Behaviour of High Strength Rubberized Concrete under Compression Loading

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THESIS ACCEPTANCE CERTIFICATE

This is to certify that the

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Submitted by

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has been accepted towards the partial fulfillment

of the requirements for the degree of

Master of Science in Structural Engineering

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DECLARATION

I certify that this research work titled "**Behaviour of High Strength Rubberized Concrete under Compression Loading**" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Signature of Student

Muhammad Ashar Ul Aleem

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This thesis is dedicated to my family.

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ABSTRACT

The process of rubber decomposition is extremely slow and time consuming, the disposal of wasted tire causes environmental issue and very dangerous for public health. The addition of wasted rubber to make green concrete is beneficial to the environment. The aim of this research is to check stress strain behavior of eco-friendly high strength rubberized concrete pre-treated with waste quarry dust (WQD), which itself is a waste material. Nine different mixes were made in which one mix contained no replacement of sand whereas four mixes were made by substituting (5%, 10%, 15%, and 20%) of sand by volume with non-treated rubber, the remaining four contained treated rubber with WQD. The stress strain curve examined completely which includes compressive strength, modulus of elasticity, ductility, energy absorption capacities, toughness index and failure mode of concrete specimens. Moreover, tensile strength of all samples was investigated. The treated samples show improvement in compressive strength, tensile strength, and modulus of elasticity with increasing percentage of the rubber content. Whereas ductility and toughness index were improved in non-treated sample compared with treated specimens. It was observed that treated rubber exhibited slightly less improvement in post peak behavior than non-treated rubber. The outcome of this novel approach of rubber treatment provides an overview about the effect of rubber treatment on the stress strain behavior of high strength rubberized concrete.

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Chapter 1: Introduction

1.1 General

Concrete is the most widely used construction material in the world, due to its numerous advantages over other materials. Each year, more than 25 billion tons of concrete are produced worldwide, with one cubic meter consumed every person in Canada([CAC]. 2018). Another pressing issue is the uncontrolled disposal of waste materials, which has direct negative consequences for the global ecology. According to a research on ELTs published by the Tire Industry Project (TRP) of the World Business Council for Sustainable Development, four billion end-of-life tires (ELTs) are now being stockpiled worldwide(WBCSD 2008). In many countries around the global there is a challenge to dispose of the waste tyre as transportation demand is increasing day after day. Every country is trying to adopt different techniques to dispose of the waste tyre. As the construction industry is growing the number of natural aggregates is decreasing. so, there is a huge gap to introduce wasted tyre rubber in construction industry as a replacement of natural aggregates. One solution to this challenge is to include scrap tires into concrete as a partial replacement for natural fine particles (El-Gammal, Abdel-Gawad et al. 2010). This will not only address the tyre accumulation problem, but it would also help to protect natural resources.

There are many areas for the consumption of wasted tire rubber is identified but due to its chemical and mechanical properties its whole quantity could not be used in specific area. There are many examples of the usage of wasted tire rubber some of them are sport surface, rubber products, to resist shocks, automotive industry, and construction industry. The best application to use the wasted tire rubber is in construction industry. Due to its flexible and lightweight behavior it is successfully being used in construction industry. To safe the natural resources and due to environmental factor wasted rubber is used as the replacement of coarse and fine aggregate in the form of shredded rubber which is obtained by cutting the worn tire.

Due to excessive use of sand in concrete industry the amount of sand is depleting from the earth. The resource of sand is decreasing day by day as the use of sand is constantly increasing. The usage of sand globally is 50 billion ton in different construction projects and this amount is double as it produced naturally every year. In common practice river is a source of sand and mountains are the source of crushed stones, by extracting them the ecology of the area is affected adversely.

To avoid this alarming situation replacement of sand with waste material like wasted tire rubber could be a great revolution in construction industry.

To introduce the rubber in concrete industry is a challenging factor which is already been studied. The distribution of rubber to make homogeneous mixture is itself a challenge. The other challenge is huge amount of strength reduction which allows a specific amount of rubber to introduce in concrete. Another problem is the bonding of rubber particles with cement paste because rubber surface is hydrophobic. In general, prior studies proposed a variety of strategies for modifying the surface of rubber particles, such as immersing them in a sodium hydroxide solution (NaOH) to increase their adherence to the cement paste (Balaha, Badawy et al. 2007, Mohammadi 2014). In addition, there are more Rubberized concrete's strength can be improved, according to the study by incorporating supplemental cementitious materials (SCMs) such silica fume (SF) as well as nano silica (NS).(Güneyisi, Gesoğlu et al. 2004) revealed that adding SF to rubberized concrete can improve its compressive strength by improving the interfacial transition zone (ITZ) bonding and reducing the pore size in the cement paste. Another method to treat the rubber surface is treatment of using waste quarry dust which itself is a waste material and locally available in large quantity in Pakistan.

In Pakistan as construction projects are growing day by day stone industry demand is rising. In the result during crushing of stone waste material is produced called waste quarry dust which itself is a problem to dispose of because it effects the environment badly. Waste Quarry dust is another a global challenge to be resolved as it effects the environment adversely and it is health hazard, and the only solution is to reuse it in the construction industry. The use of waste quarry dust in construction industry involves in brick industry, as a replacement of sand in concrete as well as the replacement of cement in concrete.

1.2 Problem statement

Wasted tire are major worldwide problem due to their non-biodegradability, their fire catching ability and their chemical composition which can cause many other problems like landfilling, environmental issues and health problems. To dispose of the wasted tyre is a worldwide challenge specially in country like Pakistan. The unrecycled tire are being used in playground surface, asphalt and in construction industry.

Currently small amount of wasted tire are being used in construction industry although the margin is quiet high. Similarly waste quarry dust is another material which can affect the environment badly. It is adhesive in nature and its transportation is tough task which open doors to use this dust in site itself. As rubber decrease the compressive strength there is a technique proven that treated rubber with waste quarry dust increase the compressive strength of concrete. By following this technique, we can improve the quality of concrete as well we can save the environment. Also, the construction industry is growing the consumption of river sand is increasing the use of rubber in concrete as the replacement of sand will help to tackle this problem.

1.3 Objective of the study

Many researches are carried out on the concept of using crumb rubber in concrete and the treatment of rubber but there is still gap of treatment of rubber with waste quarry dust. The main aim of this research is to extend the area of rubber in construction industry and save the environment from the effect of wasted rubber. The main drawback of using rubber is strength reduction which can be overcome using another waste material waste quarry dust which itself effect the environment badly. The Followings are the major points of the research.

To study the post peak behavior of high strength rubberized concrete

To compare the failure mode of Rubberized and Unrubberized Concrete.

1.4 Scope of the study

The scope of this study covers the post peak behavior of high strength rubberized concrete treated with waste quarry dust and to compare the failure mods of rubberized and unrubberized concrete. The stress strain curve will be observed of different sample contain (5 10 15 and 20) percentage of treated and untreated rubber after 28 days of curing. Sample size of cylinders are (diameter, 100xlong, 200) mm.

1.5 Significance of the study

As the construction industry is growing the demand of the sand also increasing, rivers are main source of sand and due to continuous extraction of sand from river it is causing the degradation of environment and the plants and animals. The scope of this study is to focus the construction industry on alternative material of sand and to use the wasted and bio product without compromising the quality of concrete. Quarry dust is also a waste material and available free of cost so it can reduce the concrete cost and ensure the quality of concrete. So, the replacement of sand with rubber using waste quarry dust for the treatment of rubber can be predicated positive and hence quality of rubberized concrete will be improved.

1.6 Relevance to the national needs

Tire production in Pakistan is increasing day after day. If we are interesting to prosper our construction industry, we must go beyond the conventical limit so the addition of rubber in concrete can be right option. Wasted tire is usually use for combustion to produce heat this phenomenon can be risky for environment as well as for the labor working in the site of combustion. Country like Pakistan having less resources to control the environmental factor this type of small step can help to control the climate change, similarly waste quarry dust is also considering a useless material and difficult task to dispose of so the application of waste quarry dust for the treatment of rubber can improve the properties of rubberized concrete.

1.7 Methodology

The experimental work is done on the basics of previous result. The mix design is done using the properties of concrete material like sand, rubber, Waste Quarry dust, crush and cement. The effect of these on the concrete properties like compressive strength, tensile strength, modulus of elasticity and other and refined earlier as separate substitution of sand and crush. After analyzing the data predicted model is designed so that we can obtain optimum values and then experimental work is started. Hypothetical outlines of research work is done as following: -

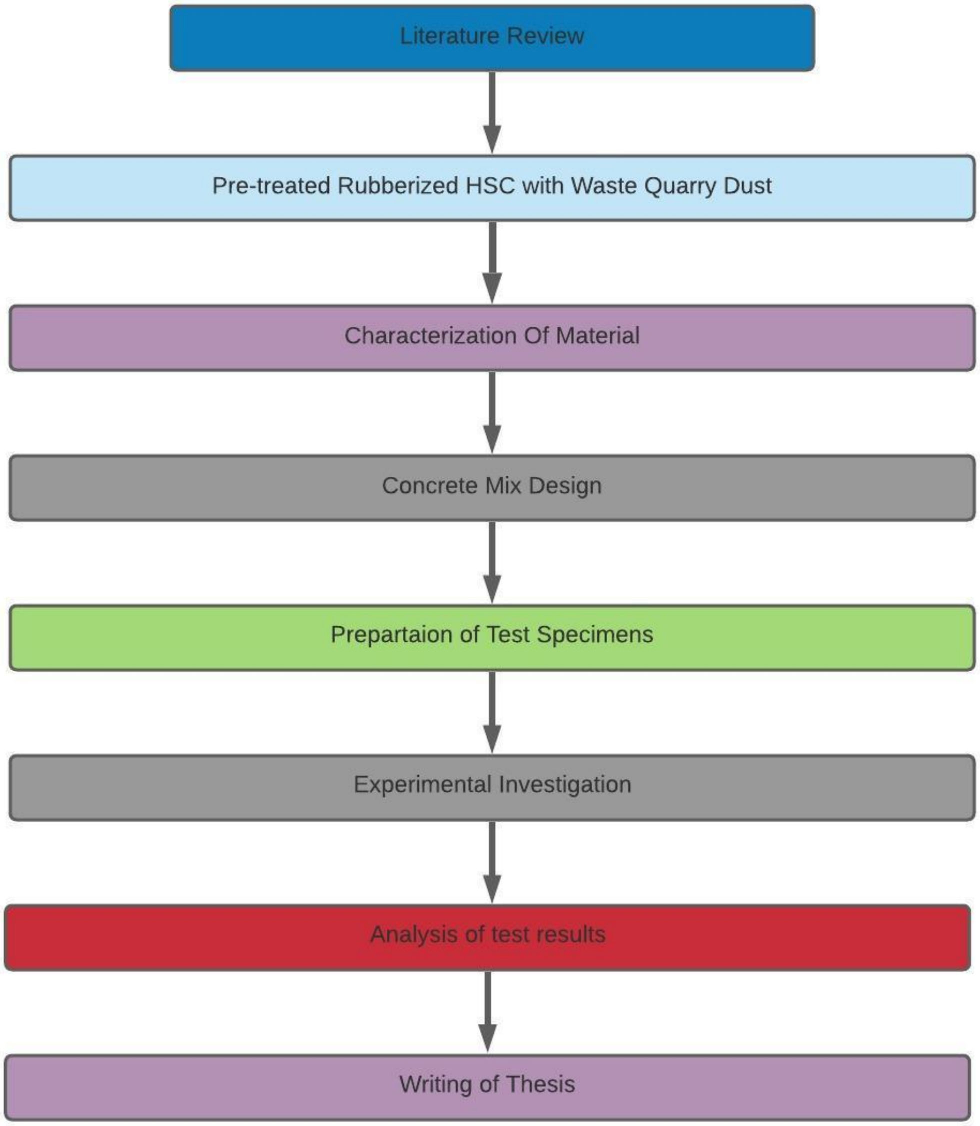

Figure 1-1:Research methodology

1.8 Organization and thesis layout

This thesis gives us comprehensive information regarding to the use of waste tyre rubber in concrete treated with waste quarry dust. This contains the properties of concrete adding with rubber treated and untreated and their effect on the cement paste and concrete properties. The procedure of mixing, testing, analyzing the result and the conclusion obtained from research. The research thesis is divided in following chapters.

