B. TECH. PROJECT REPORT

On

STUDY OF FREEZE AND THAW PERFORMANCE OF RUBBER FIBER INCORPORATED CONCRETE

BY

SUYASH GANDHI

(160004016)

DISCIPLINE OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY INDORE

NOVEMBER 2019

STUDY OF FREEZE AND THAW PERFORMANCE OF RUBBER FIBER INCORPORATED CONCRETE

A PROJECT REPORT

Submitted in partial fulfillment of the

requirements for the award of the degrees

of

BACHELOR OF TECHNOLOGY

in

CIVIL ENGINEERING

Submitted by:

SUYASH GANDHI (160004016)

Guided by:

PROF. SANDEEP CHAUDHARY

INDIAN INSTITUTE OF TECHNOLOGY INDORE

NOVEMBER 2019

<u>CANDIDATE'S DECLARATION</u>

I hereby declare that the project entitled **"STUDY OF FREEZE AND THAW PERFORMANCE OF RUBBER FIBER INCORPORATED CONCRETE"** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in 'CIVIL ENGINEERING' completed under the supervision of **PROF. SANDEEP CHAUDHARY, DISCIPLINE OF CIVIL ENGINEERING,** IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student with date

<u>CERTIFICATE by BTP Guide</u>

It is certified that the above statement made by the students is correct to the best of my/our knowledge.

Signature of BTP Guide with dates and their designation

Preface

This report on “Study of freeze and thaw performance of rubber fiber incorporated concrete" is prepared under the guidance of Prof. Sandeep Chaudhary.

Through this report, I have tried to explain the effect of incorporation of waste tire rubber fiber in concrete to study its freeze-thaw resistance. The mechanical and durability properties of rubberized concrete.

I have tried to the best of my abilities and knowledge to explain the content in a lucid manner. I have also added graphs and figures to make it more illustrative.)

SUYASH GANDHI

160004016

B.Tech. IV Year

Discipline of Civil Engineering

IIT Indore

Acknowledgments

I wish to thank Prof. Sandeep Chaudhary for his kind support and valuable guidance.

It is his help and support, due to which I became able to complete the experiment and technical report.

Without his support, this report would not have been possible.

I also Thank Akshay Thakare and Sapan Gaur for assisting me with the experiments.

Suyash Gandhi

160004016

B.Tech. IV Year

The discipline of Civil Engineering

IIT Indore

Abstract

Freezing-thawing leads to the deterioration of concrete structures in cold regions. Conventional methods use costly air-entraining agents for enhancing the freeze-thaw resistance of concrete. Therefore an alternative method for increasing the durability of concrete is required. In this study, recycled waste rubber tire fibers of size 0.6 mm-4.75 mm are used as a partial replacement of fine aggregate by volume at 5%, 10%, 15%, and 20% replacement levels. Freeze-thaw performance is evaluated through mass loss, Ultrasonic pulse velocity and residual compressive strength. Mechanical properties such as compressive strength, split tensile strength, impact resistance and durability property of abrasion are also tested. Results show that the inclusion of rubber fiber enhanced Freeze-thaw resistance. Abrasion resistance and impact strength were also increased at a higher percentage of Rubber fiber incorporation.

Table of Contents

List of Figures

List of Tables

1. Introduction

Concrete to be used in regions that experience harsh environmental conditions such as freezing temperatures must withstand the effect of repeated freezing-thawing during its service life. The durability of concrete is reduced due to the effect of freezing-thawing [1,2]. The main reason which leads to a decrease in durability in such condition is the drastic change in temperature. If the temperature falls below the freezing point of water, the water present inside cavities in concrete freezes, thus exhibiting volume change. The increase in volume due to the formation of ice produces internal stresses if it gets no space to expand. The tensile strength of concrete is low due to its rigidity; thus can lead to the formation of cracks. Traditionally air entraining admixtures are used to increase air voids, which can act as a pressure release system during freezing of water, increasing resistance to freezing-thawing. This method is used only for significant building elements due to its high cost. Lower cost alternative for freeze-thaw resistance has to be used. This study focuses on the use of recycled waste tire rubber fiber as partial replacement of fine aggregate in normal concrete. The freeze-thaw resistance is expected to increase by the inclusion of waste tire rubber fibers.

According to the European Tire Recycling Association (ETRA), each year in the 28 European member states and Norway, around 300 million post-consumer tires are discarded as waste [3]. By the year 2030, the number can reach up to 1200 million tires per annum, representing almost 5000 million tires (including stockpiled) to be discarded on a regular basis [4]. Vehicle tires are made up of durable polymers that require about a century to decay. Existing disposal methods of waste tires such as Stockpiling, landfilling, burning are Hazardous to the Environment [5]. The increase in waste rubber tires and their inappropriate disposal leads to hazardous environmental impacts. Also, according to Forbes, due to the depleting source of natural river sand, the price has quadrupled in the last three decades. Thus inclusion of waste tire rubber fiber as a partial replacement for natural river sand improves sustainability by preventing environmental pollution as well as conserving natural aggregate from depletion without an increment in the cost.

Many studies have been carried out on the inclusion of rubber as a replacement of fine aggregate [3,6–8]. The inclusion of waste tire rubber in concrete has significant effects on the physical and mechanical properties of the concrete. According to Gupta et al. [9], with increasing rubber ash content, the workability of rubber ash concrete decreases and the compressive strength of the rubberised concrete also decrease to a certain extent. The air content increases with the increasing percentage of rubber replacement [8,10]. Thus rubber particles can be used as an alternative to air-entraining agents. Furthermore, Angelin et al. [11] reported that rubber particle shape influences the porosity of concrete. Rubber fiber is able to introduce more voids than granulated and also act as a bridge between the cement matrix. In previous studies done by Gupta et al. [8], it was observed that the plain concrete, when exposed to freezing-thawing, deteriorated more compared to the concrete with crumb rubber additions. Yet, to the best of the knowledge of the author, no study has been conducted on freeze-thaw resistance of concrete using waste tire rubber in form of rubber fibers as a replacement of fine aggregate by volume.

2. Experimental studies

2.1. Materials

Concrete mixtures were cast using ordinary Portland cement (OPC) 43 grade. High range water-reducing (HRWR) admixture superplasticizer (MasterGlenium SKY 8777) was used. Fig. 1 shows the aggregate materials used in this study. Natural river sand having a specific gravity (SG) of 2.65 was used as fine aggregates. Naturally available crushed stone was used as coarse aggregates with two different sizes of 10 mm and 20 mm, having SG of 2.85 and 2.88, respectively. Rubber aggregates used in the present study were produced by mechanical shredding of waste tire rubber. The rubber fiber (RF) of size 0.6-4.75 mm was used as partial replacement of FA by 5%, 10%, 15%, 20% by volume. The specific gravity of rubber fiber used was 1.12. Fig. 2 shows the particle size distribution of all aggregates used in this study obtained. Physical properties of raw materials is shown in Table 1.

Figure 1 Raw materials used as concrete ingredients

Table 1 Physical properties of raw materials

Sr. No	Raw materials	Tests performed	Test results	
1	Cement: OPC-43 Grade	Fineness (dry sieving)	6.75	
		Specific Gravity	3.11	
		Consistency	28%	
2	Fine Aggregates: Natural river sand 4.75mm passing	Sieve Analysis	Zone II	
		Specific Gravity	2.65	
		Surface Moisture	0 %	
		Water Absorption	0.65 %	
3	Coarse Aggregates:		10 mm	20 mm
	Crushed angular aggregate 10mm and 20 mm	Specific Gravity	2.85	2.88
		Surface Moisture	0%	0%
		Water Absorption	1.51%	1.30%
4	Rubber Fiber: Width – 4.75 – 0.60mm Length – up to 25mm	Specific Gravity	1.12	
		Surface Moisture	0%	

