.21		

The sieve analysis graph of the sand used is shown in Figure 4.1

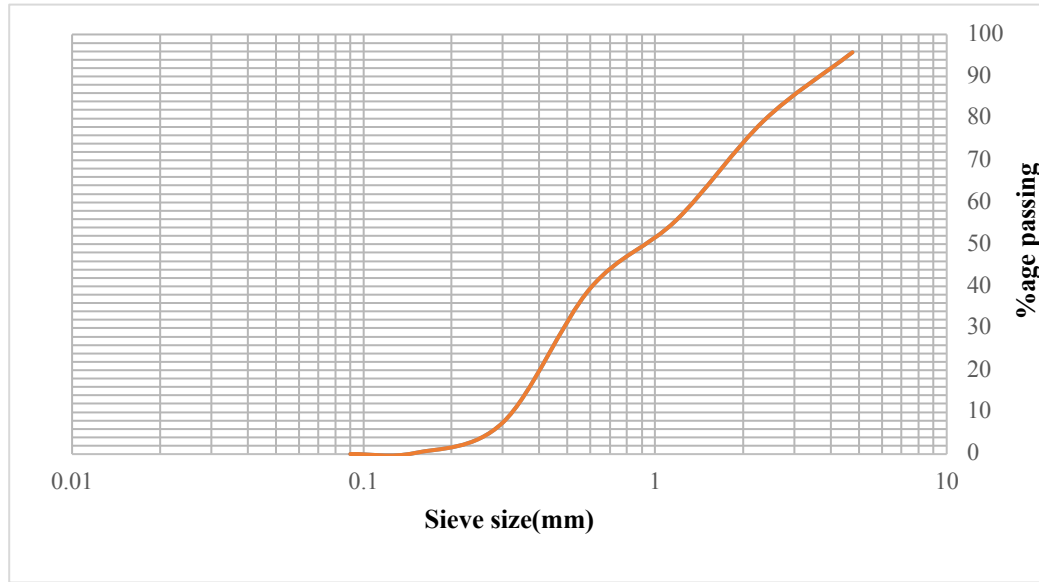


Figure 4.1 Sieve analysis of sand

4.1.4 Crumb tire rubber

Crumb rubber used was tested for its physical characteristics which are shown in Table 4.7, the chemical composition is shown in Table 4.8 and the sieve analysis is shown in Figure 4.2

Table 4.7 Physical properties of crumb rubber

Property	Values
Specific Gravity	0.47
Water Absorption	4.21%
Fineness Modulus (30 Mesh rubber)	3.15
Fineness Modulus (60 Mesh rubber)	2.01

Table 4.8 Chemical composition of tire rubber

Constituents	% Weight
C	80.85
O	6.92
Fe	5.03
Zn	3.34
S	2.87
Ca	0.20
Ti	0.02
Na	0.75

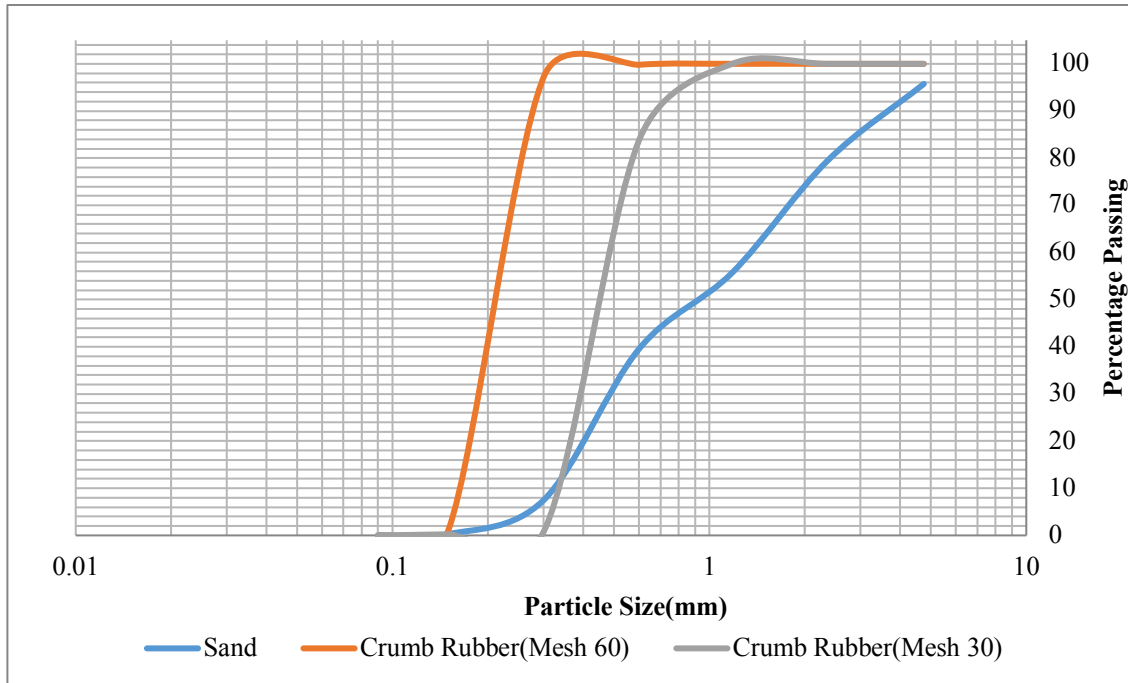


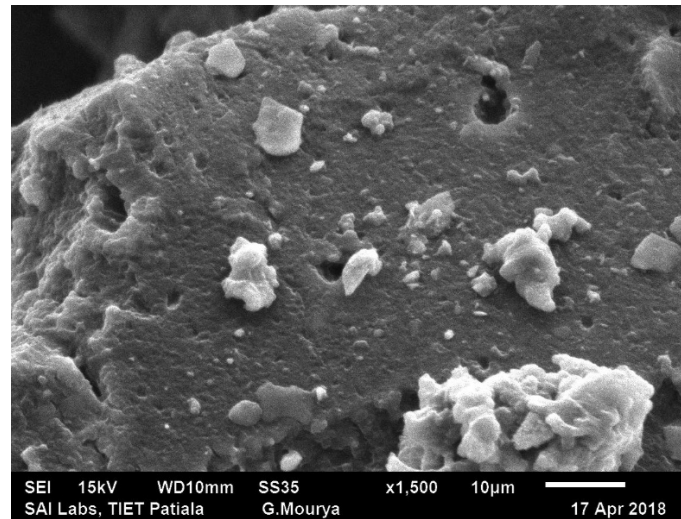
Figure 4.2 Sieve analysis of the crumb rubber and sand

4.1.3.1 Treatment of crumb tire rubber

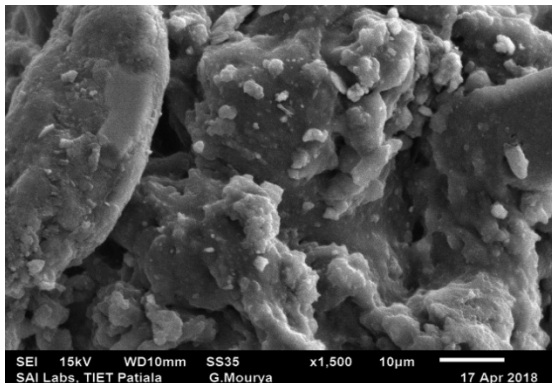
Why treatment required /done?

The inherent property of rubber concrete is that addition of rubber causes a decrease in mechanical strength of concrete. The reason for the loss of strength is mainly due to lesser load carrying capacity of rubber due to soft nature of rubber and also poor bond performance due to slippery surface and also hydrophobic nature of rubber. To address these problems treatment of rubber can be done before its usage in to concrete as a partial replacement of sand.

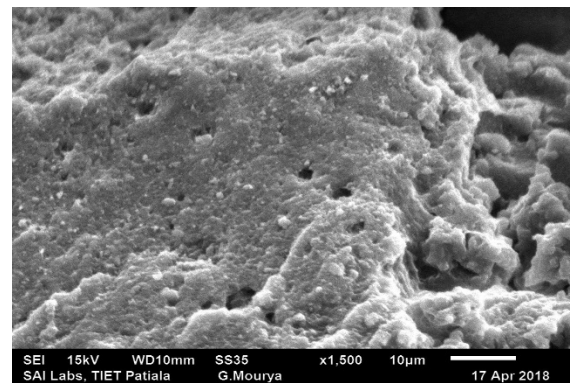
To study the effect of chemical treatment on tire rubber's surface, microscopic evaluation was done using SEM analysis. The surface of tire did not have any noticeable effect in case of NaOH treatment, whereas the use of $KMnO_4$ for treatment showed some surface variation as compared to original tire sample which may be due to oxidizing effect of $KMnO_4$ which may have helped to remove any undesirable particles adhere to rubber surface.



(a)



(b)



(c)

Figure 4.3 (a) Surface of Untreated Rubber Sample (b) Surface of NaOH Treated Rubber Sample (c) Rubber Surface of KMnO_4 Treated Sample

4.2 CONCRETE MIX DESIGN

Concrete mix design was prepared according guidelines of BIS: 10262-1982. The mix proportion is initial step toward the formation of concrete, a mix proportion should be carefully designed such that it provides good workability and also have the required strength. The mix proportion for all the mixes prepared is shown in Table 4.9

Table 4.9 Concrete mix proportions

Mix	Cement (Kg/m ³)	Water (Kg/m ³)	Fine aggregate (Kg/m ³)	Coarse aggregates (20mm) (Kg/m ³)	Coarse aggregate (10mm) (Kg/m ³)	Rubber (Kg/m ³)	% Replacement
T0	420	205	765	567	378	0	0
T5	420	205	726.75	567	378	38.25	5
T10	420	205	688.5	567	378	76.5	10
T15	420	205	650.25	567	378	114.75	15
T20	420	205	612	567	378	153	20
T5N	420	205	726.75	567	378	38.25	5
T10N	420	205	688.5	567	378	76.5	10
T15N	420	205	650.25	567	378	114.75	15
T20N	420	205	612	567	378	153	20
T5K	420	205	726.75	567	378	38.25	5
T10K	420	205	688.5	567	378	76.5	10
T15K	420	205	650.25	567	378	114.75	15
T20K	420	205	612	567	378	153	20

4.3 PROPERTIES OF CONCRETE CONTAINING UNTREATED AND TREATED CRUMB TIRE RUBBER AS SAND REPLACEMENT

4.3.1 Unit Weight

The results of unit weight of hardened concrete incorporating crumb tire rubber as replacement of sand are presented in Table 4.10. It was observed that inclusion of crumb tire rubber decreased the unit weight of concrete regardless rubber type. Concrete mixture incorporating 20% untreated crumb tire rubber as replacement of sand displayed minimum value of unit weight.

Figure 4.4 shows the unit weight trend of different mixes.

Table 4.10 Unit weight of hardened concrete containing untreated and NaOH and KMnO₄ treated crumb tire rubber

Replacement level (%)	Unit weight of concrete (kN/m ³)		
	No treatment	NaOH treated crumb tire rubber	KMnO ₄ treated crumb tire rubber
0	24.21		
5	23.70	23.74	23.71
10	22.87	22.93	22.86
15	19.12	19.20	21.69
20	18.97	19.17	20.80

The results show that unit weight of concrete decreases with increase in crumb tire rubber content. This is due to lower specific gravity of the tire compared to sand. Bisht and Ramana(2017) also reported decrease in density of hardened concrete with increase in rubber content. The decrease in density of concrete on inclusion of crumb tire rubber may also be attributed to non-polar nature of rubber which lead to air entrapment at rough surfaces and caused reduction in density of crumb tire rubber concrete. (Siddique and Naik, 2004)

The decrease of unit weight was 2.1%, 5.53%, 25%, 25.77% for untreated rubber sample, for NaOH treated sample the unit weight decrease was 1.94%, 5.28%, 20.69%, 20.81% and for KMnO₄ treated samples the decrease was 2.06%, 5.57%, 10.40, 14.08% with replacement level at 5%, 10%, 15%, 20% of sand with crumb tire rubber, respectively.

