Kaunas University of Technology

Faculty of Civil Engineering and Architecture

Making Magnificent Mechanical and Durable White Topping Concrete Mix Using Wastes

Master's Final Degree Project

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Structural and Building Products Engineering (6211EX008)

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Making Magnificent Mechanical and Durable White Topping Concrete Mix Using Wastes

Declaration of Academic Integrity

I confirm that the final project of mine, Balamurugan Muthaiah, on the topic " Making Magnificent Mechanical and Durable White Topping Concrete Mix Using Wastes " is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

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KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF CIVIL ENGINEERING AND ARCHITECTURE

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Summary

My research plot is a white topping mix investigation utilizing crumb rubber (CR) as a fine aggregate, waste glass powder (GP) and fly ash as a cementitious material. White topping is one of the laying technique for the damaged asphalt layers. The damaged asphalt layer will mill off up to destructed depth, and concrete mix will be laid above the milled asphalt layer is called white topping. A standard white topping mix will contain powerful superplasticizers, admixtures, and fibers. In this research, I am planning to prepare three sets of mixes. The control mix was prepared using water-reducing admixture, shrinkage reducing admixture, prefabricated air bubbles, and macro synthetic polypropylene fibers. These materials were selected according to white topping industry's recommendation

In the First Set, crumb rubber is substituted as a fine aggregate by the proportion of 5 kg/m^3, 10 kg/m^3, 20 kg/m^3. Aim of adding crumb rubber in concrete to get an excellent freezing-thawing effect compared to a special air-entraining agent. Naturally, rubber will dispense good toughness and excellent energy absorption. In the Second Set, crumb rubber was treated with carboxylate styrene-butadiene latex (SBR) to change rubber hydrophobic nature to hydrophilic. After treatment, rubber surface will attain a hydrophilic nature; a hydrophilic nature will create a proper bond with hydrated cement paste and avoid agglomeration (due to low-density crumb rubber). Same amount 5 kg/m^3, 10 kg/m^3, 20 kg/m^3 of treated crumb rubber substituted as a fine aggregate.

Generally, concrete strength is getting reduced by adding crumb rubber. So, I decided to add waste glass powder and fly ash as a part of portland cement to make an extra pozzolanic reaction for concrete strength. There are three batches in the third set; the first two batches consist of waste glass powder and treated crumb rubber (TCR). In the third batch, 10%(weight of cement) of fly ash added along with waste glass powder as an additive in rubber concrete. We prepared three batches in each set to investigate concretes' workability, durability, and mechanical properties. At the end of research, we prepared two batches with new rubber material (fibrous crumb rubber); it is finer than normal crumb rubber and contains more microfibers.

The following tests: slump test, fresh concrete density, fresh concrete air content, compressive strength, pozzolanic strength activity index, dry density, flexural strength, fracture energy, freezing-thawing, porosity parameter, and scanning electron microscope are conducted for untreated rubber, treated rubber, and treated rubber glass powder concretes. For fibrous crumb rubber concretes, conducted fresh concrete tests and freezing-thawing investigation. After all samples investigation, ultra-thin white topping design procedure was described according to New Jersey state and finally discussing white topping laying procedure.

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Santrauka

Mano tyrimo tikslas yra plonasluoksnių betoninių sistemų "white topping" betono mišinio bei sukietėjusio betono tyrimai, kuriuose kaip smulkus užpildas naudojamas smulkinta padangų guma (CR) bei kaip cementinė medžiaga tyrimuose naudojami malto stiklo atliekų milteliai (GP) ir lakieji pelenai. Plonasluoksnės betoninės sistemos "white topping" yra viena iš pažeistų asfalto sluoksnių atstatymo technikų. Pažeistas asfalto sluoksnis nufrezuojamas ir virš frezuoto asfalto sluoksnio klojamas betono mišinys, vadinamas "white topping". Standartiniame "white topping" mišinyje dedami efektyvūs superplastikliai, traukumą mažinančios įmaišos ir plaušai. Šiame tyrime planuoju paruošti tris mišinių varijantus. Kontrolinis betono mišinys buvo paruoštas naudojant vandenį mažinančias įmaišas, traukimą mažinančias įmaišas, specialias poras formuojančias įmaišas ir sintetinį makro polipropileninį plaušą. Šios medžiagos buvo parinktos pagal gamintojų rekomendacijas, gaminant "white topping" sistemas.

Pirmo tyrimo metu smulkinta padangų guma, kaip smulkus užpildas pakeičiamas 5 kg/m^3, 10 kg/m^3, 20 kg/m^3 dalimi. Tikslas - įdėti smulkintą padangų gumą į betoną, kad gautumėme geras ilgaamžiškumo savybes veikiant užšalimo-atšildymo ciklams, bei palyginti su kontroline betono sudėtimi, kurioje dedamos kietas poras formuojančios įmaišos. Antro tyrimo metu smulkinta padangų guma buvo apdorota karboksilintu stireno-butadieno lateksu (SBR), kad gumos hidrofobinis pobūdis būtų pakeistas į hidrofilinį. Po apdorojimo tikėtina trupintos gumos paviršius įgis hidrofilinį pobūdį; hidrofilinis pobūdis sukurs tinkamą ryšį su hidratuota cemento pasta ir bus išvengta gumos aglomeracijos (dėl mažo tankio trupintos gumos). 5 kg/m^3, 10 kg/m^3, 20 kg/m^3 taip apdorotos smulkintos padangų gumos buvo pakeista vietoje smulkaus užpildo.

Paprastai dedant smulkintos padangų gumos, mažėja betono stiprumainės savybės. Taigi, nusprendžiau papildomai įdėti malto stiklo atliekų ir lakiųjų pelenų keičiant portlandcemenčio dalį, kad kompensuoti dalį stiprio praradimo dėl papildomai vykstančios pucolaninės reakcijos. Trečio tyrimo metu buvo sumaišyti trys mišinių varijantai; pirmuosius du mišinius sudaro malto stiklo atliekų milteliai ir apdorota smulkinta padangų guma (TCR). Trečiajame mišinyje 10% nuo cemento masės buvo įdėta lakiųjų pelenų kartu su malto stiklo atliekų milteliais bei smulkinta padangų guma. Nustatėme betono fizikines bei mechanines savybes, bei ilgaamžiškumą. Tyrimo pabaigoje papildomai paruošėme dvi naujas betono mišinio partijas su nauja smulkesne trupinta padangų guma (su pluoštu bei be pluošto); jis yra smulkesnis nei įprasta trupinių guma ir turi daugiau mikropluoštų.

Buvo atlikti tokie betono bandymai su neapdorota bei apdorota trupinta padangų guma: šviežio betono slankumo bandymas, šviežio betono tankio, šviežio betono oro kiekio nustatymo bandymas, stipris gniuždant, stipris lenkiant, irimo energija, šalčio bandymai, poringumo nustatymo sukietėjusiame betone bandymai, pucolaninio aktyvumo indeksas nustatymas, vizualiniai tyrimai naudojant skenuojantį elektroninį mikroskopą. Atlikus visus tyrimus, atlikta plonasluoksnių betoninių sistemų "white topping" betono projektavimo procedūra bei aprašyta naudojant New Jersey modelį.

Table of contents

List of figures **9**
List of tables **10**
Introduction **11**
1. Literature review **13**
1.1. Research methodology 19
1.1.1. Experimental research 19
1.1.2. Physical properties of crumb rubber and waste glass fresh concrete 19
1.1.3. Mechanical properties of crumb rubber and waste glass concrete 22
1.1.4. Durable properties of crumb rubber and waste glass concrete 27
1.2. Objective and scope 31
1.2.1. Experimental program 32
2. Materials and mix proportion **33**
3. Specimen preparation and methodology **39**
4. Results and discussion **42**
4.1. Fresh concrete test results 42
4.2. Hardened concrete test results 46
5. White topping investigation **74**
5.1. New Jersey design procedure for ultra-thin white topping 74
5.2. Advantages of white topping system 77
5.2.1. Conditions for white topping construction 77
5.3. White topping construction techniques 78
Conclusion **80**
List of references **83**

List of figures

Fig. 2. 1. Particle size distribution of crumb rubber and fibrous crumb rubber 35
Fig. 2. 2. Crumb rubber (<0.315mm) 35
Fig. 2. 3. Unsieved fibrous crumb rubber (>0.315mm).. 35
Fig. 2. 4. Sieved fibrous crumb rubber (<0.315mm)... 36
Fig. 2. 5. Crumb rubber dispersed in SBR latex under the ultrasonic dispersion method 36
Fig. 4.1. 1. Slump cone test results...43
Fig. 4.1. 2. Fresh concrete density test results.. 44
Fig. 4.1. 3. Air content test results.. 45
Fig. 4.2. 1. Control mix, set 01, and set 02 batches compressive strength results after 28 days ... 47
Fig. 4.2. 2. Compressive strength results of set 03 batches after 28 days and 56 days 47
Fig. 4.2. 3. 20UCR concrete 48
Fig. 4.2. 4. 20TCR concrete 48
Fig. 4.2. 5. Strength activity index of glass powder and fly ash.. 48
Fig. 4.2. 6. Dry density results... 49
Fig. 4.2. 7. Flexural strength test results.. 51
Fig. 4.2. 8. Fiber during loading (10UCR) 51
Fig. 4.2. 9. Fibers after breakage (10UCR) 52
Fig. 4.2. 10. Flexural stress-strain curves ((a) Control mix, (b) 5UTR, (c) 10UCR, (d) 20UCR, (e) 5TCR, (f) 10TCR, (g) 20TCR, (h) 10TCRGP, (i) 20TCRGP, (j) 20TCRGP&10%FA) 56
Fig. 4.2. 11. Rubber particles distribution ((a) 20UCR, (b) 20TCR, (c) 20TCRGP, (d) 20TCRGP&10%FA, (e) 10SFCR, (f) 10UFCR)... 58
Fig. 4.2. 12. Compressive strengths before and after freezing-thawing cycles................................ 60
Fig. 4.2. 13. Control concrete after 500 cycles.. 61
Fig. 4.2. 14. (a) 10UCR concrete after 200 cycles and (b) 20UCR concrete after 200 cycles.......... 62
Fig. 4.2. 15. Samples after 200 cycles ((a) 5TCR, (b) 10TCR, (c) 20TCR, (d) 10TCRGP, (e) 20TCRGP, (f) 20TCRGP&10%FA, (g) 10SFCR, (h) 10UFCR).. 64
Fig. 4.2. 16. Porosity content in concrete is determined by water absorption kinetics 66
Fig. 4.2. 17. SEM images of control concrete ((a) & (b) Prefabricated air bubbles in different sizes) 68
Fig. 4.2. 18. SEM images of untreated crumb rubber concrete ((a) Improper bonding between untreated crumb rubber and cement paste and (b) Pore occupied by untreated crumb rubber)........ 69
Fig. 4.2. 19. SEM images of treated crumb rubber concrete ((a) Porous nature of untreated crumb rubber concrete, (b) Good bonding between treated rubber and cement paste)............................... 70
Fig. 4.2. 20. SEM images of set 03 batches ((a)Ettringite due to glass powder, (b) Glass powder pozzolanic reaction filling pores, (c) Combined pozzolanic reaction of glass powder and fly ash filling pores) 72
Fig. 4.2. 21. SEM images of (a) Glass surface, (b) SFCR, (c) UFCR.. 73

List of tables

Table 1. 1. The typical constituent material of tyres (united states) [10] 15
Table 1. 2. The typical constituent material of tyres (Europe) 15
Table 2. 1. Raw materials for concrete preparation 33
Table 2. 2. Chemical composition of portland cement, glass powder, and fly ash 37
Table 2. 3. Details of mix proportion 38
Table 3. 1. slump class and degree of workability 39
Table 4.2. 1. Samples area, fracture energy, residual flexural strength 53
Table 4.2. 2. Concretes density before and after freezing-thawing cycles 60
Table 4.2. 3. Concrete durability parameters 66
Table 5.1. 1. Standard normal deviation with the design reliability factor [44] 76

Introduction

Road network is of vital importance for every country in their part of economic growth. In European countries, almost 90% of roads are of bituminous pavement. The maintenance cost of bituminous pavement is high compared to the construction cost. In Lithuania, road maintenance decreased by 32% from 2008 to 2011. The Lithuanian government established a program called the road maintenance and development program (RMPD). This program is supporting road construction and maintenance investments. The government collects funds based on road tax and extra duties on gas and fuel. Collected funds were used to construct and maintain the roads. Due to economic crises and other problems, the funding will not be satisfactory for the maintenance. The asphalt pavement could withstand stresses caused by vehicle loads and environmental factors. However, due to improper maintenance, asphalt pavement deteriorates during rutting, fatigue cracking, and thermal cracking.

The damaged asphalt layer is covered by cement concrete instead of bituminous concrete is known as a white topping. White topping is an effective rehabilitation solution for the damaged asphalt pavements. White topping construction consists of two important techniques: 1) milling machine (used to remove the destructed asphalt layer's thickness), 2) slip form paver (used to lay cement concrete). The initial cost of cement concrete is high compared to bituminous material. Still, cement concrete maintenance cost is less; moreover, cement concrete has higher strength and durability. The main advantage of cement concrete is its high albedo value (see 5.2).

White topping construction is particularly suitable when the existing roadway structure is no longer enough due to high static and dynamic traffic loads. A low-shrinkage, fiber-modified high-performance concrete usually replaces a milled layer to increase traffic areas' load-bearing capacity. After milling, asphalt layer thickness should be at least 8 cm, and the thickness of the new cement concrete layer should not be less than 10 cm. The above-described thickness values are given in the form of theory. In reality, the thickness of cement concrete pavement depends on traffic loads, environmental conditions, and previous asphalt stages.

White topping is classified into three types: Conventional white topping (thickness more than 200 mm), Thin white topping (thickness from 100 mm to 200 mm), Ultra-thin white topping (thickness from 50 mm to 100 mm). In this research, crumb rubber (CR) substituted as fine aggregate, waste glass powder (GP) and fly ash are substituted as a cementitious material. For experimental research, the concrete mix‘s are categorized into three sets: (1) Untreated crumb rubber (UCR), (2) Treated crumb rubber (TCR) (rubber treated with polymer), (3) Treated crumb rubber and Glass powder (TCRGP). The durability and mechanical tests were performed, and the test results were compared with the Control mix (CM) (the control mix prepared by the guidance of Heidelberg white topping construction).

There is a massive amount of different waste products getting dispose every year all over the world. Among wastes, rubber tyres, waste glass, and fly ash are concentrated in this research. Worldwide automobile manufacturing increases every year, due to this, the production of tyres also getting rises. Vehicle tyres are made from chemicals. By disposal, chemicals will become toxic to the environment. Years ago, the rubber wastes were usually dumped into the land, stockpiled in the industry, and disposed of by burning, which belongs to environmental decline. As a result of waste disposals, humans faced many problems like fire cause and reproduction of mosquitoes and rats in stockpiled areas.

In the European Union, tyres production from 2010 to 2018 is 4.5 million tonnes to 5.1 million tonnes. According to the directive disposal of waste 1000/31/EC, European countries banned disposal and stockpile of whole tyres from July 2003; from July 2006 banned ground rubber disposal. The end of life vehicle directive 2000/53/EC introduced three legislation to improve tyre management's use: extended producer responsibility, a tax system, and the free market system. According to this legislation, 100% of waste rubber tyres are reused all over European countries, and disposal rates also started reduced. The European tyre and rubber manufacturers association (ETRMA) is managing end-life tyres data; up to 2017, 92% of (ELTs) were collected and recycled. According to ETRMA, in 2017, 105 tonnes of waste tyres were used in the civil engineering field. In the same year, 6000 end-life tyres were collected in Lithuania. In that, 5,000 tyres went under material recovery, and 1,000 tyres went under energy recovery. So, 100% of end-life-tyres were treated. The uses of waste rubber tyres: making plastic and rubber products, fuels for cement kiln, and base layer for asphalt pavement. Naturally, rubber will provide toughness, impact resistance, and freezing-thawing effect in concrete.

Let us discuss the production and recycling of glass. In the overall world, about 130 million tonnes of glasses generating annually. In 2018, the European Union's glass production reached about 36.5 million tonnes, which is slightly higher than before year (2017). So, year by year, glass production is increasing, and in this way, glass wastes are also being increased. Europe is one of the largest glass producers globally compared to China and North America. Only a small fraction of the solid wastes are recycling directly to the primary market (i.e.)- bottling and container industry. The remaining glass wastes are discarded into the land.

Glass is inert material; it will not decompose and remains in the land for many years. The disposed glass will affect the land quality and water table. Hazardous glasses like cathode ray tubes and fluorescent lamps are even more high risk for land. According to AASHTO, waste glass absorbing a high load when substituting as a base layer for pavement, and glass providing good results than conventional asphalt. Benefits of glass in the pavement: increases night vision, low shrinkage, high abrasion, low water absorption.

Rubber is hydrophobic due to zinc stearate (zinc stearate is one of the tyre manufacturing product). During hydration, the zinc stearate is forming a soap layer on rubber that repelling water. Rubber hydrophobic nature can eliminate by treating with adhesive material. An adhesive material can be liquid or solid; it is used to create bonding between two dissimilar materials. Generally, polymers are used as an adhesive material in concrete. The coupling agents are also creating a better bond between two dissimilar materials. In this research, we planned to use SBR latex to bring a good bond between rubber and cement paste. The secondary advantage of polymers is keeping rubber particles stable and avoiding agglomeration during vibrator compaction.

Using waste glass powder in concrete leads to an alkali-silica reaction. Adding fly ash can reduce ASR expansion and water permeability. Fly ash concrete also performing well during freezing-thawing [31]. Nearly 100 million tonnes of coal combustion ash is generating in the USA. During that process, 60 million tonnes of fly ash wastes are generating. From 60 million tonnes, Only 27% of the fly ash is recycling, and the remaining fly ash is landfilled. This research paper's advantage is using three landfill wastes in concrete and targeting to achieve good durable and mechanical properties by wastes.

1. Literature review

This paper explains industrial waste treatment methods in concrete because industrial wastes are non-biodegradable, causing pollution in the environment. Conventionally sand, gravel, cement, bitumen are using in roads. Due to much construction, natural resources are decreasing daily; for example, in Lithuania, bitumen production lessens to 24% from 2007 to 2012. To reduce the usage of natural resources, many researchers finding substitute materials to overcome these problems. Literature explaining different industrial waste types can be used in highway constructions like fly ash, steel slag, blast furnace slag, cement kiln dust, used engine oil, rubber waste, and glass waste [1].

Siddique and Naik [2] are explaining the classification of scrap-tyres: a) Shredded/chipped tyres: rubber chip's size depending upon the chip model, usually sized from 76 mm to 13 mm, b) Ground rubber typically sized from 19 mm to 0.15 mm, c) Crumb rubber size from 4.75 mm to less than 0.075 mm. Usually, the cracker mill, micro mill, and granular operation are used to convert scrap tyres to crumb rubber. We need to spend more money and time on coarse rubber to fine rubber conversation. Spending money and time will show better results.

In European countries, pavement structures are mainly affected by the freezing-thawing effect, which reducing concretes age. Air-entraining agents can control a freezing-thawing effect. The researchers found that waste crumb rubber is acting similar to a traditional air-entraining agent because rubber entrapping air in concrete due to its non-polar surface nature—entrapped air creating pores called air-voids. Those pores help to hold and release the water pressure and protects from a freezing-thawing effect. Pore size depends on aggregates, and pore spacing should be around 0.25 mm for better freeze-thaw.

Richardson, Coventry, Edmondson, and Dias [3] are founded better size crumb rubber to substitute as a fine aggregate in concrete for excellent freezing-thawing performance. The freezing-thawing test was conducted with different sizes of crumb rubber varying from <0.5 mm to 2.5 mm. Crumb rubber size <0.5 mm is providing more excellent freezing-thawing protection. The important reason for that performance is due to the large specific area of crumb rubber (0.5 mm) entraps sufficient air in concrete. After freezing-thawing cycles, less than 0.5 mm rubber concrete showed a better compressive strength than the control concrete.

Richardson, Coventry, and Ward [4] are found the perfect amount of crumb rubber for freezing-thawing effect and concrete strength. Experimental works are divided into two parts, the first part finding how much amount of crumb rubber providing adequate compressive strength, slump, density, air content. Researchers used five different amounts of crumb rubber in experiments (0.3%, 0.6%, 0.9%, 1.2%, 1.5%). In that, 0.6% provided nearer compressive strength compared to the control concrete, and the second part of the research focused on the freezing-thawing effect using 0.6% of crumb rubber. Three batches carried a freezing-thawing test: the first batch consists of washed rubber, the second batch consists of unwashed rubber, and the third batch is a control concrete. The active freezing-thawing resistance was provided by both batches (1&2). The above two literature concluded that smaller size and perfect crumb rubber amount would execute efficient compressive strength before and after freezing-thawing cycles.

Using crumb rubber in the concrete pavement will perform well compared to the traditional air-entraining agent. The durability of the concrete is increased by using crumb rubber as a fine aggregate. So, durable concrete can withstand for longer life compared to normal concrete.

Most of the researchers were focusing on the freezing-thawing effect in concrete by using crumb rubber. However, when adding 1% of an air-entraining agent in concrete, nearly 5% to 6% of concrete strength decreases. While adding rubber about 5% by volume of the fine aggregate reduces concrete strength by approximately 5% [10]; therefore, the strength of concrete will decrease when rubber content increases.

Issa and Salem [5] discussed, to decrease the landfill by using waste rubber in the civil engineering field and strongly commanded that not all disposal materials can substitute in concrete. This paper explained that concrete contains a constant amount of cement, natural sand, coarse and medium aggregates, and a varying amount of crushed sand. Crumb rubber is substituted as crushed sand in different percentages (15%, 25%, 50%, 100%). However, less than 25% of crumb rubber contains concrete was achieved compressive strength nearer to the control concrete. Same in this literature [6], when increasing rubber content as a part of fine and coarse aggregate, it decreasing concretes compressive and flexural strength because cracks were easily forming around soft rubber materials. Literature said to use less than 20% of rubber amount to achieve reasonable strength.

The literature is explaining that rubber size is influencing concrete properties. In this research, three different size rubbers (sizes are 3 mm, 0.5 mm, 0.3 mm) are substituted as a fine aggregate. Three samples were prepared using three different rubber sizes, and one more sample has prepared by mixing all three rubber sizes. Concrete workability, mechanical property, and water permeability are decreasing by adding rubber material compared to the control mix. However, in the fresh concrete test, coarser rubber concrete executed better workability than finer rubber concrete. But, fine rubber concrete executed excellent compressive, flexural, tensile, and water permeability resistance than coarser ones. The mixed fine and coarse rubber sample showed considerable performance compared to fine rubber concrete [7]. In this literature, high strength concrete was prepared using silica fume as supplementary cementitious material and mixed different size rubbers (25% - size from 2 mm to 4 mm, 35% - size from 0.8 mm to 2 mm, 40% - rubber powder) as a fine aggregate. Same as every literature, when rubber content increased, compressive and flexural strength gets decreased. The experimental results showed rubber content up to 12.5% executing significant compressive and flexural strength. Literature concluded that rubber amounts 12.5% are suitable for making high strength concrete, and all rubber concretes were performed better abrasion and water absorption than the control concrete. Due to high abrasion results, rubber concrete can be used in pavements and brittle structures [8].

Many researchers explained that fine crumb rubber is more efficient than coarse rubber in the concrete strength phase. But, there is some opposite opinion. Girskas and Nagrockiene [9] are described concrete containing rubber fraction 4/6 expressed higher compressive strength than the rubber fraction 2/4 due to coarse rubber concrete density. In that research, coarse rubber concrete exhibits high density than fine rubber concrete. Due to its high-density, it withstands load for a long time compared to fine rubber concrete explained by literature. However, both rubber concrete strength was lesser than the control mix. The same literature predicted that freeze-thaw resistance was increasing when rubber content increased. In that, fine rubber has substantial freeze-thaw resistance compared to coarse rubber particles.

Generally, there are many opinions on adding rubber waste in concrete and about their results. Concrete mechanical properties depend on rubber geometry and surface texture. Ganjian, Khorami, and Maghsoudi [10] shared information about suitability substitution area in concrete for different types of rubbers: 1) chipped tyres can replace as coarse aggregate (gravel), 2) crumb rubber can replace as fine aggregate (sand), and 3) ground rubber can replace as a part of cement. In the same literature, they used chipped rubber tyres (their size equal to coarse aggregate) substituted as gravel (in the percentage of 5%, 7.5%, 10%) and ground rubber tyres (size from 45 micrometers to 1.2 mm) substituted as part of cement (in the percentage of 5%, 7.5%, 10%). In both cases, the compressive, flexural, tensile strength of concrete decreases when rubber content increases. 5% of chipped rubber and ground rubber are showed acceptable results. However, rubber powder concrete performed well in the flexural and tensile field compared to coarser rubber concrete. The reason behind the loss of coarse rubber concrete was improper bonding with cement paste. As part of cement, fine rubber concrete provided satisfactory water absorption test results than coarse rubber concrete and control concrete. In the united states, typical constituent materials of tyres are given in Table 1.1.

Table 1. 1. The typical constituent material of tyres (united states) [10]

Composition weight(%)	Car tyre	Truck tyre
Natural rubber	14	27
Synthetic rubber	27	14
Black carbon	28	28
Fabric, filler accelerates, and antiozonants	16-17	16-17
steel	14-15	14-15

Sienkiewicz, Lipka, Janik, and Balas [11] gave information about tyres' typical constituent materials in the European Union below Table 1.2.

Table 1. 2. The typical constituent material of tyres (Europe)

Composition weight(%)	Car tyre	Truck tyre
Natural rubber	22	30
Synthetic rubber	23	15
Black carbon	28	20
Fabric, filler accelerates, and antiozonants	14	10
steel	13	25

The researchers proved that waste rubber is increasing concrete toughness, impact resistance, and sound absorption. Generally, rubber is an elastic material that can withstand the flexural load. The above works of papers showed that fine rubber concrete has more significant mechanical properties than coarser rubber concrete. Crumb rubber as fine aggregate increases water absorption, but it decreases water absorption when substituting as cement. The mixed-size rubbers as fine aggregate are showed lower water absorption than the control mix. It is recommended to substitute rubber as fine aggregate instead of cement because cement reduction leads to strength loss, as explained by [12]. Generally, the reason for concrete strength loss is improper bonding between rubber and cement paste because rubber consists of high silicon content. Silicon is a non-polar substance that repels water and attracts air. To solve this problem, researchers started to concentrate on bonding between rubber and cement paste.

Researchers Li, Stubblefield, Garrick, Eggers, Abadic, and Huang [13] are intimated about the Intermodal surface transportation efficiency Act of 1991 (ISTEA), which is compulsory to use the waste tyres in federally funded projects. In this research, they used different forms of rubbers in concrete: a) untreated chipped rubber, b) treated chipped rubber with NaOH solution for better bonding, c) chipped rubber holed at the center to make cement column through a hole for bonding, and d) rubber fiber. 50 mm thin rubber fiber concrete yielded significant strength and toughness than a chipped rubber concrete. Surface-treated chip rubber concrete and holed chip rubber concrete did not give better results. The authors suggested surface-treated finer rubber particles will perform better than surface-treated chipped rubber particles.

Chou, Chang, and Lee [14] explain that using rubber in concrete leads to decreased compressive strength. Researchers motive to increase compressive, flexural, and tensile strength by modifying the rubber surface. Many researchers believed that improper bonding between rubber and cement was reducing the strength of concrete. There is another substantial reason for strength loss is the irregular and rough surface rubber restricting the concrete's water flow channel. As a result, improper hydration in concrete leads to strength loss. This problem is due to less Van der Walls force in rubber surface than cement paste. To solve this problem, they treated rubber with NaOH solution to get better interaction with cement paste. Experimental results conveyed that treated rubber concrete executed well than untreated rubber concrete. The coming literature is taken from the workshop (Proceedings of the international workshop on sustainable development & concrete technology by Kejin Wang). Xi, Li, Xie, and Lee [15 p.45] clarified that bonding between rubber and cement paste could be improved by increasing electrostatic interaction or chemical bonding. At last, researchers discussed that promising bonding could reach by surface treating with coupling agents – PAAM (polyallylamine), PVA (polyvinyl alcohol), and silane. PAAM is efficacious compared to PVA and silane.