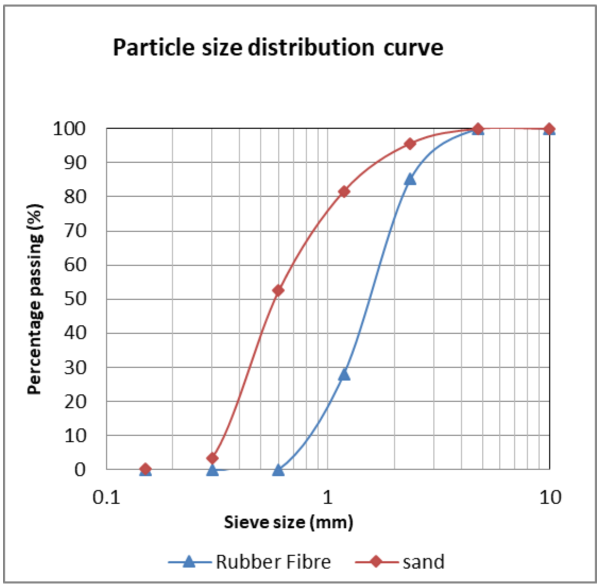

Figure 2 Particle size distribution of fine aggregates and rubber fiber

2.2. Mix proportions and preparation of concrete

A normal concrete mix of M 45 strength grade was designed and prepared as per IS 10262 [12]. A total of five series of concrete mixes were prepared to keep water to cement (w/c) ratio and a dose of superplasticizer (0.30% weight of cement) constant. A dose of superplasticizer of 0.30% (wt. of cement) was determined for the concrete mix, which showed a compaction factor of 0.93. A reference concrete mix was prepared without rubber fiber content (0%) and was designated as 0RF. In the other four concrete mixes, fine aggregates were replaced by 5%, 10%, 15%, 20% rubber fiber, which were designated as 5RF, 10RF, 15RF, 20RF, respectively. The mixing proportion for M 45 grade concrete is shown in Table 2.

Table 2 Concrete mix proportions

Mix	0RF	5RF	10RF	15RF	20RF
Cement	394.32	394.32	394.32	394.32	394.32
Fine Aggregate	881.44	862.78	844.11	825.45	806.79
CA II (20 mm)	534.14	534.14	534.14	534.14	534.14
CA I (10 mm)	533.00	533.00	533.00	533.00	533.00
Water	158.99	158.99	158.99	158.99	158.99
Chemical Admixture	1.14	1.14	1.14	1.14	1.14
Rubber fiber	0.00	18.66	37.32	55.99	74.65

The preparation of concrete mixes was started with dry mixing natural and rubber aggregates for 30 s using a rotatory tilting drum mixer. Cement was added, and the mixture was mixed for another 30 s. Some water was mixed with superplasticizer and kept aside while remaining was added to the mixture and mixed for another 1 minute. After that, mixing was continued for 3 min during which the remaining water and chemical admixtures were gradually added. The total concrete mixing time was 5 min.

3. Testing program

3.1. Fresh properties of concrete

Before casting, the concrete fresh properties, including compaction factor, air content and unit weight, were calculated. Table 2 summarises the fresh properties of the concrete mixes. Concrete was cast in the molds using two layers of casting in accordance with IS 516 [13] and was compacted on a vibrating table. The specimens were then cured in the molds for 24 h and in water for 28 days after demoulding.

3.1.1. Workability

The workability of fresh concrete containing rubber fiber (0%-20%) was measured using the compaction factor test in accordance with IS 1199 [14]. The apparatus for the compaction factor test is shown in Fig. 3.

Figure 3 Compaction factor test set-up

3.1.2. Fresh density

The fresh density of all rubber fiber concrete mixes was determined as per IS 1199 [14].

3.1.3. Air content

The air content of fresh concrete was calculated using the test apparatus and the procedure is given in ASTM C231 [15]. Fig. 4 shows the test apparatus used for finding air content.

Figure 4 Test apparatus for air content in concrete

3.2. Hardened properties of concrete

3.2.1. Freeze and thaw test

The freeze-thaw resistance of concrete cubes was measured in the basis of : (i) mass loss due to damage caused by freeze-thaw action; (ii) change in the compressive strength of concrete before and after freeze and thaw; (iii) damage of concrete cubes through the evaluation of their relative dynamic modulus (RDMs) using the measurements obtained from ultrasonic pulse velocity (UPV); (iv) impact strength of concrete before and after freeze and thaw. Procedure B of ASTM C666 [16] was followed for freeze and thaw test on concrete containing rubber fiber (0%-20%). The setup and apparatus of freeze and thaw test are shown in Fig. 6. The concrete specimens were placed in stainless steel containers and were immersed in water during thawing and frozen in the air. The containers were then placed into Freeze-thaw chamber that was programmed to apply continuous cycles of freeze and thaw with temperature varying from -18 °C to 4 °C. Fig. 5 shows the freeze-thaw cycle with the desired temperature profile specified in ASTM C666 [16].

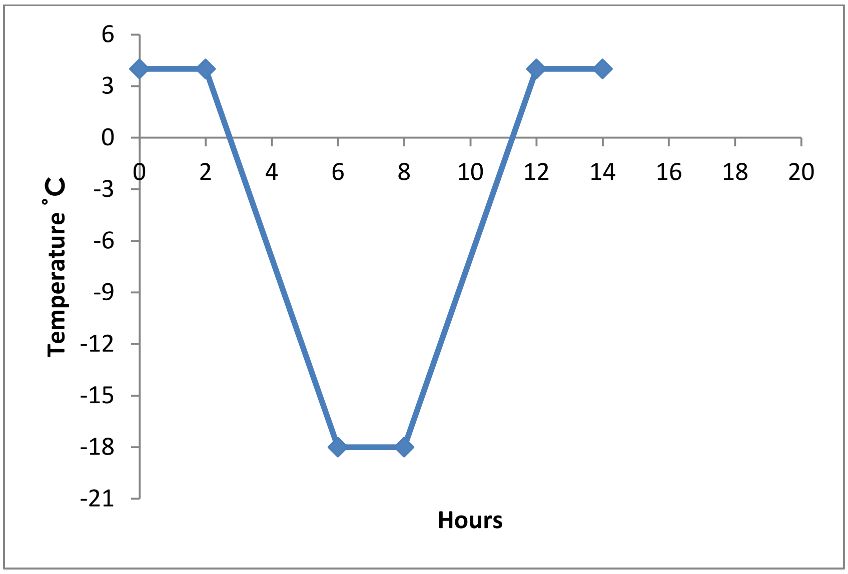

Figure 5 Freeze-Thaw cycle

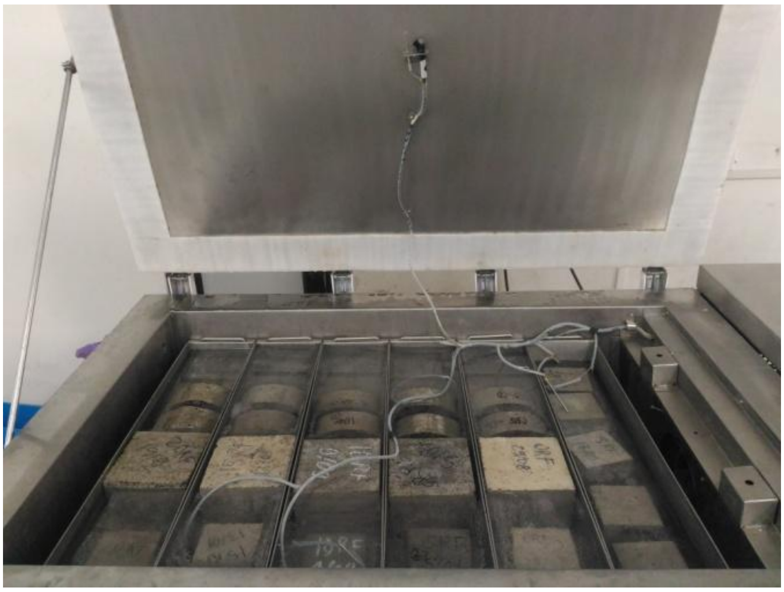

Figure 6 Arrangement for freeze and thaw test on concrete

The mass loss and UPV were determined after 6, 12, 18, 24, 30, and 36 freeze-thaw cycles. During the thawing phase of each of these defined cycles, the concrete cubes were removed and first visually examined in terms of surface damage. The cubes were then thoroughly brushed to remove any loose parts and then weighed. All detached materials were collected, oven-dried for 24 h at 110 °C, and weighed to the nearest 0.1

g. Ultrasonic Pulse Velocity test was then performed on cubes. The percentage of cumulative mass loss after 36 cycles, was calculated using Eq. (1).