Chapter 1 contains the brief introduction of concrete the discussion about the treatment of rubber, significance of the research, the effect of research on the country, research methodology and the workflow of research work.

Chapter 2 contains the literature review which contains the mechanical properties of rubberized concrete of previous result. The problem created by using the rubber and the positive affect of rubber in concrete and the research gap is also mentioned in this chapter.

Chapter 3 contains the research methodology which involves the different material used in concrete their properties and their effect on the properties of concrete. The research also contains the testing methodology. Finally, the specification of different mix designs and selection of final design which is required.

Chapter 4 is dedicated to explain the results. First, select the ranges of different variable. The water cement ratio, rubber specification and the superplasticizer is investigated. After checking the result, the treatment method is applied. The results are prepared from the data of testing using excel sheets.

Chapter 5 is based on the recommendation and conclusion of research. The effect of treatment on the rubber particles. Some recommendation is also given for future studied to be carried out.

Chapter 2: Literature Review

2.1 General

The increased interest in employing High Strength Concrete (HSC) because of its greater durability, strength and deflection control, researchers are looking into ways to improve its brittle behavior. Natural building resources are becoming increasingly limited, and the necessity to utilize waste materials to decrease environmental effect is a global trend in the built environment. Developed countries investigate material recycling to fulfil various economic and environmental goals. The recycling of used tires, for example, has gotten a lot of attention. Tires dumped on the ground as stockpiles provide a harm to the environment and human health (Siddique and Naik 2004). To address this issue, numerous researches including the incorporation of discarded tires in the form of rubber particles into concrete have been done. The inclusion of appropriate ingredients to change the properties of concrete is a popular subject of concrete research. The brittle nature of concrete, as well as its poor loading toughness when compared to other materials, has led to the usage of scrap tyre particles as a replacement of aggregate to potentially mitigate or lessen these drawbacks. Concrete properties could be improved by using elastic and deformable tire–rubber particles. The usage of wasted tyre rubber particles as substitutes for virgin aggregates can reduce natural aggregate consumption while also reducing the detrimental environmental effects of solid waste disposal. The utilization of wasted tyre rubber in concrete is covered in detail in this chapter.

2.1.1 Rubberized concrete

Rubberized concrete is a type of concrete that contains rubber particles as a partially or completely replacement for aggregates. Rubber's use in construction material can be traced back to the late 1990s (Heitzman 1992). However, the idea of incorporating tyre rubber into asphalt cement was originally proposed in the 1950s, and it was initially used in asphalt concrete in the 1840s as natural rubber (Heitzman 1992). Although recycled tyre rubbers have gained popularity in asphalt paving, the opportunity for their usage in cement cementitious materials was not explored until 1993 (Senouci and Eldin 1993). Though recycling tyre rubbers have gained steam in asphalt paving, the possibility of using them in cementitious materials was not been investigated till 1993 (Khatib and Bayomy 1999). However, over the last 20 years, experts have looked into the possibility of employing recycled rubber particles as concrete aggregates compositions.

Rubberized concrete is currently widely used in a variety of non-structural and structural applications (Topçu and Unverdi 2018). This study focuses primarily on the usage of recycled aggregate in concrete, and the parts that follow provide in-depth explanations of this topic.

2.1.2 Rubber aggregates

Rubber particles collected from ELT recycling are filtered and used as rubber aggregates in concrete, Figure 2.1. As mentioned in ASTM D5603 standard (ASTM International 2015b) On the basis of two key criteria – particle size distribution and the type of material of the original rubber from which the recycled vulcanized particulate rubber was generated – recycled vulcanized particulate rubber particles can be divided into numerous grades. Rubber particles of 425 m and larger, regardless of polymer composition or processing method, Coarse rubber powders are used to designate sizes. Rubber granules finer than 425 m, on the other hand, Fine rubber particles have a size of 75-300 m and are classified as such. Furthermore, recycled rubber can be classified into six categories based on the parent rubber's polymer or compound type. The most typical grades are grade 1, grade 2, and grade 3, which are made by recycling the entire tyre, only tread tyre, and only tyre retread buffing tyre, respectively, from passenger vehicle, bus, and truck tires (ASTM International 2015b) .

Figure 2-1: Crumb Rubber (CR)

Moreover, ELT regenerated rubber can be processed into four kinds of particles: rubber chips ,shredded rubber, ground rubber and crumb rubber (CR) (Eldin, Senouci et al. 1993, Li, Mills et al. 2016). rubber chips and shredded rubber are used in concrete as a substitute for natural coarse aggregates (NCA) and are typically sized from 10 to 25 mm (Topçu and Unverdi 2018). On the other hand, selected shredded rubber aggregates with particle sizes ranging from 13 mm to 76 mm. Ground and crumb rubbers, on the other hand, are smaller than natural fine aggregates (NFA) in concrete, measuring 0.50-4.75 mm and 0.50- 1.50 mm, respectively (Li, Mills et al. 2016). Tire Obtained aggregates (TOA) are made from scrap tires that have been mechanically processed. Cryogenic grinding, ambient grinding, devulcanization, and surface treatment are all common mechanical processing procedures. Furthermore, the main thermal conversion techniques to Pyrolysis and microwave processes are two methods for recycling scrap tires, however they are not widely used in Canada. Due to the greater investment and provision costs for facilitating liquid nitrogen necessary for cryogenic grinding, mechanical milling at ambient temperature is perhaps the most often employed procedure in industry. Cryogenic facilities, on the other hand, may generate a bigger quantity of fine crumb rubber at a higher market price (Pehlken and Essadiqi 2005). A magnetic field is used in both procedures to separate the steel wires in the tires, and the rubber particles are then extracted from the metal mesh using vibrating sieves. Furthermore, three methods for extracting CR from scrap tires are used: granular, cracker mill and micro-mill techniques (Topçu and Unverdi 2018). In this work, only Crumb rubber was used as a Fine aggregate substitute in the rubberized concrete experimental examination.

2.1.3 Why in concrete

Aside from reducing solid waste disposal to landfills, another key advantage of using rubber particles in concrete is that they are contained as replacement of aggregates in concrete mixture, preventing environmental damage due to leaching (Meherier 2016). Studies have found harmful leachate in landfills containing zinc, barium, calcium, aluminums, mercury, lead, iron, and cadmium, among other elements.(Norquay 2004). Rubber is a novel and environmentally favorable sustainable solution of energy and material recovery when compared to conventional concrete (Nehdi, Khan et al. 2001, Siddique and Naik 2004). Rubberized concrete, on the other hand, can suffer severe losses in compressive, flexural, and splitting tensile strength, limiting its usage to non-structural usage in most circumstances (Nehdi, Khan et al. 2001, El-Gammal, Abdel-Gawad et al. 2010).

When ELTs are dumped in landfills after their serviceability life has expired, they constitute a major environmental danger because they are non-biodegradable and combustible. According to WBCSD's (Development 2018) most current study a total of 26 million tons of ELTs are produced each year in 51 nations, accounting for 89 percent of all cars on the planet. Every year, 69 percent of the 26 million tons of ELTs produced are collected as tire-derived fuel (TDF), tire-derived materials (TDM) and reclaim rubber for civil engineering and backfilling, totaling 17 million tons of ELTs. The other 31% of ELTs are now being disposed in landfills or stockpiled in various locations throughout the world. The United States of America (US) is one of the world's (Development 2018) leading tyre producers, with a moderate-to-high market share in the US tyre manufacturing business, accounting for 65 percent of yearly industry sales in 2018. According to research issued in July 2018 by the Rubber Manufacturing Association (RMA) in the United States, 249 million net trash tires weighing 4189 thousand tons were generated in the United States alone in 2017. A total of 687 thousand tons of scrap tires were dumped in landfills, accounting for around 16% of the total production. Another 81.4 percent of the overall generated scrap tires was used in the market as TDF, shredded rubber, civil engineering disciplines, and other value-added goods. When compared to 2015, the total volume of land dumped scrap tires increased by 43% in 2017 (US Tire Manufacturers Association %J USTMA 2018). However, by 2017, over 94 percent of the one billion tires that were accumulated in landfills in the United States in 1990 had been cleaned up. As a result, in contrast to the 40 million waste tires disposed of in 2017, another 60 million tires are stacked in landfills (US Tire Manufacturers Association %J USTMA 2018). This suggests that after their useful life were through, all the ELTs were used as a value-added product. Furthermore, in 2017, British Columbia (BC) gathered 50 thousand tons of scrap tires from stockpiles and landfills (Sutton 2016). Furthermore, around 355 million tires are produced in Europe each year, accounting for 24 percent of global tyre manufacturing (Lo and Materials 2013). As per the European Tyre and Rubber Manufacturers' Association (ETRMA), the 31 nations analyzed in 2013 created around 3.6 million tons of old tires, including the EU28, Norway, Switzerland, and Turkey. According to ETRMA, about 96 percent of these ELTs, totaling 2.7 million tons, were recovered, and repurposed in 2013. In contrast to the millions of tires that were previously illegally hoarded, the remaining tires are being thrown in landfills (Rashad 2016). Furthermore, every year, around 63 percent of the 850 metric tons of scrap tires in Russia are disposed of in landfills. Starting in 2019, the Russian Federation will restrict the landfilling of scrap tires in order to encourage the recycling of this massive waste into useful end products (Longvinenko 2018). Notably, the Canadian government has classified waste tires as municipal solid trash, which must be disposed of in accordance with provincial and municipal standards. space and can serve as a breeding ground for harmful insects and rodents. For example, the rapid spread of the lethal West Nile virus across North America has been linked to tyre piles as a high potential mosquito breeding site, as tires can hold a lot of stagnant water (Pehlken and Essadiqi 2005). Furthermore, the disposal of scrap tires in landfill space poses a significant risk of massive fires. For example, in 1990, a fire broke out in a tyre dump in Hagersville, Ontario, burning 10 million tires in 17 days, and the shredded tyre was accidentally ignited. The drainage layer in Iowa City's landfill is manifested by the burning of approximately 1.3 million tires in 18 days, the seriousness of the fire hazards (BARPI. 2007). In such a situation, recycling scrap tires into valuable products can be extremely beneficial to both the economy and the environment. Overall, the use of CR as a partial replacement of fine aggregate in concrete provides an environmentally friendly and effective solution including both natural aggregate demand and environmental hazards.

2.2 The effects of CR in concrete

According to studies, the use of CR in concrete significantly reduces its compressive strength. Furthermore, the flexural strength of crumb rubber concrete (CRC) is lower(Senouci and Eldin 1993) and tensile strength (Batayneh, Marie et al. 2008, Corredor-Bedoya, Zoppi et al. 2017) when compared to traditional concrete. However, its greater toughness and impact resistance than conventional concrete relate to its suitability for a variety of structural and non-structural applications (Kaloush, Way et al. 2005, Gerges, Issa et al. 2018). At this point, various measures can be taken to enhance the strength of rubberized concrete. Rubber pre-treatment, the use of silica fume, steel fiber, and chemical 16 admixtures, optimized rubber content, and a very well distribution of rubber size of particles are among them (Li, Mills et al. 2016). The sub-sections that follow provide a detailed discussion of the impacts of rubber on the mechanical properties of concrete.