The unit weight of concrete mixtures containing NaOH and KMnO₄ treated crumb tire rubber is slightly higher than that of concrete mixtures containing untreated crumb tire rubber. This is due to the fact that NaOH helps in reducing hydrophobicity of tire rubber which in turn causes the reduced air void retention at its surface in concrete hence the density of hardened concrete increase. (Atahan and Yücel, 2012)

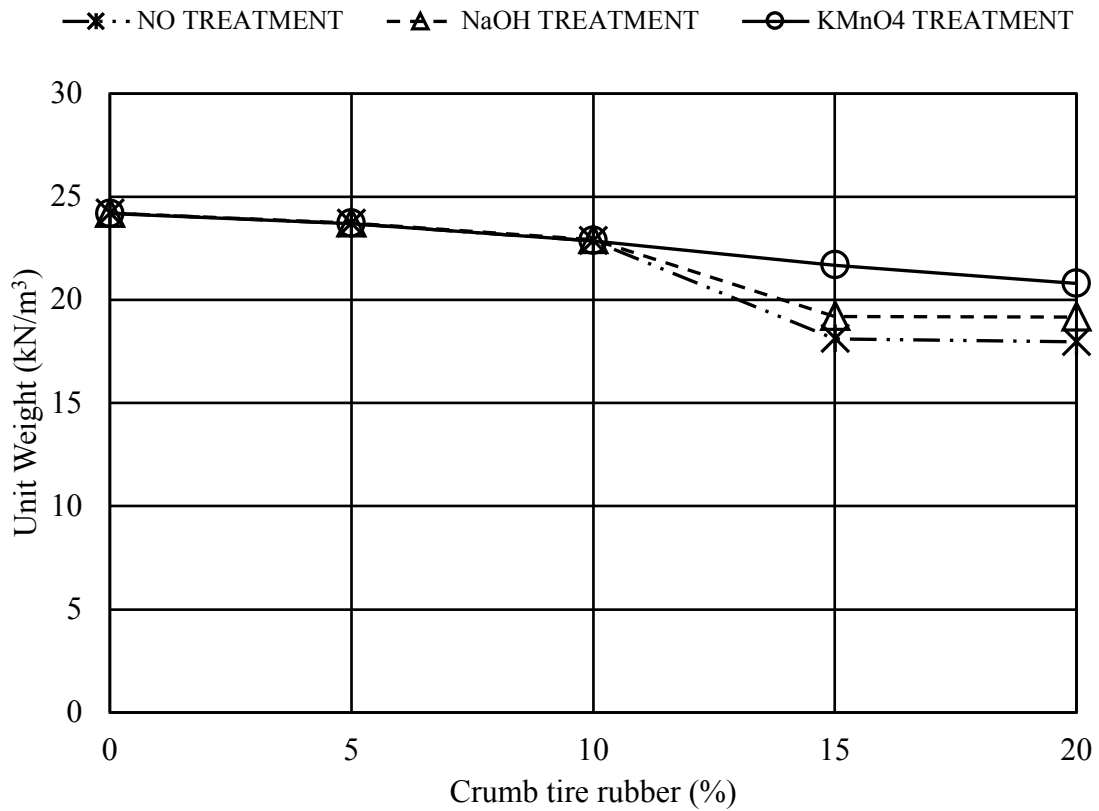


Figure 4.4 Unit weight of hardened concrete mixtures containing untreated and NaOH and KMnO₄ treated crumb tire rubber.

4.3.2 Workability

Slump values of fresh concrete mixtures containing untreated, NaOH and KMnO₄ treated crumb tire rubber as replacement of sand are presented in Figure 4.5 and Table 4.11.

The replacement of sand with crumb tire rubber in concrete caused decrease in its workability. The concrete mixtures incorporating crumb tire rubber appeared to be dry. The reason attributed to this behaviour is the higher water absorption of tire rubber as compared to the sand. The tire rubber absorbs some water from mix thus having negative impact on workability.

Table 4.11 Slump values of concrete mixtures containing untreated and NaOH and KMnO₄ treated crumb tire rubber

Concrete mix	SLUMP VALUES (mm)		
	Untreated rubber	NaOH treated rubber	KMnO ₄ treated rubber
T0 (Control concrete)	62		
T5	52	50	57
T10	34	42	44
T15	31	30	39
T20	21	23	20

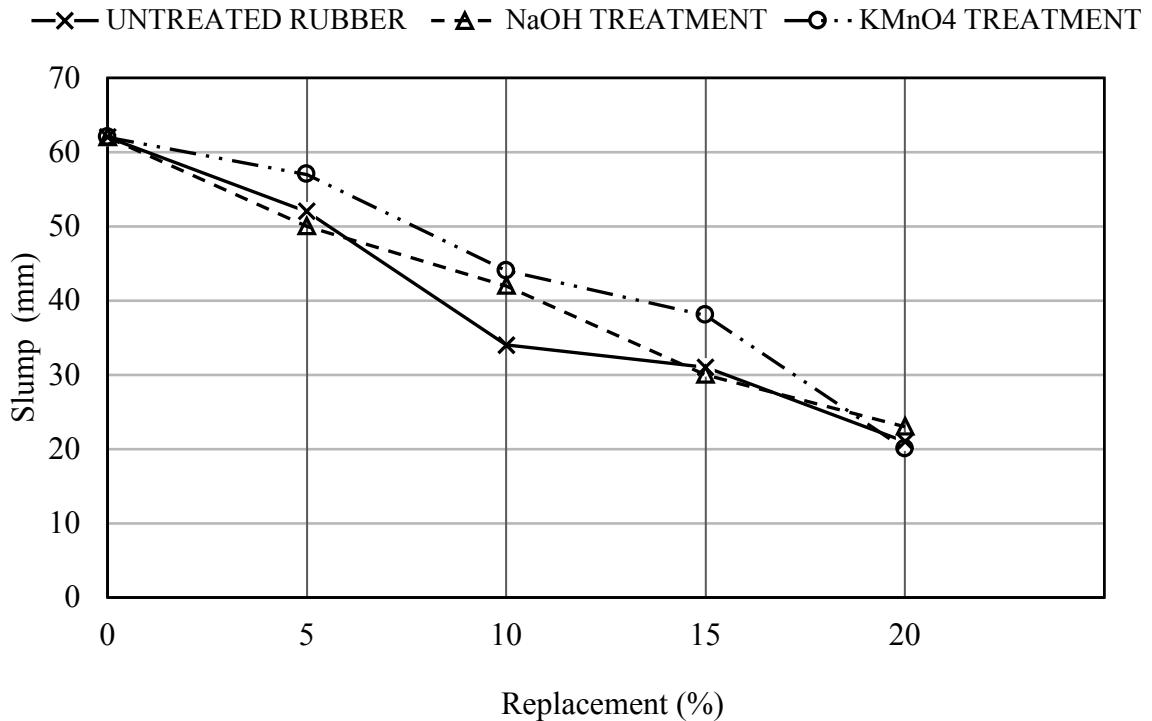


Figure.4.5 Slump of concrete mixtures containing untreated and NaOH and KMnO₄ treated crumb tire rubber

The slump values comparison across different treatment shows almost similar trend confirming the previous results of surface of tire rubber which did not show any noticeable effect on tire surface on NaOH treated rubber but showed a cleaner surface in case of KMnO₄ treated rubber which have marginal increase in slump as compared to other mixes.

The slump value decrease was 16.12%, 45%, 50%, 66.12% for the untreated rubber as compared to 19.35%, 32.25% ,51%, 62.90% for NaOH treated and 8.06%, 29.03%, 37.09%, 67.74%.for KMnO₄ treated with replacement at 5%,10%, 15%, 20% respectively.

The results showed a decrease in workability of concrete mix with addition of rubber irrespective of the size of rubber added to mix. The reason for decrease in workability is due to the reason that the tire water absorption is high and also because the surface area of crumb tire added is more than the sand replaced which has larger size of up to 4.75 mm (Su et. al., 2015).

The higher workability of KMnO₄ treated rubber may also be due the reason that rubber may have retained some amount of water even after drying during its treatment process with chemical, also the treatment may have oxidized any organic matter sticking to surface of rubber and in the process making rubber smoother at surface.

4.1.3 Compressive Strength

The addition of tire rubber with replacement level of 5 %, 10%,15% and 20 % were studied also the same were studied for treated crumb rubber. The corresponding results are presented in Table 4.12

Table 4.12 Compressive strength (MPa) of rubberized concrete

Tire replacement %AGE	Compressive strength (MPa)								
	Untreated rubber			NaOH treated			KMnO ₄ treated		
	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days
T0	19.83	28.60	29.11	19.83	28.60	29.11	19.83	28.60	29.11
T5	10.21	21.30	23.13	9.56	19.10	20.2	9.12	13.60	19.66
T10	7.00	16.63	16.87	8.65	16.8	17.2	7.78	13.1	15.00
T15	5.43	9.20	9.24	5.89	13.21	13.6	5.70	8.47	9.2
T20	2.7	6.53	6.48	4.21	7.90	7.92	4.42	8.2	9.26

The 7 days compressive strength is compared in Figure 4.6. The replacement of sand with tire rubber causes a decrease in compressive strength at 7 days. There is a sharp decrease in

compressive strength with addition of 5 % of tires afterwards the decreasing trend continues with increasing of the rubber replacement percentage. It is seen that there is improvement in initial strength values with usage of both kind of pre-treatments. The strength decrease at 5%, 10%, 15% , 20% replacement level for no treatment rubber are 48.51% ,64.69%,72.61%,86.38% ,for NaOH treated rubber are 51.79%, 56.37%, 70.29%, 78.76% , and for KMnO₄ are 54.00%, 60.76%, 71.25%, 77.71% respectively. Comparing along with the various treatment it is seen that there is regain of some strength after 5% replacement the regain strength for 10%, 15%, 20% replacement are 23.57%, 8.47%, 55.92%.with NaOH treatment and 11.14% ,4.97, 63.70%.

The factors responsible for decrease in compressive strength is because the adhesive force is weaker in rubber cement combination as opposed to the highly adhesive nature between cement and natural sand, the tire rubber also has low elastic modulus and the addition of rubber also increases the air voids (Atahanand Yücel,2012)hence a decrease in mechanical properties is inevitable.

The use of NaOH treatment seems to be viable method to recover some of the strength. The treatment causes removal of zinc stearate over the rubber surface which is majorly responsible for previously discussed poor adhesion of rubber with cement (Segre et al.,2002)