$$\text{Cumulative mass loss (\%)}, CML(n) = \frac{\sum_{i=1}^{n} M_n}{M_0} \times 100 \qquad \text{Eq. (1)}$$

Where, n is the number of freeze and thaw cycles, M_0 is the mass of the specimen before the freeze and thaw test, $M_{d,n}$ is the mass of oven-dried scaled material of the specimen after n number of freeze and thaw cycles

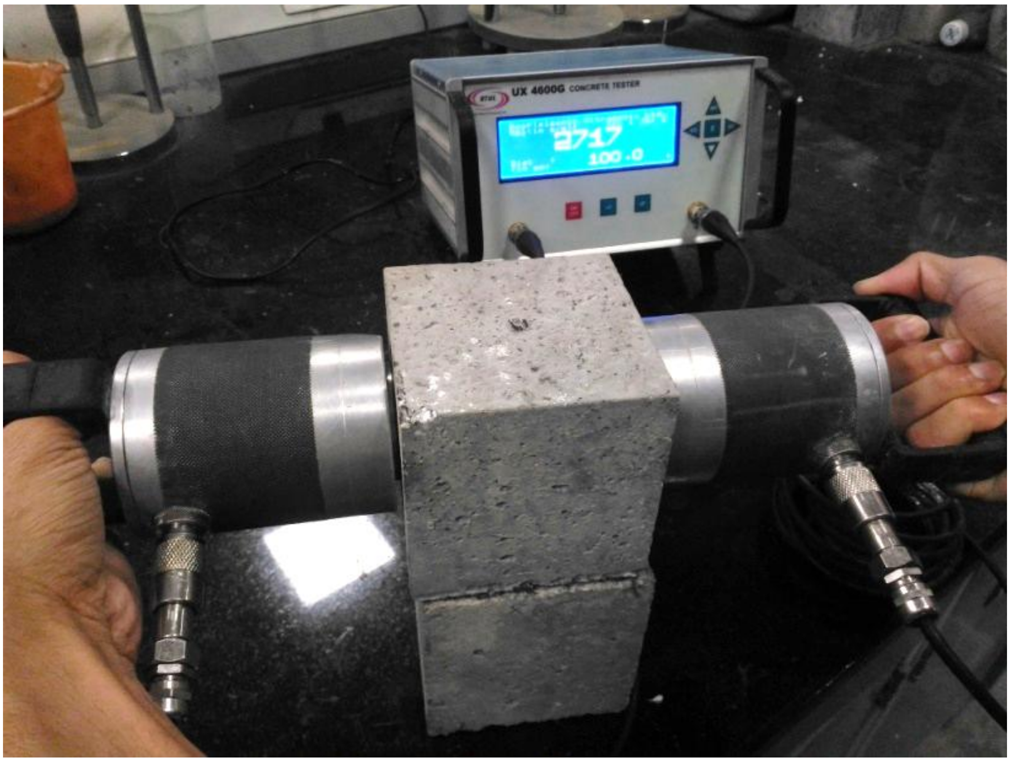

Figure 7 UPV on the concrete specimen

The compressive strength test was conducted according to IS 516 [13] using a hydraulic compression testing machine on three 100 mm cube specimens of each concrete mix after 28 days of curing.

Figure 8 Compressive strength test on concrete

For the impact tests, the drop-weight test method described in ACI 544 [17] was performed on the cylinder specimens of 150 mm diameter and 63 mm thickness. The test was performed in a modified state with a hammer weighing 6 kg and a drop height of 350 mm, and the surface of the specimen was observed. The number of blows required for a full dent was determined through the first crack appearing on the surface of the specimen. The impact energies of the specimens were calculated using Eq. (3).

$$E_{initial} = N_1 \times m \times g \times h \quad \text{Eq. (2)}$$

$$E_{ultimate} = N_2 \times m \times g \times h \quad \text{Eq. (3)}$$

where, $E_{initial}$ and $E_{ultimate}$ are the impact energy absorbed at the initial crack and ultimate crack, N_1 and N_2 are the number of blows for initial and ultimate failure, m is the weight of the hammer (6 Kg), g is the gravitational acceleration, and h is the fall height (350 mm)

3.2.2. Split tensile strength test

The split tensile test was performed on 28 days cured 150 mm cube specimens, according to IS 5816 [18]. The specimens were fitted diagonally on universal testing machine, and loading was applied, as shown in Fig. 9 .The split tensile strength (σ_{st}) was then calculated as per Eq. (4).

$$\sigma_{st} = 0.5187P/S^2 \quad \text{Eq. (4)}$$

where P is the ultimate load, S is the length of the side of the specimen.

Figure 9 Set-up of split tensile strength test

3.2.3. Abrasion test

Abrasion resistance was determined using Test conforming to IS 9284 [19] on 28 days cured specimen. Initial weight (w_1) of the specimen was measured before testing, and weight (w_2) was measured after testing. The abrasion resistance was calculated in term of the depth of wear using the following relation:

$$Depth\ of\ wear = \{(w_1 - w_2) \times \mathrm{V}_1\} / \left(\frac{w_1}{A}\right) \quad \text{Eq. (5)}$$

where V_1 is the initial volume of the specimen in $mm^{3,}$ and A is the surface area of the specimen in mm^2.

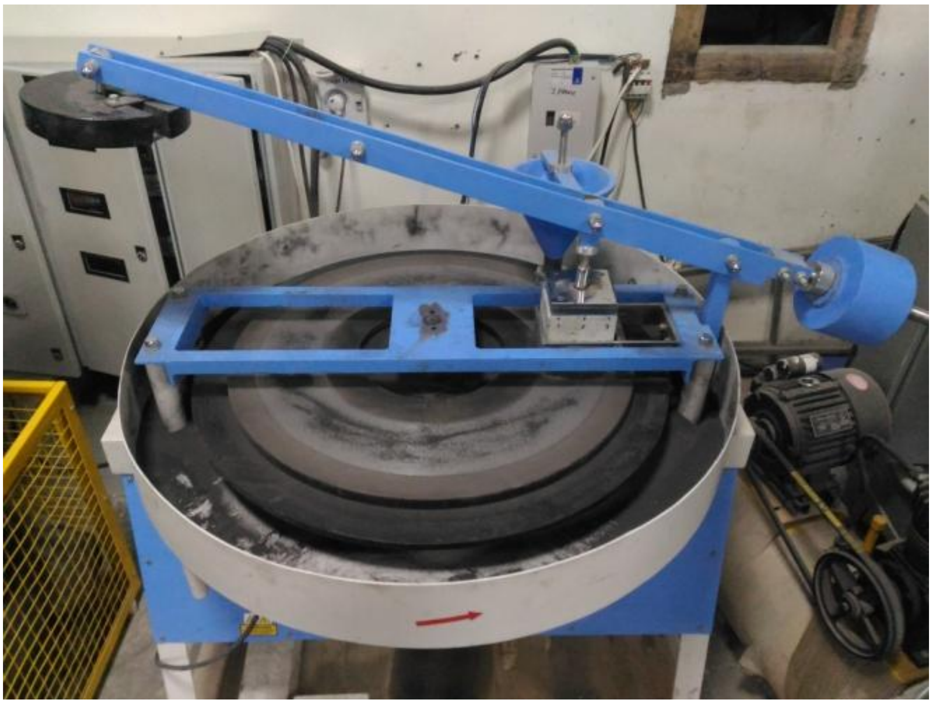

Figure 10 Abrasion test on concrete specimen

3.2.4. Capillary water absorption test

The capillary water absorption test was performed in accordance with ASTM C 1585 [20]. Cube specimens of size 100 mm were prepared for the sorptivity test. A total of 15 cube specimens were produced, containing three specimens per series. After 28 days of curing, the specimens were air-dried for two days and then oven-dried for 48 hrs at 110° C. After drying, only the top and bottom surfaces of the specimens were left open, and other surfaces were converted into a water-impermeable state by applying a coating of wax. The specimens were placed on support in a container and exposed to water up to 5 mm above the bottom surface of the specimen Fig. 11. The weights of the specimen were determined for water uptake rates of capillaries by weighing the water at the following 1 min, 5 min, 10 min, 20 min, 30 min, 60 min, 3h, 4h, 5h, 6 h, once a day up to 7 days.