2.2.1 Compressive strength

The majority of researchers discovered that rubberized concrete has a lower compressive strength than the corresponding control mixture. Eldin and Senouci (1993a), the pioneers of rubberized concrete research, used two types of coarse rubber chips – Edgar chips sized 38, 25, and 19-mm and Preston rubber particles of 6-mm sizes replacing NCA and also CR of 1-mm maximum size as a fine aggregate replacement (Eldin, Senouci et al. 1993). They investigated four levels of volumetric replacement for coarse and fine rubber particles – 25, 50, 75, and 100 percent – and found a reduction in compressive strength of up to 85 percent and 65 percent for the two types of rubber, respectively. As a result, the compressive reduction in compressive strength for CR was lower than for coarse rubber chips. Until now, subsequent studies have produced similar results in terms of compressive strength reduction. The compressive strength of concrete mixtures containing chipped rubber (5 to 20 mm) and Crumb Rubber (sized from 1 to 5 mm) was investigated at volumetric replacement levels of 25, 50, 75, and 100% of NCA and NFA, respectively.For the four replacement levels – 25, 50, 75, and 100 percent – they discovered a strength reduction of 40, 48, 73, and 78 percent for NCA replacement by chipped rubber and 15, 25, 50, and 67 percent for NFA replacement by CR compared to the control mixture. When coarser rubber particles were used in concrete mixtures, they resulted in a greater reduction in strength than crumbed rubber particles (Reda Taha, El-Dieb et al. 2008). Once again, in a recent experimental study conducted by (Stallings, Durham et al. 2019) NCA was replaced by tyre chips with a maximum size of 19 mm on the properties of rubberized concrete, and NFA was replaced by CR (maximum size of 2.38 mm) volumetrically up to 50 and 40 percent, respectively, with a ten percent increase for each. Compressive strength was reduced by up to 31% when CR was replaced, but it was reduced by up to 86% when tyre chips were replaced. Thus, concrete mixtures containing CR had a 24–30% increase in compressive strength when compared to mixtures containing tyre chips. Overall, they reported an optimum replacement level of up to 40% FA by CR and up to 10% NCA by tyre chips to achieve the 20.7 MPa compressive strength target for Georgia Department of Transportation (GDOT) Class A concrete for barriers (Stallings, Durham et al. 2019). However, Khaloo, Dehestani, and Rahmatabadi (2008) discovered that concrete containing coarser rubber particles (maximum size of 20 mm) had a slightly higher compressive strength than mixtures containing finer rubber particles (maximum size of 4.75 mm) up to a volumetric replacement of 25% of the mineral aggregates.

Nonetheless, the strength change trend was reversed for higher replacement levels (Khaloo, Dehestani et al. 2008). The higher strength loss when using coarser rubber particles is associated with the high porosity of the concrete mixture, supposing that rubber elements act as porous structure inside the concrete. As a result, when Stress concentration happens in these pores as a result of external loadings, starting to affect the strength of the concrete unfavourably combine. As a result, the greater the size of the rubber aggregate, the greater the stress concentration.The greater the porosity, the lower the compressive strength of the mixture (Longvinenko 2018). According to Gerges et al. (2018), the slight drop in compressive strength of concrete mixture caused by the addition of rubber powder with particle size less than 1 mm was up to 63 percent for a maximum FA replacement level of 20 percent. As a result, the optimum level of FA replacement by rubber powders discovered was 10% with a strength properties of 35 MPa for the rubberized concrete (Gerges, Issa et al. 2018). Several studies have suggested that a maximum replacement level of 25% FA 18 by CR is needed to monitor a desired concrete strength of more than 30 MPa (Valadares, Bravo et al. 2012). However, when the percentage of rubber in the mixture exceeds 20%, the compressive strength of the mixture begins to decline significantly. As a result, for structural applications of rubberized concrete containing fine rubber particles (5 mm), a maximum rubber replacement level of 20% is recommended (Li, Mills et al. 2016). The reduction in compressive strength resulting from the addition of rubber particles in concrete can be likened to the weaker adhesion between the rubber and cementitious matrix, which has a negative impact on the mechanical and exchange properties of rubberized cementitious composites (Reda Taha, El-Dieb et al. 2008, Stallings, Durham et al. 2019). Another significant element is the significant difference between rubber and concrete in Young's modulus of elasticity and Poisson's ratio. To clarify, the modulus of elasticity of concrete is nearly three times that of rubber, whereas the Poisson's ratio is half that of rubber (Eldin, Senouci et al. 1993, Reda Taha, El-Dieb et al. 2008). When subjected to external loading, this causes higher relative deformations between the two, resulting in subsequent early cracking. Topçu (1995) also stated that the rubber particles cause high internal tensile stress due to their lower modulus of elasticity perpendicular to the direction of applied compression load, resulting in initial failure in the cement mortar. Furthermore, the rubber particles are assumed to act as voids, causing initial cracking and crack propagation and thus lowering the corresponding compressive stress (Senouci and Eldin 1993, Gerges, Issa et al. 2018).

Furthermore, because of the poorer interaction between the boundaries of the rubber particles and the surrounding cement matrix, rubber particles have a lower permeability, resulting in a weaker interfacial transition zone (Youssf, ElGawady et al. 2017).

2.2.2 Pre-treatment of CR

Main methods used to improve the strength of rubberized concrete have been surface pre-treatment of the rubber and the use of additives such as silica fume and fibre (Li, Mills et al. 2016). Rubber surface treatment involves the application of natural (water) or chemical agents to modify the surface, resulting in a rougher and improved surface for improved bonding with the surrounding cement paste. Several pre-treatment methods, such as washing with water, have been reported in the literature (Senouci and Eldin 1993). Yang (2013) used partial oxidation of CR to convert the hydrophobic surface of rubber into a hydrophilic surface and patented their method after achieving significantly enhanced mechanical properties of rubberized concrete. Another study conducted by Y. Li, Wang, and Li (2010) used a total of eight interfacial modifiers to pre-treat the rubber particles before using them in the concrete mixture. The modifiers are as follows: three types of silane coupling agent (SCA), styrene-acrylate emulsion (SAE), three types of silicone modified styrene-acrylate emulsion (SMSAE), and re-dispersible polymer powder (RPP). Among all chemical methods of treatment, surface treatment with a NaOH solution was found to be the most effective in improving the hydrophilicity of the rubber surface. Furthermore, it is less expensive and more convenient (Su, Yang et al. 2015, Mohammadi, Khabbaz et al. 2016). Segre and Joekes (2000) used a sodium hydroxide (NaOH) solution to treat the crumb rubber for surface treatment, and they discovered that this enhanced the bond strength between the rubber and cement paste, resulting in increased strength and toughness. Other researchers have used a NaOH solution to treat a rubber surface and found similar results (Chou, Lu et al. 2007). For example, Chou et al. (2007) discovered an increase of 12, 3, and 2.6 percent in the compressive, tensile and flexural strength of NaOH treated rubberized concrete when compared to that of untreated rubberized concrete. (León-Martínez, Cano-Barrita et al. 2014) presented a comprehensive study on the pre-treatment of rubber with NaOH, which found increases in compressive strength of concrete by 6% and 15% at 7 and 28 days, respectively, due to increased adhesion between the rubber and the surrounding cement paste. These findings were supported by the following study by (Youssf, Mills et al. 2016), who discovered a 15.3 percent and 17.2 percent increase in compressive strength at 7 and 28 days, respectively, when compared to the nontreated rubberized concrete mixture.

(Mohammadi, Khabbaz et al. 2016) obtained comparable results for a 24 hour NaOH treated method with a 25% and 5% improved performance in average for mixtures containing 20% and 30% CR in flexural and compressive strength, respectively. Su, Yang, Ling, Ghataora, and Dirar (2015), on the other hand, used both a saturated NaOH solution and a Silane Coupling Agent (SCA) to change the surface of the rubber particles and discovered that SCA had a better effect on compressive strength enhancement than NaOH pre-treatment. Furthermore, few studies have found insignificant improvements in CRC strength after NaOH and Silane treatment of rubber (Marques, Akasaki et al. 2008, Mohammadi, Khabbaz et al. 2016).

2.2.3 Flexure strength

Most studies conducted to date have reported a decrease in the tensile strength of specimens contains rbberized concrete (Eldin, Senouci et al. 1993, Topcu and research 1995, Gerges, Issa et al. 2018). Strength reductions of up to 50% were obtained for coarse and crumb rubber sustainable levels of up to 100% by (Eldin, Senouci et al. 1993). Similarly,(Topcu and research 1995) reported a maximum reduction of 48 percent and 62 percent for CR and coarse tyre rubber, respectively, for a 45 percent replacement level. Thus, as with compressive strength reduction, tensile strength reduction is greater for coarser rubber particles in the rubberized concrete mixture than for CR. Furthermore, due to their high plastic energy absorption capacity, the specimens did not experience brittle fracture even after significant cracking under loading (Eldin, Senouci et al. 1993, Topcu and research 1995). Another study conducted splitting tensile strength on concrete samples containing up to 100 percent CR and mentioned a maximum strength reduction of 92 percent. However, when the replacement level was 20% by volume of the FA, the strength reduction was only 35%(Batayneh, Marie et al. 2008). Rubberized concrete had a similar reduction in splitting tensile test by 31% and 55% for 10% and 20% CR replacement levels, respectively, when compared to its non-rubberized counterpart. Rubberized concrete had a similar reduction in splitting tensile test by 31% and 55% for 10% and 20% CR replacement levels, respectively, when compared to its non-rubberized counterpart (Gerges, Issa et al. 2018). Furthermore, the failure of the cylindrical specimens under tensile loading was observed 24 to be more cohesive because it retained its shape without completely splitting into halves, in contrast to the control specimens (Gerges, Issa et al. 2018). Overall, it appears that the rate of strength drop for splitting tensile strength is comparable to compressive strength (Batayneh, Marie et al. 2008).

Increased porosity and a commensurate loss in solid load-carrying material cause stress concentrations around rubber particles in rubberized concrete, resulting in a drop in strength (Senouci and Eldin 1993).

2.2.4 Impact strength

Rubberized concrete's improved performance under impact loading is one of its most notable features. Rubberized concrete performs better under impact loading due to the lower stiffness and enhanced energy absorption capacity of rubber particles. Several studies have been conducted.Rubber particles were added to the concrete mix, which resulted in a significant increase in impact energy (Topcu and research 1997, Nehdi, Khan et al. 2001, Reda Taha, El-Dieb et al. 2008). To explain (Reda Taha, El-Dieb et al. 2008) examined the effect of introducing chipped and crumbed tyre rubber particles into concrete at four different replacement rate (25, 50, 75, and 100 percent) by volume of NCA and NFA, respectively. The impact energy of the specimens improved significantly as the amount of rubber in the concrete was increased. For both chipped and crumbed tyre particles, however, it began to decline after reaching a replacement level of 50%. Furthermore, Taha et al. (2008) discovered that rubberized concrete containing 25% chipped tyres has a higher fracture energy than conventional concrete. Considering the joint impact of compressive 25 strength and flexure toughness, they determined that the optimum tyre rubber replacement level is 25-50 percent. In a similar study, (Atahan, Yücel et al. 2012) discovered that as the level of rubber replacement in concrete increased, the load carrying capacity and energy dissipated at the maximum load decreased and increased, respectively. To be specific, between the control sample and the 100 percent rubber replacement specimens, there was a 71.6 percent decrease in maximum load and a 160.8 percent increase in energy dissipated at maximum load, respectively. To summarise, the optimum replacement level for preserving preferred concrete strength with outstanding energy absorption capacity was discovered to be 20-40%. When used in non-structural high-impact zone applications such as highway barriers, up to 60% of the original material can be replaced (Atahan, Yücel et al. 2012). Furthermore, Al-Tayeb et al., (2013) discovered that sand replacement by CR increased fracture energy by 194 percent and 268 percent at 10 percent and 20 percent, respectively. Several studies have found a similar trend of increasing impact strength with increasing rubber content in rubberized concrete (Gupta, Tiwari et al. 2017).

Impact resistance of rubberized concrete with coarser rubber particles was found to be significantly higher than CR, in contrary to the compressive strength trend (Topcu and research 1997, Reda Taha, El-Dieb et al. 2008, Gerges, Issa et al. 2018). Insignificant particle bridging of tiny rubber aggregates limits crack propagation in concrete, resulting in higher energy absorption under contact with chipped tyre particles (Gerges, Issa et al. 2018).