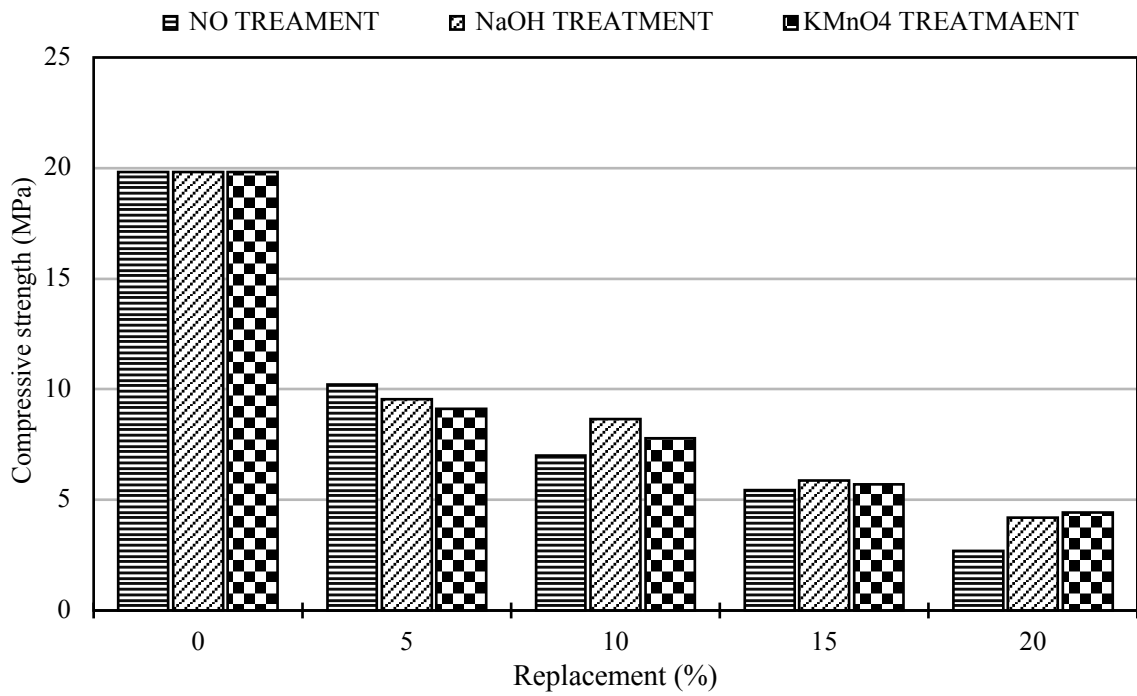


Figure 4.6 Compressive strength comparison at 7 Days

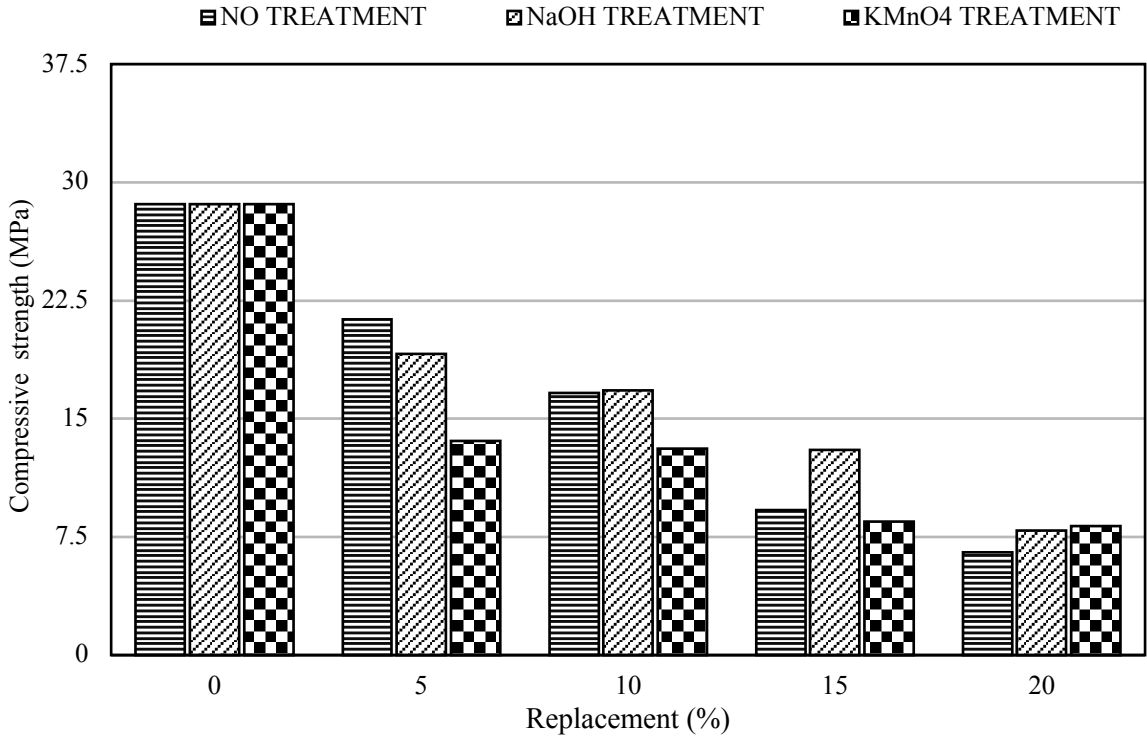


Figure 4.7 Compressive strength comparisons at 28 Days

28 days results of compressive strength are shown in Figure 4.7. It can be seen from the result that addition of rubber causes the compressive strength this can be explained by the fact that rubber has less load carry capacity as compared to sand due to soft nature, and also because it has smoother surface which hinder its capacity to for good bond with cement (Bisht and Ramana, 2017).

The loss of strength with increasing percentage of rubber at 5%, 10%, 15%, 20% was shown to be 25.52%, 41.85%, 67.83%, 77.16% for untreated rubber in concrete, and 33.21%, 40.94%, 53.81%, 72.37% for NaOH treated rubber concrete, and 52.44%, 54.19%, 70.38%, 71.22% for $KMnO_4$ treated rubber concrete. It can be observed that decrease in percentage strength (28 days) is less as compared to 7 days.

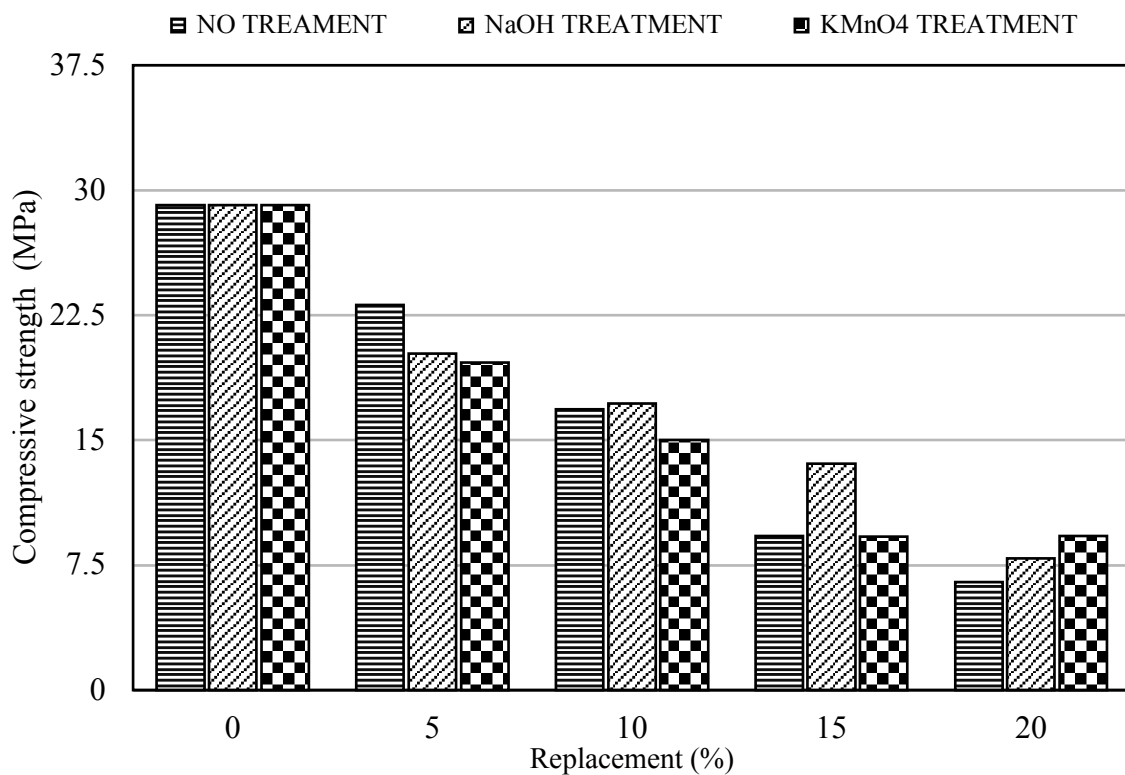


Figure 4.8 Compressive strength comparison at 56 Days

The results for 56 days are shown in Figure 4.8. The loss of strength at 56 days was 20.54%, 42.04%, 68.25%, 77.56% for untreated rubber concrete. The NaOH treatment helped to gain

some of the lost strength which was an improvement of about 5.16%, 3.78% , 47.18%, 22.22% over the untreated rubber at replacement level of 5%, 10%, 15%, 20% .The KMnO_4 treatment to rubber caused to increase the strength at 20% replacement level by 42.90%.

4.1.4 Split Tensile Strength

Split tensile strength of samples including tire rubber showed a decreased performance which is explained as same in previous mentioned case of compressive strength i.e. the weaker bond between rubber and cement. Table 4.13 shows the results for the split tensile strength for all the mixes prepared

Table 4.13 Split tensile strength (MPa) of rubberized concrete

Tire Replacement % age	Untreated rubber			NaOH treated			KMnO_4 treated		
	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days
0	1.89	2.67	2.71	1.89	2.67	2.71	1.89	2.67	2.71
5	1.46	1.75	1.76	1.34	2.35	2.38	1.48	2.01	2.15
10	1.08	1.71	1.71	1.37	1.97	2.00	1.23	1.62	2.09
15	1.05	1.72	1.77	1.35	1.51	1.61	1.1.	1.32	1.39
20	0.73	1.28	1.31	1.29	1.35	1.36	1.01	1.31	1.42

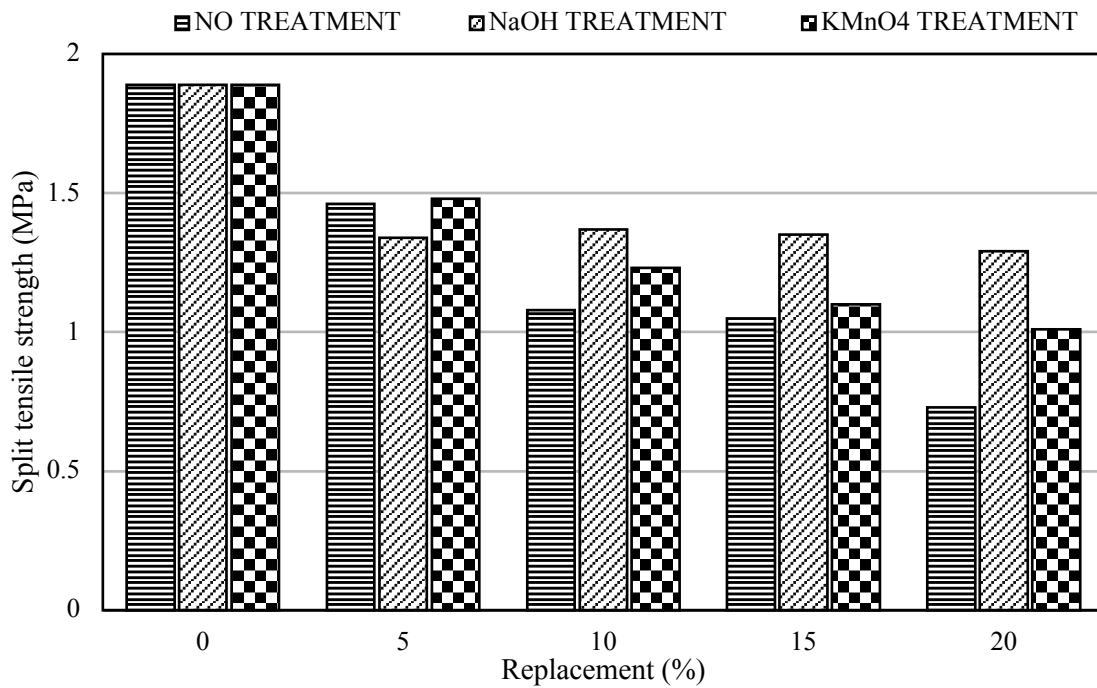


Figure 4.9 Split Tensile Strength at 7 Days

The value of 7 days split tensile (see Figure 4.9) strength when compared among the untreated rubber with the treated rubber suggests that the pre-treatment with NaOH was more successful as compared to KMnO₄, which in fact performed better than the untreated rubber.

The strength loss (split tensile) was about 22.75%, 42.85%, 44.44% , 61.37% for untreated rubber , 29.10%, 27.51% ,28.57%, 31.74%, for NaOH treated rubber, 21.69%, 34.92%, 41.79%, 46.56% for replacement of 5%,10%, 15%, 20% respectively.

The reason for the above mention results can be due to following reasons (a) inter facial zone area can lead to micro level cracks as the materials bonding formation is weak as a consequence of this concrete breakdown is accelerated (b) rubber addition can be held responsible for cavity action concentrated at a point leading to faster concrete failure (c)the region of segregation at boundary of bigger particles and cement paste may cause a low strength interfacial zone.(Ganjian et al.,2009)

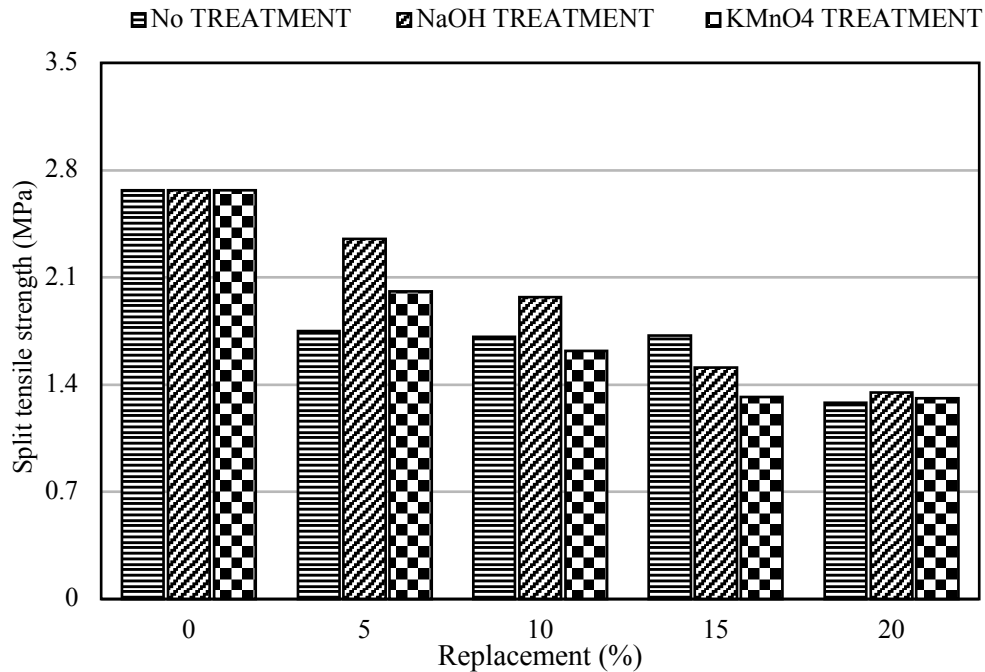


Figure 4.10 Split tensile strength comparison at 28 Days

The study of 28 days split tensile (see Figure 4.10) shows loss of strength with addition of rubber .It is seen that NaOH treated rubber performed better than untreated rubber at replacement level of 5%, 10% and 20 %. On the contrary the KMnO₄ treated rubber did not seem to have any improvement other than at 5% replacement levels. The loss of strength for untreated rubber was 34.45%, 35.95%,35.58%,52.05% , for NaOH treated rubber was 11.98%, 26.21%, 40.82%, 49.43% and for KMnO₄ the loss in strength was 24.71%, 39.32%, 50.56%, 50.93%. The results are in agreement with Su et. al. (2015) reporting which also showed a decreasing value with tire rubber addition.