Grinys, Augonis, Dauksys, and Pupeikis [16] are experimented with crumb rubber as a fine aggregate to make durable concrete. They used different size rubbers (fraction 0/1 mm and 1/2 mm) treated with and without SBR latex. Fine-size rubber concrete was performed well during durable testes (sulphate and freezing-thawing resistance) compared to coarse rubber concrete (size from 1 mm to 2 mm). Irregular fine rubber surface protected against freezing-thawing and provided less open porosity and high durability factor (kf) than a smooth surface coarse rubber concrete. Fine crumb rubber is performing similar to a traditional air-entraining agent. Literature concluded that rubber treated with SBR has no impact during mechanical and durable tests.

Adhesives can be Liquid or solid. Chen, Guo, and Sun [17] succeeded in using two water soluble-polymers (dispersible latex powder and polyvinyl alcohol powder). This type of powder polymers will be dissolved by water (amount of water used, includes in w/c ratio). Researchers concentrated on improving concrete bending toughness and fatigue performance. In concrete, ordinary portland cement and silica fume were used as binding material, and waste rubber tyres were used as a fine aggregate. Experimental results showed that rubber particles with two polymers were performed better in bending toughness and fatigue cycles, and samples without rubber, contain only polymer powder is executed substandard performance than rubber polymer concrete. This research achieved high bending toughness and fatigue performance by using high elastic and crack-resistant rubber. According to XRD analysis, latex powder and PVC powder extracting a high amount of silica and calcium during hydration, which can be a secondary reason for rubber concrete performance.

Along with polymers, the coupling agents can be used for adhesive promotion. Li, Wang, Leung, Tang, Pan, Huang, and Chen [18] explain that waste rubber aggregate will lead to substantial strength loss. Researchers came up with a new vision to break that problem by treating rubber with a silane coupling agent and SBR latex to form a strong bond with cement paste. Experimental results showed that up to 15% of treated rubber concrete were performed well in mechanical and durable fields than the control concrete. In every test, treated rubber showed a positive outcome than untreated rubber. This paper clearly explained bonding; there are three interfacial bondings: chemical bonding, mechanical interlocking system, van der Waals force. Among these three, chemical bonding is more effective in improving bonding behavior. In this experiment, by treating rubber with a silane coupling agent and SBR latex, they accomplished a chemical bond between rubber and cement paste. Detailly, the hydroxyl (-OH) group from silane and Carboxyl (-COOH) group from SBR formed a stronger bond between rubber and hydrated cement paste. Treated rubber will avoid rubber agglomeration in concrete; it will be a secondary advantage for treated rubber concretes. In this research, large size pores are noticed in untreated rubber concrete. Due to large size pores, untreated rubber concrete executed high chloride penetration than treated rubber concrete. Researchers explained that the most critical thing is that using more polymers will lead to substantial strength loss.

To improve rubber concrete properties, many researchers followed different ways of treating like rubber has been treated with NaOH, SBR, silane coupling agent, and rubber has been washed by water. For example, Dong, Huang, and Shu [19] are treated the chip rubber with silane and coated by cement paste. Vazquez, Orduna, Torres, and Bolanos [20] are treated with different solvents (ethanol, acetone, methanol) to improve rubber adhesive towards cement paste.

Adding additives like silica fume, fly ash, GGBS, and metakaolin will improve rubber concrete properties. The literature explained that fly ash and metakaolin with fine rubber aggregate exhibited strength loss and sulphuric attack. But, only fly ash with fine rubber aggregate expressed less water absorption [21]. In this literature, silica fume content increases from 0% to 15% by keeping fine rubber aggregate constant; when silica fume content increases, rubber concrete's workability and mechanical properties are decreased [22]. Among fly ash and GGBS, glass powder concrete executed excellent mechanical performance is explained by [23].

Ismail and Al-Hashmi [24] experimented with glass waste as a partial replacement of concrete's fine aggregate. They sieved glass wastes according to the sand's size, and they informed concrete will attain high strength at a later stage because glass pozzolanic reactions will take place at later stages. According to that statement, after 28days, 20% of glass replacement executed better results in compressive and flexural strength than the control mix. With increasing glass content, the workability of concrete is getting reduced due to poor glass geometry. Literature is recommending to use fine glass particles to reduce the alkali-silica reaction.

The coming literature is taken from the workshop (Proceedings of the international workshop on sustainable development & concrete technology by Kejin Wang). Xi, Li, Xie, and Lee [15 p.45] intimated that ASR (Alkali-silica reaction) expansion is the main problem for using glass in concrete. When silica contains glass reacts with alkali contain cement, forms alkali-silica gel, which expands and affects concrete's strength. To reduce ASR expansion, literature suggesting: 1) use silica fume, fly ash, and other additives as a cementitious material, 2) fine-sized glass waste, and 3) soda-lime glass, Pyrex glass, fused glass can use to neglect ASR expansion. Glasses' colors also played a significant role in ASR, so researchers concluded that using green color glass does not cause expansion. However, color glasses are reducing concrete workability and mechanical properties due to color chemicals creating a poor bond between glass and cement paste, explained by Abdallah, Fan [25].

Researchers' Serelis and Vaitkevicius [26] aim to detect ultra-high-performance concrete (UHPC) activity after 200 freezing-thawing cycles. Waste glass powder, silica fume, quartz powder are used for concrete preparation. Freezing-thawing results are expressed in three experimental methods: compressive strength, dynamic modulus of elasticity, ultrasonic pulse velocity. Researchers concluded their work by saying that the dynamic modulus of elasticity was a well-founded method for exposing freezing-thawing results. The Sample with glass powder and standard sand was performed well after freezing-thawing (approximately 800 cycles) and exhibited high dynamic modulus after the salt-scaling process. In this research [27], they prepared two different concretes; one of them consist of glass (sizes from 4.75 mm to 0.075 mm) as a fine aggregate and another one consist of glass powder (<0.075 mm) as portland cement. That two concrete went under freeze-thaw test, and freeze-thaw results are expressed in compressive and flexural strength. Glass as fine aggregate and cement were performed well after 230 freezing-thawing cycles than the control concrete (without glass). After cycles, literature finished that cement replaced glass concrete has greater flexural strength than fine glass aggregate.

Many researchers have proven that glass waste is upgrading the mechanical properties of concrete. Waste glass can use as fine aggregate. However, using glass as a cementitious material in concrete is performing great. In this research, they used glass powder as a part of cement. For experiments, they followed two different methods for substituting glass powder. The first method is a regular direct substitution of glass powder as cement; in the second method, they dissolved glass powder into water and mixed in cement. Method two samples were performed more efficiently during compressive, flexural, and water absorption tests than samples from the first method. Researchers said that silica, calcium, sodium from glass are dissolved into water. That dissolved water is forming more C-S-H products when adding to cement, which making concrete more strong. However, two methods exhibited markable performance than the control concrete at later stages [28].

These researchers Parghi and Alam [29] prepared mortar using 25% of waste glass as cementitious materials with 10% fly ash, 10% silica fume, and 10% SBR latex showed a tremendous response in compressive, flexural, water absorption, ASR expansion after 80 days compared to the control mix. The reason for that excellent performance depends on the materials used in mortar. Fly ash and silica fume made the samples more compact and reduced alkali-silica reaction and water absorption, SBR latex upgraded bond between particles in mortar. Researchers suggested that glass powder's size should be between 35 μm to 75 μm for a better pozzolanic reaction with cement.

Ramdani, Guettala, Benmalek, and Aguiar [30] are used glass powder as a cementitious material and waste rubber as a fine aggregate. The workability of fresh concrete increased when combining both rubber aggregate and glass powder. But, the compressive and tensile strength are decreased for rubber glass concrete compared to the control concrete. After 90 days, rubber glass concrete attains a satisfactory result than a control mix due to glass's later pozzolanic reaction. So, glass powder providing excellent mechanical properties to rubber concrete. Glass powder and fly ash do not react with water alone. However, they react chemically with the hydration product of cement ($Ca(OH)_2$) to form calcium silicate hydrate (C-S-H).

Researchers Karakurt and Bayazit [31] concentrated on the freeze-thaw effect between high strength concrete (contains a high amount of silica fume and low w/c) and normal strength concretes (contains a standard amount of silica fume and fly ash). In this paper, the freeze-thaw test is expressed by the results of surface scaling and water uptake. Literature gave general information about concrete prevention from the freeze-thaw effect. Frost attack occurring in concrete due to capillary pores, reducing w/c ratio or using water-reducing admixture can prevent the capillary pores in concrete. The unwanted air-voids can reduce by using additives like silica fume, fly ash, GGBS because small-size pores are occupied by silica fume and fly ash in concrete, which decreases the total amount of freezable water in concrete. Air-void-size is important for freezing-thawing resistance than air-void spacing. At last experimental results expressed, fly ash concrete with and without prefabricated air bubbles showed significant freeze-thaw results than silica fume concrete and control mix. However, high strength concrete achieved better results than all other samples.

1.1. Research methodology

1.1.1. Experimental research

Experimental research discussing results and their problems was made with untreated and treated crumb rubber, glass powder, and fly ash additive concretes from literature's respective works.

1.1.2. Physical properties of crumb rubber and waste glass fresh concrete

Slump cone test. The concrete was made by substituting (10% to 100%) fine, coarse, mixed fine and coarse rubber as fine aggregate. When rubber content increased, the slump value gets decreased. Rubber content above 80% showing zero slump value. From slump test results, coarser rubber contains fresh concrete with a high slump value than fine and mixed rubber. Fresh concrete contains fine rubber made concrete more compact and reduced concrete workability is explained by [6].

Here the literature explaining the same, coarser rubber concrete (rubber size 3 mm) has a high slump value than the fine rubber concretes (sizes 0.5 mm & 0.3 mm). Literature shared that when decreasing rubber size, slump value is getting decreases. The reason explained by literature was rubber used in this experiment is absorbing more water than sand. Basically, fine rubber has a large specific area, so it absorbed more water than coarser rubber, and due to less free water in fine rubber concrete leads to low workability. Another reason got from literature is due to rubber geometry. In that research, a coarse rubber surface was smoother, which increases slump value than fine rubber [7]. Fine and coarse rubber aggregates were added in the proportion of 0% to 40%. Finer rubber showed a linear decrease, and coarser rubber showed a non-linear decrease in slump value when increasing rubber content [32].

The slump value of fresh concrete contains treated (with NaOH) and untreated coarse rubber, rubber fiber are nearer to the control mix ranging from 14 cm to 15.2 cm. The main thing is to notice that rubber fiber is not influencing workability is shown by [13]. The same results were explained in this literature: rubber fiber does not negatively influence workability [33]. Chou, Chang, and Lee [14] expressed that 5% of treated crumb rubber (with NaOH) samples showed 20% to 25% of higher workability than no rubber samples. In the coming literature, rubber was treated with NaOH solution for 0.5 hr, 1 hr, and 2 hr. Researchers proved that treated rubber lost its stiffness when treating time increased, which reduced the slump value than untreated rubber concrete. But, all treated rubbers having a higher slump value than the control mix. The second part of this research discussed rubber with silica fume, fixed rubber content with increasing silica fume amount (about 5%, 10%, 15%) is directed to low slump value. At last, tested fixed rubber content with increasing cement quantity (about 300 kg/m^3, 350 kg/m^3, 400 kg/m^3) showed higher slump value [22].

When glass content increased as fine aggregate is declining slump value due to its poor geometry and fineness. However, glass concrete is workable, explained by [24][25]. Here, the literature explained that increasing glass powder amount (from 0% to 30%) as a part of portland cement, which increasing slump value due to free water in concrete. The water for hydration in concrete becomes free water due to cement reduction, which increased the glass powder concretes workability [28]. Concrete workability is getting reduced by substituting glass as coarse and fine aggregate. But, glass powder as a cementitious material showed high slump value than the control mix. This literature suggests three essential things influencing glass concrete workability: glass geometry, glass surface smoothness, and a glass specific area. In this research, the glass powder surface was smooth so that only glass powder concrete attains a high slump value [34].

The researchers experimented using glass powder with and without a superplasticizer (water reducing agent). Glass concrete with superplasticizer increased slump value than glass concrete without superplasticizer because oil characteristic superplasticizer reduced glass surface tension and made glass to flow smoothly [35]. Ramdani, Guettala, Benmalek, and Aguiar [30] conveying that concrete contained rubber as a fine aggregate and glass powder as a cementitious material reveals a high slump value than rubber concrete (without glass powder) and control mix. Researchers reason for that high slump is due to great friction between glass particles and cement particles.

Fresh concrete density. Due to rubbers' low specific gravity, fresh concrete densities are decreases with increasing rubber content. The literature explains slump, air content, fresh concrete density are interconnected. When rubber content increased, fresh concrete density gets decreased with increasing air content. Fine and coarse rubber is added above 50% in that research, which showed a 75% reduction in density than the control mix [6]. The literature discussed that fresh concrete density is reducing with increasing rubber size (sizes are 3 mm, 0.5 mm, and 0.3 mm). Fine rubber concrete exhibits a lower fresh density than coarser rubber concrete. Naturally, rubber is non-polar nature; it entrapping air in concrete. So, researchers concluded that fine rubber has a large specific area it entraps more air in concrete than coarser rubber, which made fine rubber concrete to attain less fresh density [7]. If rubber content less than 10 to 20% of the total aggregate volume will not affect concrete density. The fresh concrete density of treated rubber (treated with a silane coupling agent and coated with cement) is less than untreated rubber concrete is explained by [19].

The fresh concrete density decreased when glass content increased as fine aggregate due to low specific gravity than sand. Still, the fresh concrete density of glass is nearer to the control mix [24]. The glass powder was replaced as cement, showing less fresh concrete density than fine glass aggregate and control mix because of cement reduction is described by [34]. The literature experimented in dry density using glass powder as cement (from 0% to 30%). Same as every literature, when glass content increased, dry density gets decreased. Dry density test after 90 days showed a high-density value in glass concrete than the control mix due to the pozzolanic reaction of glass formed more hydrated products. However, 30% of glass replacement has no significant result due to a massive cement reduction. So, glass will start works at a later stage, explained by [28]. We all know that increasing rubber content fresh concrete density will decrease. This literature showed that rubber concrete's fresh density increased by combining glass powder as portland cement. Glass powder occupying more pores and making rubber concrete denser than rubber concrete without glass powder is proved by [30].

Air content. Due to its non-polar nature, rubber is entrapping air in concrete. So, definitely increasing rubber content is going to increase air content in concrete, which leads to a decrease in concrete density. The literature carries different sizes of rubbers (sizes are <0.5 mm, 0.5-1 mm, 1-1.5 mm, 1.5-2 mm, 2-2.5 mm) in that <0.5 mm fine rubber has a large specific area it entraps a high amount of air than other coarse rubbers. Air content of <0.5 mm rubber concrete is 3.3% is more generous than the control mix (obtains 1.9%). Usually, 3% of air is sufficient for freezing-thawing resistance. From results, <0.5 sizes rubber is perfect for the freezing-thawing effect [3]. 30% of silane treated rubber as a fine aggregate increased air content than 15% treated, 15% and 30% of untreated rubber [19]. The treated chip tyre (with NaOH) exhibits more air content than untreated chip rubber [13].

Increasing glass quantity as a fine aggregate, it increasing air content in concrete. Literature explained that glasses are carrying air into concrete due to their irregular shape, rough surface, high aspect ratio, and sharp edges [36]. In this literature, the glass powder is substituted as cement, which executes high air content than fine glass aggregate and control mix. Researchers described that if the crushed glass is flat and elongated, there is more chance for high air content [34].

1.1.3. Mechanical properties of crumb rubber and waste glass concrete

Compressive strength. In that research, Issa and Salem [5] replaced 0% to 100% of crushed sand with crumb rubber. They sieved crumb rubber according to the size of sand. As the amount of crumb rubber increases, compressive strength start to decreases. Experimental results showed that less than 25% of crumb rubber content is holding nearer strength to the control mix. The coming literature was used three different sizes of rubbers (sizes are 3 mm, 0.5 mm, and 0.3 mm) as a fine aggregate. Experimental results conveyed that when rubber size decreases, the compressive strength got increases. From results, 0.3 mm fine rubber concrete exhibits 1.26% higher compressive strength than coarser rubber concrete. Researchers have explained that fine rubber reduced the pores in concrete by occupying them, which increased concrete strength. Coarser rubber loses compressive strength due to its smooth surface, which makes improper bonding with cement paste was explained using SEM in that research. However, both fine and coarse rubber concrete has low strength than the control concrete [7].

From the above literature, it was concluded that fine rubber is effective in concrete than coarse rubber. But other researchers had different opinions. In this research, coarse rubber (size is fraction 4/6) providing high strength than fine rubber (size is fraction 2/4). Literature explained that coarse rubber concrete has a high-density than fine rubber concrete; it was the reason mentioned in literature for coarse rubber concrete strength [9]. Ganjian, Khorami, and Maghsoudi [10] carried their experiment using two sets of samples. In the first set, chipped rubber was substituted as a coarse aggregate and in the second set, rubber powder was substituted as cement. When chipped and powder rubber content increased, concrete's strength decreased. Between chipped and powder rubber, chipped rubber was performed better than powder rubber because cement replacement by rubber powder is not worked. Researchers gave reason for compressive strength reduction: 1) Due to cement reduction by replacing rubber, 2) Crumb rubber is soft material among other aggregates, so cracks are appearing quickly around rubber and spreading throughout the concrete, 3) Improper bonding between rubber and cement paste, 4) Rubber agglomeration, 5) Due to less specific gravity of rubber, concrete density is gets reduced which leads to strength loss.

Li, Stubblefield, Garrick, Eggers, Abadic, and Huang [13] described samples prepared with different forms of rubbers (were substituted as gravel in concrete): chipped rubber treated with NaOH solution, chipped rubber holed center, rubber fiber. First, we will see treated chip rubber; surface treatment is not worked for chipped rubber, where it has not performed well than untreated chipped rubber concrete (researchers recommended to use fine rubber for NaOH treatment). Next, chip rubber holed about 5 mm at the center to create a cement column for perfect bonding. However, the hole closed before mixing, so concrete attains insufficient compressive strength due to improper anchorage. Next, rubber fiber less than 50 mm in length is discharging better strength than other forms of rubbers in this research. When increasing fiber length, concrete strength is decreasing. So researchers said to use fiber length less than 50 mm and to use thin rubber fiber.

Youssf, Mills, and Hassanli [22] explaining about to increase mechanical properties of crumb rubber concrete by using three methods: treating crumb rubber with NaOH solution (for 0.5 hr, 1 hr, 2 hr), increasing silica fume content (from 0% to 15%), increasing cement content (from 300 kg/m^3 to 400 kg/m^3). The compressive strength of 0.5 hrs treated rubber is 42.1 MPa; it is greater than one and two hours treated rubber and untreated rubber concrete. Less treating time is effective because rubber losing its stiffness during extensive time treating, and due to that, concrete also losing its stiffness. Afterward, they tested rubber with silica fume. When silica fume content increased with fixed crumb rubber amount (about 20%), results showed the least compressive strengths. Researchers found that strength reduction is because of adding more than the required amount of silica fume. So, research authors said to use <5% of silica fume for good results. The compressive strength of 5% silica fume and 20% crumb rubber is 39.7 MPa, and researchers decided to study later age effects of silica fume using 5%. On the 84th-day, rubber with silica fume concrete increased its strength up to 42.5 MPa. Everyone knows that increasing cement content (from 300 kg/m^3 to 400 kg/m^3) with 20% crumb rubber will increase rubber concrete compressive strength. As expected, the strength of concrete with cement amount 400 kg/m^3 and rubber is 45.9 Mpa higher than 300 kg and 350 kg cement concrete. At last, literature suggest 0.5 hrs treating, 0% SF, cement content about 350 kg/m^3 for essential crumb rubber concrete performance.

Grinys, Augonis, Dauksys, and Pupeikis [16] prepared different samples with different materials. They were used: traditional air-entraining agent, 1.5 kg and 2.5 kg of prefabricated air bubbles, fine size treated and untreated rubber (with SBR), coarse size treated and untreated rubber. Concrete contains traditional air-entraining agent was performed lower compressive strength than other samples. Both treated and untreated fine crumb rubber concrete showed less compressive strength (about 45.6 MPa and 46.8 MPa) than treated and untreated coarse rubber concrete (46.9 MPa and 48 MPa). In both cases, treated rubber concretes executed a little bit lower performance than untreated rubber concretes. Concrete with 2.5 kg of prefabricated air bubbles (special air-entraining agent) reached good strength equal to control mix. Researchers gave a reason for rubber concrete's lower compressive strength: Due to rubber's elastic nature, cracks are appearing quickly around rubber and extending throughout concrete.

Li, Wang, Leung, Tang, Pan, Huang, and Chen [18] treated their rubber with SBR latex and silane coupling agent (additional bond strength for rubber). They replaced both treated and untreated crumb rubber from 5% to 30% as a fine aggregate. In that, untreated rubber concretes exhibited lower compressive strength compared to treated rubber concretes and control mix. The compressive strength of 5% and 10% treated rubber concrete is 4.2% and 0.2% higher than the control concrete. The remaining treated rubbers concretes exhibited lower strength than conventional concrete due to an increase of porosity. The paper [16] explained that treated rubber concretes are executed with lower strength than untreated rubber concretes. Here [18], explained that treated rubber has more excellent performance than untreated rubber because they added an extra supporting agent (it is a silane coupling agent).

Higher-strength was reached when rubber was treated with a silane coupling agent and coated with cement to attain a fitter bond with hydrated cement paste. The compressive strength of coated rubber concrete is higher than the uncoated rubber concrete, but both concretes are lower than the control mix. Fracture energy was calculated from the compressive strength stress-strain curve. Concrete with 15% of coated rubber exhibited higher fracture energy than the control concrete and uncoated rubber concrete. In the end, researchers conveyed that rubber has high energy absorption, and it can withstand stress for a longer time than a control concrete [19]. In rubber concrete, fly ash and metakaolin were added to bring high performance. In the beginning, fly ash and metakaolin concrete without rubber were performed well during the compressive test. That performance was get lowered when crumb rubber amount increased in fly ash and metakaolin concrete. However, 5% rubber waste (as fine aggregate) and 30% fly ash (as cement) contains concrete executed sufficient strength about 40 MPa, and the same nearer strength was obtained when substituting 5% rubber, 15% fly ash, and 15% metakaolin [21].

Ismail and Al-Hashmi [24] consumed different percentages (10%, 15%, 20%) of glass as a fine aggregate in concrete, and when glass percentage increased, the strength of concrete is also increased. In that research, the compressive strength test was carried at 3, 7, 14, 28 days. Ongoing each day, the compressive strength was getting increases gradually. After 28 days, the strength of 20% glass contains concrete was reached 45.9 MPa; it was 4.23% greater than the control concrete. At concrete later ages, the significant pozzolanic reactions of glasses are taking place with cement hydration products. A similar process happened in this literature [25].

Researchers Elaqra, Haloub, and Rustom [28] accomplished their experiment in two different manners. First, they substituted glass powder (from 0% to 30%) directly to cement, and they dissolved glass powder into water and mixed it as part of cement. In the first method, glass powder concretes yielded lower compressive strength during the earlier stages. After 90 days, 10% and 20% glass powder concrete performance was more significant than the control mix due to later age pozzolanic reaction of glass with cement. During the second method, glass contains minerals (sodium, silica, calcium) are dissolved in water. That mineral water reacted with cement paste, and it made more hydration products (C-S-H). So, the second method samples were executed better compressive strength during an earlier stage than a control mix and conventional method. In both methods, 10% and 20% glass powder concrete has significant compressive results, and 30% glass powder concrete executed lower strength during the earlier stage and later stage. So, when glass powder exceeds 30%, it reducing concretes strength.

In this literature, they are monitoring glass powder, fly ash, and GGBS concretes performance. This concretes were prepared with different w/c ratios (0.65, 0.55, 0.40, 0.35). The compressive strength results were calculated after 1, 28, 56, 91, 365 days. Glass powder, fly ash, GGBS concretes compressive strength increased along with days rises (because the pozzolanic reaction will happen continuously without dropping). The experimental results concluded that concretes with a water-cement ratio of 0.35 executed effective compressive results. Among cementitious materials, glass powder concrete showed greater performance in the compressive test. So this literature concluded that glass powder could act as an effective cementitious material in concrete [23]. In this literature, researchers experimented with glass concrete with and without superplasticizer (they used a water reduction agent). They concluded that superplasticizer improved glass concrete mechanical properties [35].

Parghi and Alam [29] aimed to make high mechanical and durable property mortar using glass powder, additives, and polymer. Four different samples were used in the experiment: a) 5% to 25% of glass powder contains concrete, b) glass powder and fly ash contains concrete, c) glass powder, fly ash, silica fume contains concrete, and d) glass powder, fly ash, silica fume, and SBR latex contains concrete. These materials are substituted as a part of cement. From experimental results, glass powder showed excellent pozzolanic reaction with cementitious materials. Glass powder, fly ash, silica fume, SBR were upgraded mortars strength than control mix (sample (a) increased up to 40%, sample (b) increased up to 45%, sample (c) increased up to 74%, sample (d) increased up to 77%).

Researchers Ramdani, Guettala, Benmalek, and Aguiar [30] are used fine rubber aggregate and glass cementitious material together in concrete. When rubber content increased with constant glass content showing strength loss, but it executed better results than rubber concrete without glass powder. After 28 days, 10% rubber with 15% glass powder yielded 36.01 MPa, higher than rubber concrete without glass powder. Generally, glass has a great pozzolanic reaction with cement paste at later stages. So, after 90 days, researchers tested rubber and glass concrete; it showed 41.46 MPa, which is higher than conventional concrete and rubber concrete without glass powder.

Flexural and tensile strength. This research used different sizes of rubbers (sizes are 3 mm, 0.5 mm, and 0.3 mm) in their concrete. In this same paper, we have discussed compressive strength results. According to that result, fine rubber concrete showed good compressive performance than coarse rubber concrete. Now, in the flexural test, crumb rubber concrete (size is 0.3 mm) executed 2.09% higher flexural strength than coarser rubber concrete (size is 3 mm). That same crumb rubber concrete executed 4.47% higher split tensile strength than coarser rubber concrete. From the results, we can see that fine crumb rubber is providing better mechanical properties to concrete. Literature explained that fine rubber occupied the pores, making concrete compact and reducing stress development in concrete pores [7].

Ganjian, Khorami, and Maghsoudi [10] are demonstrated chipped rubber as coarse aggregate and rubber powder as a part of cement in concrete, and they substituted materials in different percentages (5%, 7.5%, 10%). The flexural strength decreased 37% for coarse rubber and 29% for ground rubber compared to the control concrete. Coarser rubber concrete attains less flexural strength than rubber powder concrete due to improper bonding of coarse rubber with cement paste. The authors confirmed improper bonding by noticed that coarse rubber had been easily removed from concrete after breakage. In this same research, tensile strength for coarse rubber and ground rubber decreased 44% and 24% compared to a control mix. Researchers explain that rubber will act as a barrier during crack development. However, in this research, results happened in the opposite direction. The reason for that worst performance due to poor bonding between rubber and cement paste, which developed a crack during loading, that crack segregates rubber and cement separately. It brings concrete to weaken for a breakdown.

Li, Stubblefield, Garrick, Eggers, Abadic, and Huang [13] are carried out their experiment using treated chip rubber (NaOH), untreated chip rubber, and rubber fiber. Here, rubber fiber concrete executed the highest stress-strain curve than the control mix and chip rubber concrete because chip rubber does not have enough length to carry a load, but rubber fiber has enough length to carry a load. Researchers said rubber fiber length should less than 50 mm for remarkable performance. Researchers also discussed high toughness attained by using rubber fiber along with polypropylene fiber, which is called a hybrid fiber model.

Youssf, Mills, and Hassanli [22] planned to increase rubber concrete tensile strength by treating NaOH solution (for 0.5hr, 1hr, 2hr), adding silica fume additive, and increasing cement content. Two hours of treated rubber attains high tensile strength (3.2 MPa) than untreated rubber (attains 2.7 MPa). However, increasing the treating time for rubber is influences in a good way for tensile strength. Next, when silica fume content increased in rubber and conventional concrete (up to 15%), it decreased tensile strength by 4% for crumb rubber and 8% for conventional concrete. When cement content increased (up to 400 kg/m^3), it increases tensile strength up to 10% for crumb rubber concrete and 22% for conventional concrete.