Figure 11 Capillary water absorption test

4. Results and discussion

4.1. Fresh properties of concrete

4.1.1. Workability

The workability of concrete is a prime factor for the acceptance of any waste material for its probable use in the concrete. In this study, the dosage of high range water reducer (superplasticizer) for the concrete mixes with rubber fibers contents was kept constant. Compaction factor test was performed on the fresh concrete mix. Measured compaction factor is shown in Table 3. The compaction factor decreased with the increasing rubber fiber percentage showing less workability with an increase in rubber fiber content. It shows that the air content in fresh concrete mix increases with the increase in the rubber fiber content showing less workability with an increase in rubber fiber content.

4.1.2. Fresh Density

Table 3 gives the fresh density of the concrete mixes. The fresh density of concrete mixes also decreased with increasing rubber fiber percentage, which supports the decrease in compaction factor. The reason behind it may be the increase in porosity, as shown by previous results. Another reason can be that the specific gravity of rubber fiber is less than that of the sand. The replacement of denser sand with less dense rubber fiber may lead to a decrease in the overall density of concrete. The density of crumb rubber concrete decreases with an increase in replacement level [21].

4.1.3. Air content

The air content test conforming to ASTM C231 [15] was performed on the fresh concrete mix. It was observed that as the rubber fiber percentage increased, the value of air content also increased. Thus incorporation of rubber fiber increases the void content in the concrete mix. Similar results have been shown by Richardson et al. [8], which used crumb rubber instead of rubber fiber. The reason behind this is the jagged shape of rubber fiber leading to entrapment of air. Also, due to the hydrophobic nature of rubber fiber, more air voids are generated.

Table 3 Fresh properties of concrete

Fresh property	0RF	5RF	10RF	15RF	20RF
Compaction factor	0.92	0.91	0.90	0.88	0.85
Air content (%)	5.00	6.00	6.50	7.50	9.00
Fresh density (Kg/m^3)	2609.10	2483.50	2464.00	2453.30	2443.20

4.2. Hardened properties of concrete

4.2.1. Freeze and thaw test

4.2.1.1. Mass loss

Weight of the freeze-thaw samples was taken after every 6 cycles during the thawing phase. The samples were removed from the water and kept in air for 5 min for the surface to get dry. The surface was then brushed off, and the loose materials collected were weighed after oven drying. In this study, it has been observed that till 36 Freeze-thaw cycles, no significant mass loss has been observed due to the negligible scaling of concrete. The weight loss becomes significant with an increase in FT cycles, especially after about 45 FT cycles, which corresponds with the surface scaling of specimens [22].

4.2.1.2. Compression strength test

Compressive strength test was done on 28 day cured 100mm concrete cubes using Universal testing machine. Fig. 12 presents the 28 day compressive strength of concrete mixes with varying percentage of rubber fibers before and after freeze-thaw cycles. It has been observed from Fig. 12 that the compressive strength of concrete decreases with an increase in the percentage of rubber fiber. The 28 day compressive strength of the control mix (0RF) was 66 N/mm^2 while that of 5RF was 46.46 N/mm^{2,} which on further addition of rubber fibers decreased to 28.58 N/mm^2 for 20RF concrete mix. The incorporation of 5% and 10% rubber fiber in concrete as a volume replacement of fine aggregates results in a reduction of compressive strength by 29% and 38.4%, respectively, as compared to control mix (0RF) specimens. The decrease in strength is generally due to the lack of adhesion between the rubber particles and cement paste. Cracks will develop quickly around the rubber particles at the time of loading, which results in the rapid rupture of concrete. The lesser stiffness of substitute material as compared to its surrounding fine aggregate also leads to a reduction in compressive strength. The decrease in compressive strength occurs also due to the generation of voids, which might have developed due to the hydrophobic nature of rubber particles leading to less compaction. It is clear from Table 3 that as the percentage of rubber fiber in concrete mix increases, the percentage of voids also increases. Benazzouk et al. [23] have shown in their experimental study that the packing of lightweight rubber particles becomes difficult at high content of these particles and voids are introduced into the concrete mix. Gupta et al. [5] also observed that compressive strength decreases due to the generation of voids by using rubber ash in concrete. This type of rubberized concrete can find applications where high compressive strength is not needed such as curbs, pavements.

After 36 cycles of freeze-thaw (F-T), all concrete specimens exhibit compressive strength loss compared to the control specimens of the same mixes. Post 36 freeze-thaw cycles, the compressive strength of the control mix was 49.05 N/mm^2 and 39.59 N/mm^2 for the 5RF mix. It is observed from Fig. 12 that there is a reduction in the decrease of compressive strength with the increase in rubber fiber percentage post-freeze-thaw cycles. The compressive strength decrease was of only about 7% in 20RF specimens as compared to a 26% decrease in the 0RF specimen. The increased Freeze-thaw resistance of rubber fiber is due to the more available voids for the expansion of water. The reduction in the compressive strength indicates that the freeze-thaw action has affected the internal structure of concrete.

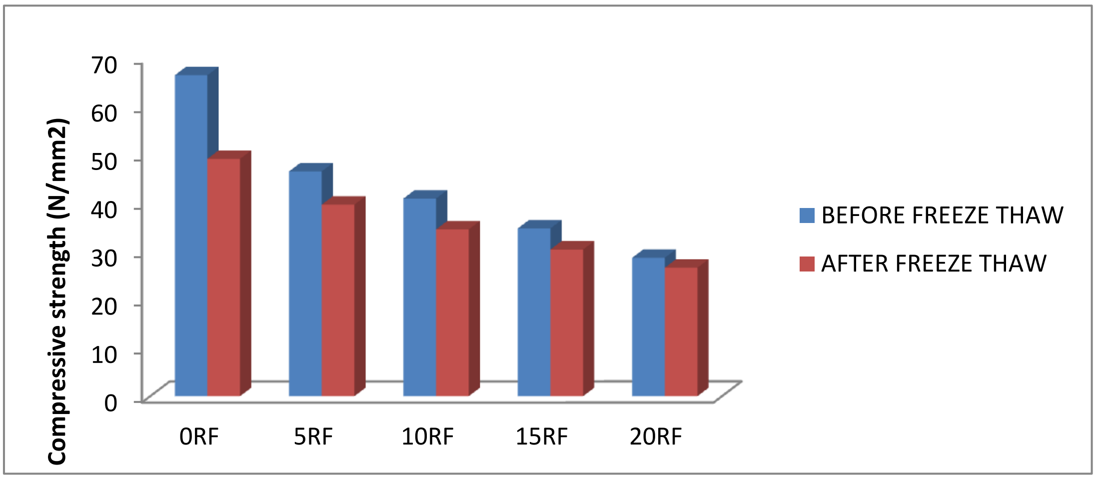

Figure 12 Compressive strength of concrete mixes before and after 36 Freeze-Thaw cycles

4.2.1.3. Ultrasonic pulse velocity test

Ultrasonic pulse velocity test was conducted to obtain the Relative Dynamic Modulus (*RDM*) of Concrete as given in Eq. 6.

$$RDM\ (\%) = \left(\frac{\text{UPVn}}{\text{UPVo}}\right) \times 100 \qquad \text{Eq. (6)}$$

It can be seen from Fig. 13 that there is a reduction in the *RDM* value for each of the concrete mixes. The Ultrasonic pulse velocity depends upon the compactness of the concrete. During Freezing –thawing, there is the generation of Internal cracks and expansion of voids. The presences of micro-cracks and gaps decrease the Ultrasonic Pulse Velocity, which in turn leads to a decrease in the Relative Dynamic Modulus of the concrete. In general, the RDM values decrease with the increasing number of freeze-thaw cycles [24].All the mixes are above threshold RDM value as specified in ASTM C 666 [16] thus can be labeled as durable.