The reason for the decrease in split tensile strength is the water repellent nature of rubber used in tire leading to a higher contact angle with water in addition to more thickness of water film leading to an overall more porous arrangement at the cement –aggregate interface, leading to lower bond strength (Ganjian et al.,2009).

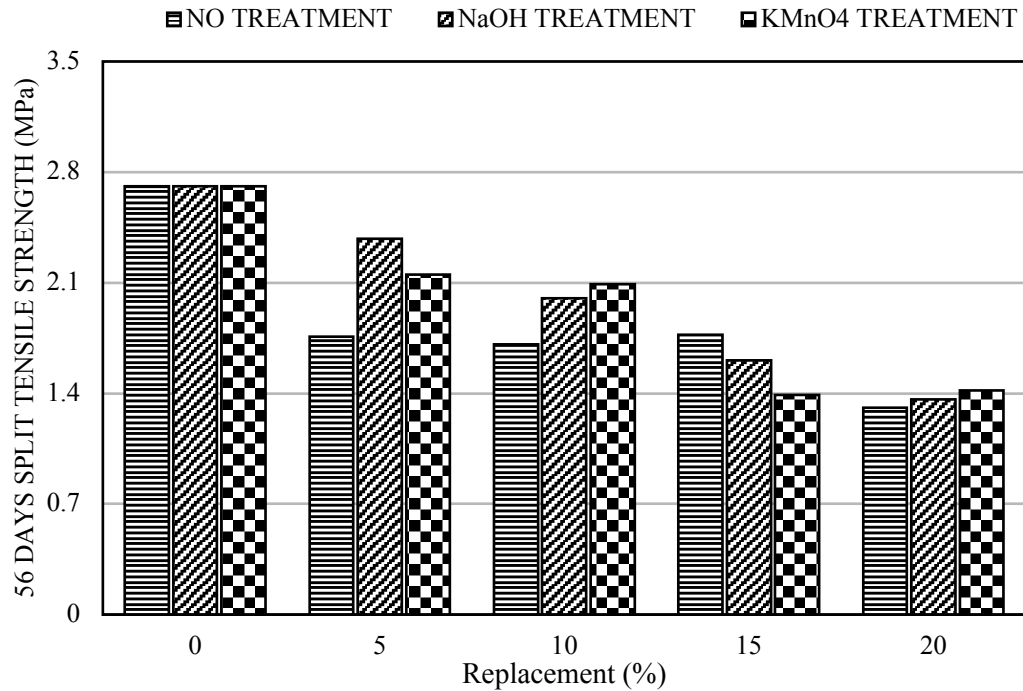


Figure 4.11 Split tensile strength comparison at 56 Days

The results of 56 days split tensile strength are shown in Figure 4.11. The NaOH treatment helped to recover some of the strength at 5% , 10%, and 20% and KMnO₄ improved the strength at 5%, 10% and 20 % replacement levels. The loss of strength in terms of percentage was for untreated rubber was 35.05% , 36.90% , 34.68%, 51.66% , for NaOH treated rubber concrete was 12.17% ,26.19% , 40.59%, 49.81% and for KMnO₄ treated rubber concrete was 20.66%, 22.87%, 48.70%, 47.60%.

The maximum split tensile strength for the replacement was observed in 5% replacement with NaOH treated rubber concrete. The KMnO₄ treated particles showed maximum value in comparison to other rubber replacement was at 10% replacement.

The reason for increase in strength in case of KMnO₄ may be due to reason that the treatment caused a decrease in contact angle hence alleviate some of the hydrophobicity of rubber (Kashani et al., 2018)

4.1.5 Rapid Chloride Permeability Test

Table 4.14 Charge passed in RCPT of rubberized concrete

Tire replacement %age	CHARGE PASSED (Coulombs)								
	Untreated rubber			NaOH treated			KMnO4 treated		
	7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
0	3850	2891	1347	3850	2891	1347	3850	2891	1347
5	2699	2402	1187	2464	1927	1009	2789	2475	1215
10	3305	2661	1701	3189	2393	1621	2350	3491	1865
15	5246	3938	1889	4423	3499	1723	4891	3896	2294
20	7385	4156	2280	6788	3724	2645	6009	3902	3101

The results of Rapid Chloride penetration test which is a durability test are reported in Table 4.14. The value of results for 7 day performance to the allowance of charge passing through the concrete shows that the value of charge passed decrease till replacement level upto 5% but later increase till the replacement level upto 20 % .This phenomenon is in agreement with research reported by *Onuaguluchi and Panesar (2014)* which was explained by the fact that the addition of tire rubber which is an insulator reduces the value of charge passed as opposed to reference mix but soon after increasing the replacement above 5% the value start to increase till replacement upto 20% this is due to fact that after 5% but after that the value increased as other factors like moisture content, microstructure, amount of voids started to play the dominant role. The results are opposed to findings of *Oikonomou and Mavridou(2009)* which showed a decreasing trend with the increase in percentage of replacement.

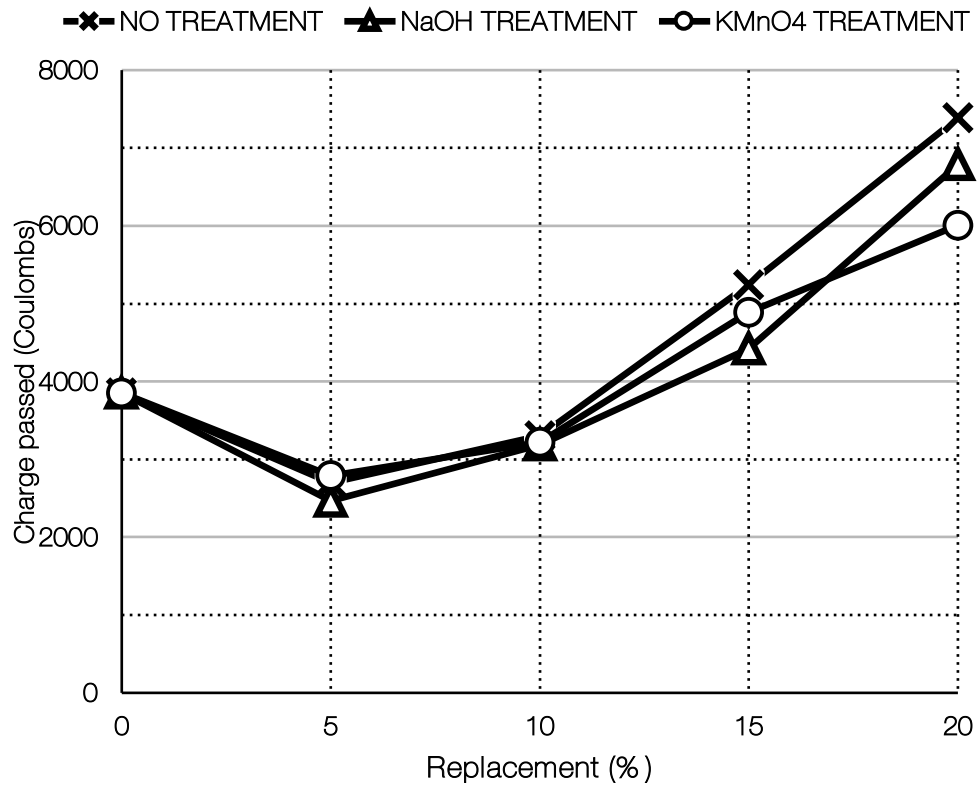


Figure 4.12 Charge passed comparison (RCPT) at 7 Days

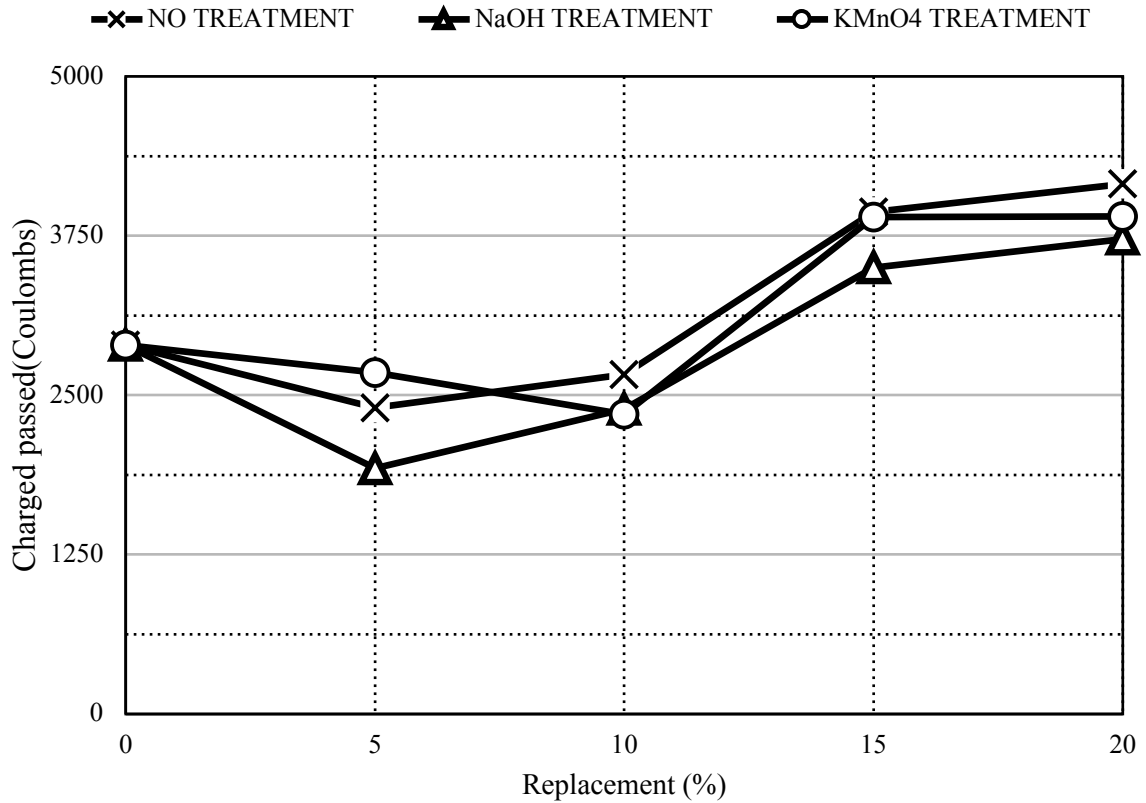


Figure 4.13 Charged passed comparison (RCPT) at 28 Days

The charge passed comparison at the end of 28 days (see Figure 4.13) curing period shows that the NaOH treated rubber concrete shows least value at all the replacements this can be due to the fact that NaOH treatment enhances the bond strength of the rubber with cement and hence forms a dense packing and thereby disrupting the flow of charge through sample.

The KMnO₄ shows the higher value of charged passed as opposed to NaOH treated rubber this phenomenon may be due to the fact that due to presence of K⁺ ions which may have adhered to surface of rubber during the treatment process .

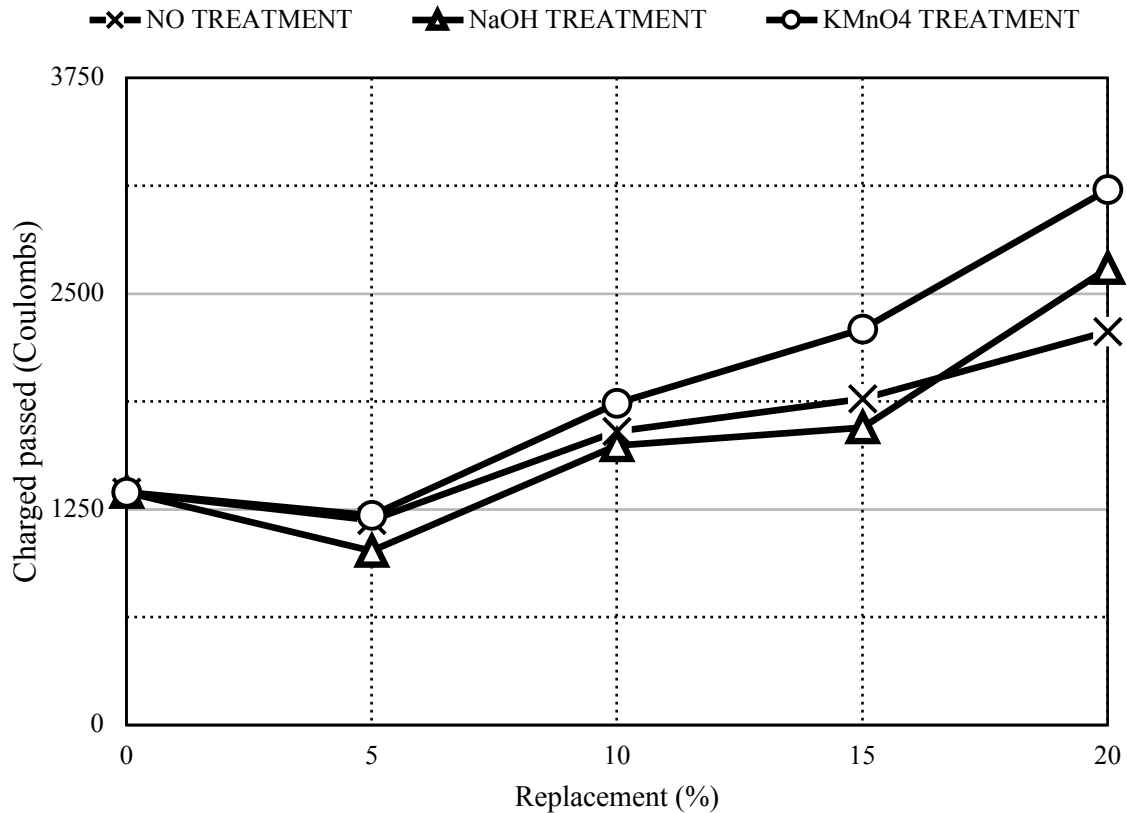


Figure 4.14 Charge passed comparison (RCPT) at 56 Days

A comparison with 28 days and 56 days will show that values of charge decreased, this can be easily understood by the fact that with age the CSH compounds concentration increases as the hydration of concrete is increased to due availability of moisture. The least value is shown by NaOH treated rubber at 5% replacement. So we can conclude that we can have better durability in concrete samples with 5% replacement of NaOH treated rubber.