2.2.5 Shrinkage

Shrinkage is described as the contraction that occurs as a result of the removal of gel water owing to evaporation or cement hydration (Neville and Brooks 1987). Rubberized concrete shrinkage is more than regular concrete shrinkage. The shrinkage of rubberised concrete increases as the quantity of rubber particles increases, according to Bravo and de Brito (2012). When coarse aggregate was changed with chipped rubber, the fluctuation was reduced. The reduction in size in the beginning, the contrast between standard concrete and rubberized concrete was more pronounced.15 days after casting, and by the end of 90 days, it had diminished (Bravo and de Brito 2012). The shrinkage of rubberized concrete is dependent on the size of the rubber utilised as well as the rubber content, according to (Sukontasukkul, 2012). The concrete specimens containing ground rubber (passing the 26 sieve) shrank more than those containing crumb rubber (passing 6 sieve). This could be owing to the rubber particle' flaky particle size, which allows them to function like a spring.The combined effect of lowering the water–cement ratio and introducing silica fume to a high-strength concrete mix cut 28-day shrinkage in half. Reduce the water–cement ratio and add mineral admixtures to improve the behaviour of rubberized concrete against shrinkage (Sukontasukkul, Tiamlom et al. 2012).

2.2.6 Impact resistance

Many structural applications, such as machinery foundation pads, airport runways 29, bridge decks, and highway pavement, demand high-impact resistance and better energy absorption capacity. Due to their decreased rigidity, adding rubber particles to concrete can help improve impact resistance and energy absorption. Various studies have looked at the energy absorption potential of rubberized concrete based on impact resistance tests (Liu, Chen et al. 2012, Al-Tayeb, Bakar et al. 2013, Dong, Huang et al. 2013). The findings showed that adding rubber particles to concrete increased energy absorption when compared to plain concrete.

It was also discovered that when the amount of rubber in concrete increases, the average amount of energy wasted increases. Furthermore, rubberised concrete has a higher energy absorption capacity than traditional concrete. Between regular concrete and 100 percent rubber replacement samples, the length of impact increased by more than 6 times (Atahan, Yücel et al. 2012). This is possibly due to the fact that rubber has a far lower rigidity than concrete. As a result, replacing natural aggregate with rubber particles makes concrete more ductile. Ozbay et al. (2011) discovered that the higher the amount of rubber aggregate, the better the rubberised concrete's energy absorption capabilities.

Rubberised concrete, based on these findings, offers a significant potential to be applied such as safety barriers, as it results in smaller deceleration forces and hence less damage (Atahan, Yücel et al. 2012). One advantage of employing this recycled material is that it improves energy absorption by using rubber aggregate.

2.2.7 Thermal conductivity

Under steady-state conditions, thermal conductivity is defined as the amount of heat transported through a unit thickness in a direction normal to a surface of unit area due to a unit temperature 30 gradient (Mohammed, Hossain et al. 2012). The thermal conductivity of crumb rubber hollow concrete blocks was examined. Their findings revealed that when rubber content increases, heat conductivity falls (Sukontasukkul, Tiamlom et al. 2012). According to one study, the heat conductivity of rubberized concrete is 20–50% lower than that of regular concrete, although another study claims the figure is closer to 60% (Yesilata, Isıker et al. 2009). This variation is largely determined by the content and size of the rubber replacement (Mohammed, Hossain et al. 2012). It was also reported that when silica fume and fly ash are used to substitute cement in rubberised concrete, the thermal conductivity is reduced. This could be because silica fume and fly ash have poorer heat conductivity than cement (Sukontasukkul and Materials 2009). The thermal conductivity of a substance is inversely proportional to its density, therefore adding rubber particles improves the thermal conductivity of a concrete mixture significantly.

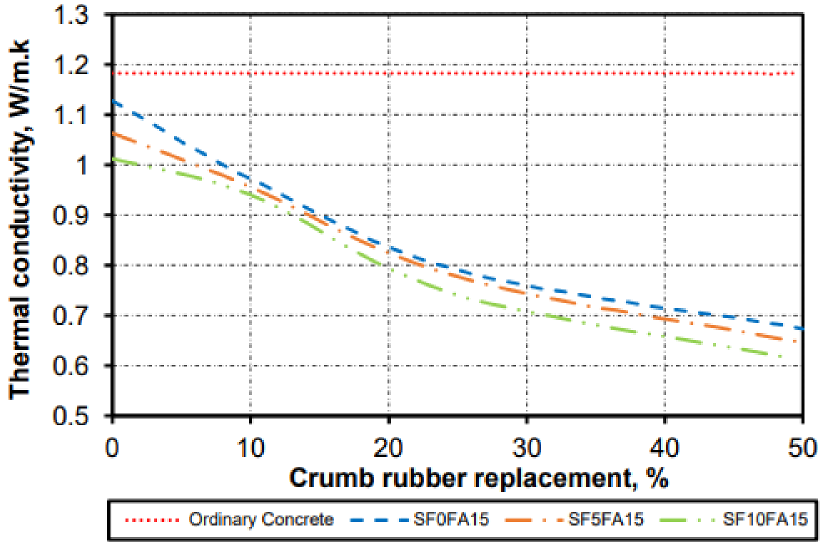

Figure 2-2:Effect of CR replacement on thermal conductivity(Mohammed, Hossain et al. 2012)

2.2.8 Sound absorption

The incident sound that strikes a medium and is not reflected back is characterised as sound absorption. In comparison to traditional concrete, rubberised concrete offers better sound absorption qualities. As the amount of rubber used increases, the sound absorption coefficient rises. The amount of air trapped on the rubber surface increases as the amount of rubber aggregate increases, resulting in a higher porosity (P) of rubber concrete. As a result of the lower reflection from the pores, sound energy is absorbed more readily (Khaloo, Dehestani et al. 2008). Because of its microfilling powers, silica fume affects the sound absorption qualities of rubberized concrete (Mohammed, Hossain et al. 2012). Rubberized concrete's sound absorption qualities were investigated experimentally. They claimed that in low, normal, and high temperature conditions, crumb rubber concrete was considered to be more efficient than plain concrete at absorbing sound. Crumb rubber 2–6 mm and 10–19 mm, which were utilised to replace fine aggregates by 15%, had higher absorption coefficients. Because of the larger surface area involved, crumb rubber concrete performed better as an absorber for high frequency sounds (Holmes, Browne et al. 2014). It should be emphasised that rubberized concrete is a good sound and vibration absorber.

A porous composition for rubberised concrete is demonstrated by a substantial fall in ultrasonic modulus with increasing rubber content (Pacheco-Torgal, Ding et al. 2012), The RuC absorption coefficient ranges from 0.013 to 0.2, compared to 0.018 in plain concrete, which is consistent with earlier research in this area (Fedroff, Ahmad et al. 1996). The level of absorption was higher in concretes with bigger volumes and larger rubber grades, according to the findings. For example, replacing 7.5 percent of fine aggregate with dust resulted in a 32 absorption co-efficient of 0.013, compared to 0.018 in the control. The converse is true when particle size and volume grow, as the greater surface area and heavier graded rubber is capable of absorbing more sound. For example, between the 7.5 percent and 15 percent replacement levels for dust, 1–3 mm, 2–6 mm, and 10–19 mm crumb rubber particles, the absorption coefficient increased by 623 percent, 107 percent, 33 percent, and 21 percent, respectively. This enhanced absorption reveals that RuC acoustic absorbance capabilities are affected by both rubber volume and grading. It was also discovered that the control sample had similar sound insulation capabilities, notably at 63 and 125 Hz, where the volume of sound preserved was roughly 15 and 11 dB, respectively. Higher frequencies (250 and 500 Hz), control sample appears to be a little stronger insulator than the RuC, with a 3–4 dB improvement overall due to the longer wavelengths allowing it to penetrate a broader surface area. For example, between the 7.5 percent and 15 percent replacement levels for dust, 1–3 mm, 2–6 mm, and 10–19 mm crumb rubber particles, the absorption coefficient increased by 623 percent, 107 percent, 33 percent, and 21 percent, respectively. This enhanced absorption reveals that RuC acoustic absorbance capabilities are affected by both rubber volume and grading (Holmes, Browne et al. 2014). According to previous study (Khaloo et al., 2008b, Sukontasukkul, 2009), higher density materials offer better insulating capabilities than lower density materials for all RCs. Furthermore, small cracking on the surface of the largest rubber grade (10–19 mm) resulted in a minor reduction in the insulating effectiveness of RuC at elevated temperatures. No previous studies have looked into the acoustic qualities of rubberized concrete with nano silica. As a result, the acoustic properties of rubberised concrete with nano silica added will be compared to NC and RuC as part of this research.between the 7.5 percent and 15 percent replacement levels for dust, 1–3 mm, 2–6 mm, and 10–19 mm crumb rubber particles, and 21 percent between the 7.5 percent and 15 percent replacement levels for the dust, 1–3 mm, 2–6 mm, and 10–19 mm crumb rubber particles, respectively.

This enhanced absorption reveals that RuC acoustic absorbance capabilities are affected by both rubber volume and grading (Khaloo, Dehestani et al. 2008, Sukontasukkul and Materials 2009).

Chapter 3: Experimental Program

The goal of this research is to test the efficacy of employing recycled waste materials as aggregates in concrete at various replacement amounts. Wasted tyre crumb rubber as a partial replacement of fine aggregate is used as non-standard materials and another waste material waste quarry dust is also used for the treatment of rubber in the manufacturing of High Strength rubberized concrete using a 1:1.35:2.80 mix ratio. Individual properties and proportions of all standard and non-standard ingredients, such as cement, water requirements, coarse and fine aggregates, and so on, were first defined for the design mix of the concrete sample. The effect of each substitute material on the mechanical properties of concrete, such as compressive and tensile strengths, was then examined to determine their optimum percentages for the design mix. This chapter goes through the raw materials in depth, including their qualities as established by material testing.

3.1 Material testing and physical properties

3.1.1 Cement

Ordinary Portland Cement (OPC) Type I according to ASTM C150 was utilized in all specimens for the experimental purpose of investigation, and it was locally accessible brand "Askari Cement." The properties of the specified cement, as determined by ASTM C187-191, are as follows: -

Table 3-1: Cement properties

Ser. No	Properties	Values Obtained	Standard Range
1	Setting Time - Initial	47 minutes	$\geq 30\ minutes$
2	Setting Time - Final	287 minutes	$\leq 600\ minute$
3	Normal Consistency	32%	Vicat's Test
4	Specific Gravity	3.15	OPC : 3.10 – 3.16
5	Fineness	4.5%	<10%

3.1.2 Grading of aggregates

The distribution of aggregates according to the particle sizes present is known as grading. Fine and coarse aggregates sieve analysis are determined according to ASTM C136/ C136M. A representative aggregate sample would be shaken through a succession of sieves, with the largest openings sieve on top and the smallest openings sieve at the bottom, in sequence of size, with the largest openings sieve on top and the smallest openings sieve at the bottom of the sieves set(Greene and Burg 2016). These sieves, composed of wires and meshes, have square apertures. A closed pan at the bottom collects the material that passes through the smaller sieves above. In most cases, coarse and fine materials are sieved separately. The fraction of an aggregate that passed through the 4.75 mm (No. 4) sieve and was primarily retained on the 75 mm (No. 200) screen is known as fine aggregates or sand. Coarse aggregate refers to the portion of the aggregate that is greater than the above-mentioned criterion. Coarse aggregate comes in a variety of sizes, ranging from 37.5mm to 19 mm (1-1/2 to 3/4 in.). The simplified technique is listed in ASTM C33/C33M, Standard Specification for Concrete Aggregates, which provides numerous similar size categories.

3.1.3 Sand

Fine aggregates were employed in accordance with ASTM C136 – 04 for grading and ASTM C128 – 04 for water absorption and fine aggregate specific gravity calculation. Lawrencepur sand, which was readily available, was used for this purpose. Sand was graded by choosing material that passed a 4.75mm (No. 4) sieve and holding it for 150 meters (No.100). Physical inspection and sieve analysis revealed that the sand was of acceptable quality. All of the samples were made with the same sand.