Li, Wang, Leung, Tang, Pan, Huang, and Chen [18] prepared treated rubber (with SBR and silane) and untreated rubber. Here, rubbers are substituted as a fine aggregate (from 5% to 30%). The rubber used in this research was looked like fiber from a microscopic view. When they increased untreated rubber content, flexural strength decreased. In that, 30% untreated rubber concrete reduced flexural strength up to 38% than the control concrete due to cracks that appeared quickly around unbonded rubbers. But, the 5% untreated rubber concrete executes high flexural strength than control concrete. Following 5%, 10%, and 15% of treated rubber increased 9%, 13%, and 3% flexural strength than a control concrete. Treated rubber had a healthier bond with cement paste, which controlled the tensile cracks in concrete. However, 25% and 30% of treated rubber performed lower flexural strength because voids increased due to a rubber amount rises. Dong, Huang, and Shu [19] conducted a split tensile test after 60 days, rubber was treated with a silane coupling agent and coated with cement, which evinced high split tensile strength than uncoated rubber but the 15% and 30% coated rubber reduced tensile strength by about 5% and 23% than control concrete. Coated rubber was observed on the fractured concrete surface during split tensile strength, so researchers concluded that treated rubber has excellent bonding with hydrated cement.

Abdallah and Fan [25] described that they were getting high flexural strength when increasing fine glass aggregate. They clearly explained that glass concrete's flexural strength increased when the days moved (after 7, 14, 28 days). A large amount of glass (about 20%) was showed unfavorable flexural results during the earlier stage. After 28 days, 20% of glass aggregate increased its flexural strength of about 8.9% than the control mix; it happened due to a later age pozzolanic glass reaction. Simultaneously, the same 20% glass concrete increased its split tensile strength by about 18.38% than a control mix. The coming literature discussed the flexural strength of concrete contains glass powder as a part of cement. When glass powder increased (from 10% to 30%), concrete starts to lose its flexural strength. Glass powder concrete failure was happened due to porosity in concrete. Researchers were trusting that 10% of glass powder concrete has less and delicate pores because it showed satisfactory flexural strength [28].

Parghi and Alam [29] explain that replacing cement with glass powder (from 5% to 25%) was had positive flexural results than the control mortar. Introducing silica fume, fly ash, and SBR latex with glass powder as part of cement creates a good link between cement particles and aggregates at the interfacial transition zone. So, the flexural strength gets increased by adding additives and polymer with glass powder at each sample: 1) glass powder mortar increased flexural strength up to 47% than control mix, 2) glass powder and fly ash mortar increased up to 55% than control mix, 3) glass powder + fly ash + silica fume rises to 76% than control mix, 4) glass powder + fly ash + silica fume + SBR rises to 79% than control mix.

Ramdani, Guettala, Benmalek, Aguiar [30] proved that concrete contains rubber as a fine aggregate and glass powder as cement exhibited lower split tensile strength than the control mix. Up to 20% rubber and 15% glass powder containing concrete gave comparative better tensile results than the control mix. However, 10% rubber and 15% glass powder concrete enhanced 0.43% than rubber concrete without glass powder. In this literature, glass rubber concrete has a significant split tensile performance than rubber concrete without glass powder.

Strength activity index. It is used to calculate the pozzolanic activity of cementitious material in concrete. The research proved that glass powder mortar has high strength activity index than the control mix. After 90days, Mortar with fine glass powder showed pozzolanic activity above 90%. Additives (fly ash, silica fume) and polymer (SBR) with glass powder gave exceptional strength activity index above 150% [29].

1.1.4. Durable properties of crumb rubber and waste glass concrete

Water permeability depth and water absorption. Both water permeability and water absorption characteristic are essential for concrete freezing-thawing. Usually, adding rubber to concrete will increase water permeability. The literature explained that fine crumb rubber reducing water permeability depth than coarse rubber because fine rubber acts as a filler and fills the pores in concrete. Due to fine rubber activity, concrete becomes compact and reduced pores for water flow [7]. However, fine crumb rubber is resisting water permeability than coarse rubber. The coming literature clearly explained that increasing crumb rubber amount is also a disadvantage for water permeability and water absorption. They prepared concrete using crumb rubber as fine aggregate (used amount from 4% to 5.5%). The results proved that concrete with 5.5% crumb rubber exhibited the highest water absorption (about 3.21%) than the control mix (is about 1.91%). In the same literature, water permeability test results were the same as water absorption results. Large water permeability was founded at 5.5% crumb rubber concrete (about 33.3%) than 4% crumb rubber concrete (about 6.6%). Researchers explained that the amount of pores is enlarged by increasing rubber amounts, which increases water absorption and water permeability [37].

Concrete was prepared by rubber powder as cement, which reduces water absorption than the control mix. Very fine rubber was filling more pores and showed notable performance than a control mix is explained by [10]. The researchers prepared rubber mortar with SBR. They treated crumb rubber with SBR, which was substituted as fine aggregate (from 20% to 100%). When treated rubber increased, water absorption was reduced due to fewer pores in a concrete mortar, which was achieved by treated rubber [38]. When increasing rubber as fine aggregate (from 5% to 15%) is executing high water absorption. However, when 30% and 60% fly ash were added along with rubber concrete, it reduces water absorption than rubber concrete without fly ash. Specifically, 15% rubber and 30% fly ash contain concrete were significantly reduced water absorption by about 57% compared to rubber concrete without fly ash [21].

Abdallah and Fan [25] showed that water absorption was reduced when the glass amount increased as fine aggregate. The literature explains that glass pozzolanic reaction produces more hydration products, and those hydration products filled concrete pores and made concrete compact. Due to that reason, the water absorption of glass concrete was reduced.

The same results were obtained when concrete contains glass powder as cement; it reduces water absorption when glass content increases. At later stages, concretes attains a shallow water absorption results due to later age pozzolanic glass reaction. So, glass concrete's efficient water absorption results are getting only at later stages [28].

Parghi and Alam [29] discuss when glass powder increases, causing less water absorption in mortar. In this research, fly ash, silica fume, SBR latex are added along with glass powder. So, glass powder, fly ash, silica fume have occupied the pores between cement and aggregates during hydration. According to these additives, they minimized the pores, and SBR latex made proper bonding between additives and cement, which made concrete less water absorption. The silica fume is an essential factor for less water absorption because it fills micropores and produces high-density package concrete.

Alkali-silica reaction. Abdallah and Fan [25] explained that ASR is forming when hydroxide ions break silica in aggregates that silica reacts with alkali presence cement. Sometimes alkali-silica reaction will combine as cementitious material with the cement during hydration, which increasing concrete strength. In this research, when they increased fine glass aggregate (from 5% to 20%), alkali-silica expansion is reduced than the control mix. Less expansion explained by literature is alkali content gets lowered by utilizing a lime (which breaked during cement hydration) that reacted with fine glass aggregate.

Parghi and Alam [29] discussed that glass powder less than 75-micrometer is reducing the ASR expansion. This literature [39] explained that glass powder with fly ash has the least ASR expansion.

Ultrasonic pulse velocity. Ultrasonic pulse velocity will explain concrete internal defects (voids, cracks) and mechanical properties of concrete. According to Ramdani, Guettala, Benmalek, and Aguiar [30], when increasing fine rubber aggregate, ultrasonic pulse velocity is decreasing. Generally, decreasing pulse velocity leads to strength loss. When glass powder was added with rubber, it increased ultrasonic pulse velocity than rubber concrete without glass powder. After 90 days, concrete with 10% rubber and 15% glass powder executed high pulse velocity (about 4840 m/s) and high compressive strength (about 41.46 MPa) than the control mix (4750 m/s and 40.89 MPa).

After 28 days, the ultrasonic pulse velocity increased. But, when a fine glass aggregate increased in concrete, ultrasonic pulse velocity is get decreased. Glass geometry will be the reason for decreasing pulse velocity explained by researchers. However, glass concrete compressive strength is more significant than the control mix because of the glass pozzolanic reaction [25]. Karakurt and Bayazit [31] proved that fly ash concrete carried high pulse velocity than silica fume concrete.

Freezing-thawing resistance. Richardson, Coventry, Edmondson, and Dias [3] were performed a freezing-thawing experiment using different sizes of crumb rubbers (they are <0.5 mm, 0.5-1 mm, 1-1.5 mm, 1.5-2 mm, 2-2.5 mm). The freezing-thawing experiment results were expressed in different testing methods; 1) Pulse velocity: after 70 freezing-thawing cycles, rubber concrete had stable ultrasonic pulse velocity than the control mix. 2) Mass loss: after 70 cycles, control concrete showed a greater mass loss than concrete contains <0.5 mm rubber, and other rubber concretes also had less mass loss than conventional concrete. 3) Compressive strength: pre-freezing-thawing compressive strengths of all concrete were higher than the post-freezing-thawing strengths, in that <0.5 mm rubber concrete were achieved significant post-freeze-thaw strength than other size rubber concretes. Researchers said that less density concrete would have more tiny pores, which will boost excellent freezing-thawing performance. 4) Durability factor: durability factor was calculated in that research according to equations given in ASTM 666. Control concrete was holding a less durable factor (is 101.3%) than other samples. Concrete with 1.5 mm to 2 mm size rubber is showed a high durability factor (is 105.2%). 5) Surface scaling: rubber concrete with <0.5 mm rubber showing no damage on the surface after 70cycles. This experiment concluded that rubber performs well during the freezing-thawing test, in that fine rubber (size <0.5 mm) was had more excellent results than other coarse rubbers.

Grinys, Augonis, Dauksys, and Pupeikis [16] carried their freezing-thawing test with a traditional air-entraining agent, prefabricated air bubbles, treated fine & coarse rubber, and untreated fine & coarse rubber. The freezing-thawing results were expressed in terms of compressive strength. From freezing-thawing results, concretes strength with a traditional air-entraining agent and prefabricated air bubbles were increased by about 27% and 30% after 400 cycles. The result of untreated fine crumb rubber and treated fine crumb rubber concretes strength increased by 24% and 12% after 400 cycles. Untreated coarse rubber concrete showed a negative effect after 400 cycles but treated coarse rubber concrete was not affected negatively and not influenced concrete during the freeze-thaw effect. The hydration process was continued during cycles. So that concretes strength was increased after cycles, explanation gave by researchers.

Serelis and Vaitkevicius [26] are explaining the activity of high-performance concrete after freezing-thawing cycles. Three samples (sample 1- silica fume, quartz powder, quartz sand; sample 2- glass powder and quartz sand; sample 3- glass powder and natural sand) were made for tests. The freezing-thawing results were expressed in compressive strength, ultrasonic pulse velocity, and dynamic modulus of elasticity. 1) compressive strength: sample strengths are reduced after 200 cycles. Sample 1 and 3 were executed with the same strength (is 131 MPa), which was higher than sample 2 (is 127 MPa). In this research, glass powder was performed equal to silica fume and quartz powder. 2) Ultrasonic pulse velocity: after 200 cycles, ultrasonic pulse velocity were decreased very low for all samples than before freezing-thawing values. 3) Dynamic modulus of elasticity: sample 3 got a high dynamic modulus of elasticity (is 31.073 GPa) than samples 1 (is 27.153 GPa) and 2 (is 28.11 GPa) after 200 cycles. The paper was concluding that glass powder has remarkable performance after freezing-thawing cycles.

The coming researchers were prepared their samples using crushed glass as cement and fine aggregate. These samples were tested under freezing-thawing, and they expressed that freezing-thawing results by compressive and flexural methods. After 230 cycles, glass contains concrete reached a high compressive strength of about 48% than the control mix (is 34%). Increasing glass amount as fine aggregate up to 20% showed a valuable performance in the compressive field. But when substituting glass as cement, it loses compressive strength when the amount of glass powder increased above 15%. In flexural strength, glass powder as cement gave generous support to concrete compared to glass fine aggregate and control mix [27].

Karakurt and Bayazit [31] are proved that concrete with fly ash and air-entraining agent (it is prefabricated air bubbles) is exhibiting the least surface scaling damage and least water uptake than silica fume concrete. Fly ash concrete has worked better than silica fume concrete during the freezing-thawing effect. Dauksys, Ivanauskas, Juociunas, Pupeikis, and Seduikyte [40] are said that when increasing coarse aggregate content, it decreasing close porosity numbers in concrete, which causing defects during the freezing-thawing effect. In this research, a freezing-thawing test was done between concrete without and with coarse aggregate. Concrete with coarse aggregate showed compressive strength below 5% than the control concrete due to large-size pores. According to LST 1428.17, a strength less than 5% is not suited for the freezing-thawing test. Concrete with only fine aggregates (it was mortar) was performed better during freeze-thaw.

Porosity parameter. The porosity parameter of concrete is calculated by using the water absorption method. The porosity parameter test will give information about the number of open porosity, close porosity, total porosity in concrete. Along with that, it will also provide water absorption percentage, frost resistance factor (kf), and frost cycle prediction. Grinys, Augonis, Dauksys, and Pupeikis [16] are explained that fine crumb rubber concrete is executed with more close porosity than coarse rubber and control concrete. So, fine crumb rubber concrete exhibited a high frost resistance factor and predicted freeze-thaw cycles were more than 800. Treated fine crumb rubber concrete was also performed equal to untreated rubber concrete.

In my research, the investigation was started by substituting crumb rubber as a fine aggregate because fine rubber particles were showed better performance than coarser rubber particles in the mechanical and durable field (especially in freezing-thawing resistance). However, fine rubber gave a more substantial freezing-thawing effect, but it decreased concretes strength (when the amount rises). The reasons for that failures are due to improper bonding and rubber agglomeration. So, in our second set, we treated rubbers with SBR latex to create a bond with cement paste. But, researchers conveyed that treated rubbers also not up to the level of control mix. Then, in our third set, glass powder was replaced as a part of the cement. Generally, glass is a high silica content product that can make rubber concrete even stronger. From works of papers, we can conclude that glass powder has a good profile in freezing-thawing, and it expressed better performance than silica fume and fly ash. This research aims to find a magnificent mix in the mechanical and durable field by adding crumb rubber and waste glass powder in concrete. Many researchers investigated the mechanical and durable tests using separately silica fume and fly ash, waste rubber with additives, untreated and treated rubber, and glass powder with crumb rubber. From my knowledge, it was the first time this research performed mechanical and durable tests by utilizing treated crumb rubber, glass powder, and fly ash together in concrete. Additional exploration has been made between normal crumb rubber and fibrous crumb rubber in the field of freeze-thaw.

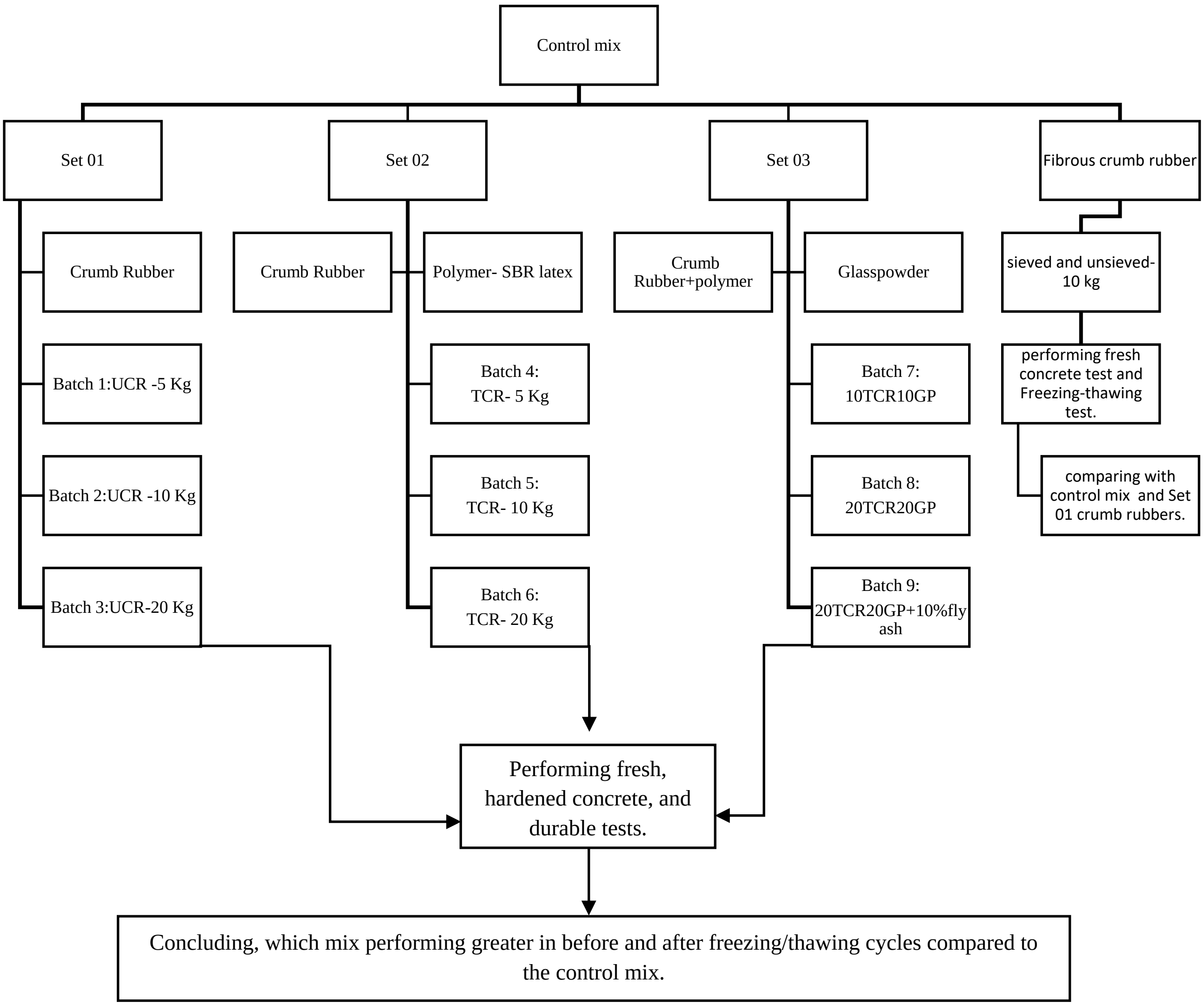
1.2. Objective and scope

The research aims to find a magnificent mechanical and durable mix by utilizing crumb rubber, waste glass powder, and fly ash against a conventional white topping mix.

- In this research, there are three sets, Set 01: Untreated crumb rubber (UCR), Set 02: Treated crumb rubber (TCR), Set 03: Treated crumb rubber and Glass powder (TCRGP). Additionally, we prepared two batches contains sieved and unsieved fibrous crumb rubber—each set carrying three batches.
- Generally, adding crumb rubber in concrete leads to strength loss due to improper bonding, improper water flow channel for hydration, and rubber agglomeration. These are the three main problems for rubber concrete strength loss. To solve these problems, we treated crumb rubber with SBR latex to create a chemical bond with cement paste. Further, we added glass powder and fly ash in treated rubber concrete to check its performance against the control concrete.
- To find slump value, fresh concrete density, air content for UCR, TCR, TCRGP, sieved and unsieved fibrous crumb rubber batches.
- To check compressive strength, dry density, flexural strength, and fracture energy for UCR, TCR, TCRGP batches.
- To check strength activity of glass powder and fly ash in treated rubber concrete.
- The central theme of this research is to attain a significant freezing-thawing effect by utilizing crumb rubber (size <0.315 mm) in concrete against a special high-efficiency air-entraining agent (prefabricated air bubbles) in the control mix, along with this need to find the freezing-thawing effect of TCR, TCRGP, sieved and unsieved fibrous crumb rubber batches.
- Moreover, to check the porosity amounts for all batches, porosity influencing concrete behavior in the mechanical and durable field.

Research's scope is to decrease the use of sand and cement (ejecting greenhouse gas). By recycling waste materials, the environment will become clean and pure. Benefits for white topping: using crumb rubber and glass powder will reduce the cost of buying cement, sand, air-entraining agents. Save natural resources and a cleaner environment for the future.

1.2.1. Experimental program



2. Materials and mix proportion

The samples were categorized into three sets. Initially preparing the control mix (not included in sets), each set contains three batches. In Set 01, untreated crumb rubber (UCR) was substituted as a fine aggregate and set 01 batches are Batch 1: 5 kg/m^3 of UCR, Batch 2: 10 kg/m^3 of UCR, Batch 3: 20 kg/m^3 of UCR. In Set 02, crumb rubber was treated with SBR latex (TCR) and substituted as a fine aggregate. Set 02 batches are Batch 4: 5 kg/m^3 of TCR, Batch 5: 10 kg/m^3 of TCR, Batch 6: 20 kg/m^3 of TCR. In Set 03, treated rubber was substituted as a fine aggregate and glass powder substituted as part of portland cement (TCRGP). Set 03 batches are Batch 7: 10 kg/m^3 of TCR and glass powder, Batch 8: 20 kg/m^3 of TCR and glass powder, Batch 9: 20 kg/m^3 of TCR and glass powder with 10% of fly ash (as a part of cement). For each batch, one 150 mm cube for compressive strength test, six 100 mm cubes for freezing-thawing and porosity parameter analysis, and one prism for flexural strength test were prepared. An additional freezing-thawing test was conducted for sieved and unsieved fibrous crumb rubbers (SFCR and UFCR). For that additional test, six 100 mm cubes were prepared for each sieved and unsieved fibrous crumb rubber batches. According to the European standard, raw materials for concrete preparation are given in Table 2.1.

Table 2. 1. Raw materials for concrete preparation

Raw materials	Type	European standard
Cement	Ordinary Portland cement (CEM 1 42.5R)	EN 197-1
Fine aggregate	Natural sand (0/4mm)	EN 12620
Coarse aggregate	Crushed granite (4/16mm)	EN 12620
Water reducing admixture	Modified polycarboxylates	EN 934-2
Shrinkage reducing admixture	Sika control 50	EN 934-2
Air-entraining agent	Prefabricated air bubbles	EN 934-2
Fiber	Polyolefine fiber	EN 14889
water	Groundwater	EN 1008

Composition of ordinary portland cement (CEM I 42.5R) contains 95% to 100% portland clinker and 0% to 5% minor components. Properties of cement: density - 3110 kg/m^3, bulk density - 1420 kg/m^3, fineness - 371 m^2/kg, specific gravity - 3.18, initial set 155 min, final set 195 min. The chemical composition of cement is given in Table 2.2. The particle density of sand and crushed granite is 2650 kg/m^3 and 2720 kg/m^3.

Water reducing admixture: A water reducing agent uses to reduce the water-cement ratio in concrete to achieve high strength and durability. It will reduce segregation, and that will improve concretes workability. Water-reducing agents are neutralizing charges on the solid particles and preparing them to carry like charges; generally, like charges will repel each other—this activity reducing cement flocculation and making a better slump. Water reducing agents fall into three categories: low range, mid-range, high range. In this research, modified polycarboxylates were used as water reducing agent. Modified polycarboxylate is subjected to the high-range water reduction category, reducing the water range from 12% to 40% and providing a slump range greater than 200 mm.

Modified polycarboxylates properties: appearance – light brown liquid, density - 1.07 ± 0.005 kg/lit, pH value - 4.5 ± 1, chlorine ion content was <0.2% by weight, sodium oxide content was <0.4% by weight. In this research, 0.8% (wt. of cement) of water-reducing admixture were used in concrete.

Shrinkage reducing admixture: The earlier cracks are appearing in concrete due to drying shrinkage. During day by day, water in concrete gets evaporated and makes concrete shrink, causing cracks in concrete. The shrinkage property is significant for white topping investigation because the laying concrete should completely cover/bond over the repaired bitumen surface without shrinking. In this research, sika control 50 were used as shrinkage reducing admixture. The chemical composition of sika control 50 is 2-methyl pentane-2,4-diol. Technical data of shrinkage reducing admixture: it is transparent liquid, density - 0.94 ± 0.02 kg/dm^3, pH-value - 6.0 ± 1, chloride content was <0.10% by weight, alkali content was <0.1% by weight. In this research, 2% (wt. of cement) of shrinkage reducing admixture were used in concrete.

Air-entraining agent: Normally, the concrete should have minimum air content to protect from the freezing-thawing effect. In concrete during water evaporation creating porosity, so high water content in concrete leads to more pores (recommended to reduce water content for durable and robust concrete). Those pores in concrete are absorbing water from the environment and getting freeze during the winter season, and in spring, freeze water is turning to normal water. This process is continuing for several cycles. During that process, water creating pressure, which developing cracks in concrete. In this research, elastic acrylonitrile-polymer base prefabricated air bubbles (special air-entraining agent) were used as an air-entraining agent. That bubbles are providing space for water pressure release. So, prefabricated air bubbles will perform efficiently during freezing-thawing. The density of prefabricated air bubbles is 0.2 g/cm^3, and the spacing between air bubbles should be <200 nanometers. In this research, prefabricated air bubbles were used only in the control mix. In the remaining batches, rubber acted as an air-entraining agent. In the control mix, we used 0.08% (wt. of concrete) of an air-entraining agent.

Fiber: The most commonly used fiber in white topping is macro polypropylene fiber. Benefits of fibers: reducing plastic shrinkage, reducing subsidence cracking, and increasing concrete toughness. The fiber used in this research is chemically based on polyolefine. Polyolefine fiber comprises 85% of polypropylene, and polyolefine is from the polypropylene and polyethylene family. Properties of polyolefine fiber: density ˜0.91 kg/l, melting point ˜170 ˚C, tensile strength ˜430 MPa, and tensile modulus of elasticity ˜6 GPa. Polyolefine fiber dimensions: ˜60 mm length and ˜0.84 mm diameter.

Crumb rubber: The crumb rubber used in this research was purchased from UAB Metaloidas (a Lithuania recycling company). Generally, the standard size of crumb rubber is from 4.75 mm to less than 0.075 mm. Crumb rubbers are produced from scrap tyres using one of the following processes according to their size: cracker mill process, granular process, micro-mill process. The size <0.315 mm crumb rubber was used in this research. According to Richardson, Coventry, Edmondson, and Dias [3], size <0.5 mm crumb rubber will provide good freezing-thawing resistance. In this research, an additional investigation was made using fibrous crumb rubber (two categories: sieved - size <0.315 mm and unsieved - size >0.315 mm). Crumb rubber properties: density - 1020 kg/m^3, bulk density - 483 kg/m^3. Shown crumb rubber (<0.315 mm) in Fig. 2.2, unsieved fibrous crumb rubber (>0.315 mm) in Fig. 2.3, and sieved fibrous crumb rubber (<0.315 mm) in Fig. 2.4.

Rubber particle size distribution (normal crumb rubber and fibrous crumb rubber) is shown in Fig. 2.1. From the figure, we can clearly understand that fibrous crumb rubber is finer than normal crumb rubber. The passing percentages of fibrous crumb rubber at each sieve is higher than normal crumb rubber. This method was performed according to LST EN 933-1 by using the sieve analysis technique.