4.1.6 SEM - EDS Analysis

For study of the composition and to view microstructure of the samples SEM-EDS was performed. The SEM images of the samples which was achieved with Scanning electron (SE) can be seen in Figure 4.15 – 4.22. The internal morphology depicting several different phases such as calcite (C), calcium silicate hydrate (CSH), portlandite (CH), ettringite (E), Tire (T) are marked on images with higher magnification.

Careful analysis of the SEM images shows high amount of CSH in case of reference mix which also show dense internal structure of the sample which impart strength to the concrete. In reference specimen Figure 4.15 a dense structure and higher amount of CSH gel formation is seen as compared to T5, T15N, T10K.

Addition of 5% of untreated rubber (T5) (see Figure 4.16) shows a large area under voids and large volume of ettringite which confirms our previous results for decrease in compressive and split tensile strength.

The T15N mix shows low volume of voids and ettringite. Calcite formation can be seen which develops strength factor of concrete.

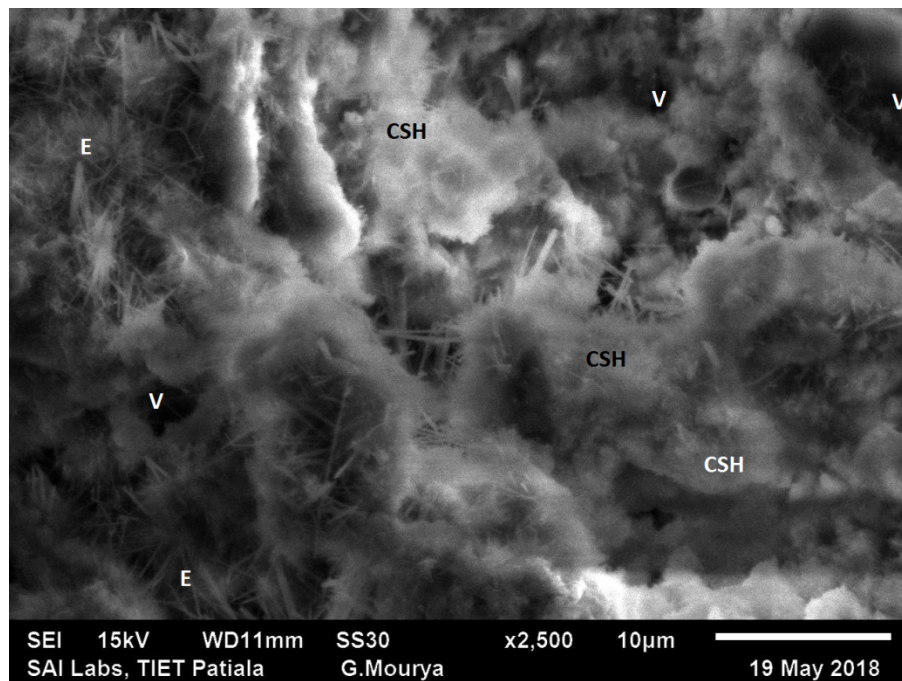


Figure 4.15 SEM EDS Analysis of Reference Mix(T0)

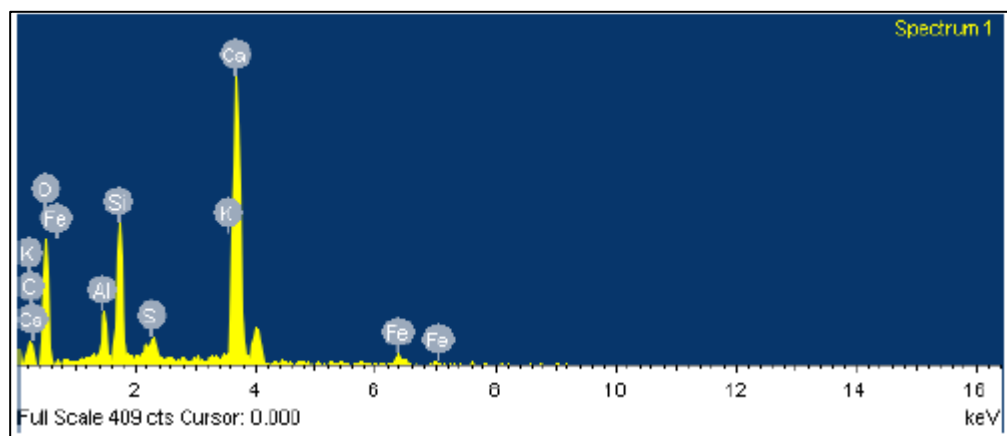
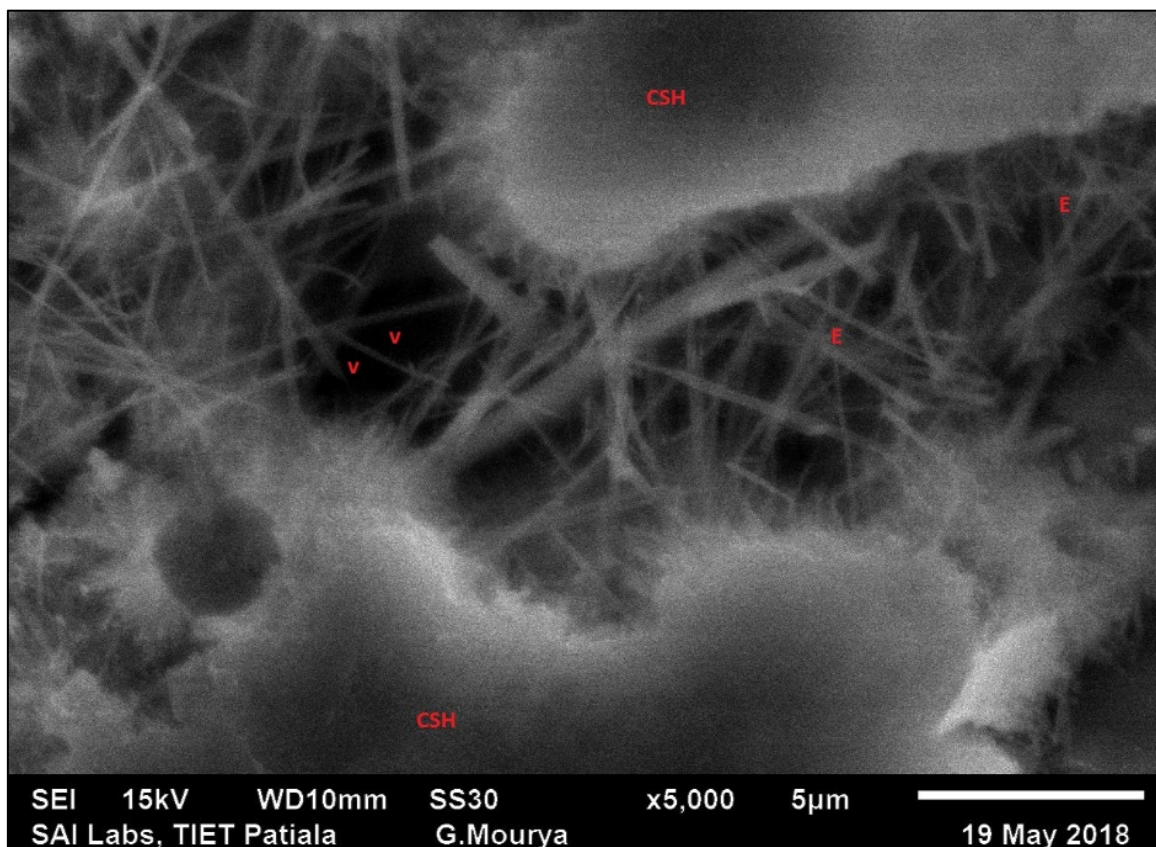


Figure 4.16 SEM EDS Analysis of Reference Mix(T0)

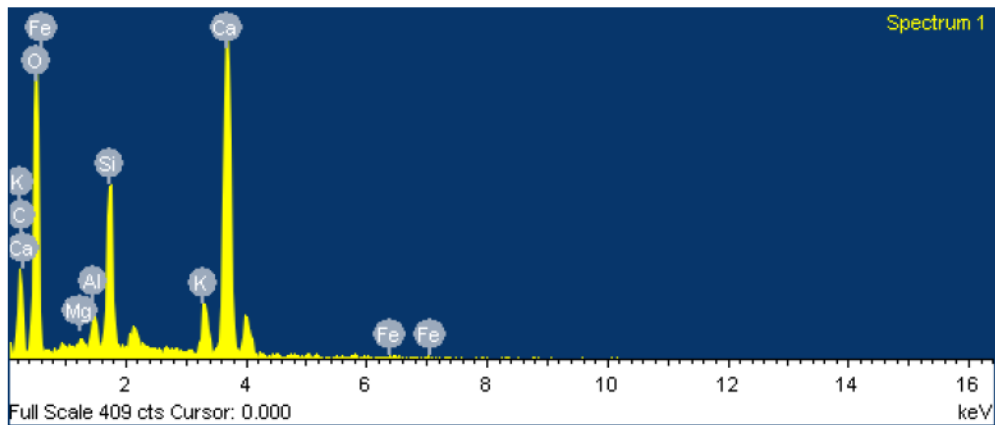
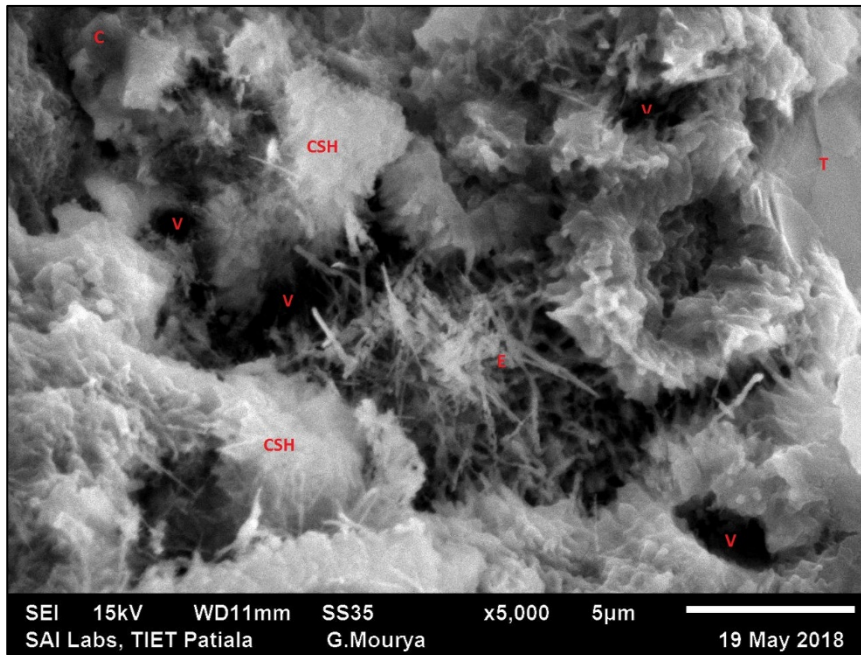
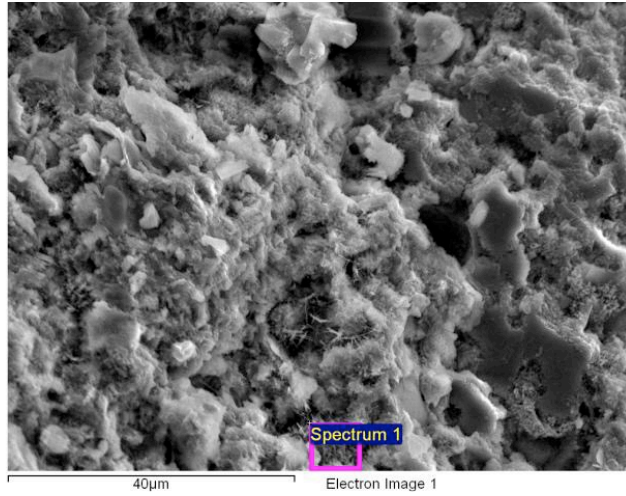