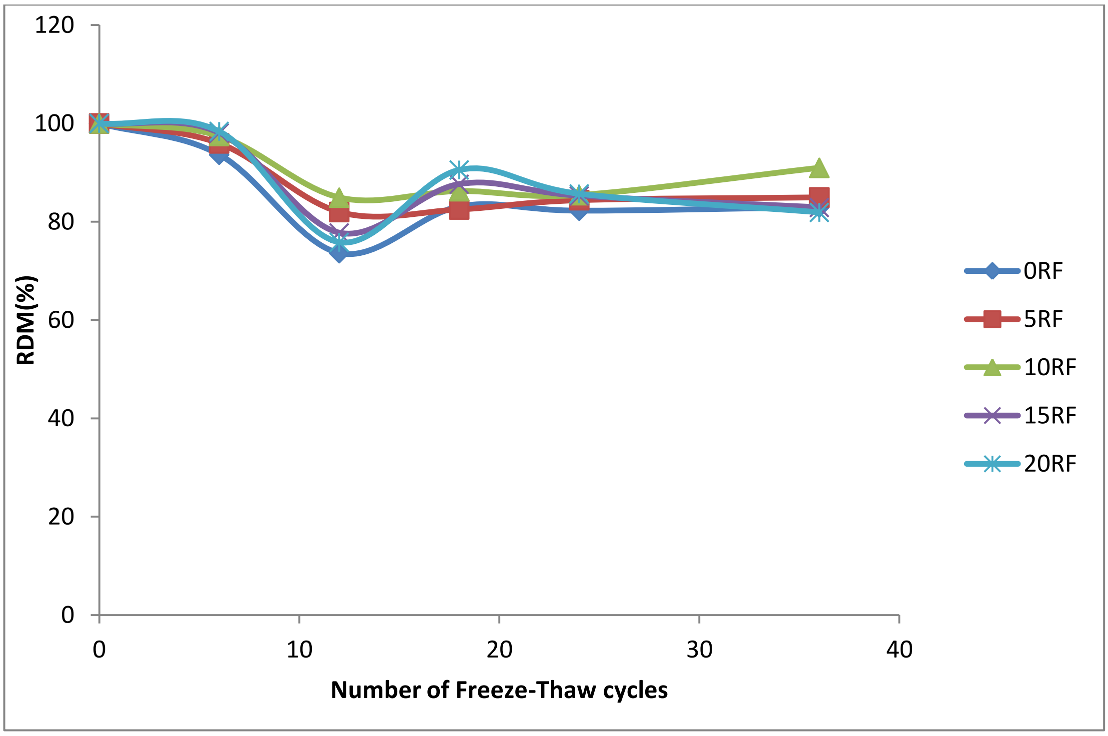

Figure 13.Relative Dynamic modulus of concrete mixes with increasing Freeze-thaw cycles

Figure 14 Impact Failure

4.2.1.4. Impact strength test

Impact resistance of concrete was calculated on the basis of Drop weight test conforming to ACI 544 [17]. From Fig. 15 it can be seen that the number of blows required for ultimate failure increases till 15RF, and there is a slight decrease for the 20RF concrete mix. The number of blows required for the first crack and ultimate failure is given in Table 4. Impact energy is calculated, and it can be seen that as the rubber fiber percentage increase, the impact resistance also increased. This is due to the deforming ability of rubber fiber, which leads to shock-absorbing action. Moreover, the rubber fibers show crack bridging action which enhances the impact resistance of concrete. Similar results have been shown by Gupta et al. [25] which states that the impact resistance of concrete improves on replacement of fine aggregate by rubber fibers.

Post 36 Freeze-thaw cycles, the drop weight test samples were oven-dried at 110 C for 48 hrs. It can be observed from Fig. 15 that the number of blows required for ultimate failure decreased for each of the concrete mixes. For the control concrete mix, the reduction was about 52%, and it decreased to 46% for the 5RF concrete mix. For 10RF, 15RF, and 20RF concrete mixes, the reduction was 33%, 30%, and 34%, respectively. It can be seen that the reduction in the number of blows decreased with an increase in rubber fiber percentage till 15RF. This suggests that rubber fiber inclusion leads to less loss in impact strength as compared to that in the control mix.

Table 4. Impact energy of concrete before and after freeze and thaw

Concrete mix	Before freeze-thaw					
	N1	N2	N2-N1	E1	E2	N2/N1
0RF	179	204	25	3555.9	4052.5	1.1
5RF	221	256	35	4390.2	5085.5	1.2
10RF	242	289	47	4807.4	5741.1	1.2
15RF	239	294	55	4747.8	5840.4	1.2
20RF	226	277	51	4489.5	5502.7	1.2
Concrete mix	After freeze-thaw					
	N1	N2	N2-N1	E1	E2	N2/N1
0RF	67	97	30	1331.0	1926.9	1.4
5RF	99	138	39	1966.7	2741.4	1.4
10RF	143	195	52	2840.7	3873.7	1.4
15RF	156	207	51	3099.0	4112.1	1.3
20RF	146	183	37	2900.3	3635.3	1.3

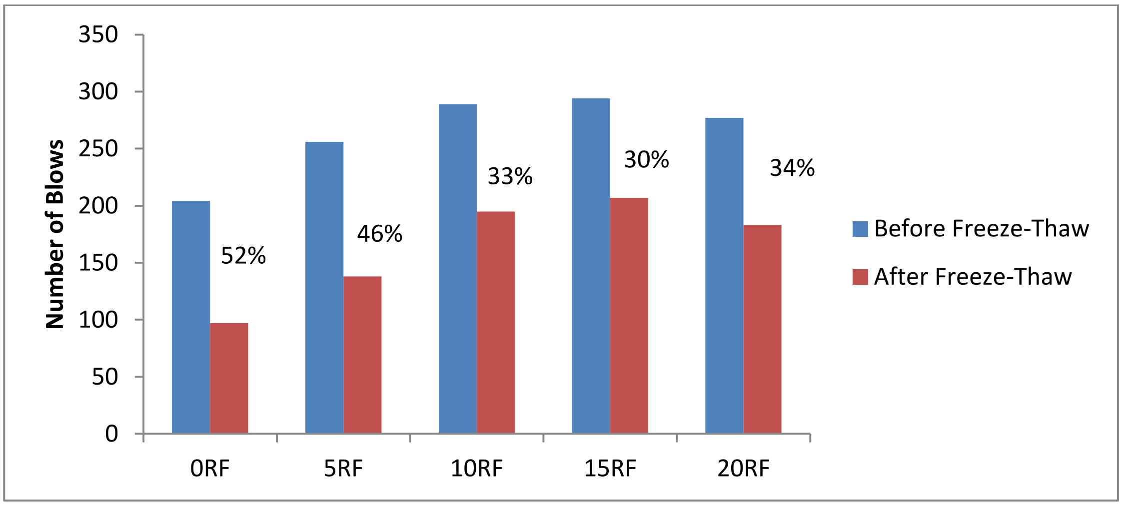

Figure 15 Impact Resistance of concrete mixes

4.2.2. Split tensile strength test

It is observed from Fig. 16 that the split tensile strength of 5RF and 10RF concrete mix is 3.5 N/mm^2 and 3.35 N/mm^2 respectively while that of control (0RF) mix is 3.27 N/mm^2. Thus the split tensile strength is more than the control mix till 10% rubber fiber replacement. Further increase in Rubber fiber content results in a decrease of split tensile strength. The reason for the decrease is due to more amount of interconnected pores in higher rubber fiber percentage replacement. The tensile failure occurs in cement paste as the tensile strength of rubber is greater than that of cement paste. Moreover, due to the ability of rubber fiber to deform leads to cracking at the surface of the interface of rubber fiber and cement matrix. The control concrete sample broke into two halves after unloading, while the rubberized concrete sample kept its integrity due to the bridging action of rubber fibers. Unlike the control concrete, which disintegrated when the peak load was reached, the rubberized concrete underwent a considerable deformation without disintegration, as shown in Fig. 8. This suggests that rubber fiber concrete can be used in crash barriers, retaining structures, and pavement structures if its strength requirement is satisfied. Rubberized concrete, including rubber fibers, has a significant capability in absorbing dynamic load and in resisting crack propagation [26].