3.1.3.1 Sand gradation

Fine aggregates were graded and determined to be consistent with and connected to the ASTM C33-04 standard. The sample size for sieve analysis was determined using modified ASTM C136, which indicates that the minimum sample size for nominal maximum size 3/4 inch (19mm) should be 300 grams. The sand utilized in this experiment had a fineness modulus of 2.3 and was medium coarse. The following is the outcome of the sieve analysis:

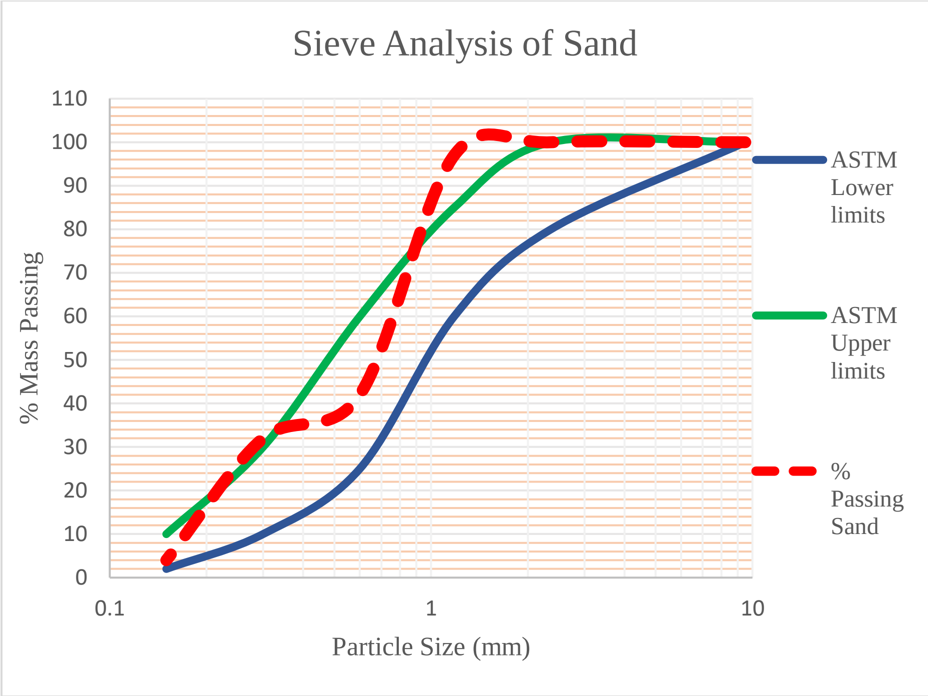

Figure 3-1:Gradation curve of Sand

3.1.3.2 Sand physical properties

Sand physical characteristics were measured according to ASTM C128 – 04 for water absorption and fine aggregate specific gravity calculation. The following are the results: -

Table 3-2: Sand properties

Ser. No	Physical Property	Value Obtained
1	Specific Gravity	2.60
2	Water Absorption	1.28

3.1.4 Gradation of crumb rubber

Sieve analysis of Crumb rubber obtained after shredding of wasted tire is done to obtain the gradation curve.

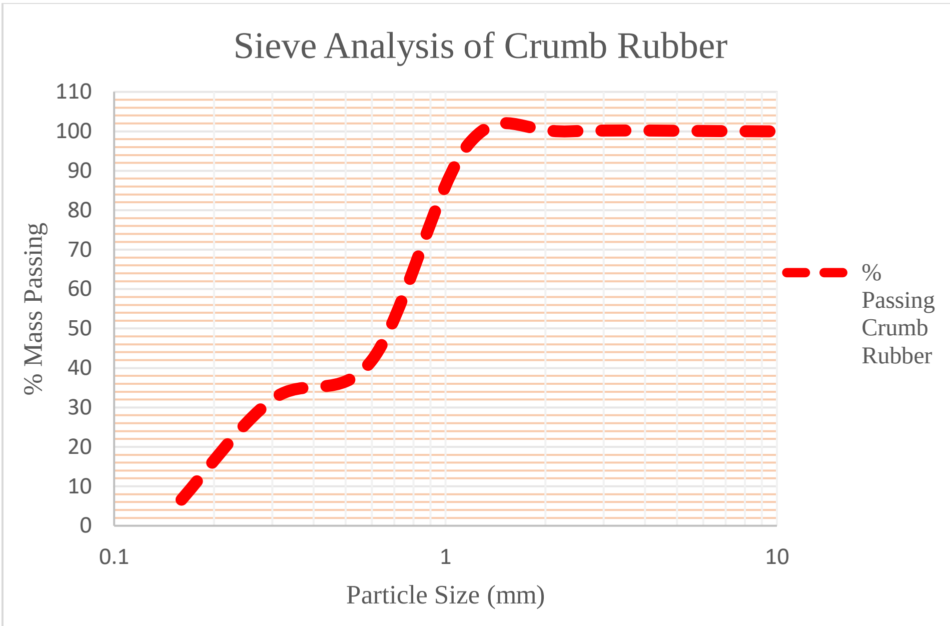

Figure 3-2:Gradation curve of crumb rubber

3.1.5 Physical properties of coarse aggregate

The experimental investigation used coarse aggregate from Khairabad crushed aggregate. In all of the specimens, coarse aggregate with a maximum size of 12.5 mm (1/2 in) was used. Sieve analysis was performed in accordance with ASTM C136 – 04. ASTM C 128-04 was used to estimate the specific gravity and percentage of water absorption.

Crushed stone from the khairabad Hills rock formations was used as the coarse aggregate. These rock formations are estimated to be 40 million years old and are rich in minerals with large traces of limestone. Before casting the specimens, standard techniques based on ASTM C-127 were used to determine the following aggregate parameters.

3.1.5.1 Aggregate crushing test

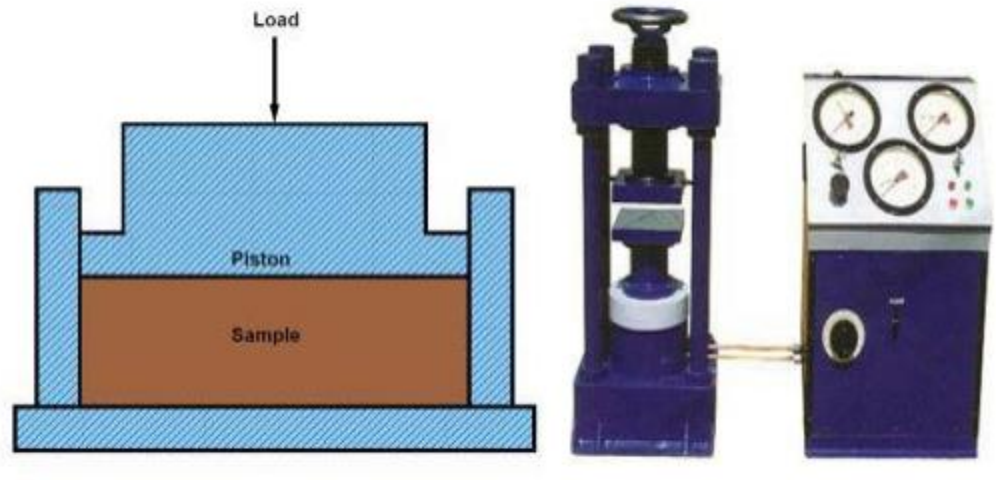

Figure 3-3: Aggregate crushing test(Magazine)

Crushing strength of aggregates is assessed by performing a crushing test to determine the load at which it collapses when compressive stress is applied. This figure represents the aggregates' relative resistance to crushing when a weight is applied gradually. In other words, it's the ability to withstand crushing under extreme conditions. The aggregates used in the test range in size from 10 to 12.5 mm. A mold with a diameter of 115mm and a depth of 180mm is included in the setup. The aggregates in the mold are subjected to a 40-tonne load that is imposed for 10 minutes. The material passing through a 2.36 mm sieve is used to determine the aggregate crushing value, which is represented as a percentage of total aggregate.

Aggregate crushing value = (B/A)*100 %

B = weight of fraction passing through 2.36 mm sieve = 485 grams

A = weight of surface dry sample taken in mold = 2875 grams

Crushing value = (485/2875) *100 = 16.86 %

3.1.5.2 Impact value

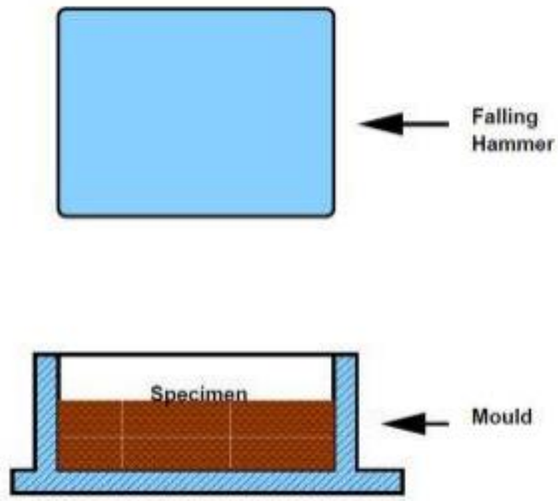

Figure 3-4: Aggregate impact value(Magazine)

The aggregate impact test is used to determine the aggregates' resilience to impact or abrupt loads. The aggregates utilized in the test should be 10-12.5 mm in size. This test is carried out in a mold that is 50 mm deep and 102 mm in diameter. The hammer used to provide the impact load to the aggregates weighs 13.5-14 kg and has a 380 mm drop. The aggregates receive a total of 15 blows. The material passing through a 2.36 mm sieve is expressed as a percentage of total aggregate to compute the impact value of the aggregates.

Aggregate Impact value = (B/A) *100 %

B = weight of fraction passing through 2.36 mm sieve = 23 grams

A = weight of surface dry sample taken in mold = 360 grams

Crushing value = (23/360) *100 = 6.38%

3.1.5.3 Water absorption and specific gravity test

Specific gravity and water absorption, two highly essential aggregate qualities, are used in the creation of concrete. For 24 hours, two kg of dry aggregates are submerged in water. The buoyant weight is obtained by finding the aggregate sample weight in water. The same aggregates are then baked for roughly 24 hours at a temperature of 100-110 C before being weighed.

By dividing the dry weight of aggregates by the weight of an equal amount of water at a certain temperature, the specific gravity is computed. The specific gravity of aggregates ranges from 2.6 to 2.9. The percentage of water absorbed in terms of oven dried weight of aggregates is known as water absorption. The water absorption value should be less than 0.6 percent of the aggregate weight.

Table 3-3: Aggregate properties

Ser.No	**Physical Properties**	**Obtained Value**
1	Specific Gravity	2.68
2	Water Absorption percentage	0.55%
3	Impact Value	6.38%
4	Crushing Value	16.86%

3.2 Treatment of crumb rubber

Stone dust, often known as quarry dust, is the byproduct of the crushing of rocks to produce coarse aggregate. Crushed stones of 1 inch (20mm), 3 4 inch (16mm), 1 2 inch (13mm), 1 4 inch (10mm) and chips are the most frequent crushed products obtained from a stone crushing facility (5mm). Smaller than 5mm (chips) are normally rejected as the most finely ground size and are not suitable for use as coarse material. As a result, these finer particles accumulate in piles outside stone crushing plants and are occasionally discharged into surrounding water drains, polluting the air and water. Surface coating of rubber particles with a paste made of WQD and water was used to pre-treat them. All of the rubber particles needed for the mix were weighed separately by gradation size and then combined in a big bucket. Following that, the pre-treatment paste was made by mass combining equal quantities powder (WQD) and water. In a small bucket, the dust and water were completely mixed, and the slurry-like liquid was poured over the rubber particles in the bigger bucket after it had reached homogeneity. The mixture was thoroughly coated the rubber particle surfaces after a few minutes of continuous stirring, before being scooped out and set on plastic sheathing to dry.

3.3 Silica fume and super plasticizer

Sika Pakistan private Ltd provided silica fume and super plasticizer. The purpose of silica fume is to offer strength, whereas the purpose of super-plasticizer is to keep workability. In high-strength concrete, the W/C ratio is usually low. The use of a superplasticizer in these concrete aids in mixing and placement.