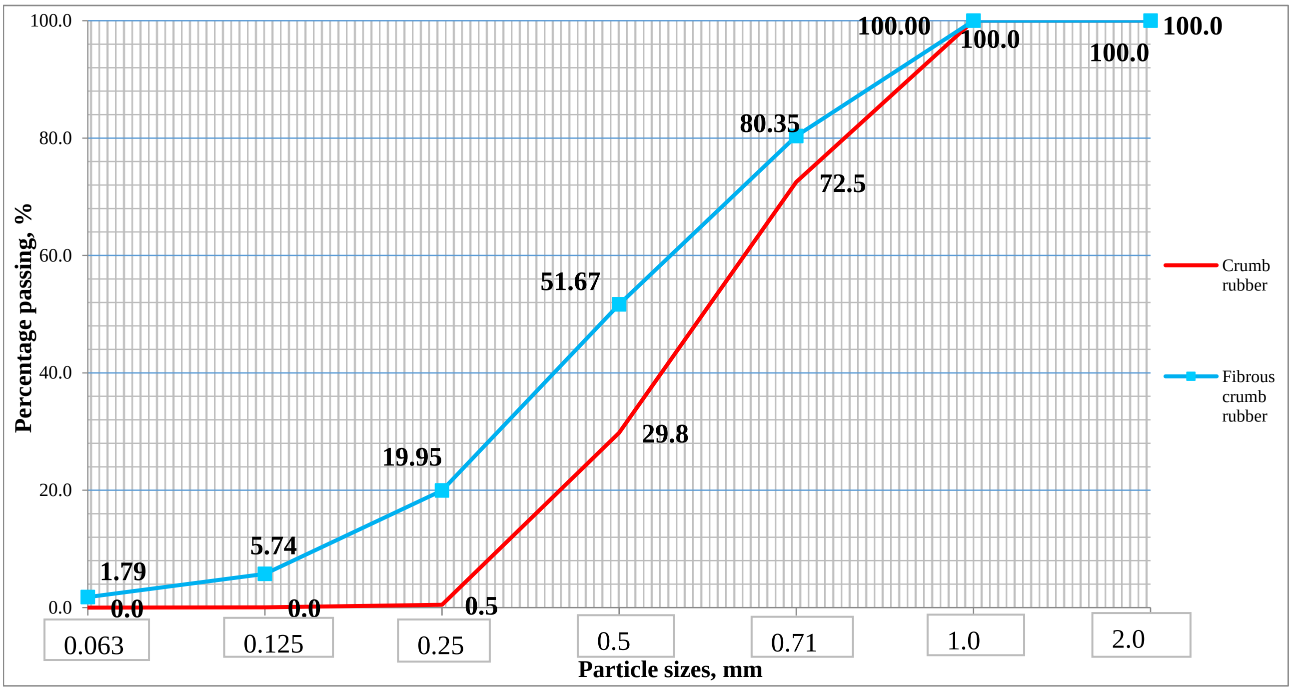


Fig. 2. 1. Particle size distribution of crumb rubber and fibrous crumb rubber

Fig. 2. 2. Crumb rubber (<0.315mm)

Fig. 2. 3. Unsieved fibrous crumb rubber (>0.315mm)

Fig. 2. 4. Sieved fibrous crumb rubber (<0.315mm)

Fig. 2. 5. Crumb rubber dispersed in SBR latex under the ultrasonic dispersion method

Polymer adhesive: In this research, liquid-polymer-based carboxylated styrene-butadiene latex was used for rubber surface treatment. Crumb rubber was dispersed entirely in SBR latex using the ultrasonic dispersion method shown in Fig. 2.5. Time taken for dispersion about 1min and this process was carried out at power 250W. Properties of SBR latex: density ˜1.03 kg/dm^3, pH value ˜10.

Glass powder: In this research, mixed white and green color waste beverage bottles were crushed by an electronic crushing machine. The green color glass will reduce the alkali-silica reaction in concrete explained by [15 p.45]. However, the color glasses will make poor bonding with cement paste and reduce the concrete strength is explained by [25]. So, in this research, we mixed both green and white color glasses. According to ASTM C618-02, the recycled glass powder is an excellent pozzolanic material. In this research, we used glass powder (size <0.315mm (<300μm)) as a block of portland cement. Properties of glass powder: density - 2266 kg/m^3, bulk density - 1245 kg/m^3. The chemical composition of glass powder is given in Table 2.2.

Fly ash: Fly ash will concentrate on the main properties of concrete like alkali-silica reaction, freezing-thawing effect, and mechanical properties. The recommended percentage of fly ash that can be used as an additive in concrete is typically 30% but can be up to 50% or more. European standard EN 206 confirmed that fly ash is suitable for use in concrete. This research was used 10% of fly ash as a part of cement. According to standard EN 450-1, conformed that the fly ash/cement ratio was less than 0.33 by mass. Properties of fly ash: bulk density - 1300 kg/m^3, specific gravity- 2.2, fineness - 450 m^2/kg. The chemical composition of fly ash is given in Table 2.2.

Table 2. 2. Chemical composition of portland cement, glass powder, and fly ash

Components	Quantity, %		
	CEM I 42.5 R	Glass powder	Fly ash
SiO_2	21.01	72.76	38 to 55
TiO_2	-	0.04	0.9 to 1.1
Al_2O_3	5.39	1.67	20 to 40
Fe_2O_3	3.23	0.79	6 to 16
CaO	62.11	9.74	1.8 to 10
MgO	1.98	2.09	1.0 to 3.5
MnO	-	0.02	-
Na_2O	0.38	12.56	0.8 to 1.8
K_2O	0.82	0.76	2.3 to 4.5
P_2O_5	-	0.02	-
Cl	-	-	<0.01
SO_3	3.1	0.1	-
SO_4	-	-	0.42 to 3.0
Na_2O_{eq}	0.92	13.06	-
Loss on ignition (%)	2.38	1	3 to 20
Free calcium oxide (%)	-	-	<0.1 to 1.0

Table 2. 3. Details of mix proportion

	Mix-ID	OPC kg/m³	FA kg/m³	CA kg/m³		Water reducing admixture kg/m³	Shrinkage reducing admixture kg/m³	Air-entraining agent kg/m³	Fiber kg/m³	Water kg/m³	W/C ratio	Crumb rubber kg/m³	Fiber crumb rubber kg/m³	SBR latex kg/m³	Glass powder kg/m³	Fly ash kg/m³
				CG	Dolomite											
	Control mix	360	922	999	-	2.88	7.2	2	3.5	152.3	0.42	-	-	-	-	-
Set 01	Batch1-5UCR	360	917	999	-	2.88	7.2	-	3.5	152.3	0.42	5	-	-	-	-
	Batch2-10UCR	360	912	999	-	2.88	7.2	-	3.5	152.3	0.42	10	-	-	-	-
	Batch3-20UCR	360	902	999	-	2.88	7.2	-	3.5	152.3	0.42	20	-	-	-	-
Set 02	Batch4-5TCR	360	917	999	-	2.88	7.2	-	3.5	137.3	0.38	5	-	30	-	-
	Batch5-10TCR	360	912	999	-	2.88	7.2	-	3.5	137.3	0.38	10	-	30	-	-
	Batch6-20TCR	360	902	999	-	2.88	7.2	-	3.5	137.3	0.38	20	-	30	-	-
Set 03	Batch7-10TCR10GP	350	912	999	-	2.88	7.2	-	3.5	137.3	0.38	10	-	30	10	-
	Batch8-20TCR20GP	340	902	999	-	2.88	7.2	-	3.5	137.3	0.38	20	-	30	20	-
	Batch9-20TCR20GP +10% FA	304	902	999	-	2.88	7.2	-	3.5	137.3	0.38	20	-	30	20	36
	10SFCR	360	912	-	999	3.6	7.2	-	3.5	172.3	0.47	-	10	-	-	-
	10UFCR	360	912	-	999	3.6	7.2	-	3.5	172.3	0.47	-	10	-	-	-

* CG – crushed granite

The Set 01, 02, 03 batches were prepared for 20 liters, and the last samples of sieved fibrous crumb rubber (SFCR) and unsieved fibrous crumb rubber (UFCR) were prepared for 10 liters, and dolomite was used as a coarse aggregate in the last two batches (SFCR and UFCR). The coarse aggregate, superplasticizer, fiber, and admixtures are constant amounts for three sets. In every set, fine aggregate varies due to rubber substitution. In Set 02 and 03, due to SBR latex addition, the water amount was reduced. In Set 03, cement amount varies due to glass powder and fly ash replacement. In fibrous crumb rubber batches, additional added 0.2% of superplasticizer and 200 ml of water for better consistency.

3. Specimen preparation and methodology

The materials preparation and concrete mixing was followed according to EN 206. The concrete mixing was done by an electric mixer called the zyklos concrete mixer. The upcoming steps were followed for mixing: First, the blender was cleaned with a water towel because not to observe water during mixing. After that, the fine and coarse aggregate was mixed for 1 min, and then cement, air-entraining agent, and fibers were mixed for ½ min to get proper mergers between cement and aggregates. Subsequently, along with water, shrinkage-reducing and water-reducing admixtures were poured into a blender and mixed for 1 min. Afterward, fresh concrete was left free for 1 min because cement and aggregates want to absorb water properly. The final mix was about 2 mins, and the overall operation took 6 to 7 mins. The same mixing process was followed for all batches. The molds were coated with oil for good concrete adhesion and to avoid water escaping. After fresh concrete tests, the molds were filled, vibrated, and kept for 24hrs to dry at room temperature. Later, the samples were placed in water for 28 days curing at 20 ± 2˚C temperature. After 28 days, hardened concrete and durable tests were performed.

Slump cone test: The slump cone test will note concrete's workability, and it was performed according to EN 12350-2. The fresh concrete was placed in the hollow-cone form about four layers and compacted 25 times at each layer, and the height difference between form and the fresh concrete was measured after pulling out the cone. There are three types of a slump: true slump, shear slump, collapse slump. The slump classes and their workability ranges have given in Table 3.1.

Table 3. 1. slump class and degree of workability

Slump (mm)	Class	Degree of workability
10 to 40	S1	Low
50 to 90	S2	Medium
100 to 150	S3	High
160 to 210	S4	Very high
≥ 220	S5	

Fresh concrete density: The fresh concrete density test was performed according to EN 12350-6. An 8-liter capacity container was filled with fresh concrete about five layers, and each layer was compacted 25 times. By using an electronic weighing machine, we weighed an empty container and filled container. A weight difference between filled and empty container divided by container volume is the density of fresh concrete. The following formula is to calculate fresh concrete density.

$$D = \frac{m_2 - m_1}{V} \qquad 3.1$$

Where D is the density of fresh concrete (kg/m^3), m_1 is the mass of empty container (kg), m_2 is the mass of container filled with compacted concrete (kg), V is the volume of the container (m^3).

Fresh concrete air content: The test was performed according to EN 12350-7. In this research, a pressure meter was used to determine the air content of fresh compacted concrete.

Compressive strength test: The compressive strength test was performed according to EN 12390-3. Compressive loading of about 0.600 MPa/s was applied to the specimens. 150 mm cube was used for compressive strength test, and 100 mm cube was used for compressive strength before and after freezing-thawing cycles.

Strength activity index: This method is used to detect glass powder and fly ash pozzolanic activity in concrete, and it was performed according to standard ASTM C311. The strength activity index is calculated by dividing the compressive strengths of glass powder and fly ash concretes by control mix strength. So, it was calculated after 56 days of curing period. SAI formula is explained by Parghi and Alam [29].

$$SAI\ (\%) = \frac{A}{B} * 100 \qquad 3.2$$

Where A= compressive strength of samples in which OPC was replaced by glass powder and fly ash. B=compressive strength of control mix.

Dry density: Dry density of hardened concrete was performed according to EN 12390-7, 150 mm cube have been used for this test, and dry density was calculated from concrete's mass and volume.

Flexural strength test: The test was carried according to EN 12390-5. Concrete specimens were stressed under three-point loading. After loading, the flexural strength and fracture energy for specimens was calculated. In that, fracture energy is calculated using an area under the stress-strain curve. The ORIGINPRO software is used in this research for finding an area under the CMOD (crack mouth opening displacement) curve. The force released by the instrument to the specimen is not only one force acting on the specimen but also involves the weight of the specimen and the loading instrument's weight. In this way, we should calculate fracture energy for concretes is explained by the literature [41]. According to EN 14889-1, fibers' effect in concrete is explained by checking residual flexural strength at displacement 0.5 mm should be 1.5 MPa, and at 3.5 mm should be 1 MPa. In this research, a 250*75*75 mm prism was used for testing. The following formula is used to calculate fracture energy.

$$G_F = \frac{W_t}{(D - a_o)b} \qquad 3.3$$

Where

G_F is fracture energy,

W_t is total energy, $W_t = W_r + 2P_W\delta f$, W_r is the area under CMOD curve, P_w is equivalent self-weight force, δf is displacement under the curve,

D is specimen depth,

a_o is notch depth,

b is the width of the specimen,

$P_W = \frac{W_o S}{2L}$ Wo is the weight of the specimen, S is span length, L is the length of the specimen.

Freeze/thaw resistance: The freezing-thawing resistance was performed by volumetric freezing after immersion in water according to the standard LST 1428.17. Samples (100 mm cubes) were kept in the climatic chamber. In the climatic chamber, samples were frozen at -20˚C temperature for 2.5 hours and thawed in the water at +20˚C for 2.5 hrs. After certain cycles, if samples lose their compressive strength less than 5% compared to pre-freeze-thaw compressive strength, then samples are not suitable for freezing-thawing performance. In the laboratory, pre-day samples will undergo three cycles. This research is planned for 200 cycles; then, it will take 65 to 67 days for each batch freezing-thawing in the laboratory.

Porosity parameter: The amount of pores and pore size is essential for durable concrete. The investigation of pores in concrete was done by water absorption kinetics according to the standard GOST 12730.4-78. This method is used to find the amount of close porosity, open porosity, and total porosity. In this research, samples were divided into four pieces, and that sample pieces were kept in the heating chamber at 105˚C. After 48 hours, samples were taken from the chamber and underwent a water absorption test. From water absorption test can determine the amount of open, close, total porosity of samples. The nomogram available in standard GOST 12730.4-78; from that, we can find the pore size index (λ) and pore size uniformity (α). The following formulas are used to find the open, close, and total porosity is demonstrated by Grinys, Augonis, Dauksys, and Pupeikis [16].

$$P_b\ (\%) = 1 - \frac{\rho b}{\rho s} \qquad 3.4$$

Where ρb = Density of concrete (kg/m^3), ρs= Specific density of concrete (kg/m^3), P_b= Total porosity (%).

$$P_a(\%) = Wp + \frac{\rho b}{1000} \qquad 3.5$$

Where Wp = Water absorption of concrete (%).

$$P_u(\%) = P_b - P_a \qquad 3.6$$

Where P_u = Close porosity (%).

The durability factor (k_f) was used to find concrete's expected performance before the freezing-thawing cycles.

$$K_f = \frac{P_u}{0.09} * P_a \qquad 3.7$$

The pores' size is essential for concrete than pore spacing. If the pores' size were >50 nm, then the concrete's durability will become weak. The size of pores can be investigated by AUTOSCA-GT60 Mercury Intrusion Porosimetry(MIP) equipment is explained by [18].

4. Results and discussion

4.1. Fresh concrete test results

Slump cone test

In this test, we can see the workability of concretes with different materials. All batches in set 01, 02, 03 has a higher slump value than the control mix, but the sieved and unsieved fibrous crumb rubbers were showed less slump value than a control mix. A control mix slump value was 195 mm, which comes under the S4 slump class (very high workability). In the untreated crumb rubber set, when rubber content increased, the slump value gets decreased due to its irregular shape and fineness. The same performance has been noticed in this literature [6], and this literature [7] explained that slump value decreased due to no free water in concrete because fine rubber absorbed more water than sand. However, in this research, I believed that fine crumb rubber acts as a filler in concrete. So, fine rubber occupied more air voids in fresh concrete when rubber amount increased, which made fresh concrete stiff/compact and reduced the fresh concrete slump. Set 01 slump results: 5UCR – 230 mm, 10UCR – 200 mm, 20UCR – 190 mm. A 5UCR comes under the S5 slump class (very high workability), and 10UCR and 20UCR are the S4 slump class (very high workability). The treated crumb rubber samples were showed high workability than untreated crumb rubber samples. In a treated crumb rubber set, 5 kg and 10 kg batches were showed the same slump value is 260 mm, and the 20 kg batch got 250 mm. A 20TCR slump value decreased a bit compared to 5TCR and 10TCR. The slump values of TCR batches are coming under the S5 class (very high workability). Treated rubber samples were showed high slump value than untreated rubber samples due to the fluid nature of SBR latex and less rubber treatment time. The rubber treatment time was also influencing the slump value [22].

When increasing glass powder and treated rubber amount, the slump value was getting higher in the third set. The reason behind this high workability: 1) The water for hydration is become free water due to the reduction of cement (glass replacement), that free water made fresh concrete high flowable, 2) Due to the smooth surface of a glass particle (the surface nature of glass described in SEM analysis), 3) The superplasticizer were reduced glass surface tension and made a glass concrete flowable. The same result with this explanation can see in this literature‘s [24][25][28][34][35]. In Set 03, slump results for 10TCRGP – 255 mm and 20TCRGP – 265 mm. Both samples are S5 class (high workability). The 10% fly ash with treated rubber and glass powder exhibits a higher slump value (275 mm – S5 class) than all other samples. The small particle size fly ash was added a very less amount in concrete, which reacted with more free water (due to further cement reduction) and made concrete flowable. The concrete with fibrous crumb rubbers has less workability than a control mix and untreated crumb rubber samples because fibrous crumb rubber is finer material than the normal crumb rubber were used in the remaining batches. So, 10 kg sieved fibrous rubber absorbed more water than sand (due to its high specific area) and made less slump than 10UCR. Sieved fibrous crumb rubber has expressed high slump value than unsieved fibrous crumb rubber because sieved rubber is a fine particle that easily creates concrete flowability than unsieved stiff/bulk rubber particles. The slump results of 10SFCR and 10UFCR were 175 mm and 155 mm. 10UFCR comes under the S3 class, and 10SFCR was S4 class. However, the water-reducing admixture made a control mix and all batches workable. The experiment results are shown in Fig. 4.1.1.

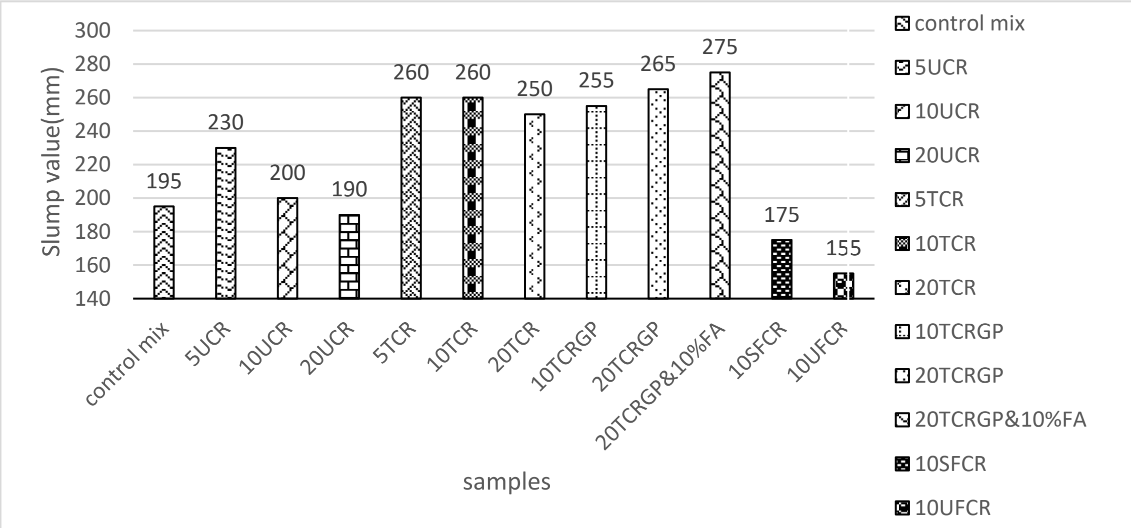


Fig. 4.1. 1. Slump cone test results

Fresh concrete density

The fresh concrete density and air content are interconnected. When air content gets increased, fresh concrete density will get decreased. Changing materials in concrete can change their property. In the fresh concrete density test, we can see that density varies for different materials. The fresh concrete density for a control mix is 2450 kg/m^3. Naturally, rubber was a low specific gravity material than the fine aggregate. In Set 01, when crumb rubber content increased, fresh concrete density was decreased due to its low specific gravity nature. There is another important reason for density lowering: Air content (entrapped by rubber – nonpolar nature) rises due to the high specific area of fine crumb rubber. Fresh concrete density results for untreated crumb rubber batches: 5UCR – 2400 kg/m^3, 10UCR – 2380 kg/m^3, 20UCR – 2350 kg/m^3. The treated crumb rubber samples expressed lower density than untreated crumb rubber samples due to the density of SBR liquid (is 1030 kg/m^3) was nearer to water density (is 997 kg/m^3). Fresh concrete density results for treated rubber batches: 5TCR – 2254 kg/m^3, 10TCR – 2221 kg/m^3, 20TCR – 2168 kg/m^3, explains increasing treated rubber content density were getting decreases.

Adding glass powder with treated rubber were showed lower density than other samples because both glass powder and rubber have a very low particle density than sand and cement. So, glass rubber concrete's fresh density will decrease when cement (glass replacement) and sand (rubber replacement) content reduced, these all are basic reasons. Additionally, there is another compelling reason for lowering glass concrete fresh density: glass particles are also entrapping air in concrete due to its surface nature and geometry. As a result, increasing rubber and glass content, air voids will increase, and fresh concrete density will decrease. Air content results of treated rubber glass concrete shown in fig. 4.1.3. This literature [30] explained that glass powder occupies voids in rubber concrete and increases fresh concrete density than rubber concrete without glass powder. Here, fresh concrete density decreased by adding glass powder to rubber concrete because this research used treated rubber (amount of air voids high than untreated rubber). These are all reasons for a lower fresh density of treated rubber and glass powder concrete batches. Fresh concrete density results for TCRGP batches: 10TCRGP – 2163 kg/m^3, 20TCRGP – 2160 kg/m^3, explains increasing treated rubber and glass powder, density were decreased slightly.

Adding fly ash with glass powder as a part of cement increases density slightly than batch 6, 7, and 8 because fly ash occupied the voids, which made concrete compact and increased density. Fresh concrete density result of 20TCRGP&10% fly ash is 2200 kg/m^3. Fresh concrete density for sieved fibrous crumb rubber is 2361 kg/m^3, and unsieved fibrous crumb rubber is 2302 kg/m^3. Unsieved fibrous crumb rubber displayed less density than sieved fibrous crumb rubber because unsieved rubber contains more microfibers and tiny rubber particles with a less specific gravity nature. 10 kg sieved fibrous crumb rubber executed a nearer fresh density to 10UCR (untreated normal crumb rubber). When seeing the below chart, density is decreasing linearly up to 20TCRGP. All samples are having less fresh density than a control mix due to each material's property (rubber, SBR, glass powder). Fresh density results of specimens are shown in Fig. 4.1.2.

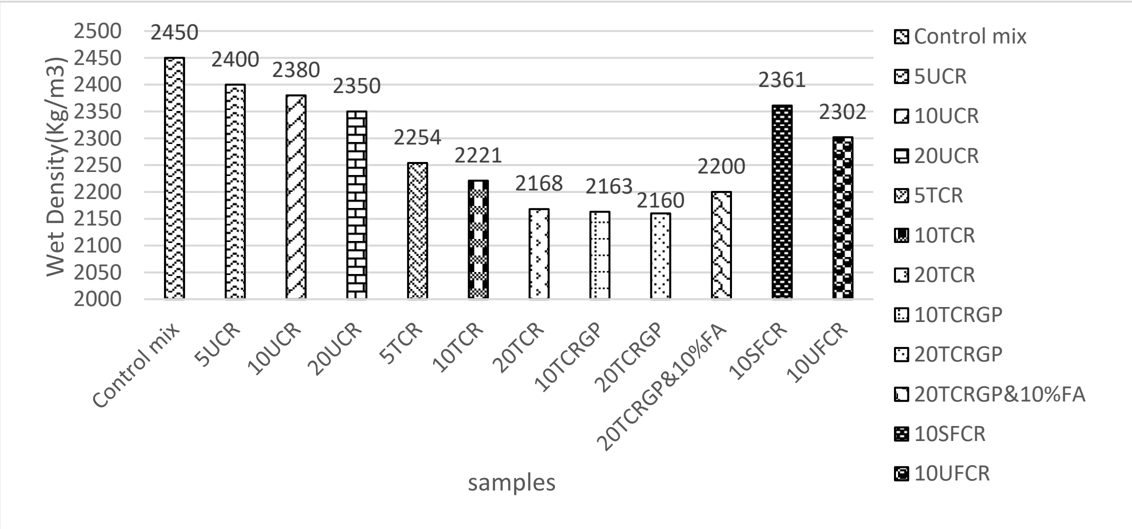


Fig. 4.1. 2. Fresh concrete density test results

Fresh concrete air content

The air in concrete is essential for freezing-thawing resistance. We used a special air-entraining agent (prefabricated bubbles) in a control mix, which executed about 2.5% air content. The fresh concrete pores are almost closed porosity. The rubbers' non-polar nature will repel water and entraps air easily into the concrete. In Set 01, when untreated fine crumb rubber increased, air content was increased due to the high specific area of fine crumb rubber. So, by increasing fine rubber, more air will get entrapped into the concrete was explained by [3]. Fresh concrete air content results for set 01 batches: 5UCR – 2.4%, 10UCR – 3.2%, 20UCR – 3.4%. From the results, we can see that crumb rubbers are providing satisfactory air content for the freezing-thawing effect. If further increasing rubber content can leads to more air, which can make concrete less dense and weak. The treated crumb rubber samples reveal a high amount of air content than untreated rubbers samples. In Set 02, crumb rubber was dispersed with SBR latex by using the ultrasonic dispersion method. This method will avoid rubber agglomeration and sedimentation in SBR liquid. More bubbles were formed during ultrasonic dispersion, which can be the primary reason for air content increase in set 02 fresh concrete batches. Generally, when increasing water content will bring more air voids in fresh concrete. In that way, SBR latex is a liquid polymer it consists of 50% water. We added SBR about 30 kg/m^3 by reducing the w/c ratio. However, the high content of SBR can be a secondary reason for high air content. Fresh concrete air content results for Set 02 batches: 5TCR – 8.5%, 10TCR – 9%, 20TCR – 10.8%, set 02 samples showed that air content was increasing when increasing treated rubber content.

The rubber glass fresh concretes exhibited high air content than all other samples. In Set 03, when increased glass powder and treated rubber amount, air content was increased. High air content in batch 7 and 8 was due to glass particle irregular shape and sharp edge, and also due to high specific area of fine glass powder, that entraps more air when glass amount increases. The following research [36] explaining that glass particles were entrapping air because of their irregular shape, and importantly, sharp edges of glass particles were carrying air into the concrete. However, we can notice that 20TCRGP has only a 0.3% higher air amount than 10TCRGP. The reason behind this result is that glass powders are acts as a filler. So, that only when glass powder increased does not show a large variant than 10TCRGP. The same activity happened for rubber glass concrete samples in the fresh concrete density test, shown in fig. 4.1.2. Fresh concrete air content results of treated rubber and glass powder concrete batches: 10TCRGP – 11.2%, 20TCRGP – 11.5%.

Fly ash added rubber glass concrete reduced air content compared to TCRGP and TCR samples because small particle fly ash was filled the micropores pores created by rubber and glass powder. Fresh concrete air content result of 20TCRGP&10% fly ash is 8.4%. The unsieved fibrous crumb rubber produced more air than sieved fibrous crumb rubber because unsieved fibrous crumb rubber contains many microfibers and micro rubbers, which also carrying air into the concrete. Fresh concrete air content for 10SFCR is 2.3% and 10UFCR is 6.1%. Among all samples, 5UCR and 10SFCR were showed less air content than a control mix. As I already mentioned, fresh concrete density and fresh concrete air content are interconnected, from fresh concrete density and air content results concluding that fresh concrete density will decrease when air content increases. Fresh concrete air content results are shown in Fig. 4.1.3.