Figure 4.17 SEM EDS Analysis of Mix (5% Untreated Tire)(T5)

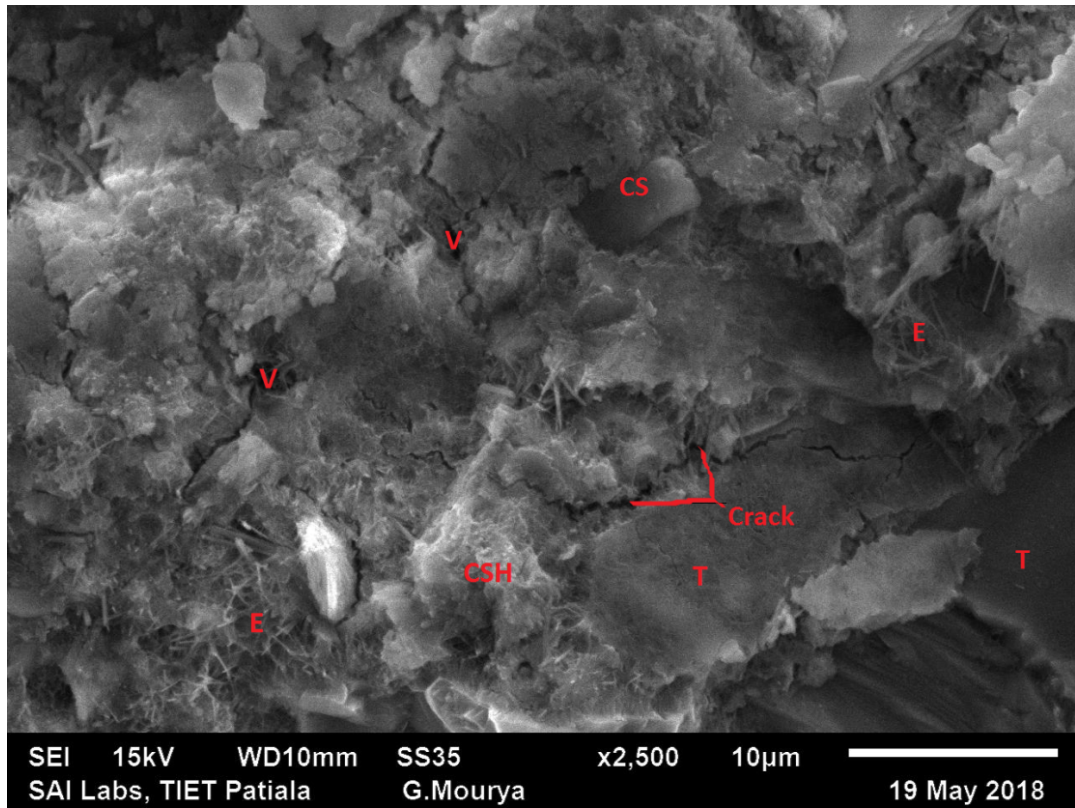


Figure 4.18 SEM EDS Analysis of Mix (15% Untreated Tire)(T15)

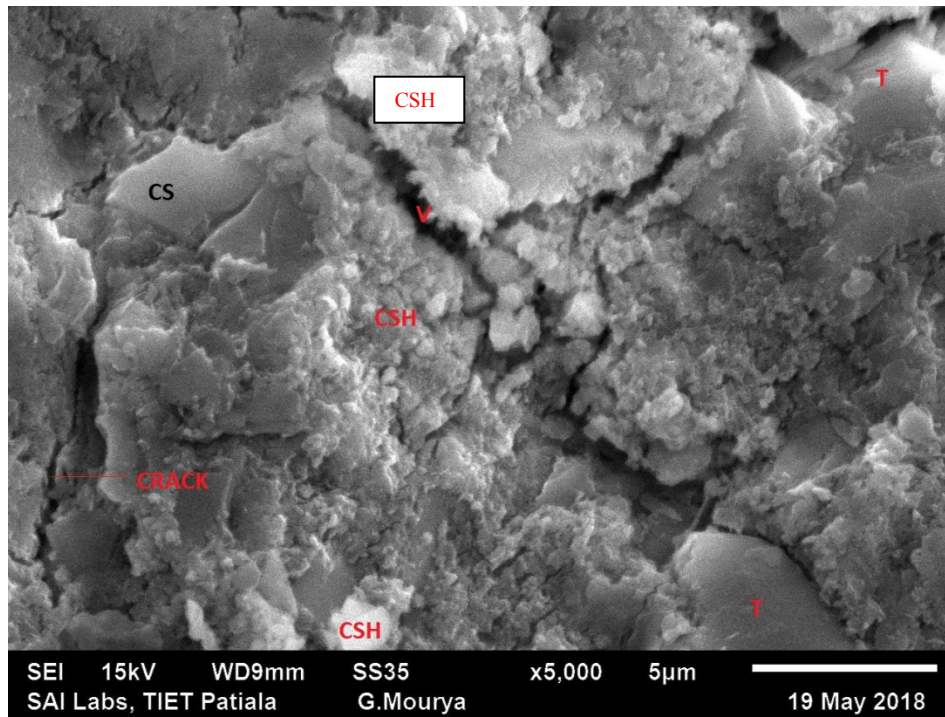
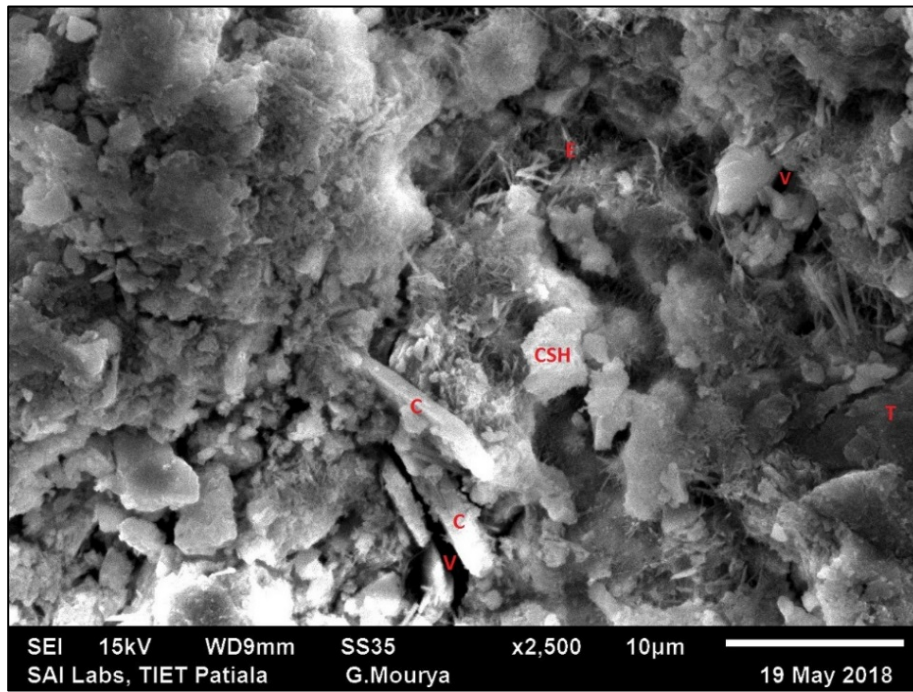


Figure 4.19 SEM- EDS analysis of Mix 15% NaOH treated tire rubber(T15N)

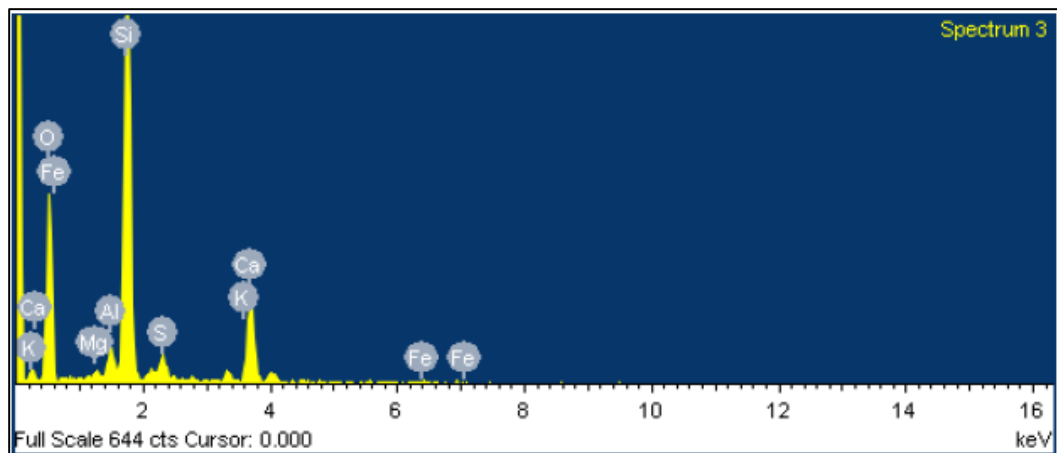
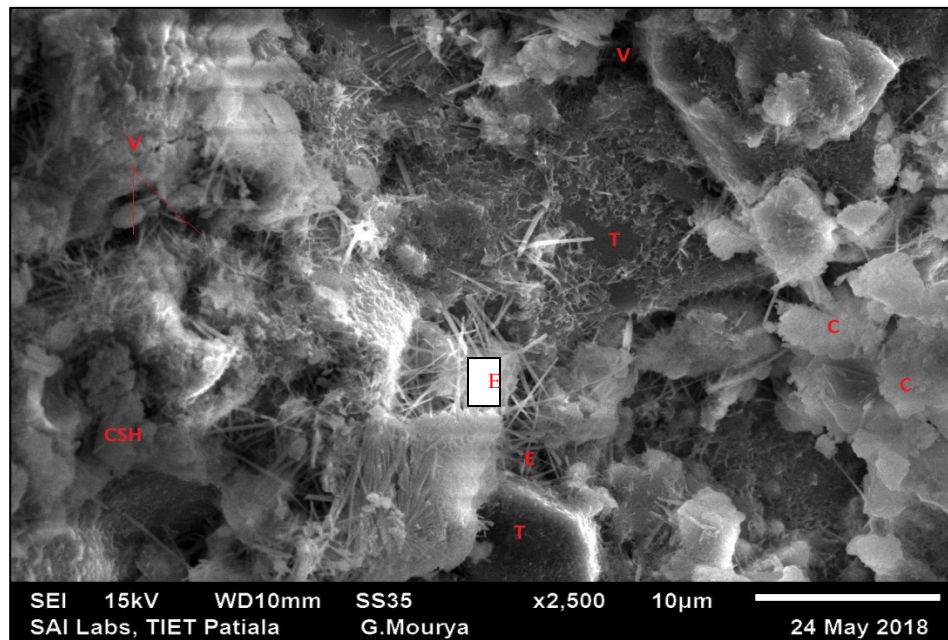
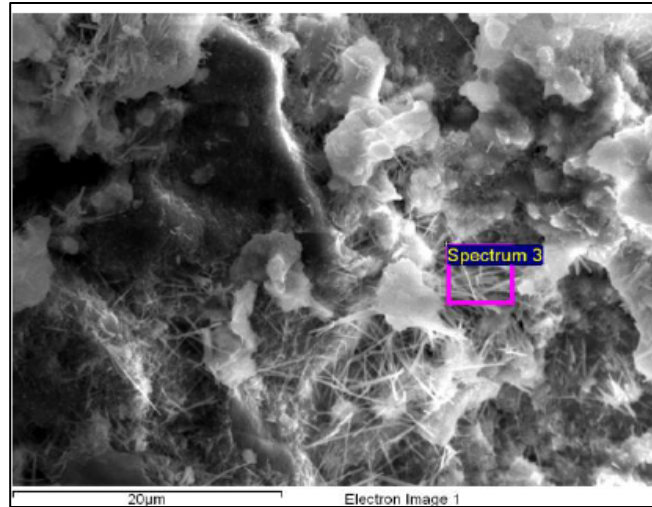


Figure 4.20 SEM EDS Analysis of Mix 10% KMnO_4 Treated Tire (T10K)