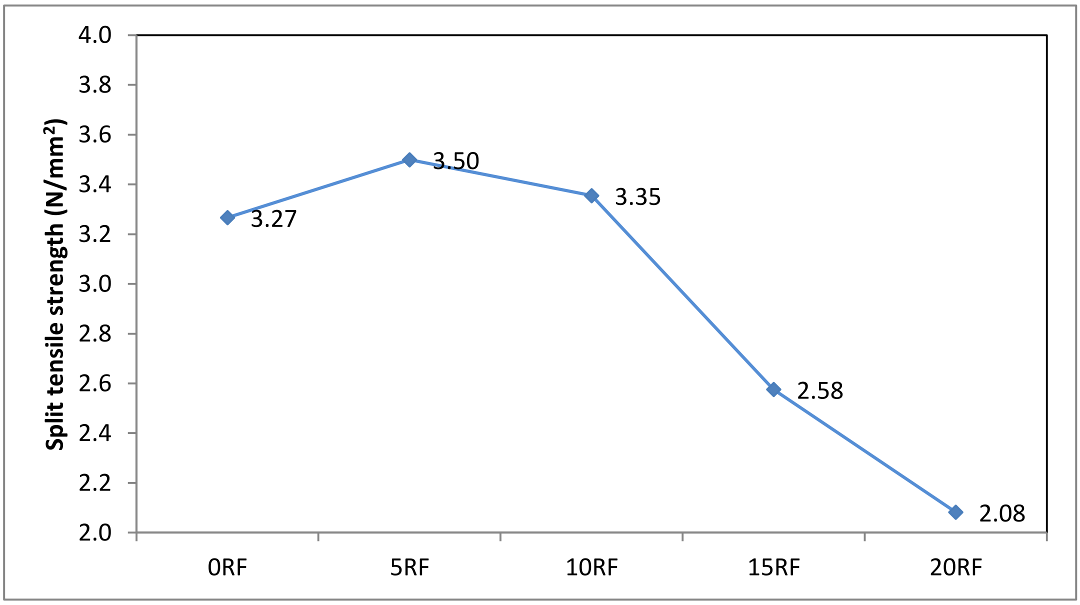

Figure 16 Split tensile strength test results

4.2.3. Abrasion test

Deterioration of concrete may take place due to abrasion caused by various exposures (skidding, rubbing or sliding of the object) on the concrete surface. Abrasion resistance is measured in terms of the depth of wear of concrete under standard testing conditions [19]. The variation in the abrasion resistance of rubber fiber concrete is shown in Fig. 17. It is observed that the depth of wear of rubber fiber concrete first decreases with an increase in rubber fiber percentage till 5% rubber fiber replacement and then increases with a higher percentage of replacement. Depth of wear is 0.33 mm for control mix, 0.14 mm for 5RF (5%), whereas the depth of wear decreases to 0.16 mm for higher replacement level of rubber fiber (20%) mix.The decrease in the depth of wear is attributed to the rubber fibers which resist the abrasive action. A higher percentage of rubber fiber in concrete offer better abrasion resistance. As per BIS-1237 [27], the limit for general purpose concrete tiles is 3.5 mm, and the depth of wear should not exceed 2 mm for heavy-duty applications. The depth of wear of rubber ash concrete and modified concrete is affected by the inclusion of rubber fiber, and the rubber fibers increase the abrasion resistance of concrete [9].

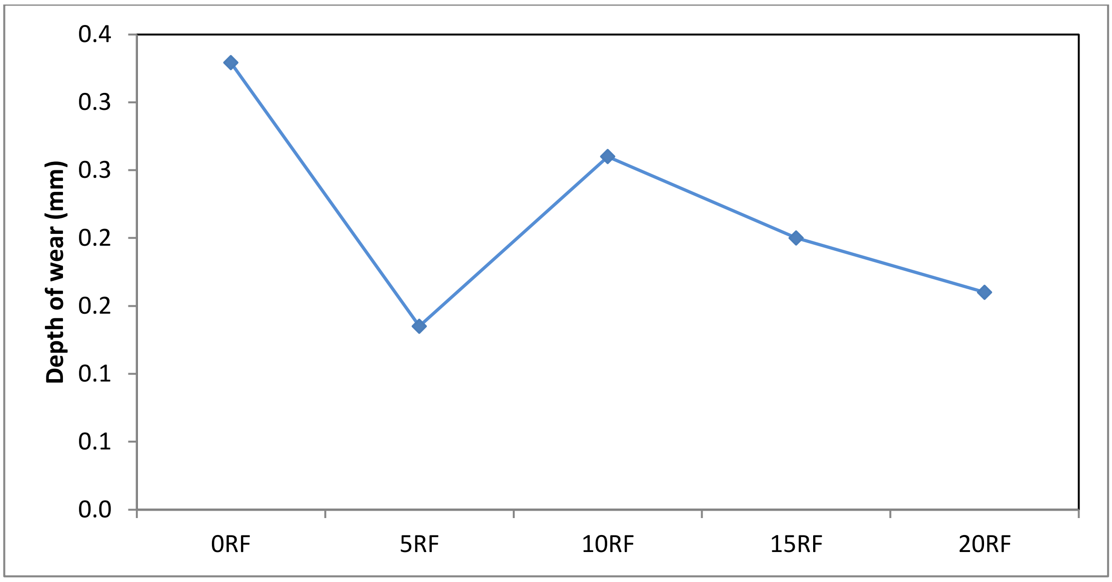

Figure 17 Abrasion test depth of wear

4.2.4. Capillary water absorption test

Capillary water absorption is important for building elements that are in contact with the ground or water. It is a critical parameter, especially for the paving stones found in the open area and on the ground. From Fig. 18, it is observed that the absorption rate increases with the increase in rubber fiber percentage. The absorption rate is 8×10^{-4} mm/sec$^{0.5}$ for the normal concrete mix and increases to 11×10^{-4} mm/sec$^{0.5}$ for 20RF concrete mix. This is due to the presence of more interconnected pores giving a boost to capillary absorption. Rubber fiber content influences the porosity of the concrete, which affects the water absorption capacity of the concrete. Water absorption of rubber fiber concrete increases with increasing replacement level due to the generation of voids and cracks due to the larger surface area of crumb rubber has led to greater water penetration [9,21].