3.4 Water utilized for making concrete specimen

Water in concrete has two key functions. The hydration of cement to bind the elements is first and foremost, and the workability of the concrete is second. ASTM C1602/C1602M Standard Requirement for Mixing Water Used in the Production of Hydraulic Cement Concrete (2018) specifies potable water free of harmful elements, salts, and chlorides (Active Standard). For the experimental study, common drinking water from Risalpur was used to make all of the samples, and the same water was also used to cure them.

Standards for Various Tests

Table 3-4: Standards used for tests

Test	Material	Standards
Sieve Analysis	Sand and Coarse Aggregate	ASTM C33 / C136
Crushing Value	Coarse Aggregate	BS 812 :110
Specific Gravity	Sand and Coarse Aggregate	ASTM C127-07
Absorption Capacity	Sand and Coarse Aggregate	ASTM C127

3.5 Batching, casting and mix design

Batching of the mix design was done by weight proportions of the materials comprising concrete. Several samples were cast as per mix designs discussed above. Basis for the replacement percentages was set from the literature review substitutions were done by means of 05%,10%,15% & 20% Crumb rubber with sand. The samples were designated as per the substitution percentages of aggregates. A concrete pan style mixer was used to combine all of the materials. All of the components (cement, sand, aggregates, and silica fume) were placed in the mixer 20 pan to make high strength concrete (HSC). The superplasticizer was dissolved in water and poured into the mixing bowl. For 3 minutes, the mixer was rotated.

Table 3-5: Casting scheme

Sr No	Sample	Cylinder
1	Control	6
2	5% Rubber	6
3	10% Rubber	6
4	15% Rubber	6
5	20% Rubber	6
6	5 Treated Rubber	6
7	10 Treated Rubber	6
8	15 Treated Rubber	6
9	20 Treated Rubber	6

Table 3-6: Mix Design Constituents (kg/m3).

Mix ID	Cement	Silica fume	Water	Coarse aggregate	Fine aggregate	Rubber	Super plasticizer
R0	611	61	235	1457	695	0	6.72
R5	611	61	235	1457	660	7.22	6.72
R10	611	61	235	1457	625	14.44	6.72
R15	611	61	235	1457	590	21.66	6.72
R20	611	61	235	1457	555	28.88	6.72
TR5	611	61	235	1457	660	7.22	6.72
TR10	611	61	235	1457	625	14.44	6.72
TR15	611	61	235	1457	590	21.66	6.72
TR20	611	61	235	1457	555	28.88	6.72

3.6 Curing process

The casted samples were left in the molds for twenty-four hours before being unmolded the next day and placed in a water bath at room temperature. The samples were cured to meet the requirements of the tests.

3.7 Properties and test of hardened concrete

3.7.1 Compressive strength

Compressive strength (ASTM C39) and split tensile strength (ASTM C496) tests were performed on hardened concrete. Hardened concrete tests are critical for determining how concrete behaves under the appropriate mix proportioning or specified criteria. The tests performed on hardened concrete are listed in the following sections of this experimental investigation.

3.7.2 Split tensile test

On concrete cylinders, splitting tensile tests were performed. The specimen was loaded at a rate of 0.7 to 1.40 MPa/minute (min) on the compression testing equipment until it failed. The splitting tensile strength (MPa) was estimated by recording the greatest load at failure.

$f't = 2 P / \pi L D$

where, P = the maximum load at failure (N)

L = Length of the specimen (mm)

D = Diameter of the specimen (mm)

Chapter 4: Results and Discussion

4.1 Stress strain curve

The stress strain curves of all specimens are shown below. The compressive strength of control sample R0 was 51.76 MPa at 28 days. The peak stress was attained at an average strain value of 0.00213 according to the stress-strain curves. The sample showed the brittle failure and sudden drop of stress occurred after failure. The compressive strength decreases as we increased the rubber percentages, but the sudden drop of strength after peak is improved. The specimen containing untreated rubber particles showed the improvement in post peak behavior of stress strain curve as compared to control sample. The strain values increases after the peak strain and rubber particles delayed the failure. The specimen contained treated rubber showed improvement in compressive strength as compared to the untreated rubber on same percentages, but the post peak behavior of sample contained treated rubber was not very impressive.

When 5 percent fine aggregates are replaced with rubber particles the curve showed Fig.4-1(a), changes in compressive strength and peak value of concrete. R5 specimen showed 20% reduction in compressive strength when compared with R0 but the ultimate strain value improved. On the other side treated rubber sample TR5 showed similar behavior of R5 but its compressive strength is improved as compared with R5.

The below Fig. 4-2(b), show that R10 sample displayed massive improvement in post peak behavior but reduced the compressive strength up to 37% compared with control sample R0. The average yield strain value of R10 recorded 0.00160 and average ultimate value 0.0050. The curve show that after the peak stress value the reduction in strength was mild compared with control specimen. Whereas, treated specimen TR10 reduced 26% compressive strength but compared with same percentage of non-treated sample, the strength reduction is improved. The average yield strain of treated specimen was noted 0.00193 and ultimate strain value was 0.00444. Although treated specimen improved the compressive strength but reduced ultimate strain value compared with non-treated sample of same percentage.

The average compressive strength of R15 sample was recorded 29.04 MPa and 44% reduction recorded when compared with R0 as seen in Fig. 4-3(c). The specimen yielded at an average yield strain 0.00155 and average ultimate strain was recorded 0.00512. The specimen exhibited great improvement in post peak behavior of curve and failure pattern of sample was smooth compared with R0. The treated rubber of same percentage TR15 improve the compressive strength and reduction loss remained only 17%. The average yield strain was noted 0.001922 and average ultimate value was 0.0034. The average ultimate strain value of treated sample was less having same percentage of non-treated concrete sample.

The average compressive stress of R20 was recorded 24.20 MPa with massive reduction up to 50% in strength as shown in Fig. 4-4(d). Specimen yielded an average yield strain 0.00148 and the average ultimate strain 0.0040 was recorded. The average compressive strength of TR20 was 48.75 MPa and sample yielded at an average value of 0.00198 and average ultimate strain was 0.00329. The treatment of rubber almost reached the same value of R0. Although post peak behavior was not very impressive but compared with control sample the loss of strength after peak was smooth which happened due to rubber elastic nature.