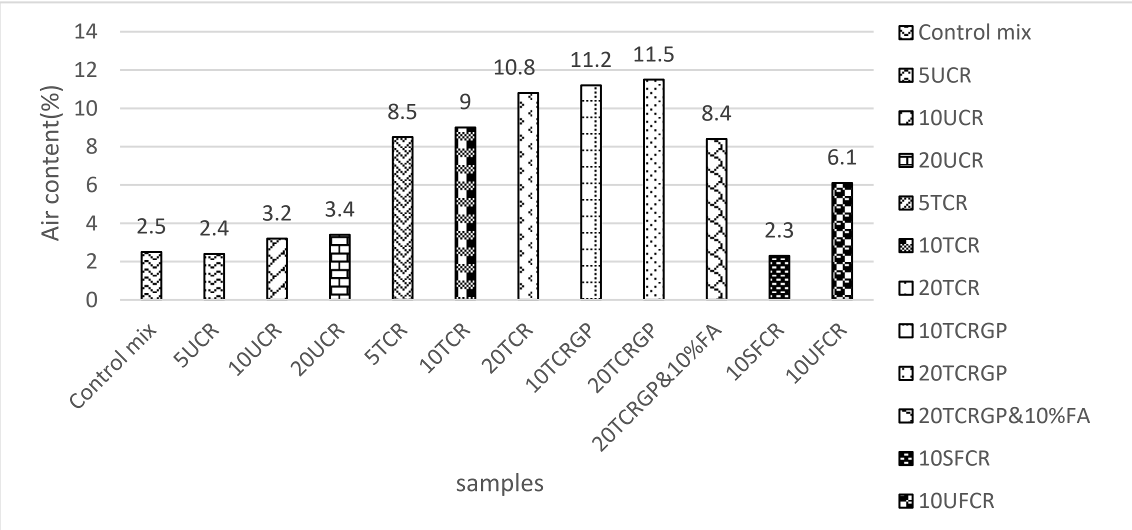


Fig. 4.1. 3. Air content test results

4.2. Hardened concrete test results

Compressive strength

After 28 days of curing, control mix and samples from set 01 and set 02 were taken from a water tube and kept in the open air for drying (one hour). After drying, samples have undergone a compressive strength test. The compressive strength of the control mix is 56.8 N/mm^2. From this literature point [10], fine crumb rubbers are more effective in concrete mechanical field than coarser rubber particles. Generally, substituting fine crumb rubber as sand instead of cement providing good compressive performance. In Set 01, (5, 10, 20 kgs) of untreated fine crumb rubbers are substituted as a fine aggregate. In Set 01, compressive strengths for untreated crumb rubber batches: 5UCR – 52.8 N/mm^2, 10UCR – 50.1 N/mm^2, 20UCR – 50 N/mm^2. Strength reduces for 5, 10, 20 kgs of UCR was about 7.04%, 11.79%, 11.97% than a control mix. When rubber amounts increased, compressive strength gets decreased due to rises of air voids and cracks (which will develop easily around soft rubber materials). Notice 20UCR concrete executed its strength nearer to 10UCR because 20 kg untreated crumb rubbers occupied more pores and made compact concrete, which increased its density. For proof, we can see in dry density results shown in Fig. 4.2.4. However, untreated rubber concretes provided sufficient compressive strength results (greater than 50 N/mm^2). The efficient compressive strengths of UCR concretes was achieved due to tiny size rubber particles occupied micropores between cement paste and aggregates. The literature [37] proved that fine crumb rubber concrete's compressive strength was nearer to the control mix.

Crumb rubber has been treated with SBR latex to ensure homogenous rubber distribution and better bonding between rubber and cement paste. SBR latex will form a chemical bond between rubber and cement hydration products (C-S-H) for superior strength. But treated rubber concrete showed lesser compressive strength than untreated rubber concrete and control mix. While increasing treated rubber content, compressive strength is reducing vigorously. Here, TCR batches' compressive strengths: 5TCR – 34.8 N/mm^2, 10TCR – 37.2 N/mm^2, 20TCR – 26.6 N/mm^2. Strength reduces for 5, 10, 20 kgs of TCR was about 38.73%, 34.50%, 53.16% than a control mix. The reason behind insufficient compressive strength due to the overdosage of SBR latex, which brings more porosity to concrete (porous nature of treated crumb rubber samples is shown below SEM pictures). That porosity made concrete less dense and weakened under compressive force. From Fig. 4.2.3 and 4.2.4, we can see in our normal vision that 20UCR concrete has less porosity and less damage than 20TCR concrete. The small amount of rubber (5 kg) with SBR exhibited high density, but 10 kg rubber with SBR executed lower density and maintained compressive strength higher than 5TCR due to strong bond with cement paste. Porosity and pore size distributions are important for concrete strength. The literature [18] showed rubber treated with SBR latex and silane coupling agent executes better compressive strength than untreated rubber concrete and control mix. The additional supporting bond (like silane coupling agent) making concrete strength high. Not used a supporting adhesive can be a secondary reason for strength loss in my research. Compressive strength results for control mix, batches in set 01 and set 02 are shown in Fig. 4.2.1.

Compressive strength was tested for set 03 batches after 28 days and 56 days because the pozzolanic reactions of glass powder and fly ash will take place at later stages. Compressive results for set 03 batches after 28 days: 10TCRGP – 24 N/mm^2, 20TCRGP – 26 N/mm^2, 20TCRGP&10%FA – 25 N/mm^2. Strength reduced after 28 days for batches 7, 8, 9 about 57.74%, 54.22%, 55.98% than a control mix. Compressive results of set 03 batches after 56 days: 10TCRGP – 30 N/mm^2, 20TCRGP – 30.4 N/mm^2, 20TCRGP&10%FA – 29.4 N/mm^2. Strength reduced after 56 days for batches 7, 8, 9 were about 47.18%, 46.47%, 48.23% than a control mix. When seeing strength results after 56 days, set 03 samples 10TCRGP, 20TCRGP, 20TCRGP&10%FA were increased 25%, 16.92%, 17.59% than 28 days compressive strengths. So, from 56th-day results, we can say that pozzolanic reactions of glass powder and fly ash were started working in treated rubber concrete. Set 03 samples did not show much strength loss when glass powder and treated rubber content increased. In Set 03, after 56 days, 20TCRGP and 20TCRGP&10%FA executed sufficient strength than 20TCR. But still, set 03 samples were not executed better results than batches 2, 3, 5. However, the pozzolanic reaction of glass and fly ash will happen every day. We can expect that glass powder and fly ash will increase concretes strength slowly at later stages. In this literature [28], researchers used fine glass powder as cement, which showed greater compressive strength than the control mix after 90 days. The same results were obtained in this literature [30] with glass powder and fine rubber aggregate achieved their strength greater than the control mix after 90 days. Compressive strength results of set 03 batches are shown in Fig. 4.2.2.

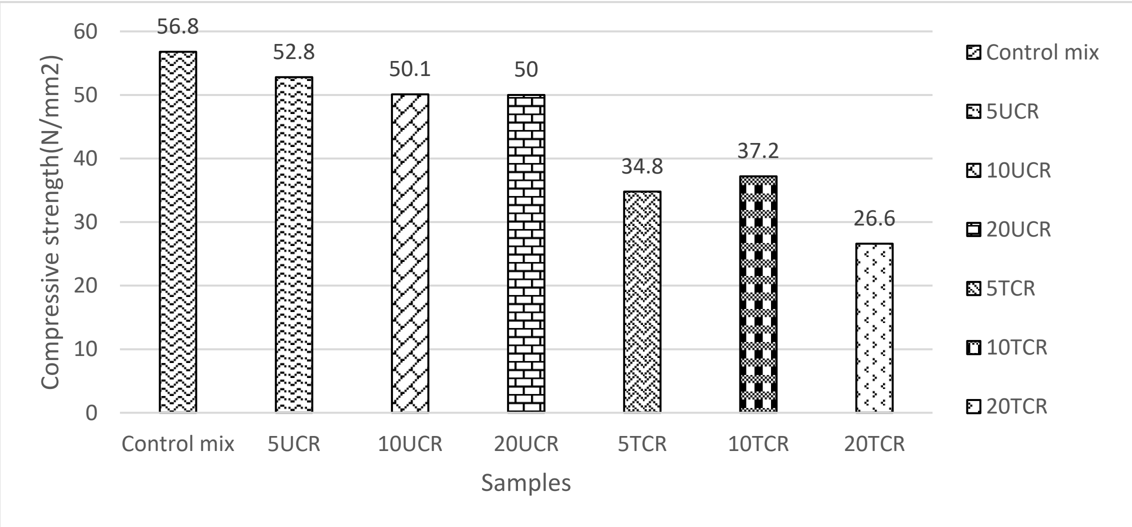


Fig. 4.2. 1. Control mix, set 01, and set 02 batches compressive strength results after 28 days

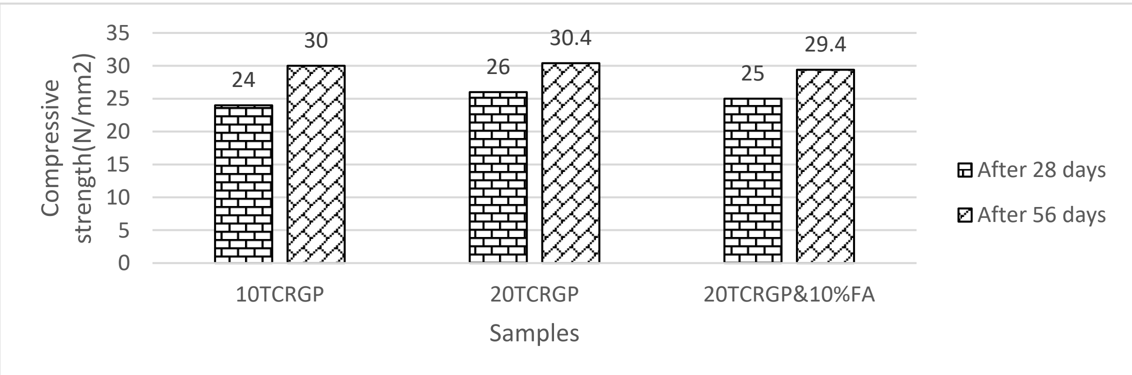


Fig. 4.2. 2. Compressive strength results of set 03 batches after 28 days and 56 days

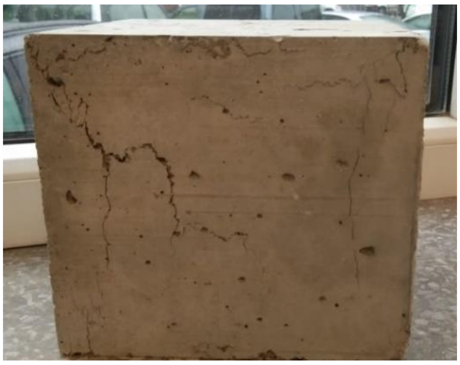


Fig. 4.2. 3. 20UCR concrete

Fig. 4.2. 4. 20TCR concrete

Strength activity index

The strength activity index was calculated to show the effect of glass powder and fly ash in rubber concrete. As we saw above, glass powder and fly ash increased treated rubber concretes compressive strength after 56 days. But to know about what amount of glass and which material (glass powder or fly ash) contributed to treated rubber concretes. The strength activity index was calculated by dividing the compressive strengths of glass powder and fly ash concretes by control mix strength. A 56th-day compressive strength results of glass powder and fly ash concretes was used for strength activity calculation. Results of strength activity index for 10TCRGP, 20TCRGP, and 20TCRGP&10%FA batches are 52.81%, 53.52%, and 51.76%. In that, 20 kg of glass powder brings off a high strength than 10 kg of glass powder. Further added fly ash with 20 kg glass powder reduced strength because fly ash reactivity with cement was low during the initial stages, so fly ash will take time to increase concrete strength. Though fly ash added concrete did not show greater loss than 20TCRGP concrete. Strength activity index for batch 03 samples shown in Fig. 4.2.5.

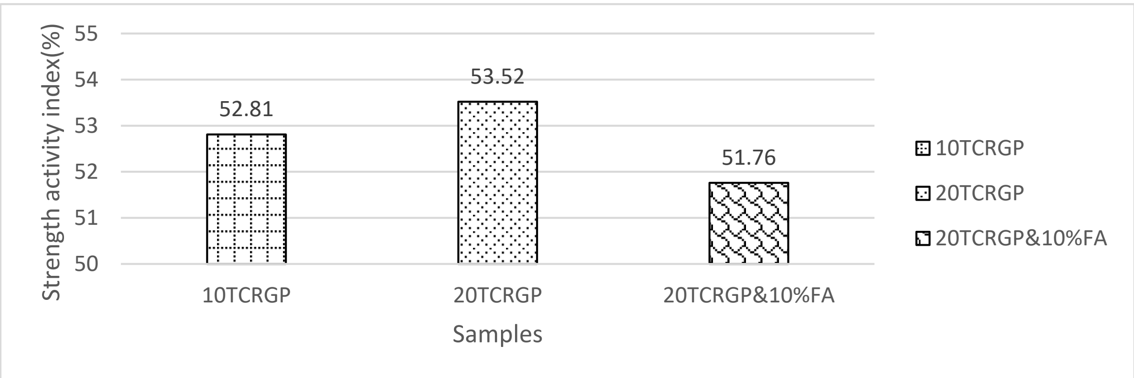


Fig. 4.2. 5. Strength activity index of glass powder and fly ash

Dry density

Dry density has been calculated during the compressive strength test using a 150 mm cube. The dry density of the control mix is 2388 kg/m^3. Generally, when increasing rubber content, density will decrease. Here, in Set 01, dry density for 5UCR, 10UCR, 20UCR batches are 2404 kg/m^3, 2335 kg/m^3, 2391 kg/m^3. In Set 01, 20UCR concrete density was increased by 2.39% than 10UCR concrete. Dry density increased for 20UCR concrete due to more rubber occupied additional pores, which made concrete compact. Dry density and mechanical properties of concrete are interconnected. Here, 20UCR concrete was showed nearer compressive strength to 10UCR concrete due to its high density. However, 5UCR and 20UCR were executed high density than a control mix, but both samples exhibited lower strength than a control mix. The reason for that lower strength due to cracks were appearing easily around soft rubber materials. Dry density for set 02 samples: 5TCR – 2333 kg/m^3, 10TCR – 2297 kg/m^3, 20TCR – 2214 kg/m^3. In Set 02, porosity increased by both rubber and SBR latex, which brings down the sample's density. Dry density for set 03 samples after 28 days: 10TCRGP – 2213 kg/m^3, 20TCRGP – 2210 kg/m^3, 20TCRGP&10%FA – 2216 kg/m^3. Dry density for set 03 samples after 56 days: 10TCRGP – 2240 kg/m^3, 20TCRGP – 2221 kg/m^3, 20TCRGP&10%FA – 2237 kg/m^3. After 56 days, 10TCRGP, 20TCRGP, and 20TCRGP&10%FA densities were increased by 1.22%, 0.49%, and 0.94% compared to 28th-day densities, density increased due to pozzolanic reaction of glass powder and fly ash. During both 28 days and 56 days, when treated rubber and glass powder content increased, density was decreased. But fly ash filled the pores and increased density than 20TCRGP concrete. However, among set 03 samples, there was no much density loss. 20TCR concrete showed the lowest density than others, and that density result reflects in compressive strength result, 20TCR has the lowest strength. Dry density results are shown in Fig 4.2.6.

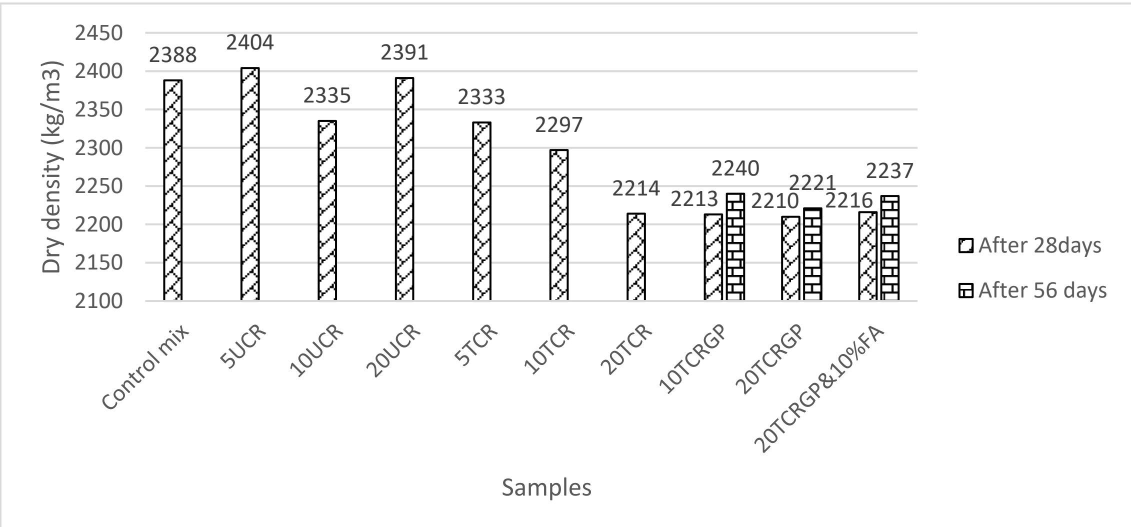


Fig. 4.2. 6. Dry density results

Flexural strength

In this research, a three-point loading method has been used for finding flexural strength. The test was performed by 250 mm prism, and the instrumental span length was 200 mm. A prism was placed in an instrument and loaded at the mid-span. After 28 days, a control mix flexural strength is 8.48 N/mm^2. The significant flexural strength of a control mix was achieved due to the service of polyolefine fibers. Fibers in each layer made concrete to withstand the load. Naturally, rubber is an elastic material; it will absorb high energy and perform positive bending toughness. In Set 01, flexural strength for 5UCR and 10UCR were increased by 27.59% and 5.66% than a control mix. Flexural strength of 20UCR was reduced by 1.17% than a control mix (but strength was nearer to control specimen). Fine crumb rubbers have filled the pores in concrete, which reduced the stress development at the pores, leading to high flexural strength for set 01 samples and another one important reason for high flexural strength was fibers. After the test, we observed that fibers were arranged in a horizontal direction and observed a bridge connecting fibers between two broken pieces, which made concrete hold out against load. 10UCR sample fibers during loading shown in Fig. 4.2.8 and after the test, samples were broken into two pieces, and from those pieces, we can see that bridge structure fibers are shown in Fig. 4.2.9. The fine crumb rubbers were performed well during the flexural test is explained by [7].

In Set 02, flexural strength for 5TCR, 10TCR, and 20TCR were reduced by 29.24%, 21.46%, and 25.47% than a control mix. In Set 02 batches, 10TCR and 20TCR had good adhesion with cement paste, which executed lower strength loss than 5TCR. Among set 02, 10 kg of crumb rubber showed satisfactory rubber amount with SBR latex because it has high flexural strength than the other two samples. The same thing we can notice in compressive strength results, 10TCR was performed well among set 02 samples. However, the flexural performance of treated rubber samples was lower than untreated rubber samples. The reason behind this failure: 1) High amount of SBR liquid used in concrete, which developed more porosity, 2) No strong bond between rubber and cement paste (need additional adhesive promotion). The literature [18] explained that rubber with an additional coupling agent and SBR latex improved flexural strength than the untreated crumb rubber concrete and control mix. The same literature said that a high amount of polymers could lead to strength loss.

In Set 03, flexural strength for 10TCRGP, 20TCRGP, and 20TCRGP&10%FA were reduced by 33.25%, 41.03%, and 43.63% than a control mix. Adding glass powder and fly ash with treated rubber has reduced flexural strength during the initial stage. The reasons for failure: 1) In our research, prims were tested after 28 days. During the initial stage, glass powder and fly ash showed improper pozzolanic reaction with cement. We can expect better strength at later stages because the pozzolanic reaction of glass powder and fly ash will activate during concretes later ages. From the compressive strength test, it has been proved that glass powder and fly ash concrete exhibited better results after 56 days. Flexural strength results are shown in Fig. 4.2.7.

The effect of fibers in concrete can evaluate by checking residual flexural strength at displacement 0.5 mm should be 1.5 MPa and at 3.5 mm should have 1 MPa. A control mix residual flexural strength is 2.4 MPa at 0.5 mm and 3.2 MPa at 3.5 mm. Residual flexural strength for 5UCR, 10UCR, 20UCR at 0.5 mm is 6.64 MPa, 1.80 MPa, 2.76 MPa, and at displacement 3.5 mm is 2.34 MPa, 1.31 MPa, 2.05 MPa. Residual flexural strength for 5TCR, 10TCR, 20TCR at 0.5 mm is 1.58 MPa, 2.91 MPa, 1.22 MPa, and at displacement 3.5 mm is 1.64 MPa, 3.01 MPa, 1.17 MPa. Residual flexural strength for batches 10TCRGP, 20TCRGP, 20TCRGP&10%FA at 0.5 mm is 1.55 MPa, 1.68 MPa, 2.28 MPa. 10TCRGP concrete did not withstand up to displacement 3.5 mm; it failed at displacement 2.93 mm due to maybe improper orientation of fibers or maybe less amount of fibers were added during casting. So that 10TCRGP concrete does not have residual flexural strength at 3.5 mm. The remaining 20TCRGP and 20TCRGP&10%FA sample's residual flexural strength at 3.5 mm is 1.61 MPa and 2.28 MPa. Residual flexural strength varies for every sample at displacement 0.5 mm and 3.5 mm. Here, residual flexural strength was based on fibers orientation, fibers toughness, and fibers geometry. According to European standard 14889-1, a control mix and all concrete batches satisfied the condition except 20TCR concrete. A 20TCR concrete at 0.5 mm exhibited 1.22 MPa, which was less than 1.5 MPa. So, 20TCR concrete was not satisfied at 0.5 mm. This fault may be due to irregular fiber distribution.

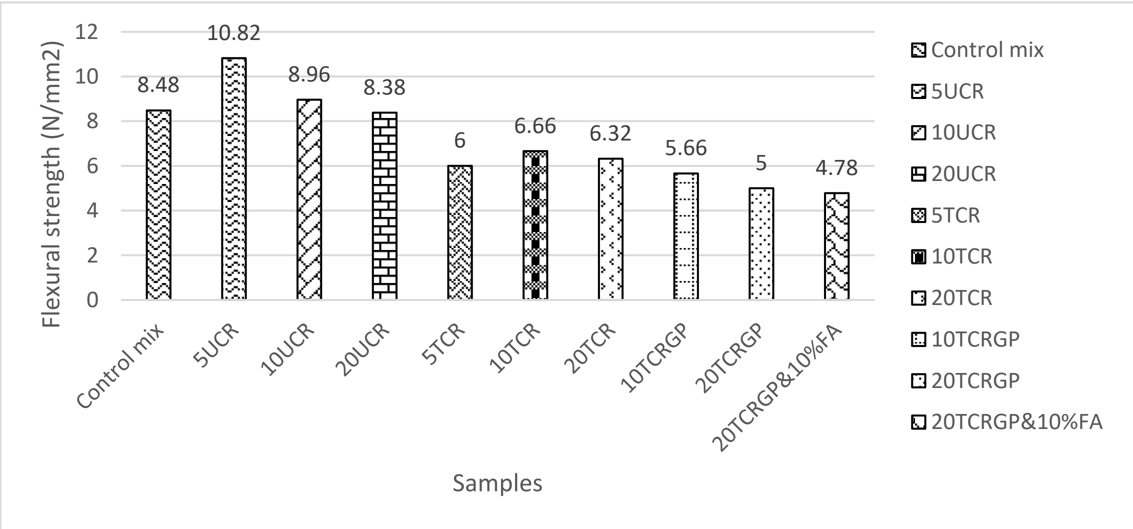


Fig. 4.2. 7. Flexural strength test results

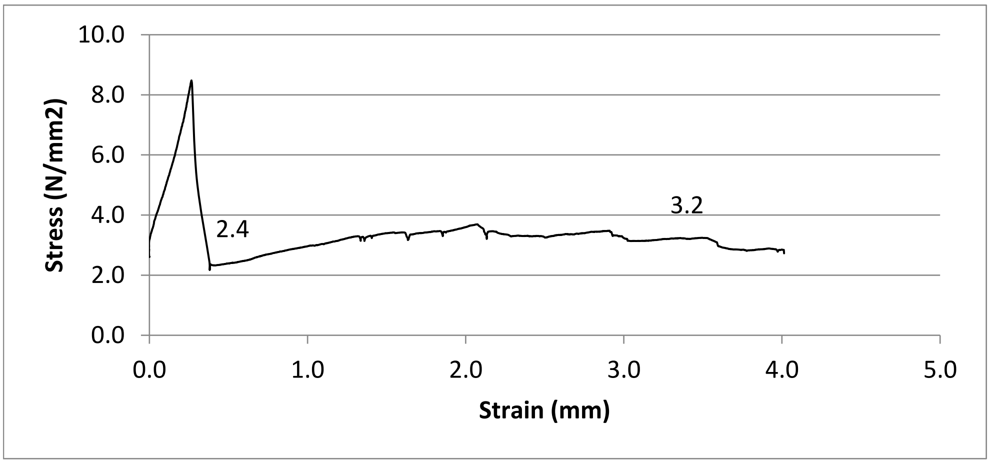
Fig. 4.2. 8. Fiber during loading (10UCR)

Fig. 4.2. 9. Fibers after breakage (10UCR)

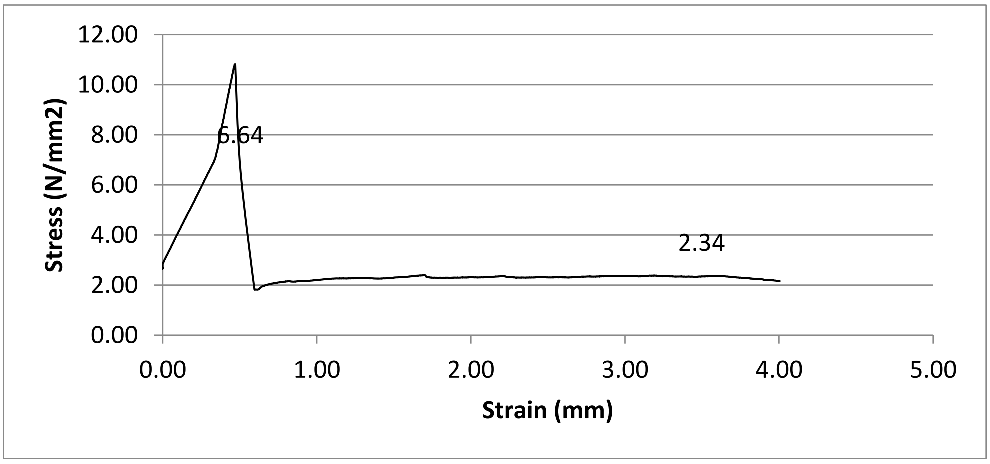
Concrete potential against fracture can be determined by calculating fracture energy. In this research, fracture energy was calculated to estimate crumb rubber toughness and fibers toughness. Fracture energy can calculate by finding an area under a flexural stress-strain curve until failure. An area under the curve tells about the ability of concrete energy absorption. For example, a larger area represents that concrete can absorb greater energy before failure. Generally, fiber-reinforced concrete will take a long time for failure than non-fiber reinforced concrete, and fiber-reinforced concrete will have more significant displacement and area (under the CMOD curve). In this research, polyolefine fiber was used in all samples, and we used ORIGINPRO analyzing software to find an area under CMOD (crack mouth opening displacement) curve. From Table 4.2.1, we can see the calculated area for respective samples. So, fracture energy was calculated from the analyzed area. A control mix fracture energy is 320 N/m. In Set 01, fracture energy for batches 5UCR, 10UCR, 20UCR are 420 N/m, 249 N/m, 231 N/m. In Set 02, fracture energy for 5TCR, 10TCR, 20TCR batches are 147 N/m, 181 N/m, 176 N/m. In Set 03, fracture energy for 10TCRGP, 20TCRGP, 20TCRGP&10%FA batches are 98 N/m, 135 N/m, 110 N/m. In Set 01, 5UCR has higher fracture energy than a control mix and all other samples. The same result founded in this literature [12], fine crumb rubber concrete got high fracture energy than the control mix. In Set 02, 10TCR concrete showed greater energy absorption power than 5TCR and 20TCR concrete. In Set 03, 20TCRGP has high fracture energy than 10TCRGP and 20TCRGP&10%FA. Overall, among three sets, untreated fine crumb rubber samples were achieved significant fracture energy. I mentioned before fiber-reinforced concrete would have a larger displacement. According to that, all sample displacements continuing over 4 mm are shown in the below figures. But, 10TCRGP concrete has the least fracture energy than all other samples because concrete got failed at 2.93 mm, shown in fig. 4.2.10(h). Failure due to concrete may contain less amount of fibers or may be irregular fiber orientation. The flexural stress-strain curve for all samples is shown in Fig. 4.2.10. All samples area (under CMOD), fracture energy, residual flexural strength are entered in Table 4.2.1.