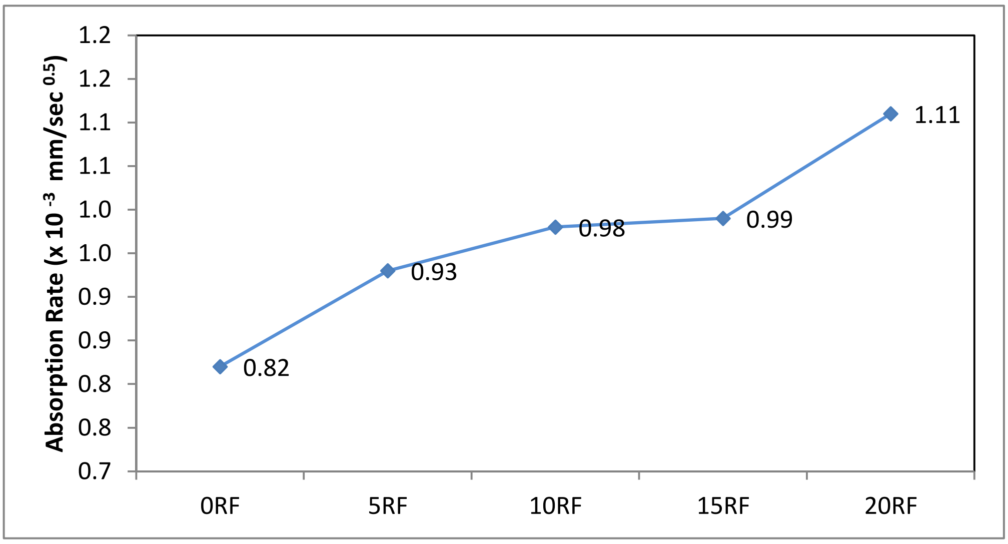

Figure 18 Capillary water absorption test results

4.2.5. Microstructural analysis

Fig. 19 shows various microstructural phases of the concrete, such as C-S-H gel and micro-cracks. Fig. 25 shows the cross-section of rubber fiber cut during the preparation of the sample. The surface of the rubber fiber is uneven and rough. Figs. 18-22 represents the microstructural phases in the rubber fiber concrete with a variable concentration of rubber fiber at different magnifications. Fig. 20 shows the microstructure of the control mix. It is observed that there is no gap between the cement paste and the aggregate, thus depicting stronger bonding. This may be the reason for higher compaction achieved in case of control mix which also leads to higher compressive strength. Fig. 21 shows the gap between the rubber fiber and cement paste in the 5RF concrete mix. The generation of the gap may be due to the hydrophobic behavior of rubber fiber. Fig. 22 shows that the microcrack generated at the ITZ. The propagation of the microcrack is stopped due to the gap between rubber fiber and the cement paste. The difference between the bonding between the fine aggregates (sand) and rubber fiber with a cementitious matrix can be seen from Fig. 22. In an earlier study [28], microcrack was seen passing through the gap between two rubber particles for tire rubber waste concrete. Fig. 23 shows the presence of pores and internal micro-cracks on the surface of the rubber fiber. This is due to the mechanical shredding of waste rubber tires. Similar internal micro-cracks on the surface of rubber particles were observed by Gupta et al. [29].The presence of pores and gaps is an important factor responsible for the decrease in density of the rubber fiber concrete. The increased porosity of rubber fiber concrete is also evident from the percentage void content values reported earlier. This increase in porosity is one of the factors which enhances the Freeze-thaw resistance of the rubber fiber concrete.

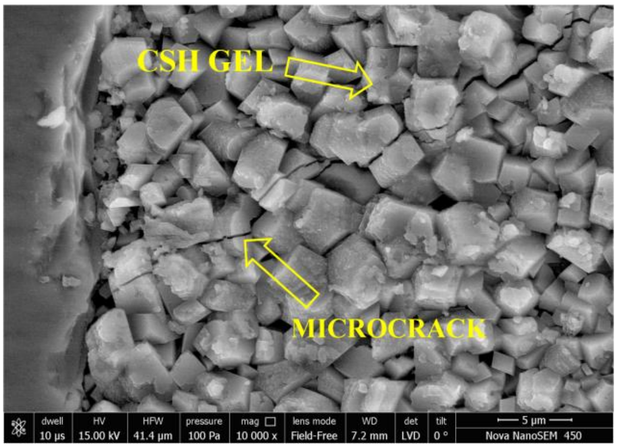

Figure 19 Microstructure of 0RF at 10000x zoom

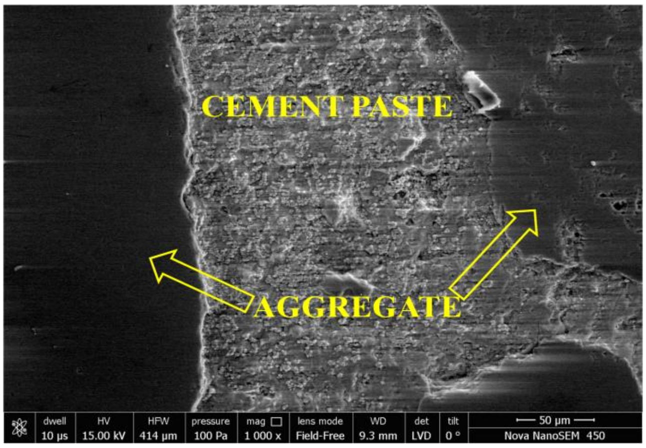

Figure 20 Microstructure of 0RF at 1000x zoom

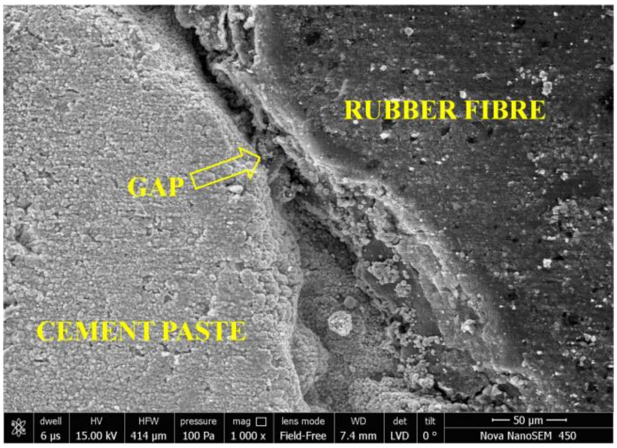

Figure 21 Microstructure of 5RF at 1000x zoom

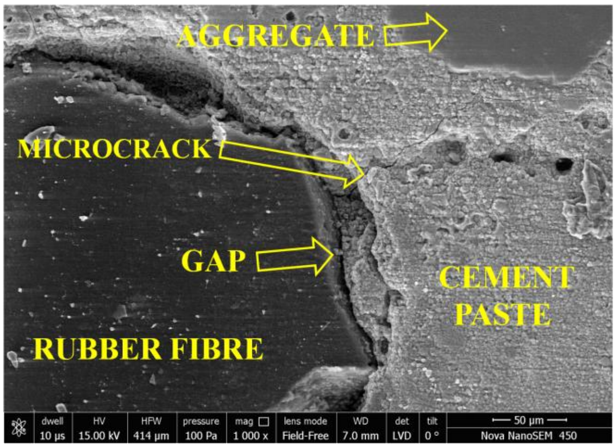

Figure 22 Microstructure of 10RF at 1000x zoom

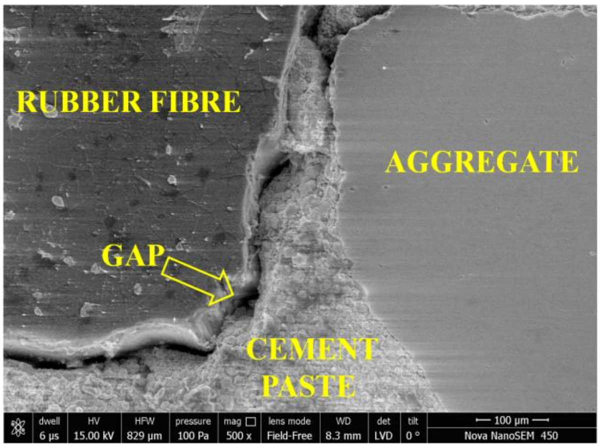

Figure 23 Microstructure of 15RF at 500x zoom

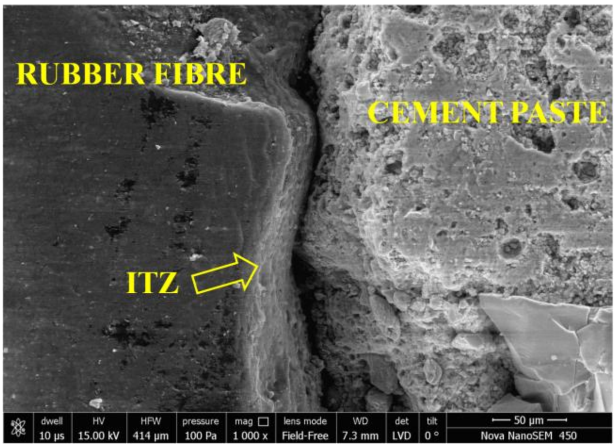

Figure 24 Microstructure of 20RF at 1000x zoom

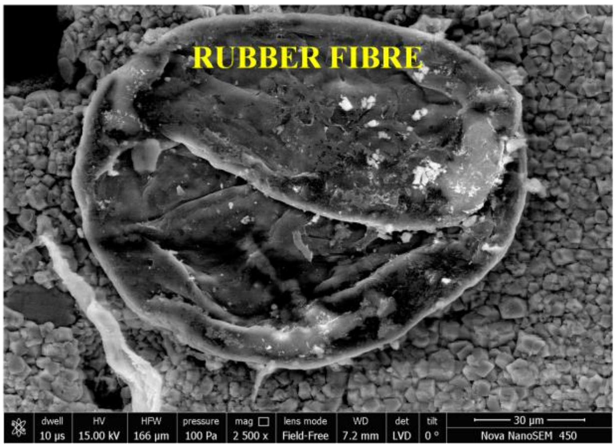

Figure 25 Microstructure of rubber fiber crosssection at 2500x zoom

5. Conclusion

In this study, the effects of using rubber fiber as a partial replacement of sand by volume on Freeze-thaw performance of concrete, split tensile strength, abrasion resistance, impact strength, and some other physical properties were investigated. Based on the results of the test, the following conclusions are made:

- After freeze-thaw cycles, the 20RF concrete mix showed the least reduction in compressive strength. No significant mass loss was observed in each of the concrete mix specimens. The 15RF concrete mix showed the least reduction of 30% impact strength after freeze and thaw. Overall, 15RF showed the best resistance against the freeze-thaw effect.
- The abrasion resistance increased with the increase in the rubber fiber content. Maximum abrasion resistance was shown by 5RF concrete mix. The concrete mixes of 0RF and 20RF concrete mixes showed wear depth of 0.33 and 0.16 mm, respectively.
- The capillary water absorption rate increased with higher percentage of rubber fibers incorporation. Control mix has absorption rate of 8×10^{-4} mm/sec$^{0.5}$ while 20RF concrete mix has absorption rate of 11×10^{-4} mm/sec$^{0.5}$.
- The impact resistance is also enhanced due to the incorporation of waste tire rubber fibers. The concrete mixes of 0RF, 15RF, 20RF absorbed impact energy of 4052.5, 5840.4, and 5502.7 J respectively.

6. References

[1] L. Basheer, J. Kropp, D.J. Cleland, Assessment of the durability of concrete from its permeation properties: A review, Constr. Build. Mater. 15 (2001) 93–103. doi:10.1016/S0950-0618(00)00058-1.

[2] R.K. Dhir, R. Moroney, K. Kopasakis, USE OF CRUMB RUBBER TO ACHIEVE FREEZE / THAW RESISTING CONCRETE K A Paine, (n.d.).

[3] A. Alsaif, S.A. Bernal, M. Guadagnini, K. Pilakoutas, Freeze-thaw resistance of steel fibre reinforced rubberised concrete, Constr. Build. Mater. 195 (2019) 450–458. doi:10.1016/j.conbuildmat.2018.11.103.

[4] F. Pacheco-Torgal, Y. Ding, S. Jalali, Properties and durability of concrete containing polymeric wastes (tyre rubber and polyethylene terephthalate bottles): An overview, Constr. Build. Mater. (2012). doi:10.1016/j.conbuildmat.2011.11.047.

[5] X. Shu, B. Huang, Recycling of waste tire rubber in asphalt and portland cement concrete: An overview, Constr. Build. Mater. (2014). doi:10.1016/j.conbuildmat.2013.11.027.

[6] T. Gonen, Freezing-thawing and impact resistance of concretes containing waste crumb rubbers, Constr. Build. Mater. 177 (2018) 436–442. doi:10.1016/j.conbuildmat.2018.05.105.

[7] T. Gupta, S. Siddique, R.K. Sharma, S. Chaudhary, Behaviour of waste rubber powder and hybrid rubber concrete in aggressive environment, Constr. Build. Mater. 217 (2019) 283–291. doi:10.1016/j.conbuildmat.2019.05.080.

[8] A. Richardson, K. Coventry, V. Edmondson, E. Dias, Crumb rubber used in concrete to provide freeze-thaw protection (optimal particle size), J. Clean. Prod. 112 (2016) 599–606. doi:10.1016/j.jclepro.2015.08.028.

[9] T. Gupta, S. Chaudhary, R.K. Sharma, Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate, Constr. Build. Mater. 73 (2014) 562–574. doi:10.1016/j.conbuildmat.2014.09.102.

[10] X. Zhu, C. Miao, J. Liu, J. Hong, Influence of crumb rubber on frost resistance of concrete and effect mechanism, Procedia Eng. 27 (2012) 206–213.

doi:10.1016/j.proeng.2011.12.445.

[11] A.F. Angelin, M.F.F.F. Andrade, R. Bonatti, R.C. Cecche Lintz, L.A. Gachet-Barbosa, W.R. Osório, R.C. Cecche, L.A. Gachet-Barbosa, W.R. Osório, R.C. Cecche Lintz, L.A. Gachet-Barbosa, W.R. Osório, Effects of spheroid and fiber-like waste-tire rubbers on interrelation of strength-to-porosity in rubberized cement and mortars, Constr. Build. Mater. 95 (2015) 525–536. doi:10.1016/j.conbuildmat.2015.07.166.

[12] IS 10262, Guidelines for concrete mix design proportioning, Bur. Indian Stand. Delhi. (2009) 1–21.

[13] M. Of, T. For, S.O.F. Concrete, IS 516-04, Methods Of Tests For Strength Of Concrete, Bur. Indian Stand. 1959 (2004) 1–23.

[14] IS 1199, Methods of sampling and analysis of concrete, Bur. Indian Satandards. (1959). doi:10.2174/187221013804484881.

[15] American Society of Testing Materials, Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method, ASTM Int. i (2010) 1–10. doi:10.1520/C0231.

[16] Astm C666/C666M, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, ASTM Int. West Conshohocken, PA. 03 (2003) 1–6. doi:10.1520/C0666.

[17] ACI 544 Committee, Measurement of properties of fiber reinforced concrete (Reapproved 2009), Aci. 544 (1999) 2–89.

[18] B. of I. Standards, Specification for splitting tensile strength of concrete -Method of Test, BIS:5816-1999 New Delhi ,India., (1999).

[19] S. For, R.D. Cabinets, Indian Standard, 1979 (2004).

[20] ASTM C1585-13, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes, ASTM Int. 41 (2013) 1–6. doi:10.1520/C1585-13.2.

[21] K. Bisht, P. V. Ramana, Evaluation of mechanical and durability properties of crumb rubber concrete, Constr. Build. Mater. 155 (2017) 811–817. doi:10.1016/j.conbuildmat.2017.08.131.

[22] X. Zhang, L. Wang, J. Zhang, Mechanical behavior and chloride penetration of high strength concrete under freeze-thaw attack, Cold Reg. Sci. Technol. 142 (2017) 17–24. doi:10.1016/j.coldregions.2017.07.004.

[23] A. Benazzouk, O. Douzane, T. Langlet, K. Mezreb, J.M. Roucoult, M. Que, Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes, 29 (2007) 732–740. doi:10.1016/j.cemconcomp.2007.07.001.

[24] A. Alsaif, R. Garcia, F.P. Figueiredo, K. Neocleous, A. Christofe, M. Guadagnini, K. Pilakoutas, Fatigue performance of flexible steel fibre reinforced rubberised concrete pavements, Eng. Struct. 193 (2019) 170–183. doi:10.1016/j.engstruct.2019.05.040.

[25] T. Gupta, R.K. Sharma, S. Chaudhary, Impact resistance of concrete containing waste rubber fiber and silica fume, Int. J. Impact Eng. 83 (2015) 76–87. doi:10.1016/j.ijimpeng.2015.05.002.

[26] W. Feng, F. Liu, F. Yang, L. Li, L. Jing, Experimental study on dynamic split tensile properties of rubber concrete, Constr. Build. Mater. 165 (2018) 675–687. doi:10.1016/j.conbuildmat.2018.01.073.

[27] BIS:1237-2012, Cement concrete flooring tiles - specification, Bur. Indian Stand. (2012).

[28] T. Gupta, A. Tiwari, S. Siddique, R.K. Sharma, S. Chaudhary, Response assessment under dynamic loading and microstructural investigations of rubberized concrete, J. Mater. Civ. Eng. 29 (2017) 1–15. doi:10.1061/(ASCE)MT.1943-5533.0001905.

[29] T. Gupta, A. Tiwari, S. Siddique, R.K. Sharma, S. Chaudhary, Response Assessment under Dynamic Loading and Microstructural Investigations of Rubberized Concrete, J. Mater. Civ. Eng. 29 (2017) 04017062.