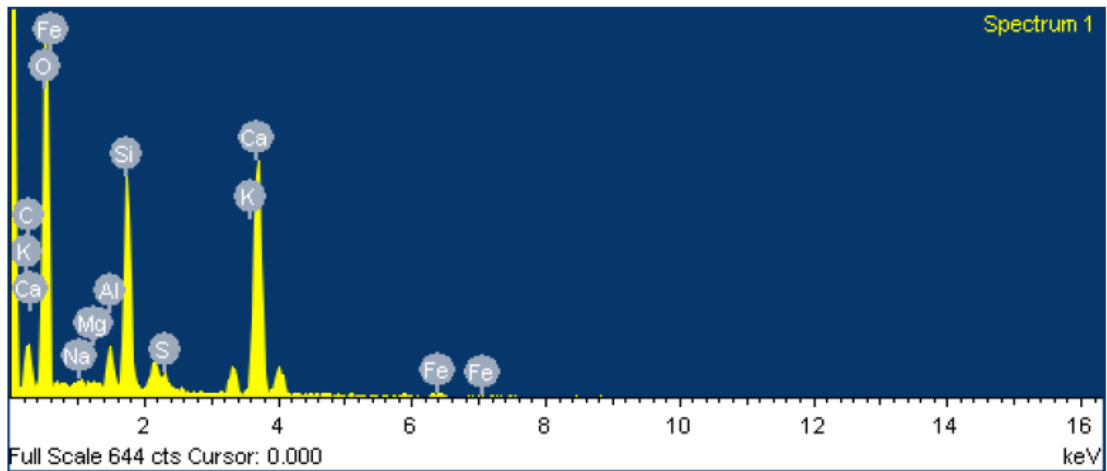
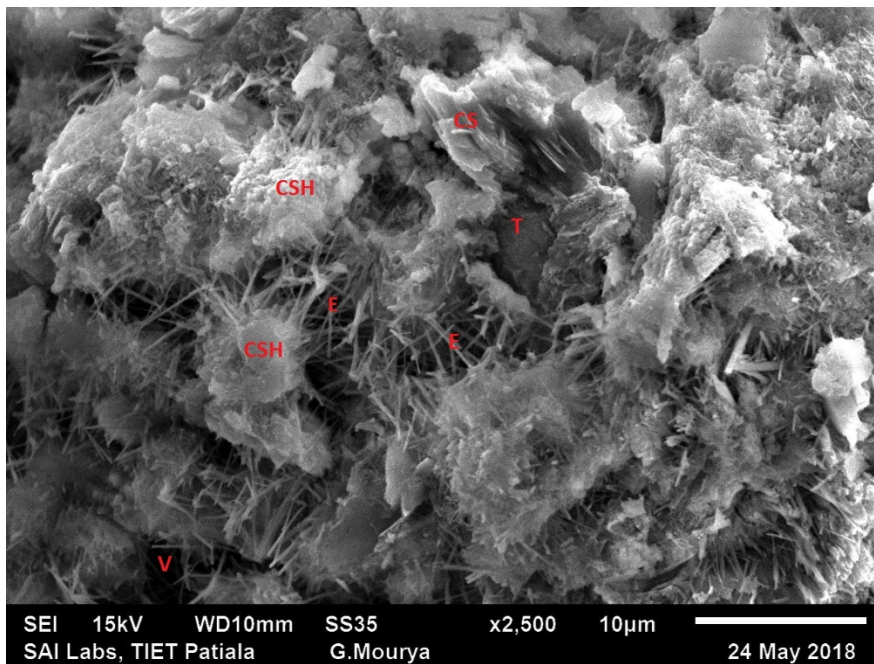
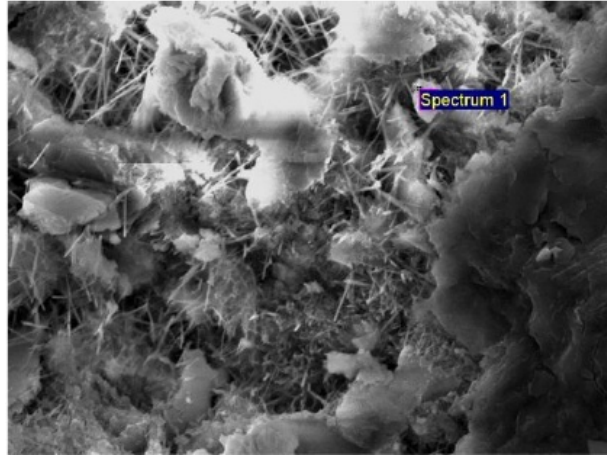


Figure 4.21 SEM EDS Analysis of Mix 20% KMnO_4 Treated Tire(T20K)

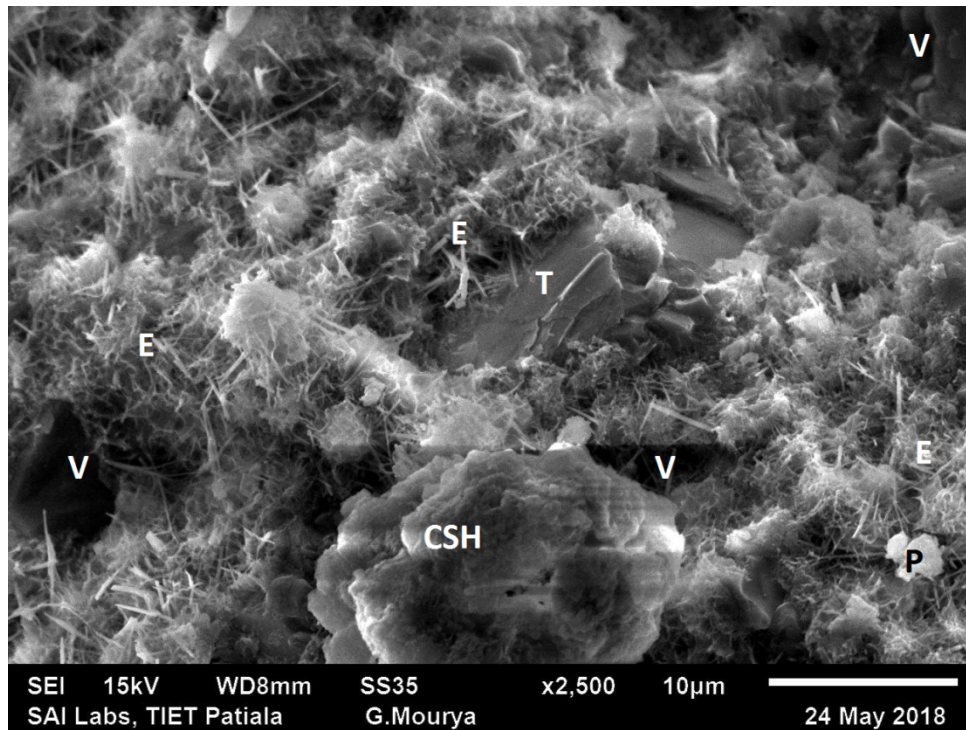


Figure 4.22 SEM EDS Analysis of Mix 15% KMnO₄ Treated Tire(T15K)

4.1.7 X-Ray Diffraction Results

The X-Ray diffraction technique is a useful technique to identify the formation of major internal composition materials like calcite formation, CSH GEL etc. which can help to identify the reasons for the physical properties of concrete. XRD analysis showed presence of quartz(Q), ettringite (E) calcite (C) by showing clear peaks. The presence of CSH gel was seen in form of bump from 25 to 35 degree (2 θ). The reference mix showed more value of CSH formation giving it better strength properties as compared to rubber concrete. NaOH treated rubber concrete showed some more formation of CSH as compared to untreated rubber hence showed some increase in mechanical property. KMnO₄ treated rubber also some improved formation of CSH gel as compared to untreated rubber concrete. The results for mix T0, T5, T5N, T15N, T10K, T15K are shown in Figure 4.23 through Figure 4.28.

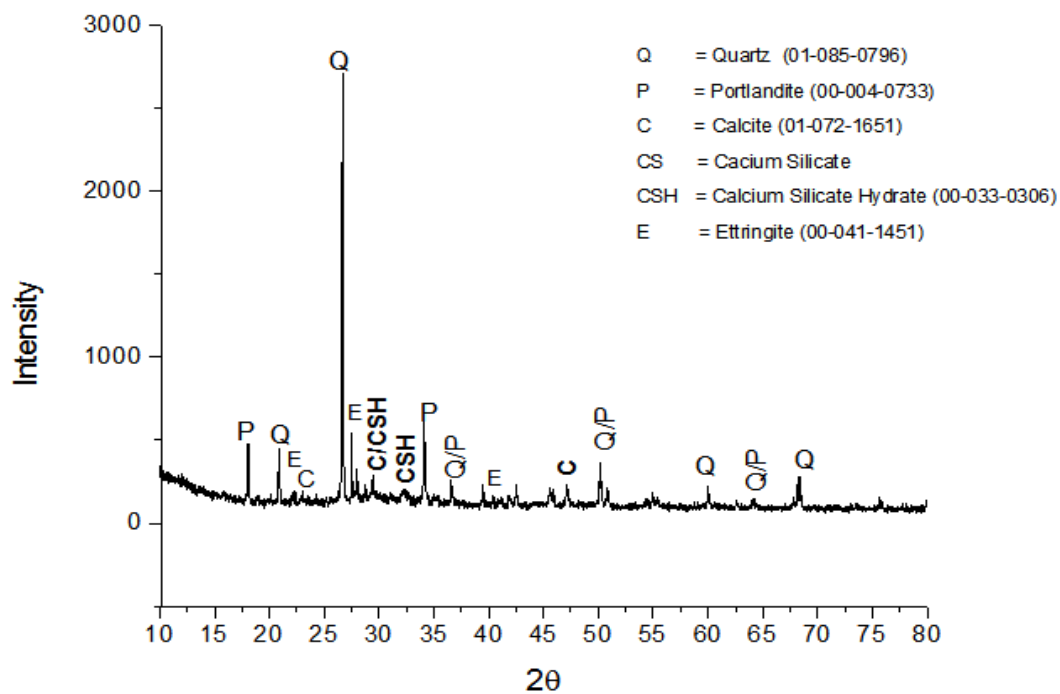


Figure 4.23 XRD Analysis of reference mix(T0)

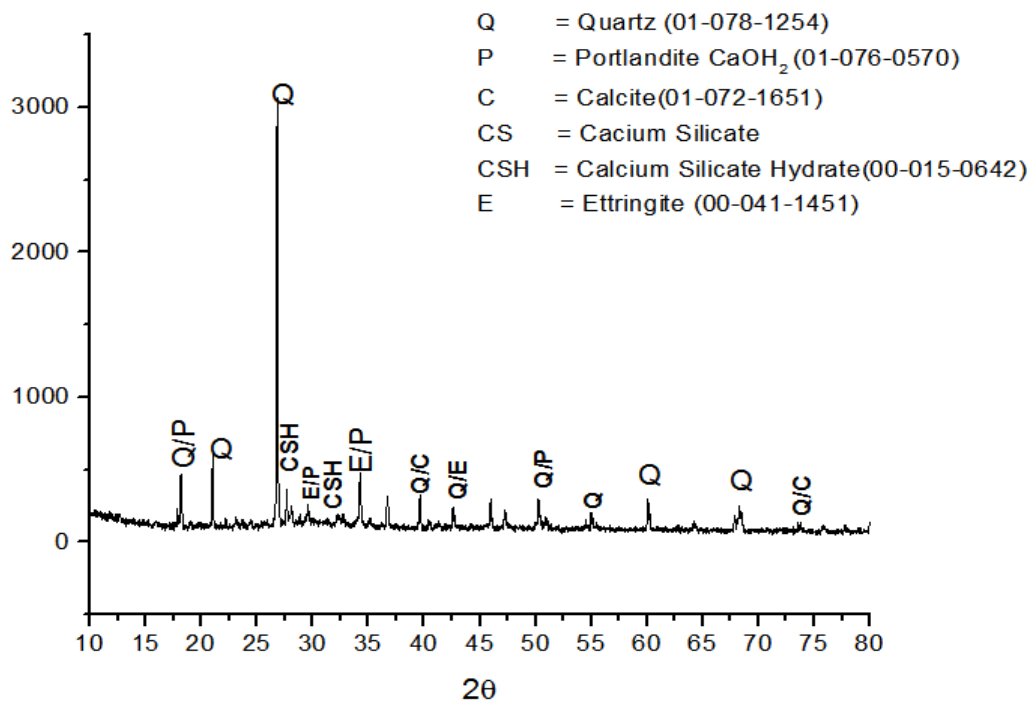


Figure 4.24 XRD analysis of Mix (5% Untreated Tire)(T5)