Table 4.2. 1. Samples area, fracture energy, residual flexural strength

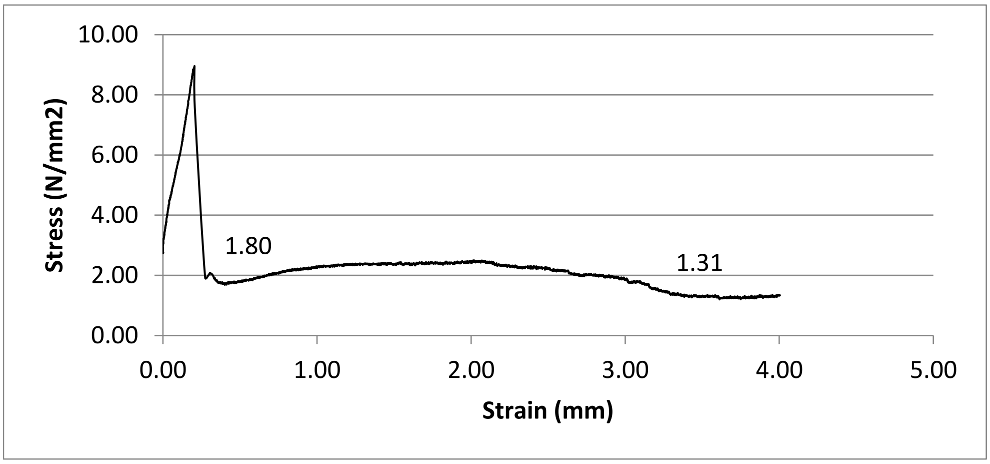
Samples	Area, N-m	Fracture energy, N/m	Residual flexural strength at 0.5 mm, MPa	Residual flexural strength at 3.5 mm, MPa
Control mix	1.71	320	2.4	3.2
5UCR	2.31	420	6.64	2.34
10UCR	1.29	249	1.80	1.31
20UCR	1.19	231	2.76	2.05
5TCR	0.69	147	1.58	1.64
10TCR	0.87	181	2.91	3.01
20TCR	0.89	176	1.22	1.17
10TCRGP	0.45	98	1.55	-
20TCRGP	0.65	135	1.68	1.61
20TCRGP&10%FA	0.47	110	2.28	2.35



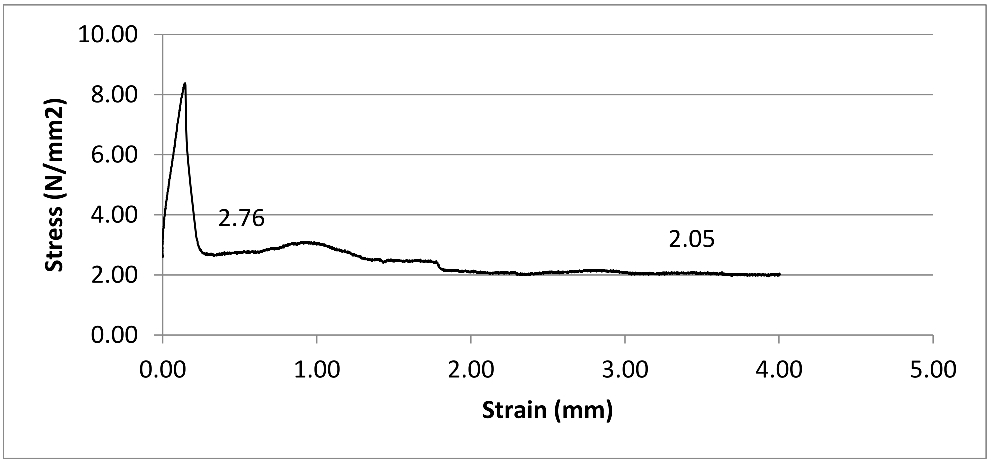
(a)



(b)


10.00
8.00
6.00
4.00
2.00
0.00
Stress (N/mm2)
1.80
1.31
0.00
1.00
2.00
3.00
4.00
5.00
Strain (mm)

(c)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6.00
4.00
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0.00
Stress (N/mm2)
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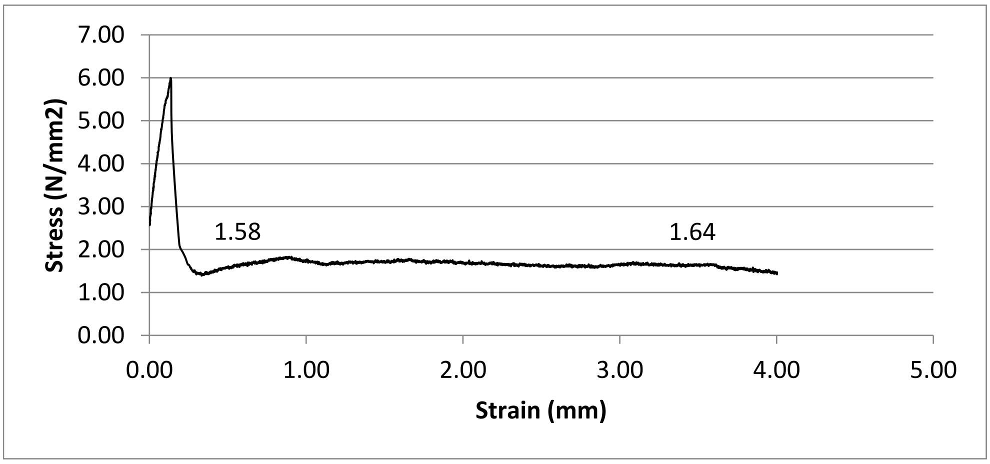
2.00
3.00
4.00
5.00
Strain (mm)

(d)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6.00
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4.00
3.00
2.00
1.00
0.00
Stress (N/mm2)
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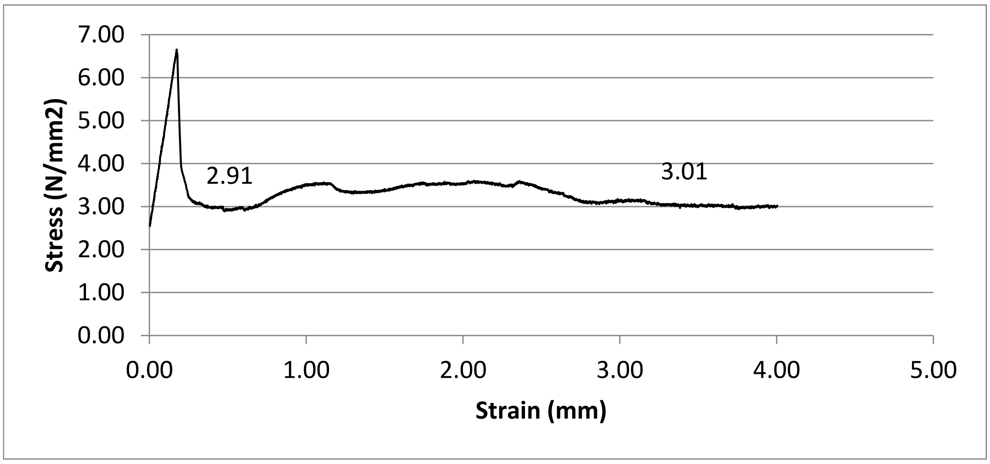
1.00
2.00
3.00
4.00
5.00
Strain (mm)

(e)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1.00
0.00
Stress (N/mm2)
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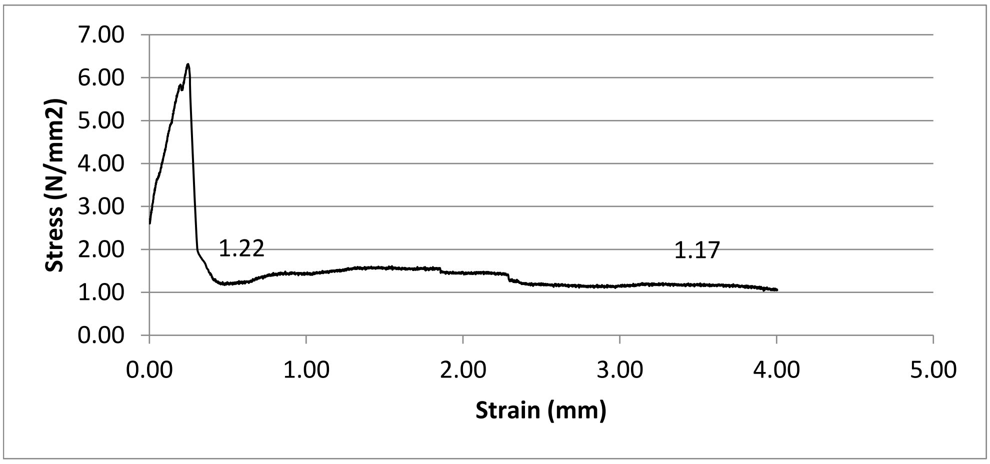
2.00
3.00
4.00
5.00
Strain (mm)

(f)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4.00
3.00
2.00
1.00
0.00
Stress (N/mm2)
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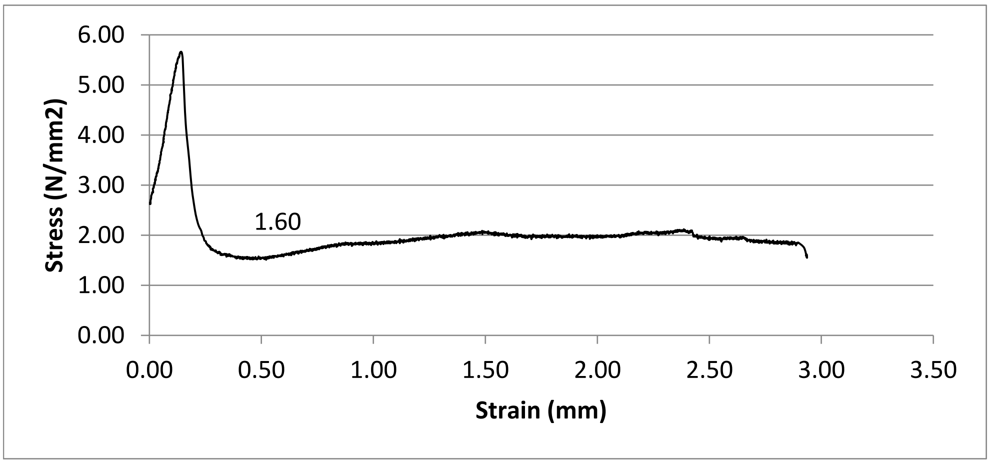
2.00
3.00
4.00
5.00
Strain (mm)

(g)


6.00
5.00
4.00
3.00
2.00
1.00
0.00
Stress (N/mm2)
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0.00
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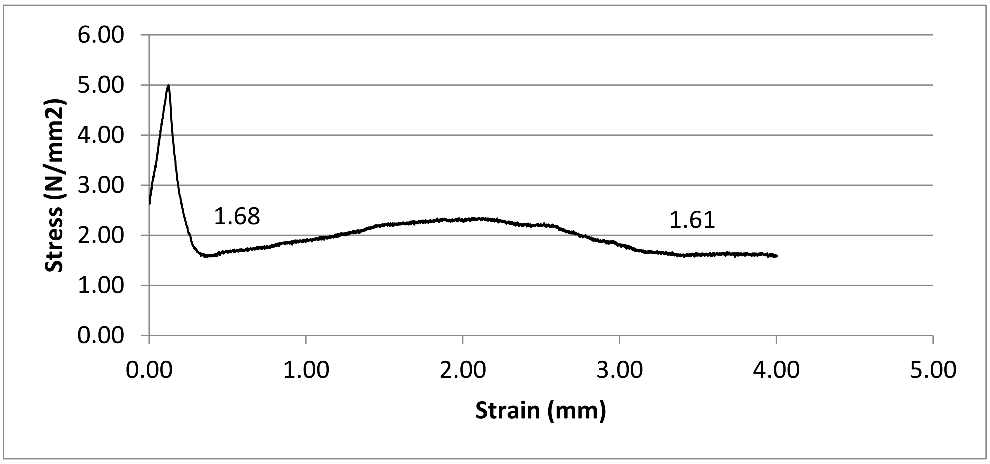
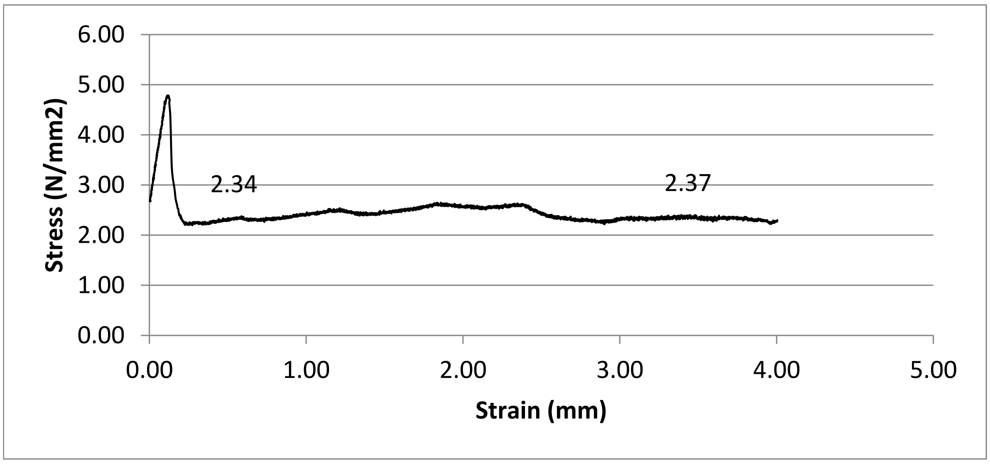
1.00
1.50
2.00
2.50
3.00
3.50
Strain (mm)

(h)



(i)



(j)

Fig. 4.2. 10. Flexural stress-strain curves ((a) Control mix, (b) 5UTR, (c) 10UCR, (d) 20UCR, (e) 5TCR, (f) 10TCR, (g) 20TCR, (h) 10TCRGP, (i) 20TCRGP, (j) 20TCRGP&10%FA)

Rubber particle distribution

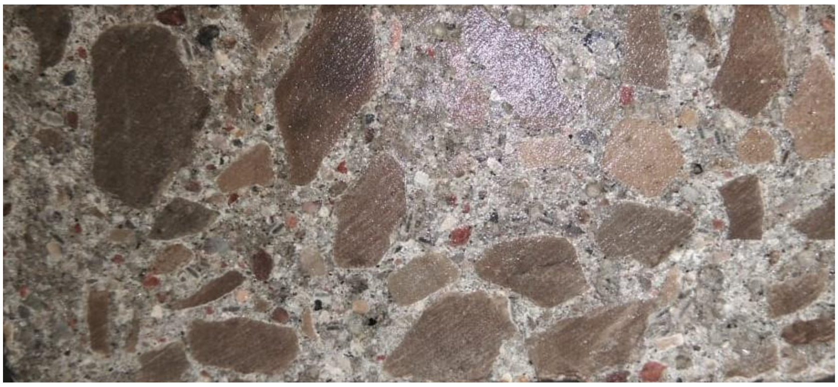
The untreated, treated, and fibrous crumb rubbers were used in concretes. After casting, fresh concrete was compacted with the help of an external electric vibrator. So, during vibration, there is a chance that rubber can agglomerate in one place or move upwards due to its low specific gravity nature. So, to ensure the distribution of rubber particles, we divided concrete into two pieces. Rubber distribution is essential for effective freezing-thawing performance because air will get entrap into concrete by rubbers, which will create voids in concrete. That air voids give space for water to release its pressure during freezing-thawing. From Fig. 4.2.11, we can see the even distribution of rubber particles in concretes. The untreated fine crumb rubbers were shared equally all over the concrete, and polymer treated rubber concrete did not show a rubber agglomeration. The fibrous crumb rubber is a very fine particle than normal crumb rubber used in the remaining batches. So it becomes complicated to see visually on the surface in both sieved and unsieved fibrous crumb rubber concretes. But somehow, we can able to identify rubbers on the surface shown in Fig. 4.2.11(e)(f).

(a)

(b)

(c)

(d)



(e)

(f)

Fig. 4.2. 11. Rubber particles distribution ((a) 20UCR, (b) 20TCR, (c) 20TCRGP, (d) 20TCRGP&10%FA, (e) 10SFCR, (f) 10UFCR)

Freezing-thawing resistance

In this research, we investigated the performance of untreated crumb rubber, treated crumb rubber, fibrous crumb rubber, and treated crumb rubber with glass powder & fly ash concretes after 200 freezing-thawing cycles. The freezing-thawing results of all samples were compared with control concrete. Generally, there should be a minimum amount of air in concrete to perform against the freeze-thaw effect. A traditional air-entraining agent or special air-entraining agent will use in concrete for a better freeze-thaw effect in the industries. So many years before, researchers found that rubber can act as an air-entraining agent in concrete. Due to its non-polar nature, rubber entraps air in concrete, which provides space for pressure release during water freezing-thawing. Fine crumb rubbers will entrap more air content than coarse rubbers because due to their high specific area. A rubber amount should be reasonable for sufficient air content in concrete. In this research, we added 5, 10, 20 kgs of crumb rubbers in concerts, and we used rubber size about <0.315 mm from batch 1 to 9, including sieved fibrous crumb rubber batch. An unsieved fibrous crumb rubber size was >0.315 mm, and prefabricated air bubbles (special air-entraining agent) were used in a control mix. Concretes performance before cycle and after 200 cycles were expressed in the way of compressive strength results. A 100 mm cube was used for freezing-thawing analysis. Concretes before cycles compressive strength was tested after 28 days.

Before 200 cycles, the compressive strength of a control mix is 58.7 N/mm^2. After 200 cycles, a control mix compressive strength is 59.4 N/mm^2; it increased by 1.19% compared to zero cycles compressive strength. In Set 01, before cycles, compressive strength for 5UCR, 10UCR, and 20UCR batches are 52.3 N/mm^2, 42.7 N/mm^2, and 46.1 N/mm^2. After 200 cycles, compressive strength for 5UCR, 10UCR, and 20UCR were decreased up to 36.13% (33.4 N/mm^2), 64.16% (15.38 N/mm^2), and 73.96% (12 N/mm^2) from zero cycles compressive strength. In Set 02, before cycles, compressive strength for 5TCR, 10TCR, and 20TCR batches are 33.4 N/mm^2, 31.4 N/mm^2, and 25.2 N/mm^2. After 200 cycles, compressive strength for 5TCR, 10TCR, and 20TCR batches were increased by 11.97% (37.4 N/mm^2), 8.59% (34.1 N/mm^2), 8.33% (27.3 N/mm^2) than pre-freeze-thaw compressive strength. A treated crumb rubber batches were performed well after freezing-thawing cycles, but it performed worst in the mechanical field. A high amount of porosity gave the bad mechanical property to concrete, but the same high amount of porosity gave the positive durable property to concrete. We can see the porosity nature (due to SBR) of set 02 concrete from the microscopic analysis. Those porosities gave space for water freezing-thawing. In Set 03, before cycles, compressive strength for 10TCRGP, 20TCRGP, and 20TCRGP&10%FA batches are 23.9 N/mm^2, 25.4 N/mm^2, 24.6 N/mm^2. After 200 cycles, batches 10TCRGP, 20TCRGP, and 20TCRGP&10%FA compressive strengths were increased up to 10.04% (26.3 N/mm^2), 7.87% (27.4 N/mm^2), and 13.0% (27.8 N/mm^2) from zero cycles compressive strength. The pozzolanic reactions of glass powder and fly ash filled the pores and reduced the amount of open porosity; due to that reason, set 3 batches were performed well during freezing-thawing cycles. The pozzolanic reaction of glass powder and fly ash shown in the SEM analysis part, and the porosity nature discussed in the water absorption kinetics part.

The sieved fibrous crumb rubber withstands the freeze-thaw effect after 200 cycles than sieved normal crumb rubber (used in set 01). Pre-freeze-thaw compressive strength of 10SFCR is 40.5 N/mm^2. After 200 cycles, it increased by 1.97% (41.3 N/mm^2) than pre-freeze-thaw compressive strength. From rubber particle size distribution (Fig. 2.1), we can see that sieved fibrous crumb rubber retained percentage in 0.063 mm is 1.79% and for normal crumb rubber is 0%. So, fine size fibrous crumb rubber created more micropores, which made concrete durable during the freezing-thawing effect. Due to coarser size rubber, 10UFCR was reduced by 39.70% (20.5 N/mm^2) than pre-freeze-thaw compressive strength (34 N/mm^2). According to LST 1428.17, after cycles, if samples reduced their strength (>5%) compared to pre-freeze-thaw compressive strength, those samples were not suitable for further cycles. Here, 5UCR, 10UCR, 20UCR, and 10UFCR were reduced by 36.13%, 64.16%, 73.96%, and 39.70% than pre-freeze-thaw compressive strength. So, 5UCR, 10UCR, 20UCR, and 10UFCR were not suitable for further freeze-thaw testing. After 200 cycles, treated crumb rubber samples showed higher compressive strength than untreated crumb rubber samples (due to the high porosity nature of treated crumb rubber concrete). After 200 cycles, in set 03, 10TCRGP concrete executed lower strength than 10TCR concrete. However, 20TCRGP and 20TCRGP&10%FA concrete maintained strength nearer to 20TCR concrete. So for further freezing-thawing cycles, there is a chance that 20TCRGP and 20TCRGP&10%FA concrete can increase their compressive strength results (due to later age pozzolanic reaction of glass powder and fly ash). But there is a disadvantage for freezing-thawing by increasing fly ash amount; it will lead to poor freezing-thawing performance. At last, before 200 cycles, 10SFCR concrete executed nearer strength to 10UCR concrete. After 200 cycles, 10SFCR concrete executed greater strength than all other samples.

In the coming literature [16], researchers achieved significant compressive results after 400 cycles using fine crumb rubber (fraction 0/1 mm) than coarser rubber (fraction 1/2 mm). Compressive strength for control concrete, set 02 and 03 samples, sieved fibrous crumb rubber concrete were increased after 200 cycles. It may be due to an unfinished hydration process were taken place during the freezing-thawing process. In my research, a control mix withstands above 500 cycles without any damages. So, prefabricated air bubbles were providing an excellent freezing-thawing effect. Control specimen after 500 cycles shown in Fig. 4.2.13. 10UCR and 20UCR concrete was severely damaged after 200 cycles shown in Fig. 4.2.14. Set 02, Set 03, sieved and unsieved fibrous crumb rubber batches are shown in Fig. 4.2.15. Compressive strength results before and after 200 cycles are shown in Fig 4.2.12.

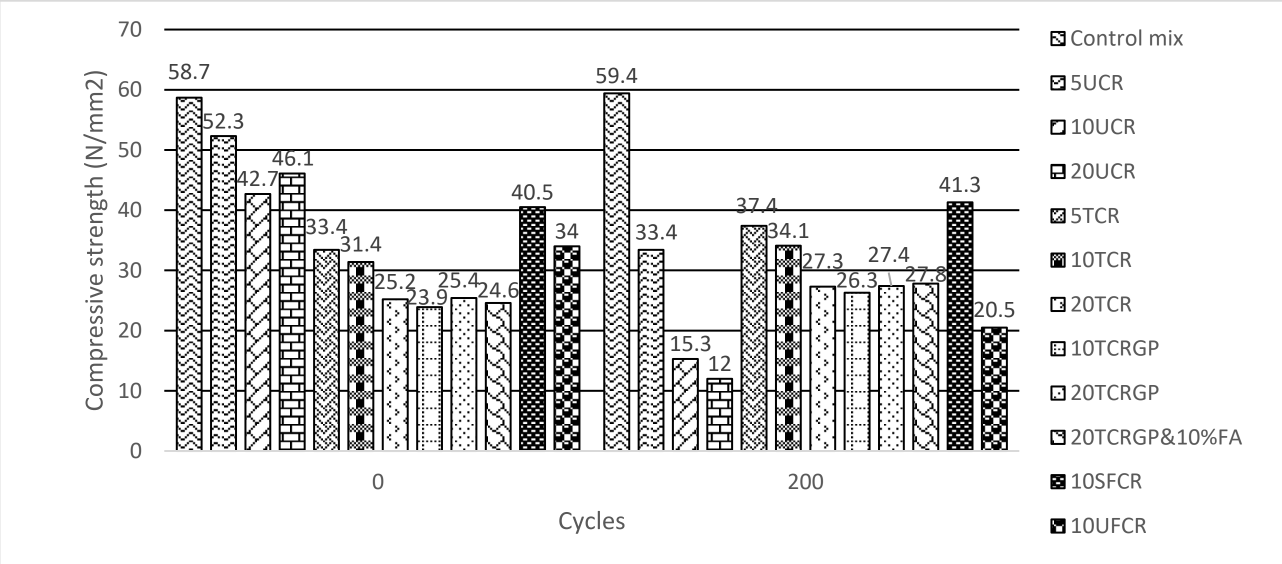


Fig. 4.2. 12. Compressive strengths before and after freezing-thawing cycles

Table 4.2. 2. Concretes density before and after freezing-thawing cycles

Samples	Before cycle, kg/m^3	After 200 cycles, kg/m^3
Control mix	2475	2480
5UCR	2422	2360
10UCR	2399	2382
20UCR	2419	2299
5TCR	2348	2342
10TCR	2375	2354
20TCR	2250	2318
10TCRGP	2301	2269
20TCRGP	2222	2281
20TCRGP&10%FA	2307	2379
10SFCR	2380	2415
10UFCR	2461	2432

Samples density before and after freezing-thawing cycles are shown in Table 4.2.2. After 200 cycles, a control mix density was increased by about 0.20% than before cycle density. The unfinished hydration process has been taken place in a control concrete during freezing-thawing cycles, which increased control concrete density and compressive strength after 200 cycles. Batches 5UCR, 10UCR, 20UCR concretes density were decreased by about 2.55%, 0.70%, 4.96% compared to before cycle density. In that, 20UCR concrete density loss was very high, due to that it has less compressive value than the other batches. In Set 02, 5TCR and 10TCR concrete density were decreased by about 0.2% and 0.8% than before cycle density. Due to the high amount of porosity, the density of 5TCR and 10TCR concrete decreases. But 20TCR concrete density was increased by 3.02% than pre-cycle density (unfinished hydration process can be a reason). In Set 03, 10TCRGP concrete density was decreased about 1.39% because less amount of glass powder (which filled few pores). However, 20TCRGP and 20TCRGP&10%FA concrete density were increased by 2.65% and 3.38% due to the high amount of glass powder and fly ash (its pozzolanic reactions were filled more pores and increased concrete density). After 200 cycles, sieved fibrous crumb rubber concrete density increased by about 1.47%, and unsieved fibrous crumb rubber concrete density decreased by about 1.17%.

Fig. 4.2. 13. Control concrete after 500 cycles

(a)

(b)

Fig. 4.2. 14. (a) 10UCR concrete after 200 cycles and (b) 20UCR concrete after 200 cycles

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Fig. 4.2. 15. Samples after 200 cycles ((a) 5TCR, (b) 10TCR, (c) 20TCR, (d) 10TCRGP, (e) 20TCRGP, (f) 20TCRGP&10%FA, (g) 10SFCR, (h) 10UFCR)

Porosity in concrete estimated by water absorption kinetics

Porosity is the prime factor for concrete performance in a mechanical and durable environment. Concretes total porosity, open porosity, and close porosity are calculated by using a water absorption test. It was the oldest and still performing technique. The procedure followed by this paper in porosity analysis: concrete samples were divided into four pieces and kept in the heating chamber at 105˚C for 48 hours (drying purpose). After drying, samples were dropped in the water tube, and after 15 mins, samples are taken from the water tube, and the mass of samples are measured. This process is repeated after 1 hour, 24 hours, 48 hours. The measured mass is used for finding porosity content in concrete.

After 48 hours of water absorption test, a control mix absorbed 4.03% of water. Untreated crumb rubber concretes absorbed little more water than a control mix. In that, 10UCR concrete showed less water absorption than a control, 5UCR, and 20UCR concretes. The reason behind less water absorbed by 10UCR concrete: it consists of less open porosity and more close porosity than a control mix and the other two batches. The amount of water absorbed by 5UCR, 10UCR, and 20UCR is about 4.11%, 3.72%, and 4.11%. In this literature [37], the water absorption rate is increased along with increased rubber content. After that, the water absorption rate was slightly increased in treated rubber concretes due to more open porosity. The amount of water absorbed by 5TCR, 10TCR, and 20TCR is about 4.46%, 4.47%, and 4.48%.