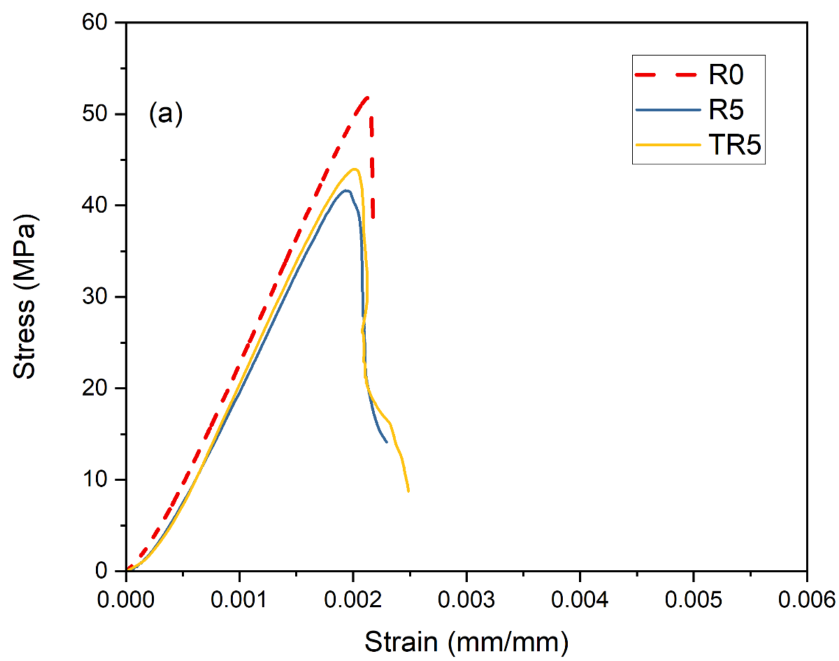

Figure 4-1: Control specimen, 5% treated and non-treated rubber

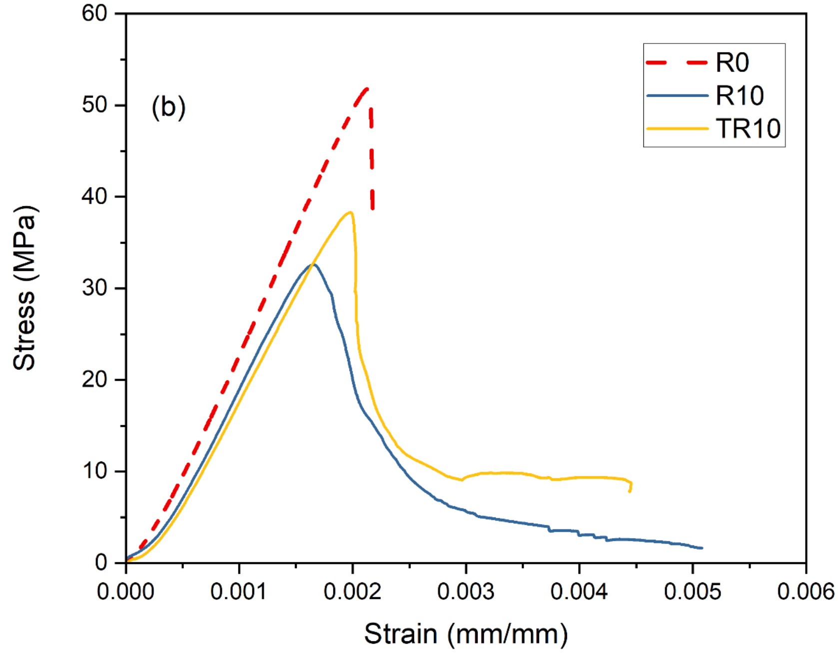

Figure 4-2: Control specimen,10% treated and non-treated rubber

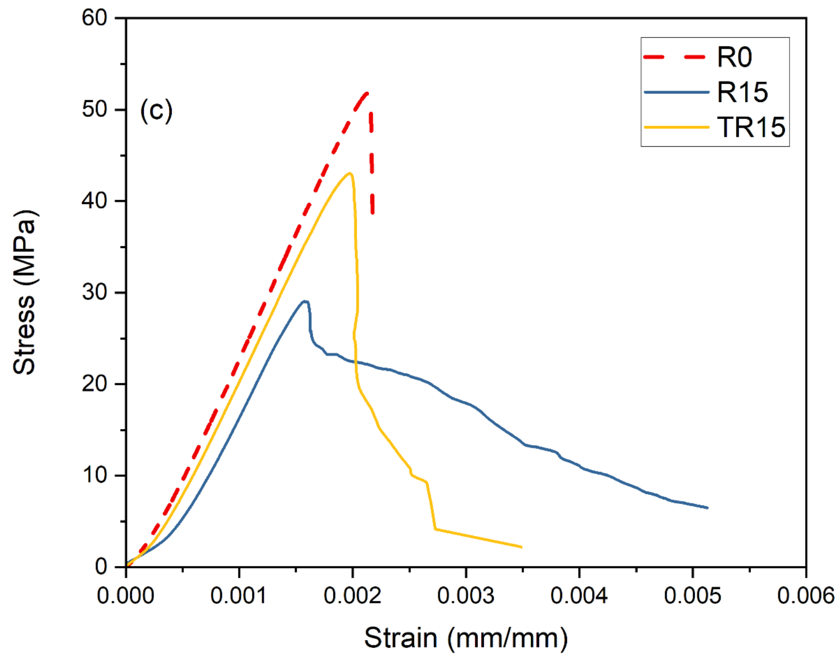

Figure 4-3: Control specimen,15% treated and non-treated rubber

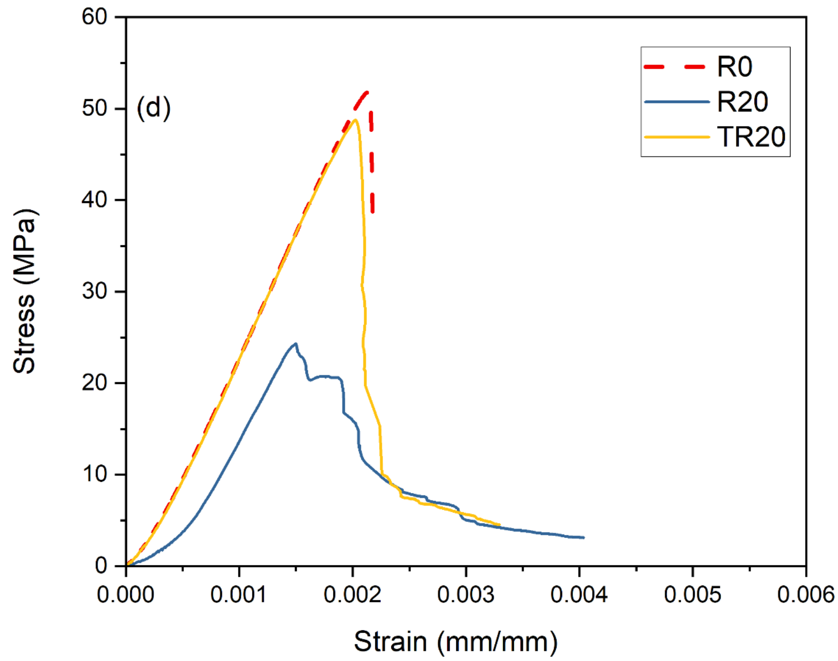

Figure 4-4: Control specimen, 20% treated and non-treated rubber

4.2 Compressive strength

The effect of rubber on the compressive strength using different rubber percentages can be seen in Fig. 4-5. Continuous loss of compressive strength can be seen when rubber is replaced in mixture without treatment. Addition of non-treated rubber with different percentages 5%,10%,15% and 20% in the mix resulted in reduction of compressive strength by 20%, 37%, 44% and 50%. The reduction in compressive strength is approximately matched according to previous researches (Abdelmonem, El-Feky et al. 2019). Several factors are involved in strength reduction due to addition of rubber. The stiffness of rubber is less compared with sand due to this the load bearing capacity of rubber resulted in reduction of compressive strength. Rubber is hydrophobic in nature also air entering agent and when rubber percentages is increased more air entered in mix resulted reduction of compressive strength (Polydorou, Constantinides et al. 2020). Rubber particles are lighter compared with sand during the process of vibration or tamping the particles moved to the upper surface and their unbalanced distribution the internal stress concentration is occurred. Rubber weekend the bond between aggregate and cement paste and expand Inter transition zone causes in strength reduction (Li, Ruan et al. 2014)

When treated rubber is incorporated in concrete mix the improvement in strength reduction is observed. Similar percentages of treated rubber 5%, 10%, 15% and 20% resulted 16%, 26%,17% and 6% loss of compressive strength compared with control specimen. The improvement in compressive strength happened due to pre-treatment technique because it changed the hydrophobic nature of rubber into hydrophilic. The porosity of treated rubber specimens reduced because air pores formation is controlled during mixing process and repelling nature of rubber is eliminated due to WQD. Bond formation between aggregate and cement paste improved due to WQD coating on rubber hence strength reduction factor also improved (Polydorou, Constantinides et al. 2020)

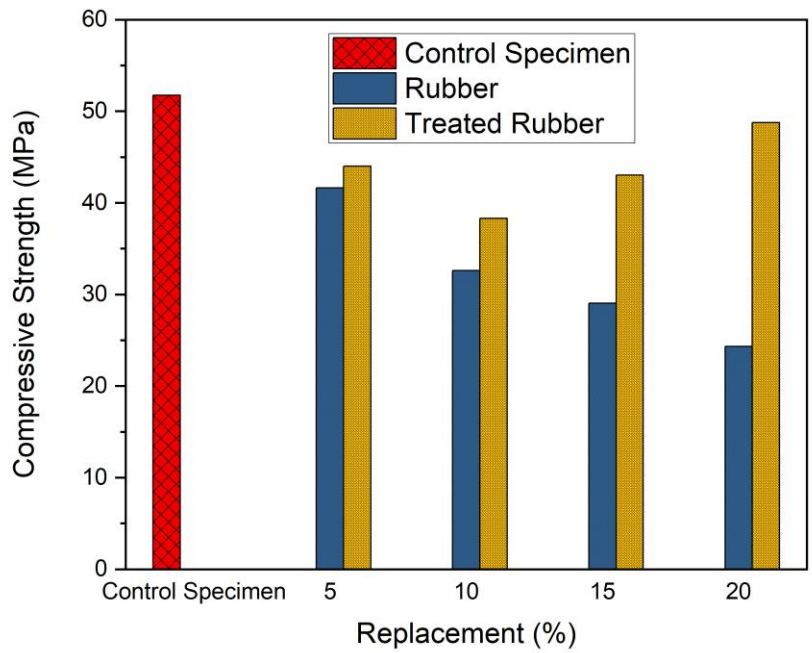

Figure 4-5: Compressive strength of control specimen, treated and non-treated specimen.

4.3 Modulus of elasticity

The stability of structure is influenced not just by the strength of its materials, but also by its stiffness. As a conclusion, another parameter for evaluating the potential of rubberized concrete to be employed as a structural material is its elastic modulus. Although it affects performance of concrete strength and modulus of elasticity, adding rubber can protect structures from becoming overly stiff based on structural stability, which is also favorable to earthquake resistance. The elastic modulus was observed to decrease when rubber was used instead of fine aggregate as shown in fig. 4-6. The calculated value of control specimen was 22.84GPa. The reduction in modulus of elasticity of rubberized concrete was 13.75%, 25%, 37% and 45% with non-treated rubber percentage of 5,10,15 and 20. From previous research it is observed that the modulus of elasticity of rubber decreased with small rubber particles size and increased rubber percentages (Li, Ruan et al. 2014). The treated specimen show improved behavior if we compare the same percentages with non-treated specimen. The reduction value of TR5, TR10, TR15 and TR20 were 10%, 23%, 19% and 1%. The treated specimen TR20 achieved almost same value of modulus of elasticity as control specimen achieved. Modulus of elasticity of concrete depends upon property of material as well as the compressive strength of concrete. The addition of rubber in concrete caused reduction in compressive strength resulted in reduction of elastic modulus values. The treated specimen show better result because of the treatment of specimen with WQD the loss in compressive strength was less compared with non-treated specimen which helped to improve the modulus of elasticity of treated specimens. The treatment of rubber can improve more elastic behavior if we use rubber particle size greater than those rubber size used in our study as it was observed from previous researches greater particle size less reduction in modulus of elasticity (Feng, Wei et al. 2010, Liu and Pan 2011, Li, Ruan et al. 2014).

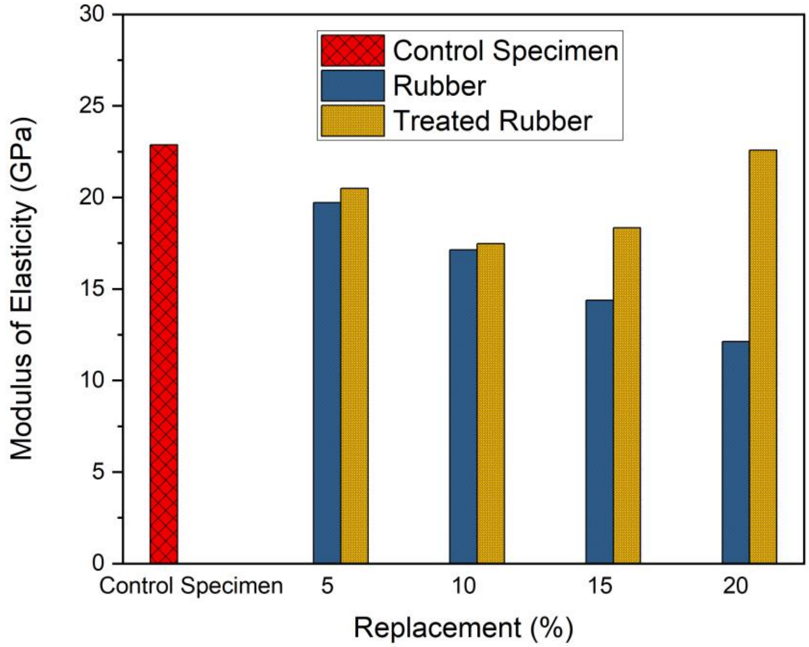

Figure 4-6: Modulus of Elasticity of all specimens.

4.4 Failure mode

An additional intention of performed compression tests was to observe failure patterns of cylinder specimens during loading and failure, as that can help to understand the overall behavior of specimens. The different sample tested under compression load showed different failure pattern shown in Fig. 4-7. The control specimen R0 achieved highest compressive strength and showed brittle failure having wide cracks appeared on the surface and sample breakdown into pieces. The rubber is ductile material and replacement of rubber in HSC should improve its sudden failure. Rubber improves the capacity of concrete to deform and improves its fracture brittleness by limiting the formation and development of fractures in concrete (Skripkiūnas, Grinys et al. 2009). The increase in rubber percentage resulted in smooth failure and the crack widths decreases.

The cracks appeared on non-treated rubberized concrete in smooth pattern and narrow cracks appeared because rubber particles bridged the cracks and resist against sudden failure of HSC. The treated specimen with same percentages of rubber showed less ductile behavior and more wide cracks appeared on the treated rubberized specimens.

The treatment of specimen with WQD helped to improve the inter transition zone of rubberized concrete between cement paste and rubber particles which resulted in reduction of ductility of specimen resulted in wide cracks propagation. The improvement in ITZ weaken the ability of treated rubberized concrete to limit compressive deformations while allowing strain to build at a faster rate than regular concrete.

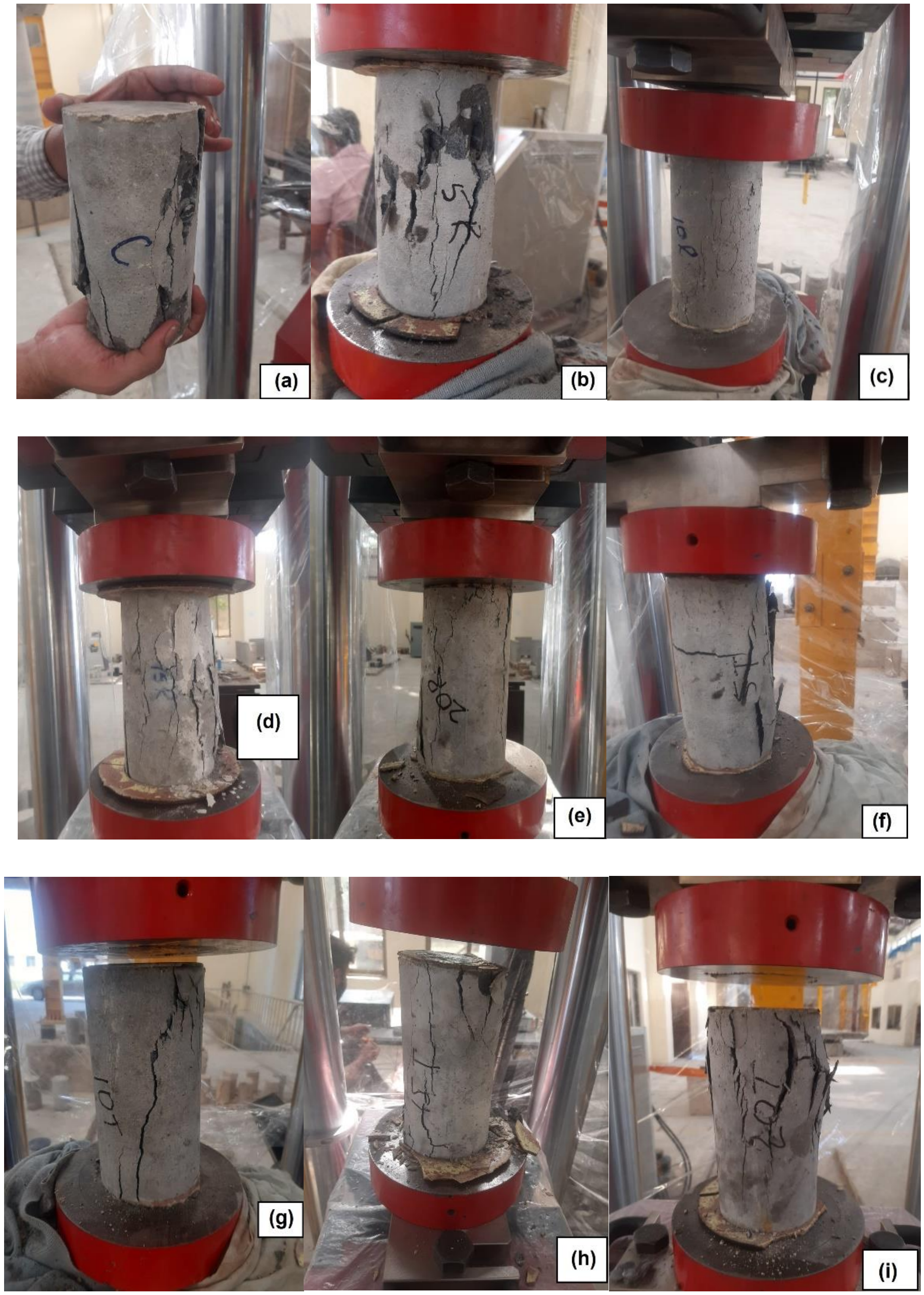

Figure 4-7: (a) Control specimen R0 (b) R5 (c) R10 (d) R15 (e) R20 (f) TR5 (g) TR10 (h)TR15 (i) TR20