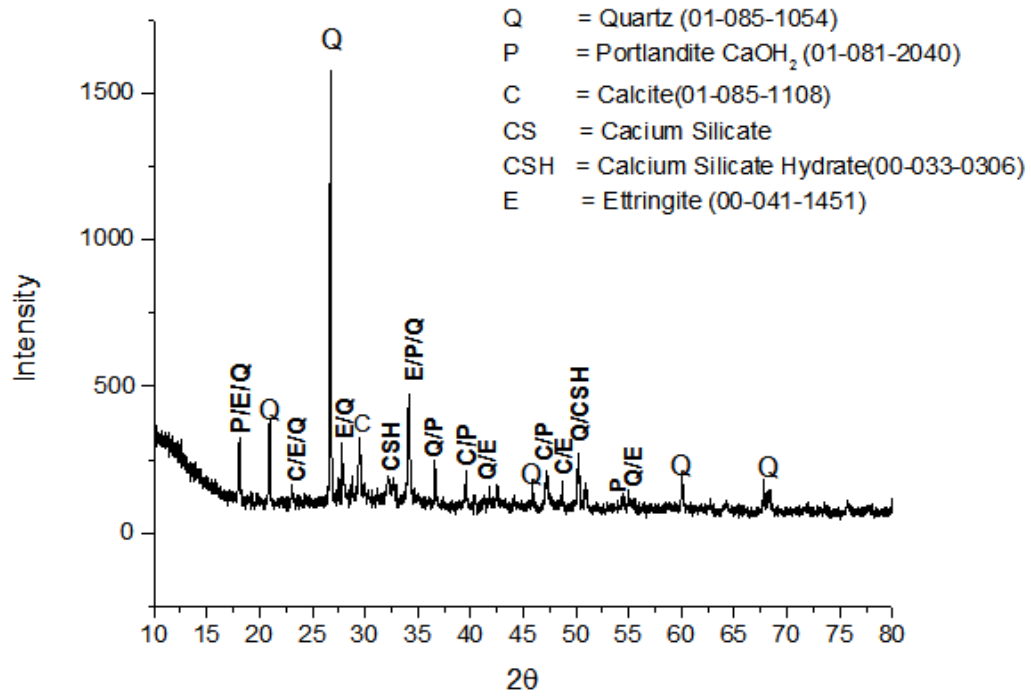


Figure 4.25 XRD analysis of Mix 5% NaOH treated tire rubber(T5N)

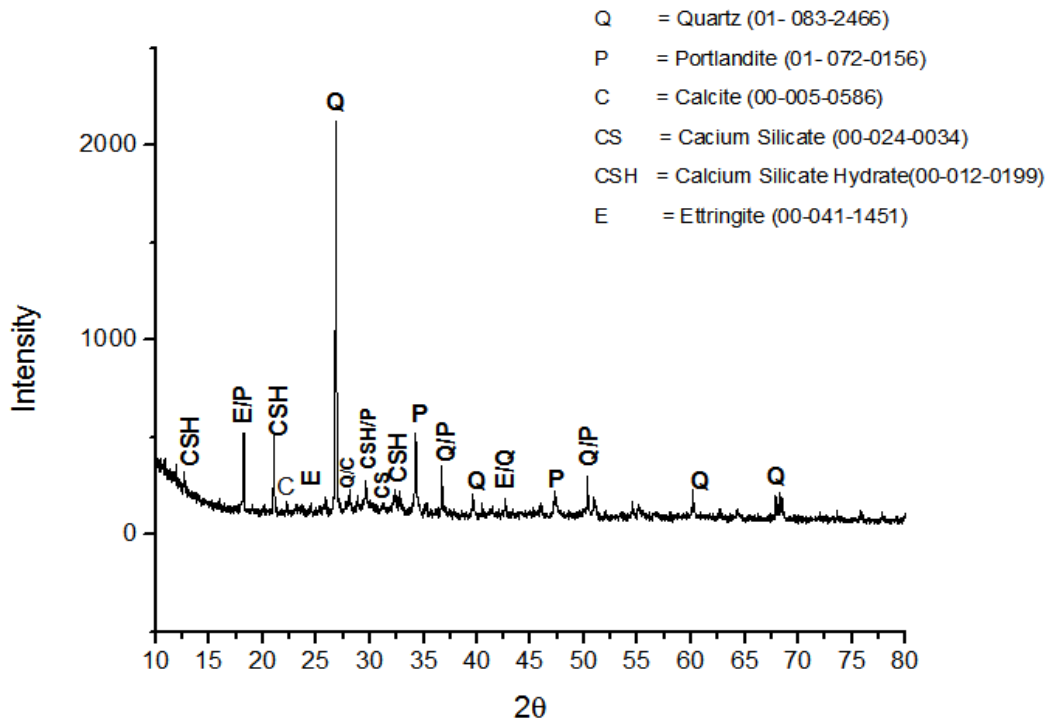


Figure 4.26 XRD analysis of Mix 15% NaOH treated tire rubber(T15N)

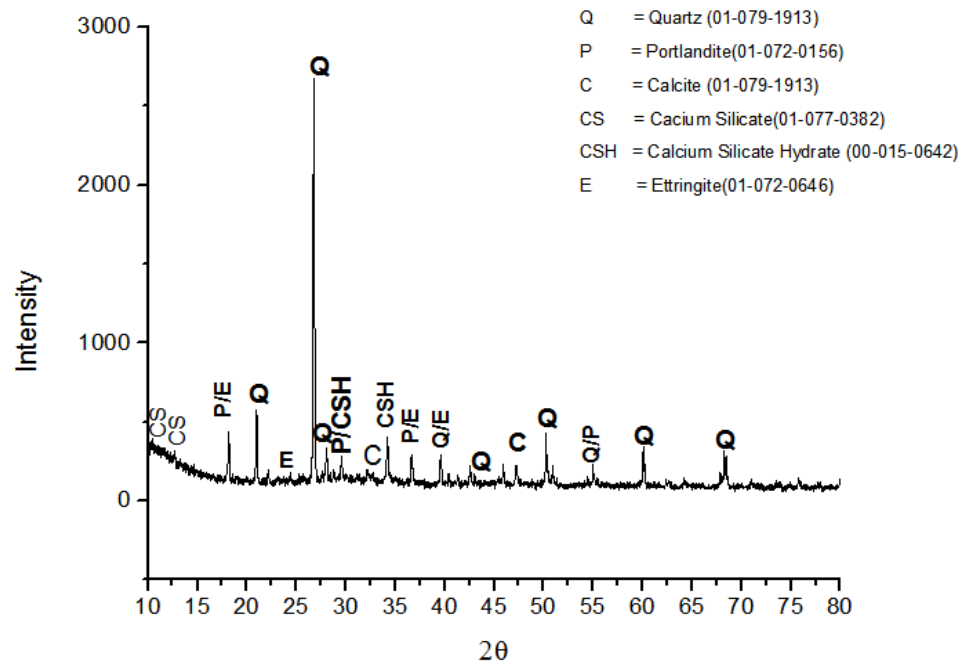


Figure 4.27 XRD Analysis of Mix 10% KMnO₄ Treated Tire(T10K)

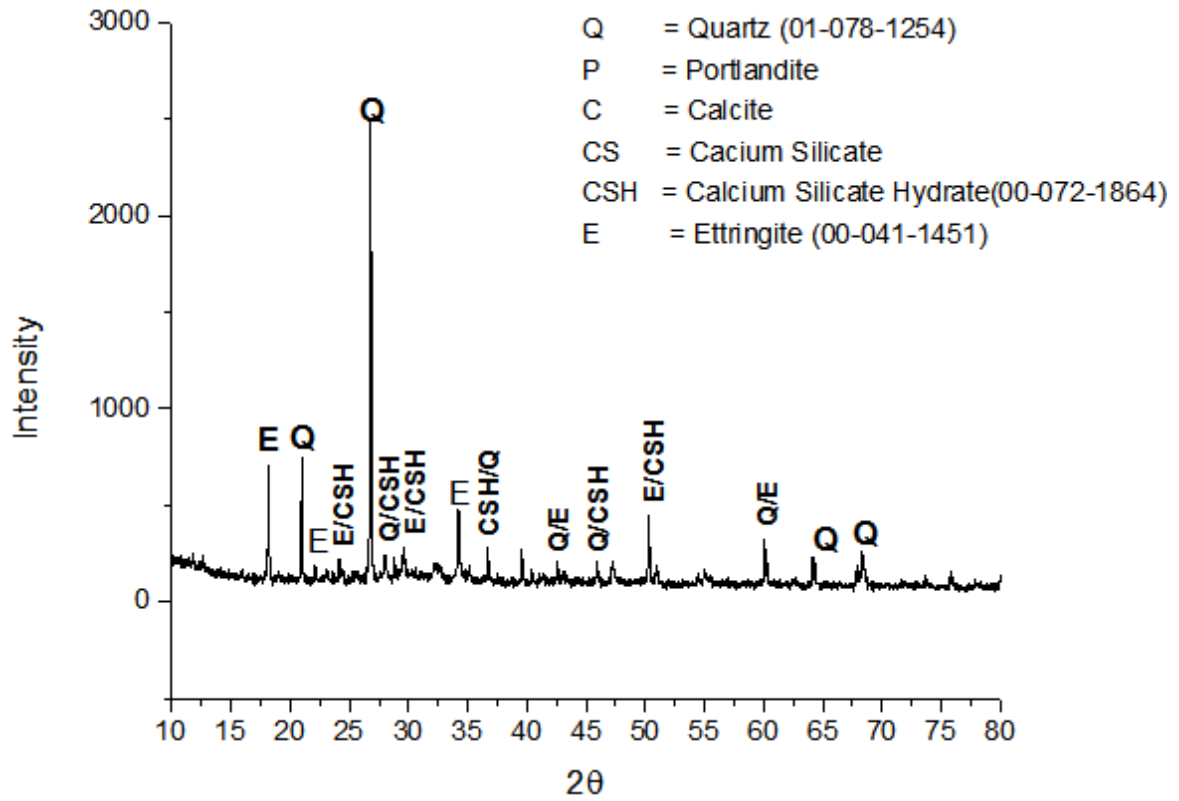


Figure 4.28XRD Analysis of Mix 15% KMnO_4 Treated Tire(T15K)

5.0 CONCLUSIONS

The results of the present study involving the comparison of reference concrete with the rubberized concrete and the concrete containing treated rubber can be concluded as following:

5.1 WORKABILITY

- The addition of rubber cause a loss of slump hence workability decreased as replacement level decreased.
- The lowest slump was observed at 20% replacement of sand
- The use of treated rubber did not affect workability in any significant way
- Use of plasticizer is recommended for an easy workable mix

5.2 HARDENED DENSITY

- The hardened density of the concrete decrease with addition of rubber hence giving light weight concrete.
- The min value of 18.97kN/m³ was observed at 20% replacement level of sand.

5.3 COMPRESSIVE STRENGTH

- The various mixes showed a decrease in value of compressive strength with the partial addition of crumb rubber
- The minimum value of compressive strength was 20% replacement of sand with crumb rubber at all days. The loss of strength with increasing percentage of rubber at 5%, 10%, 15%, 20% was shown to be 25.52%, 41.85%, 67.83%, 77.16% for untreated rubber in concrete, and 33.21%, 40.94%, 53.81%, 72.37% for NaOH treated rubber concrete, and 52.44%, 54.19%, 70.38%, 71.22% for KmnO₄ treated rubber concrete. It

can be observed that decrease in percentage strength (28 days) is less as compared to 7 days. Similar trend of strength loss was seen at 56 days also.

- Using NaOH proved to be beneficial in recovery of some of the lost compressive strength whereas use of KMnO_4 did not prove any appreciable improvement of property other than at 20% replacement.
- All the mixes showed a strength increase with age regardless of the mix

5.4 SPLIT TENSILE STRENGTH

- Splitting tensile strength displayed same trend as compressive strength because split tensile strength also decrease with increase in sand replacement with crumb rubber
- Minimum split tensile strength was observed in untreated rubber concrete as treatment to rubber had a positive effect on split tensile strength.
- The split tensile strength increased with age in all mixes
- The loss of strength for untreated rubber was 34.45%, 35.95%, 35.58%, 52.05% , for NaOH treated rubber was 11.98%, 26.21%, 40.82%, 49.43% and for KMnO_4 the loss in strength was 24.71%, 39.32%, 50.56%, 50.93%
- NaOH improved split tensile strength with KMnO_4 treated rubber also exhibiting some improvement

5.5 RAPID CHLORIDE PERMEABILITY TEST

- The chloride permeability showed decrease in value upto 5 % replacement but showed steady increase after that upto 20% replacement
- At 7 days values were in high range for 15 and 20% replacement but at 28 days the values became moderate hence showing denser packing in later stage.
- At 56 day the values were in moderate range for all mixes.
- The min value (1009 coulombs) was observed for 5% replacement with NaOH treated rubber at 56 days testing age

After the careful analysis of the studies done on rubberized concrete it is observed that while some properties are improved in advantageous way other properties may see some disadvantages. Some advantages associated with use of rubber in concrete are lower density hence light in weight, more ductility, better chloride ion penetration resistance. The disadvantages include decrease workability, decrease in mechanical strength, increasing water absorption which can lead to corrosion of reinforcement.

The use of chemical treatment of tire rubber with NaOH before use has shown to be promising in improvement of some of the properties of concrete however KMnO₄ treated did show some improvements to concrete properties as opposed to untreated rubber yet still the results were not quite satisfactory as NaOH treated rubber. It can be concluded that 5% replacement of rubber may be used satisfactorily in many non-structural applications.

It is safe to assume on basis of advantages introduced by rubber to concrete that rubberized concrete can be used for crash barriers, side walk, as shock absorber in earthquake resistance buildings, as sound barrier walls in factories, and areas where resistance to high impact load like in case of rail foundations, base of vibration inducing machinery, railway buffers, ship docks, bunkers etc. where resistance to impact or explosion is required like using as bedding for pipes and paving slabs, it can also have practical application where upto 5 % replacement of rubber can be used to protect the embedded reinforcing steel bars from corrosion.

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