When glass powder and fly ash were added to treated rubber concrete, it decreased the amount of open porosity and increased close porosity content. Due to less open porosity, the water absorption rate was decreased in rubber glass concrete. The amount of water absorbed by 10TCRGP, 20TCRGP, and 20TCRGP&10%FA is about 3.27%, 3.26%, and 3.16%. Here, we can notice that fly ash with treated rubber and glass powder concrete showed the least water absorption rate than all other batches. This literature [21] also confirmed that fly ash with rubber aggregate reduces the water absorption rate. The coming literature [25][28] explained that glass's pozzolanic reaction reduces the water absorption rate in concrete. Sieved fibrous crumb rubber concrete has less open porosity, so it absorbed less water than unsieved fibrous crumb rubber concrete. From Fig. 4.2.16 and Table 4.2.3, we can see that concretes density decreases along with increasing porosity. The same thing happened in untreated and treated rubber concretes. But, in set 03, both combined glass powder and fly ash concrete decreased porosity content and increased its density than the remaining batches in set 03. Sieved fibrous crumb rubber concrete has more porosity than unsieved fibrous crumb rubber concrete, so 10SFCR showed less density than 10UFCR. In set 03, 20TCRGP concrete has the least density than all other batches.

From Table 4.2.3, set 02 and 03 samples are having a high frost resistant factor (kf) than all other samples (5TCR – 7.93, 10TCR – 8.97, 20TCR – 9.26, 10TCRGP – 18.16, 20TCRGP – 19.97, 20TCRGP&10%FA – 14.47). According to the high frost resistant factor and high predicted cycles, compressive strength for set 02 and 03 samples are increased after 200 cycles. So, from the kf factor, we can predict the performance of concrete in freezing-thawing. The least frost resistant factors are obtained by 5UCR – 3.65, 20UCR – 5.84, 10UFCR – 3.46. According to the least frost resistant factor, samples (5UCR, 20UCR, 10UFCR) were performed worst in a freezing-thawing test.

A control mix also obtained a low frost resistant factor, but it performed well after freezing-thawing cycles. The reason behind control concrete performance is that prefabricated air bubbles contain lots of microbubbles, which protected a control concrete under the freezing-thawing effect. The same result, low frost resistant factor, and highly durable prefabricated air bubble concrete are shown in this literature [16]. Then sieved fibrous crumb rubber concrete also showed less frost resistant factor, but it exhibited good freezing-thawing performance. The reason behind that performance: sieved fibrous crumb rubber is a very finer particle than sieved normal crumb rubber, so 10SFCR entrapped more micropores in concrete (cannot detect by this method), which made good durable performance in the freezing-thawing test. Concrete durability parameters are given in Table 4.2.3, and porosity content in concrete determined by water absorption kinetics is shown in Fig 4.2.16.

Table 4.2. 3. Concrete durability parameters

Samples	Water absorption,%	Concrete density. Kg/m^3	Frost resistant factor, k_f	Number of Cycles predicted	The compressive strength change (after 200 cycles) compared to before cycle compressive strength,%
Control mix	4.03	2351	3.62	581	+1.19
5UCR	4.11	2345	3.65	586	-36.13
10UCR	3.72	2311	7.05	>1000	-64.16
20UCR	4.11	2301	5.84	843	-73.96
5TCR	4.46	2231	7.93	>1000	+11.97
10TCR	4.47	2210	8.97	>1000	+8.59
20TCR	4.48	2203	9.26	>1000	+8.33
10TCRGP	3.27	2183	18.16	>2000	+10.04
20TCRGP	3.26	2160	19.97	>2000	+7.87
20TCRGP&10%FA	3.16	2249	14.47	>2000	+13.0
10SFCR	4.35	2288	5.52	806	+1.97
10UFCR	4.49	2322	3.46	555	-39.70

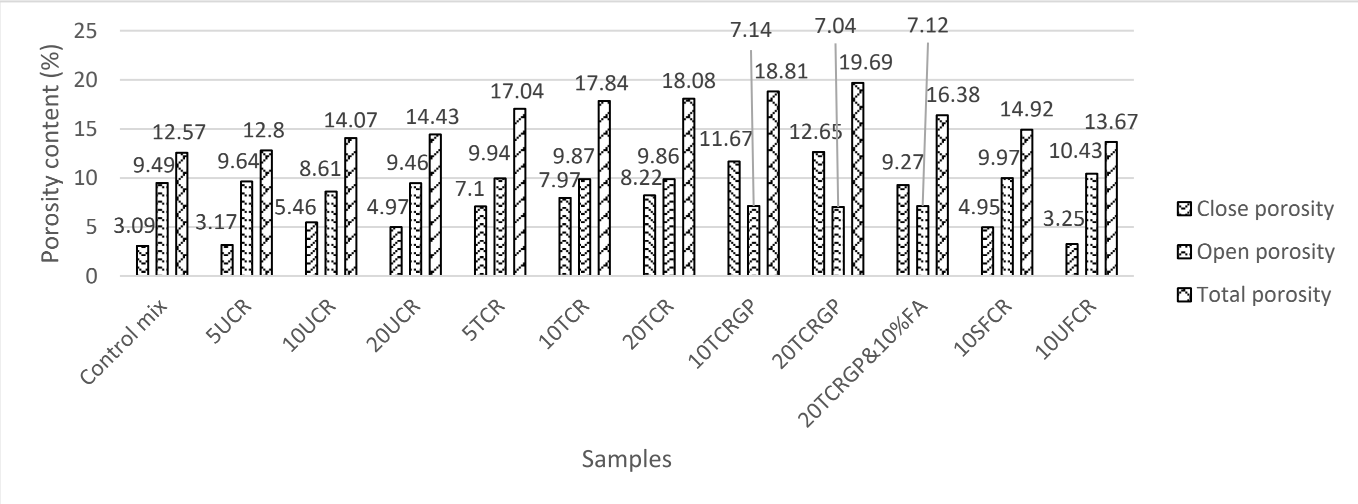
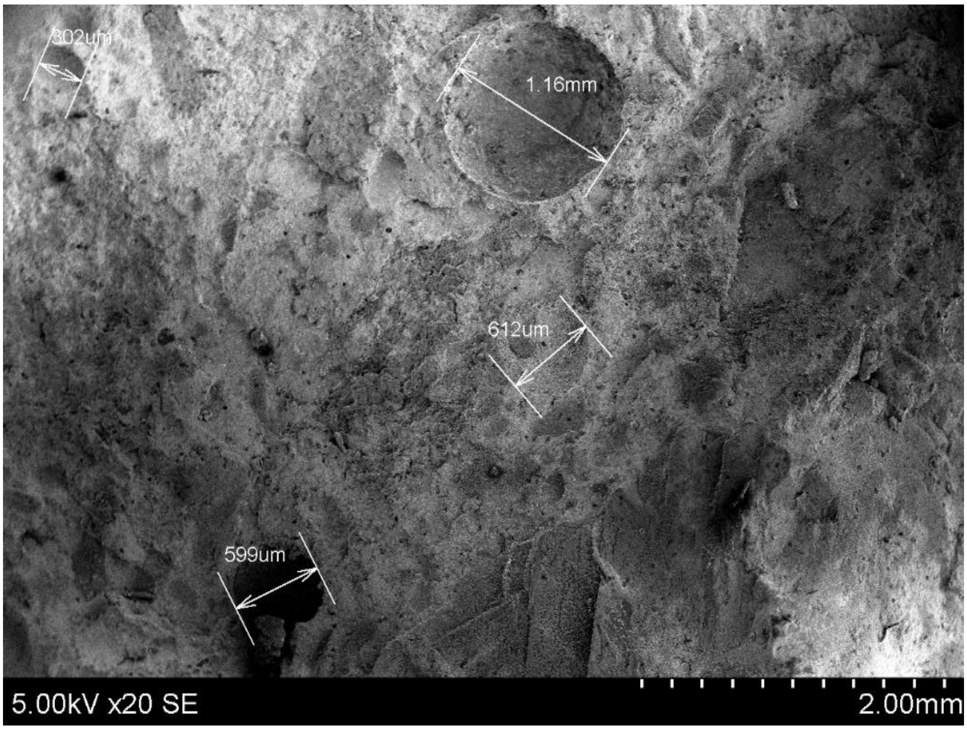


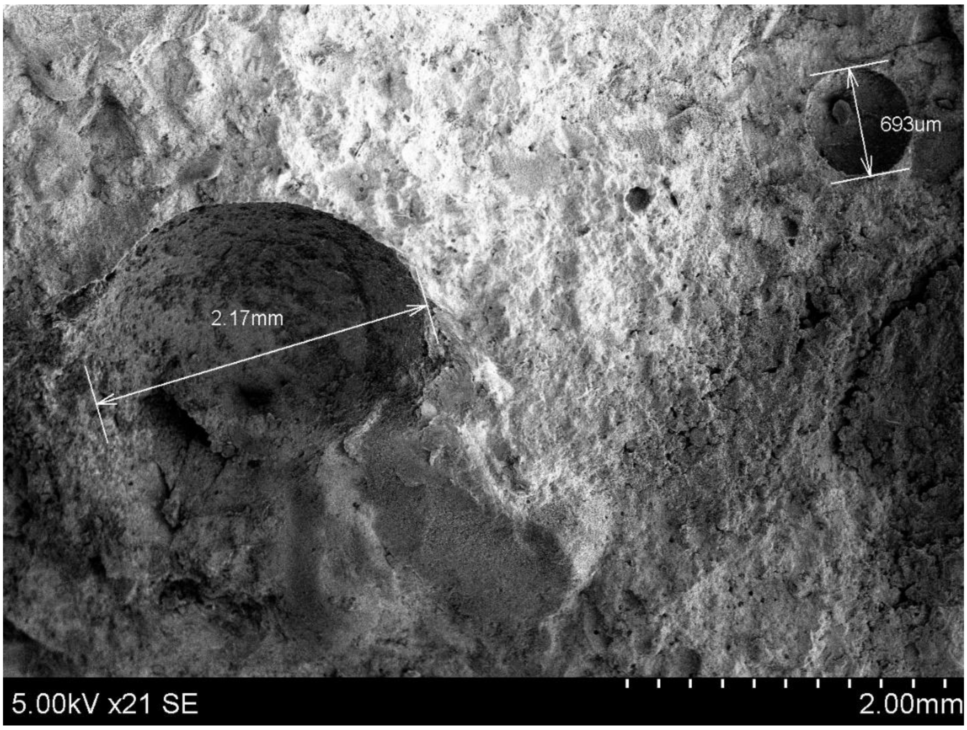
Fig. 4.2. 16. Porosity content in concrete is determined by water absorption kinetics

Scanning electron microscopic analysis

A scanning electron microscope will be used to analyze the microstructure of concrete. In this paper, a scanning electron microscope was used to project: 1) Prefabricated air bubbles in control concrete, 2) Untreated crumb rubber geometry and its bonding information with cement paste, 3) Treated crumb rubber bonding information with cement paste, 4) Pozzolanic activity of glass powder and fly ash in treated crumb rubber concrete, 5) about sieved and unsieved fibrous crumb rubbers. In Fig. 4.2.17. we can notice that prefabricated air bubbles in different sizes (fine and coarse). Prefabricated air bubbles provided enough space for water to release its pressure during the freezing-thawing effect. So that control concrete was performed well after freezing-thawing cycles.



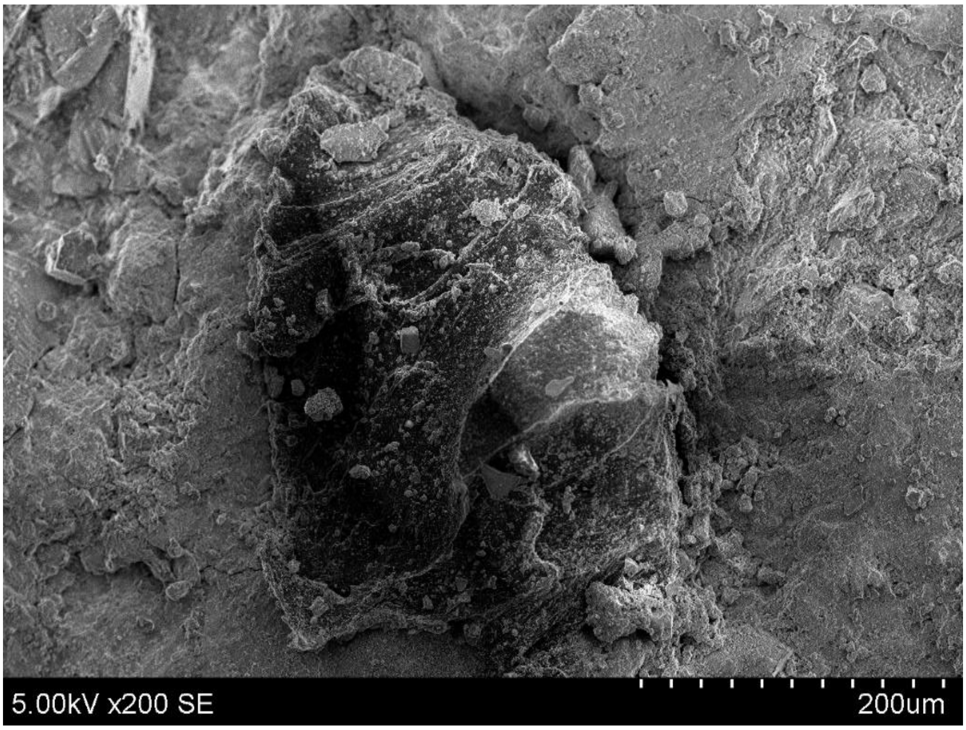
(a)



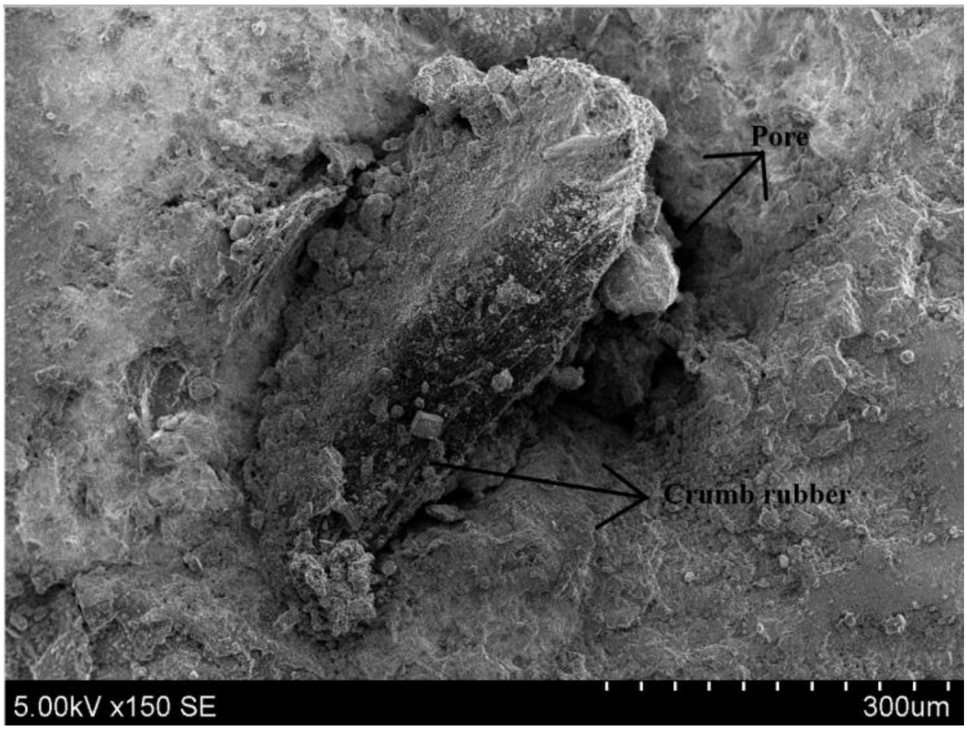
(b)

Fig. 4.2. 17. SEM images of control concrete ((a) & (b) Prefabricated air bubbles in different sizes)

Fig. 4.2.18(a) shows that improper bonding between untreated crumb rubber and cement paste. However, untreated fine crumb rubber occupied the micropores in concrete shown in Fig. 4.2.18(b). Due to pores filled by fine crumb rubber, untreated crumb rubber concretes yielded good compressive and flexural strength results. From both figures, we can notice that crumb rubber is irregular in shape. Due to its irregular shape, there is much chance that it can entrap more air in concrete when rubber amount increased.



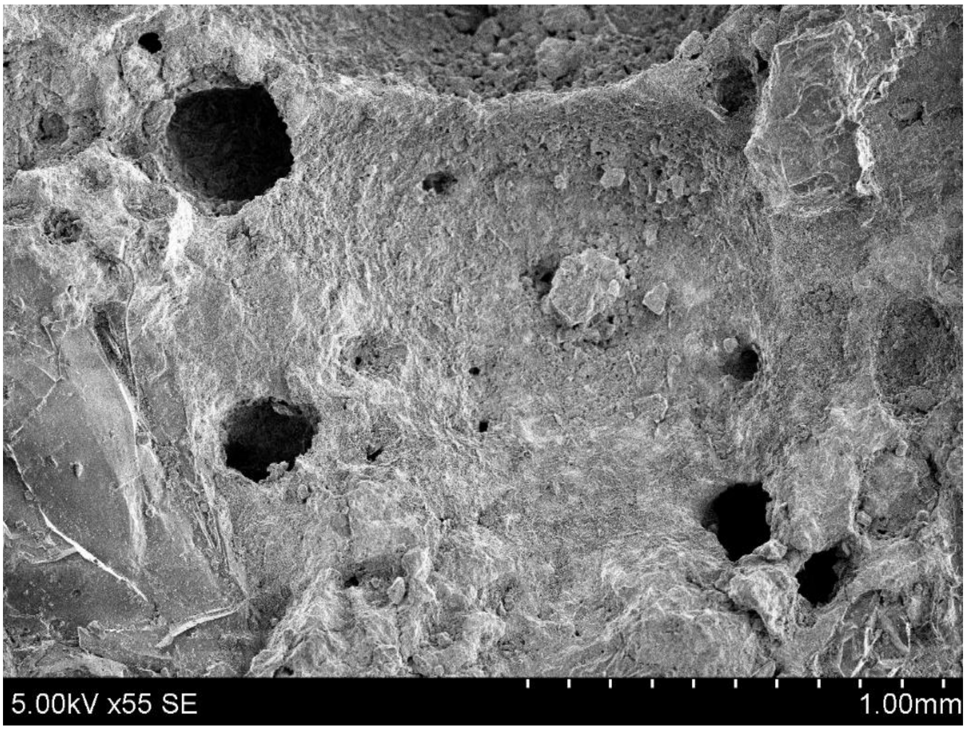
(a)



(b)

Fig. 4.2. 18. SEM images of untreated crumb rubber concrete ((a) Improper bonding between untreated crumb rubber and cement paste and (b) Pore occupied by untreated crumb rubber)

SEM analysis clearly showed that treated crumb rubber concrete contains lots of pores, that pores decreased treated crumb rubber concrete performance in both compressive and flexural field. However, the pores helped positively during the freezing-thawing effect. Porosity parameter analysis also explained that treated crumb rubber concrete has high porosity amount than untreated crumb rubber concrete. Fig. 4.2.19(a) shows the porosity nature of treated crumb rubber concrete. Along with that, Fig. 4.2.19(b) shows that treated crumb rubber has good bonding with cement paste, but concrete contains more pores due to liquid polymer (SBR latex).



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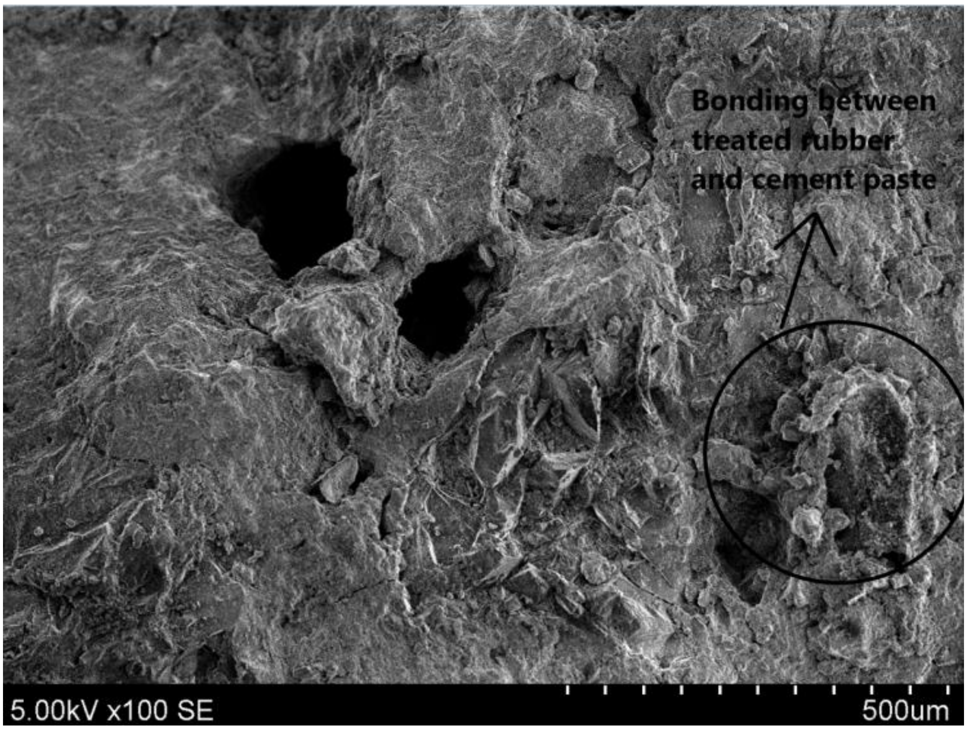
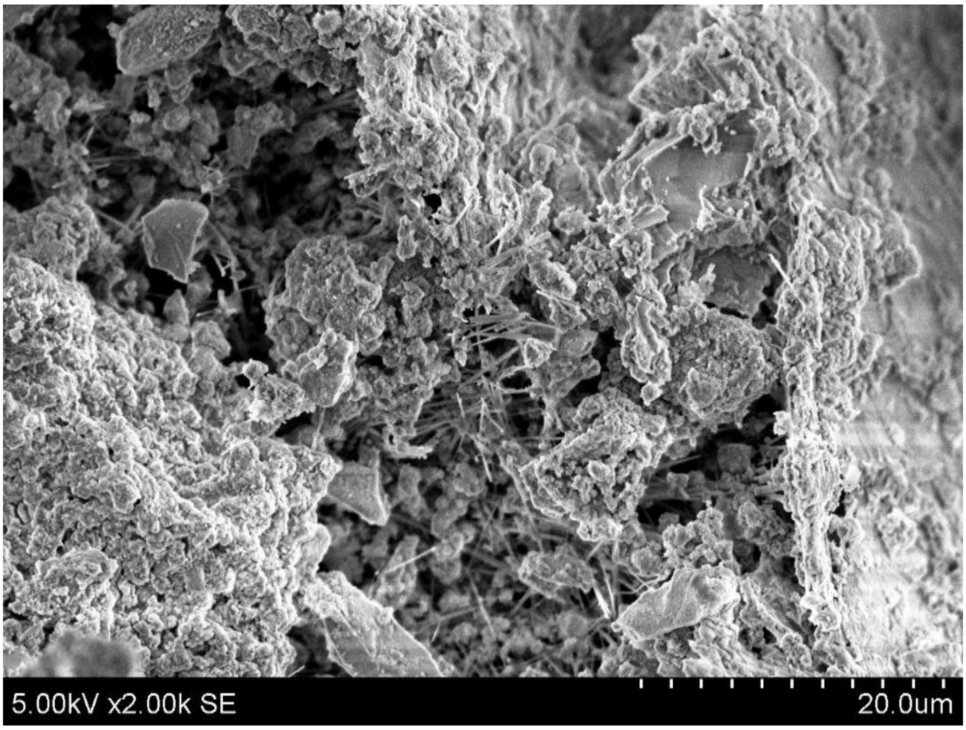


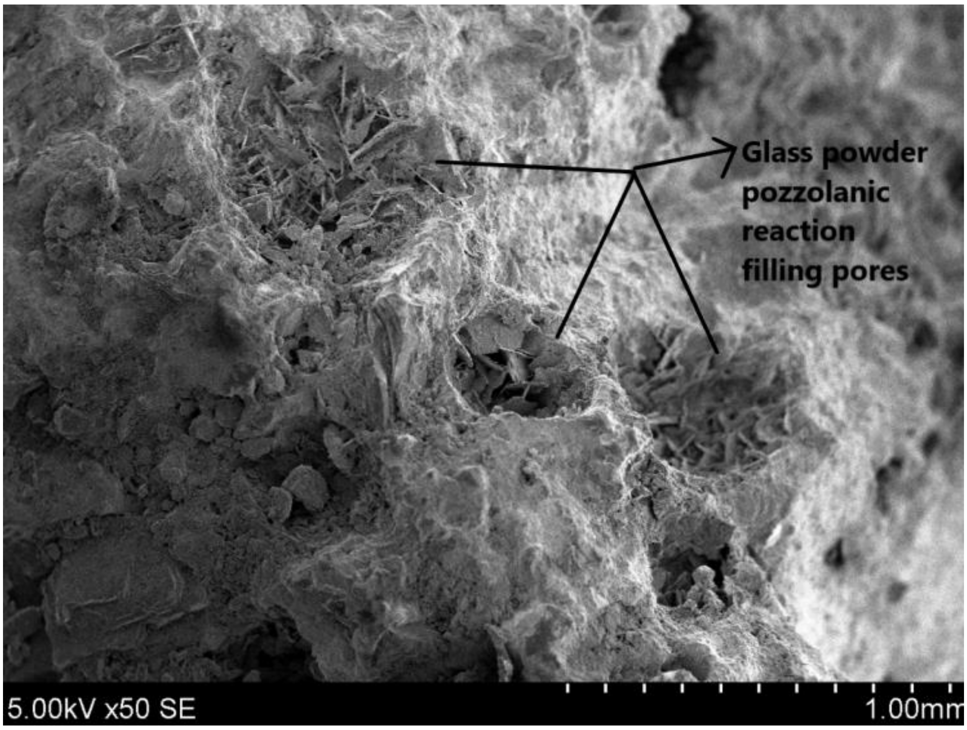
(b)

Fig. 4.2. 19. SEM images of treated crumb rubber concrete ((a) Porous nature of untreated crumb rubber concrete, (b) Good bonding between treated rubber and cement paste)

According to literature data, a type of ettringite was formed during the pozzolanic reaction of glass powder with cement paste is shown in Fig. 4.2.20(a). From Fig. 4.2.20(b)(c), we can see that the pozzolanic reaction of glass powder and fly ash were filling pores (created by treated crumb rubber). Fig. 4.2.20(b) shows that glass powder partially filled the pores during the initial stage. So, at a later stage, glass pozzolanic reaction will fill pores thoroughly, which will increase concretes compressive strength better than the 56th-day results. In Fig. 4.2.20(c), we can see that both combined pozzolanic glass and fly ash reaction. Due to the slow reactivity of fly ash, pores were not fully filled during the initial stage. Due to pore filling, set 03 batches showed efficient mechanical and durable properties.



(a)



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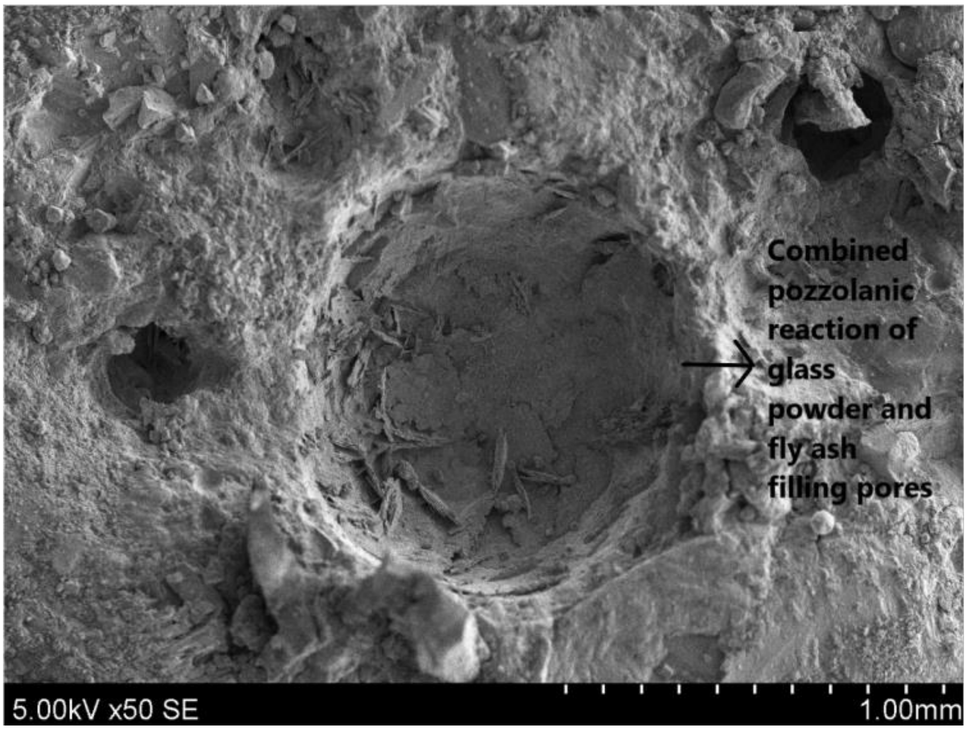
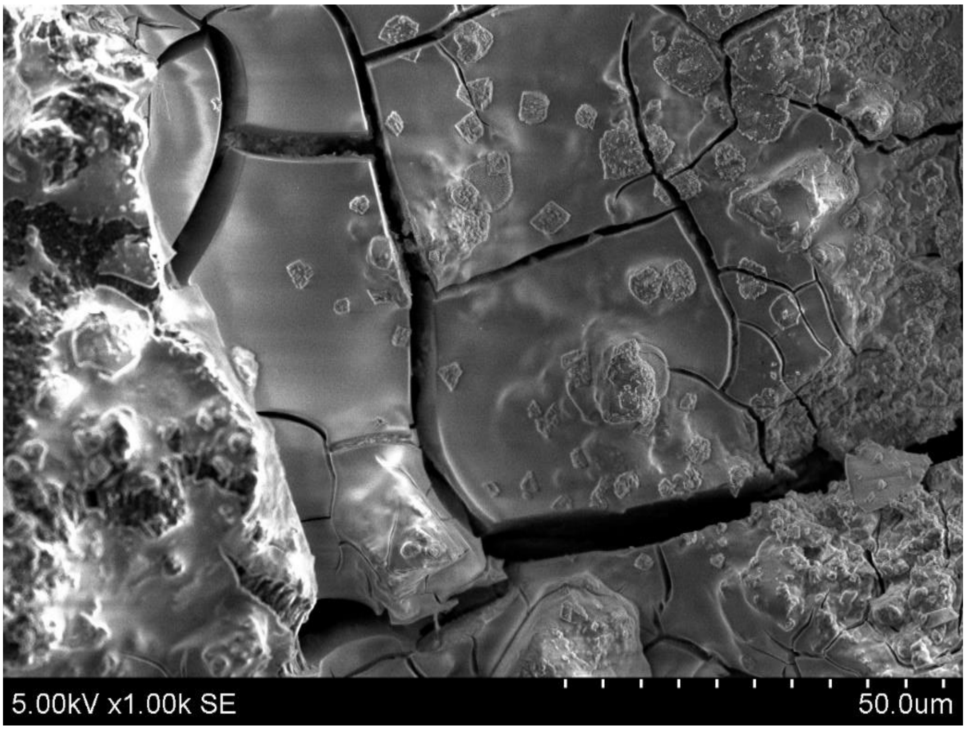


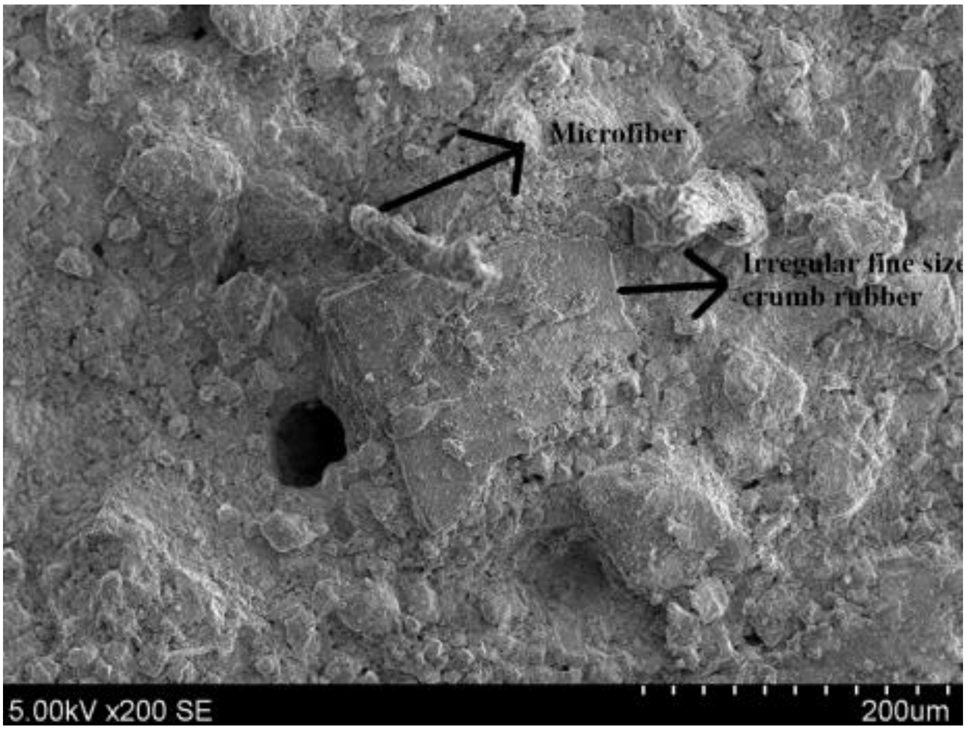
(c)

Fig. 4.2. 20. SEM images of set 03 batches ((a)Ettringite due to glass powder, (b) Glass powder pozzolanic reaction filling pores, (c) Combined pozzolanic reaction of glass powder and fly ash filling pores)

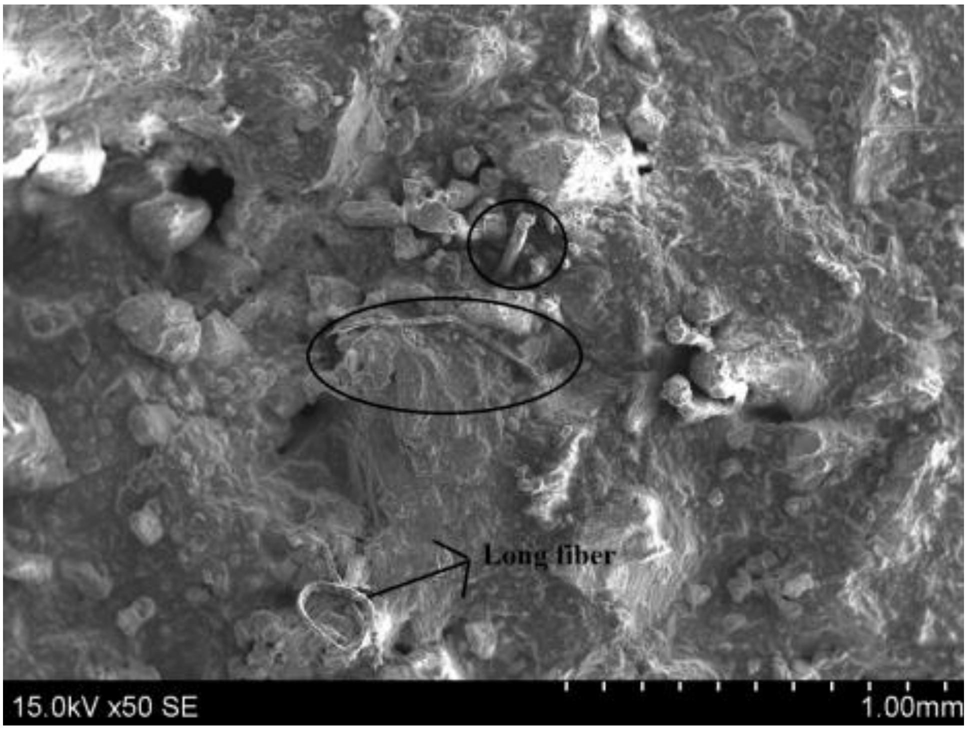
Fig. 4.2.21(a) describing that glass particles have a smooth surface and sharp edges. Due to its smooth surface nature, fresh concrete slump value gets increased for rubber glass batches. Its sharp edges carried air in fresh concrete, which increased air content for rubber glass fresh concretes. SEM image of sieved fibrous crumb rubber shows the irregular shape and fine size crumb rubber in Fig. 4.2.21(b). SEM image of unsieved fibrous crumb rubber shows many microfibers and long length microfibers in Fig 4.2.21(c).



(a)



(b)



(c)

Fig. 4.2. 21. SEM images of (a) Glass surface, (b) SFCR, (c) UFCR

5. White topping investigation

White topping is laying cement concrete mix over a damaged asphalt layer. Due to improper maintenance, the asphalt layer's deterioration rate was increasing. There are leading solutions for repairing damaged asphalt layers: structural overlay, recycling damaged asphalt, and reconstruction. In this, Structural overlay (White topping) is an effective method for repairing damaged asphalt layer. White topping is classified into three types they are conventional white topping (thickness >200 mm), thin white topping (thickness from 100 mm to 200 mm), ultra-thin white topping (thickness from 50 mm to 100 mm). These three types of white topping are further classified into two types based on these conditions: 1) Bonded condition and 2) unbonded condition. In bonded conditions, road structure will not contain an intermediate layer between cement concrete and asphalt layer. In unbonded conditions, there will be a small intermediate layer between cement concrete and asphalt layer.

There are many design procedures for white topping construction: AASHTO [43], state of Colorado [43], state of New Jersey [44], state of Texas [43], American Concrete Pavement Association [42], modified American Concrete Pavement Association [42], and the state of Illinois. In these procedures, AASHTO, the State of Colorado, and Texas's state described thin white topping design procedures. The remaining methods described ultra-thin white topping design procedures. Generally, design procedures will not provide details about bonding conditions, asphalt layer thickness, and asphalt layer modulus. This research is discussing the state of the New Jersey design procedure for ultra-thin white topping.

5.1. New Jersey design procedure for ultra-thin white topping

Necessary design procedure parameters are fatigue criterion, stresses in the pavement, and environmental conditions. The following design procedure was explained by [44].

Fatigue criterion

Fatigue criterion for asphalt pavement:

$$N = 0.058\frac{E_a^{2.437}}{\sigma^{3.291}} \tag{5.1.1}$$

N is the number of load repetitions until failure, E_a is asphalt elastic modulus, and σ is the maximum tensile stress in asphalt.

Fatigue criterion for UTW:

$$\left.\begin{aligned} &N = 10^{12(0.972-SR)}, SR > 0.55 \\ &N = \left(\frac{4.258}{SR - 0.4325}\right)^{3.268}, 0.55 > SR > 0.45 \\ &N = \infty, SR < 0.45 \end{aligned}\right\} \tag{5.1.2}$$

SR is a stress ratio; it is defined as the ratio of cement tensile stress to rupture stress.

$$SR = \frac{\sigma}{S_c} \quad 5.1.3$$

Rupture stress is calculated from concrete elastic modulus.

$$S_c = \frac{43.5E_c}{1000000} + 448 \quad 5.1.4$$

E_c is the concrete elastic modulus. If the stress ratio less than 45%, concrete can withstand unlimited loads.

Stress due to load

Prediction equation for asphalt layer maximum tensile stress (for both bonded and unbonded conditions).

$$\sigma_B^{ASPHALT} = \frac{CP(N.A. - h)}{I_B}\left[C1\ log\left(\frac{l}{b}\right) + C2\frac{N.A.}{a} + C3\right] \quad 5.1.5$$

$$\sigma_U^{ASPHALT} = \frac{CPa}{2I_U}\left[C1\ log\left(\frac{l}{b}\right) + C2\frac{a}{h} + C3\right] \quad 5.1.6$$

Prediction equation for UTW maximum tensile stress (for both bonded and unbonded conditions).

$$\sigma_B^{UTW} = \frac{CPn(N.A. - C)}{I_B}\left[C1\ log\left(\frac{l}{b}\right) + C2\frac{N.A.}{C} + C3\right] \quad 5.1.7$$

$$\sigma_U^{UTW} = \frac{CnPc}{2I_U}\left[C1\ log\left(\frac{l}{b}\right) + C2\frac{a}{h} + C3\right] \quad 5.1.8$$

I_B and I_U is a moment of inertia for the bonded and unbonded condition.

$$I_B = \frac{nc^3}{12} + \frac{a^3}{12} + \frac{nca(a+c)^2}{4(nc+a)} \quad 5.1.9$$

$$I_U = \frac{nc^3}{12} + \frac{a^3}{12} \quad 5.1.10$$

N.A. is the depth of the neutral axis from the top surface.

$$N.A. = \frac{nc^2 + a^2 + 2ac}{2(nc+a)} \quad 5.1.11$$

Where a and c are the thickness of the asphalt layer and concrete layer, n is the ratio of concrete elastic modulus to asphalt elastic modulus.

$$n = \frac{E_c}{E_a} \quad 5.1.12$$

C is the construction joint effect. C_1, C_2, C_3 can obtain from least-square analysis based on FEM.

Stress due to temperature

$$\sigma_T = CE_c\alpha\Delta T[C4\frac{C}{l} + C5] \quad 5.1.13$$

E_c and α is concrete elastic modulus and coefficient of thermal expansion. ΔT is the temperature difference between the top and base layer. C is the construction joint effect; C_4 and C_5 can obtain from least square analysis based on FEM.

Traffic data

If traffic data is not available, we can choose the 18 kip equivalency factor according to AASHTO. The combination of all vehicle loads is converted into 18 kips single axle and tandem axle loads. The load acting in the pavement from a single axle can calculate from

$$W_{18} = [\frac{W_{SAL}}{18}]^{3.3} \quad 5.1.14$$

W_{SAL} is the weight of the single axle.

Load acting in the pavement from a tandem axle can calculate from

$$W_{18} = [\frac{TW_{TAL}}{2 * 18}]^{3.3} \quad 5.1.15$$

W_{TAL} is the tandem axle weight, and T is the tandem factor, which can substitute as 1.25.

Safety factor

$$W_D = 10^{-Z_R S_0} W_{18} \quad 5.1.16$$

Z_R is the standard normal deviation from design reliability, S0 is the standard deviation for rigid pavement that can choose between 0.30 to 0.40, and for flexible pavement from 0.4 to 0.5.

Table 5.1. 1. Standard normal deviation with the design reliability factor [44]

R	70	80	85	90	91	92	93	94	95	96	97	98	99	100
Z_R	-0.5	-0.8	-1.0	-1.3	-1.3	-1.4	-1.5	-1.6	-1.6	-1.8	-1.9	-2.1	-2.3	-3.8

The following steps are useful for designing UTW.

1. From the project site, collect the traffic data information and find the number of equivalent 18-kips single axle load from Eqs. 5.1.14, 5.1.15, and 5.1.16.
2. Find out the elastic modulus and thickness of existing asphalt pavement and also find the coefficient of subgrade.
3. Calculate the allowable stress for asphalt pavement from Eq. 5.1.1.
4. Assum UTW thickness, calculate the maximum tensile stress for asphalt pavement in both bonded and unbonded condition from Eqs. 5.1.5 and 5.1.6.
5. The allowable stress and maximum tensile stress of asphalt pavement should equal. If it is not equal, should follow steps 4 and 5 again.
6. After that, calculate maximum tensile stress for UTW and temperature stress from Eqs. 5.1.7, 5.1.8, 5.1.13.
7. From the stress ratio (SR), calculate the UTW fatigue criterion.
8. If the fatigue criterion of UTW is less than the safety factor W_D, it needs to increase the UTW thickness and follow steps from 4. From the process, we can find a suitable thickness for stress action.

5.2. Advantages of white topping system

1. White topping initial construction cost is high, but the maintenance cost is low compared to bituminous pavement.
2. White topping construction technique is easy and convenient compared to bituminous pavement construction.
3. White topping will provide efficient serviceability.
4. Cement concrete will not show much damage during seasonal variation.
5. Distresses will not happen when overlaying above damaged asphalt pavement and also can easily repair cement concrete pavement.
6. Cement concrete has a high albedo value (for new concrete - range from 0.35 to 0.4 and old concrete - range from 0.2 to 0.3) where new asphalt concrete ranges from 0.05 to 0.1 and old asphalt concrete range from 0.10 to 0.15. Albedo value is defined as a ratio of reflected solar radiation (from a concrete surface) to coming solar radiation (on a concrete surface). Due to its high albedo value, cement concrete has high visibility during night time.

5.2.1. Conditions for white topping construction

The white topping technique cannot be applied for specific conditions like:

1. When bituminous pavement is not affected severely, any repairing technique will not be considered.
2. When there is no perfect vertical clearance for settling white topping concrete mix, any repairing technique will not be considered.
3. Moreover, when asphalt pavement settles down along with the base layer, a white topping method cannot be applied. During that situation, first, need to stabilize the base layer and to construct new pavement.

5.3. White topping construction techniques

White topping is classified into three types: Conventional white topping, Thin white topping, and Ultrathin white topping. A conventional white topping consists of a thick layer and its usage in national highways. In thin white topping, its thickness is less than conventional white topping, and its usage in district roads. Ultrathin white topping is a thin layer concrete structure, and it is using in parking lots and pavers sidewalks. The performance of white topping is depended upon the construction process. Five important works have to be done for white topping constructions: 1) Pre-overlay works, 2) choosing overlay materials, 3) cement concrete placement and finishing, 4) cement concrete curing, 5) joint sawing.

1. Pre-overlay works: Pre-overlay works are essential for white topping durability. The damaged asphalt pavement should not cause any failures to overlay white topping pavement. So, that needs to repair damaged asphalt pavement before laying cement concrete. For example, asphalt pavement is damaged up to a certain depth. That certain failure depth should remove; after that only cement concrete can place over asphalt pavement. The milling machine will use for removing damaged asphalt pavement. Further, the types of white topping are classified based on bonded and unbonded. Bonded pavement does not consist intermediate layer between cement concrete and asphalt pavement. Unbonded pavement consists of an intermediate layer between cement concrete and asphalt pavement.
2. Overlay materials: For white topping concrete mix, materials are chosen on the basis of construction and concrete strength.

    – Generally, for white topping construction, Type I and Type II cement will be used. In case of fast construction, to attain high early strength, Type III cement will be used.
    – Good quality aggregates like river gravel are used to provide long-life durability for white topping pavements. The size of aggregates depends on the thickness of pavement.
    – Water cement ratio (0.45) is recommended for high moist and freeze-thaw areas. For bonded overlay should use less water than unbonded overlay because when using a high amount of water in a bonded overlay, it will shrink and will not properly bond with asphalt pavement.
    – Air content (4% to 6%) is recommended in concrete to increase workability, reduce segregation and bleeding, and protect from the freeze-thaw effect.
    – Concrete developing strength will increase at the initial stage by using an accelerator (calcium chloride) in the mix. For the reinforced concrete mix, a non-chloride accelerator can use.
    – Water reducing admixture can add to reduce the water-cement ratio and to increase concretes workability.
    – Cementitious materials (fly ash, silica fume, GGBS, metakaolin) can add as a part of cement to increase concrete strength and workability, to reduce permeability and alkali-silica reactivity.

3. Concrete placement and finishing: While placing the concrete mix, the surface temperature of asphalt pavement should be less than 48˚C to neglect plastic shrinkage cracks. The white topping concrete mix can be laid by using fixed-form paver and slip-form paver. After laying, the pavement surface texture can be finish by any one of the methods: Brooming, Burlap dragging, Turf dragging, or Tinning comb.

4. Concrete curing: Curing is an important factor and curing should practice for certain days after construction to attain good concrete strength. Generally, the pavement area to volume ratio is high, so there is a high chance of moisture loss. During moisture loss, there will be many initial cracks will get formed on the surface. This problem can be solved by curing.
5. Joint sawing: Joint sawing is the final process of white topping construction. Joints in the pavement are a fundamental thing because to avoid shear cracks during vehicle movement. During saw cutting, should be careful do not to cause any additional cracks. The transverse length and longitudinal length should be perfect. For example, in the thin white topping pavement, transverse joints can be sawed one-fourth of slab thickness and longitudinal joints can be sawed one -third of slab thickness.

Conclusions

1. In the slump cone test, treated crumb rubber batches executed a greater slump value than untreated crumb rubber batches because of liquid polymer SBR latex. Crumb rubbers lost their stiffness due to SBR, which made treated crumb rubber batches flowable. When glass powder was added in treated crumb rubber batches, it increased slump value due to glass particles' smooth surfaces. Along with this, fly ash added concrete increased slump value even higher than other batches. However, control mix, UCR batches, TCR batches, treated crumb rubber with glass powder & fly ash batches, sieved and unsieved fibrous crumb rubber batches executed more excellent workability above 150 mm. The fresh concrete density results decreased gradually from the 5UCR (untreated crumb rubber) batch to 20TCRGP (treated crumb rubber with glass powder) batch. According to principle, when rubber amount increased, fresh density was decreased. In the fresh concrete air content test, treated crumb rubber batches exhibited high air amount than untreated crumb rubber batches. Sharp edges of glass powder carried air into concrete, which increased air content for treated rubber with glass powder fresh concretes. Fly ash reduced air content by filling air voids in fresh concrete. Fresh density and air content are interconnected because when air content increased, fresh density is getting decreased.
2. In the compressive strength test, untreated crumb rubber batches executed a more significant performance than treated crumb rubber batches. Untreated crumb rubber batches: 5UCR, 10UCR, and 20UCR have decreased very fewer percentages about 7.04%, 11.79%, and 11.97% than a control mix. Due to high porosity, treated crumb rubber batches: 5TCR, 10TCR, and 20TCR were decreased in high percentages about 38.73%, 34.50%, and 53.16% than a control mix. We recommend using more polymer content in concrete is forming more porosity (which made concrete weaken under compressive force). Less amount of polymers can resist the porosity nature in concrete. In the initial stage, glass powder and fly ash added rubber concrete exhibited a low compressive value than all other batches. After 56 days, pozzolanic reactions of glass powder and fly ash were activated in treated crumb rubber concrete, so the compressive strength for batches 10TCRGP, 20TCRGP, and 20TCRGP&10%FA were increased by about 25%, 16.92%, and 17.59% compared to 28th-day compressive strengths. Finally, concluding that glass powder and fly ash can increase treated rubber concretes strength at later stages. From the pozzolanic activity index, we found that 20 kg/m^3 of glass powder exhibited good pozzolanic activity in rubber concrete. However, comparing both glass powder rubber concrete and combined glass powder and fly ash rubber concrete did not show greater strength loss.
3. In the dry density test, 20UCR occupied more pores, which increased 20UCR concrete density than 10UCR concrete density. Dry density and compressive strength of concrete are interconnected. So, 20UCR concrete executed nearer strength to 10UCR concrete due to density rise. In set 03, after 56 days, batches 10TCRGP, 20TCRGP, and 20TCRGP&10%FA increased their dry density of about 1.22%, 0.49%, and 0.94% compared to 28th-day dry densities.

4. In the flexural strength test, untreated fine crumb rubber occupied micropores, which increased flexural strength than a control mix. Untreated crumb rubber batches: 5UCR and 10UCR increased flexural strength about 27.59% and 5.66% than a control mix. 20UCR concrete flexural strength was decreased very less 1.17% compared to a control mix. In set 02, due to porosity and absence of additional adhesive promotion, treated rubber batches: 5TCR, 10TCR, and 20TCR reduced their flexural strength by about 29.24%, 24.16%, and 25.47% than a control mix. Among treated rubber batches, 10TCR concrete was performed quite well compared to 5TCR concrete. Glass powder and fly ash added concrete were tested after 28 days in a flexural strength test. So, batches 10TCRGP, 20TCRGP, and 20TCRGP&10%FA were reduced by 33.25%, 41.03%, and 43.63% than a control mix. The later age pozzolanic reaction of glass powder and fly ash can increase their flexural strength in the future. We noticed that untreated crumb rubber concretes executed great fracture energy compared to all other batches. Significantly, 5UCR concrete exhibited higher fracture energy (is 420 N/m) than a control mix (is 320 N/m). Among all batches, 10 kg treated crumb rubber and glass powder (10TCRGP) concrete showed the least fracture energy (98 N/m). In this paper, fracture energy was calculated to find rubber toughness and fiber toughness. 10TCRGP concrete prism was failed at displacement 2.93 mm, but every concrete prism was continuing over 4 mm displacement. The reason for 10TCRGP concrete failure may be due to less fiber amount or improper fiber orientation.
5. The freezing-thawing test results showed that control concrete increased its strength by 1.19% than the pre-freeze-thaw compressive strength. Untreated crumb rubber batches: 5UCR, 10UCR, 20UCR were decreased vigorously about 36.13%, 63.98%, 73.96% compared to pre-freeze-thaw compressive strengths. The high amount of porosity protected treated crumb rubber concretes from a freezing-thawing effect. Compressive strength after 200 cycles for treated crumb rubber batches: 5TCR, 10TCR, 20TCR were increased by about 11.97%, 8.59%, 8.33% compared to pre-freeze-thaw compressive strengths. The pozzolanic reaction of glass powder and fly ash have filled the pores and protected set 03 concretes from a freezing-thawing effect. Compressive strength after 200 cycles for set 03 samples: 10TCRGP, 20TCRGP, 20TCRGP&10%FA were increased 10.04%, 7.87%, 13.0% compared to pre-freeze-thaw compressive strengths. After 200 cycles, sieved fine size fibrous crumb rubber exhibited better freeze-thaw performance than sieved normal crumb rubber. 10SFCR increased its strength to 1.97% from pre-freeze-thaw compressive strength. Due to coarser size, 10UFCR decreased its strength to 39.70% from pre-freeze-thaw compressive strength. Strength increases for control mix, set 02 and 03 batches, 10SFCR batch due to an unfinished hydration process.
6. The porosity content of concrete was analyzed by the water absorption method. When the porosity amount is high in concrete, the water absorption rate will get increased. Treated crumb rubber batches contain a high porosity content than control mix and UCR batches. So, treated crumb rubber concretes executed a high water absorption rate (5TCR – 4.46%, 10TCR – 4.47%, 20TCR – 4.48%) than control mix (4.03%) and UCR batches (5UCR – 4.11%, 10UCR – 3.72%, 20UCR – 4.11%). The pozzolanic reaction of glass powder and fly ash filled the concrete pores, which decreased open porosity content and increased closed porosity content. Due to that, set 03 batches absorbed less amount of water (10TCRGP – 3.27%, 20TCRGP – 3.26%, 20TCRGP&10%FA – 3.16%). According to frost-resistant factor (kf), set 02 and set 03 samples showed good performance in a freezing-thawing test. So, from the frost-resistant factor (kf), we can predict concretes' performance after freezing-thawing cycles.

7. Scanning electron microscope projected: 1) Prefabricated air bubbles in control concrete, 2) Untreated crumb rubber geometry and its bonding information with cement paste, 3) Treated crumb rubber bonding information with cement paste, 4) Pozzolanic activity of glass powder and fly ash in treated crumb rubber concrete, 5) Sieved and unsieved fibrous crumb rubbers.
8. At last concluding, in the mechanical field (compressive test and flexural test), untreated crumb rubber concretes performed nearer to a control mix. After that, we added SBR latex with crumb rubber to get better bonding and need to perform better than untreated crumb rubber concretes. But, due to overdosage of SBR, more porosity leads concrete to less strength. So, recommending to use less amount of polymer and additional adhesive promotion with SBR for better performance. After, we added glass powder and fly ash in treated crumb rubber concrete, and it showed good performance at later stages, but not up to the level of control mix. However, there is a chance that glass powder and fly ash concrete can perform better than a control mix after 90 days.
9. We used normal crumb rubber size <0.315 mm and fibrous crumb rubber size <0.315 mm in this research. But, fibrous crumb rubber provided satisfactory durable performance due to its fineness nature. So, at last, the overall recommendation: 1) Use fine size crumb rubber (at the required amount), 2) Use SBR latex with an additional adhesive agent (at required amount), 3) Use glass powder and fly ash in treated crumb rubber concrete (at required amount) to achieve magnificent mechanical and durable performance than conventional white topping concrete mix.

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