4.5 Comparison of strain value

For each type of specimen examined in this study, a comparison is done to examine the change in average strain values as the proportion of rubber particles increases shown in Fig. 4-8. The average yield strain values decreased with increase in rubber particles in non-treated specimens. Among all non-treated rubber contained samples R5 specimen showed the maximum yield strain 0.00188 whereas R20 showed minimum yield strain 0.00148 compared with control specimen R0. Similar trend is followed in peak strain values of non-treated concrete samples. Minimum reduction of average peak strain recorded 9.5% and maximum reduction was recorded 30% of R5 and R20 respectively when compared with R0. Among all strain values the ultimate strain is considered more valuable in rubberized concrete. In rubberized concrete ultimate strain is considered as failure strain (Li, Ruan et al. 2014). The maximum ultimate strain recorded 0.00512 which was 58% greater than control specimen. The final strain of is greater when the rubber content is higher, showing that rubber particles support in deformation, prevent sudden failure, and cause a delay of concrete damage.

Rubberized concrete contained treated rubber with WQD show improved trend in yield strain value compared with non-treated sample. The maximum yield strain recorded was 0.00198 which is nearer to the yield strain of control specimen. Similar trend was found in peak strain and maximum average value noted was 0.00209 which is almost equal to control specimen. Although the yield and peak strain values improved compared to non-treated rubberized concrete but increment in ultimate strain value was recorded less which was happened due to treatment of rubber. The coating of WQD on rubber particles decreased the elastic behavior of rubber and improved its stiffness.

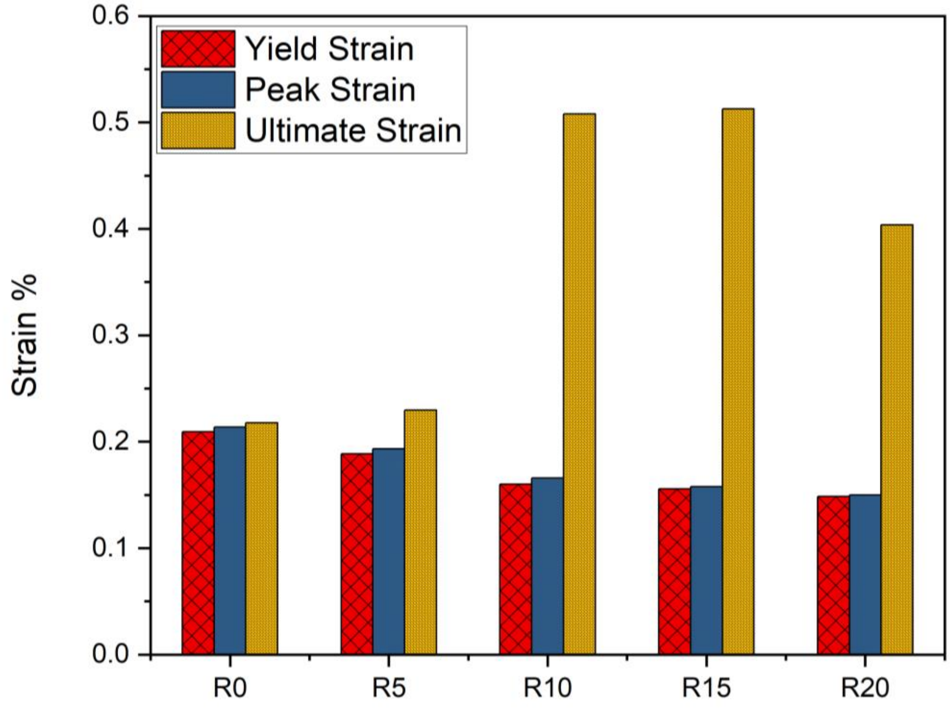

Figure 4-8: Strain values of non-treated specimens

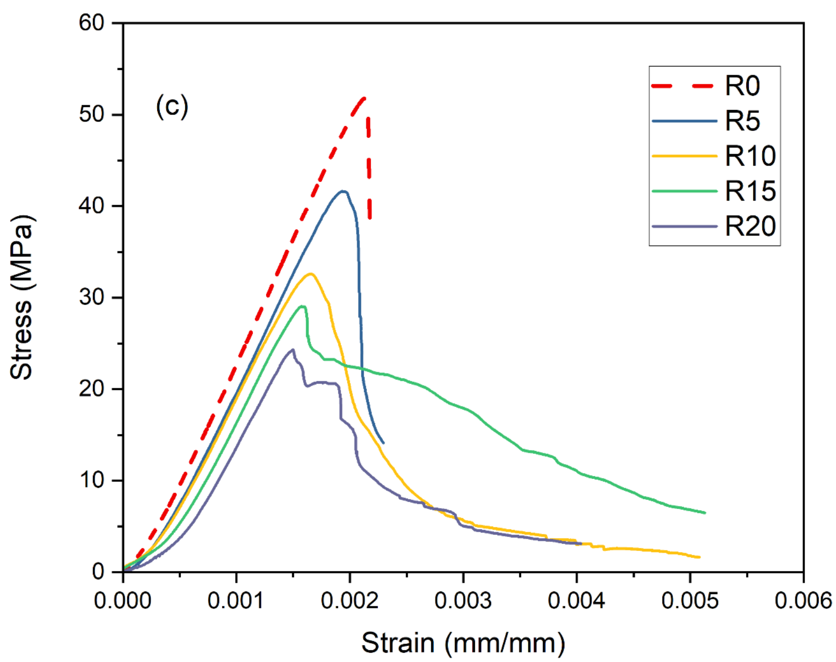

Figure 4-9: Stress strain curves of all non-treated specimen

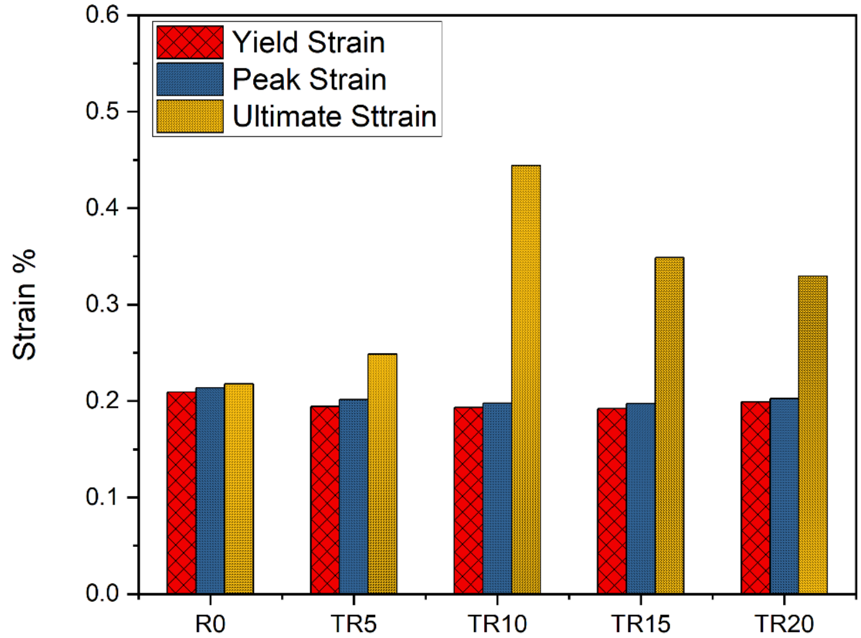

Figure 4-10: Strain values of treated specimens

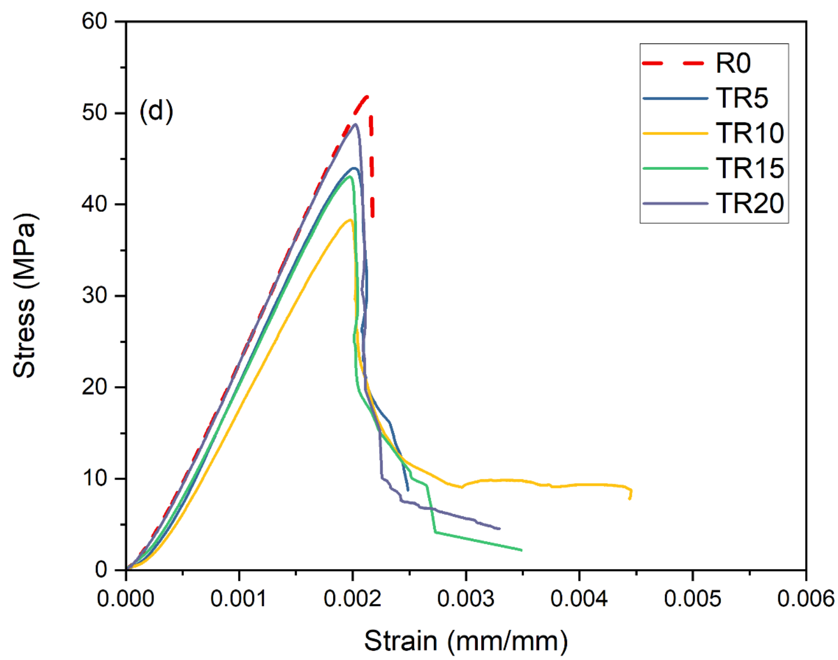

Figure 4-11: Stress strain curves of all treated specimen

4.6 Strain ductility of rubberized concrete

One of the important properties of rubberized concrete is its ductile nature. Ductility can be defined as the ability of material to stand after the yield point till the concrete failure. We know that concrete it brittle by nature and the addition of rubber in concrete can play an important role to improve its brittle nature. Incorporation of rubber can help to stop the sudden drop in strength after peak stress. Ductility values are obtained by dividing the strain of 80% of peak load by yield strain shown in Fig. 4-12. Ductility of control specimen R0 was found 1.037, as ductility of concrete depends upon the energy absorption after peak hence due to sudden drop the ductility is less of control specimen.

When we talk about the ductility of non-treated rubberized concrete the maximum ductility was 1.287 of R20. Greater the rubber content greater will be ductility. The 20% replacement of rubber with fine aggregate resulted in 24% improvement in ductility of high strength rubberized concrete. The treated rubber also improve the brittle nature of high strength concrete, but it was less when compared with same percentage of non-treated rubber. The highest ductility was shown 1.08 by the R5 specimen. The reduction in ductility value of treated sample caused due to treatment of rubber because coating of rubber with WQD change the elastic behavior of rubber. The reduction in air voids in treated concrete may also be the cause of less ductility of treated specimen compared with non-treated rubberized concrete.

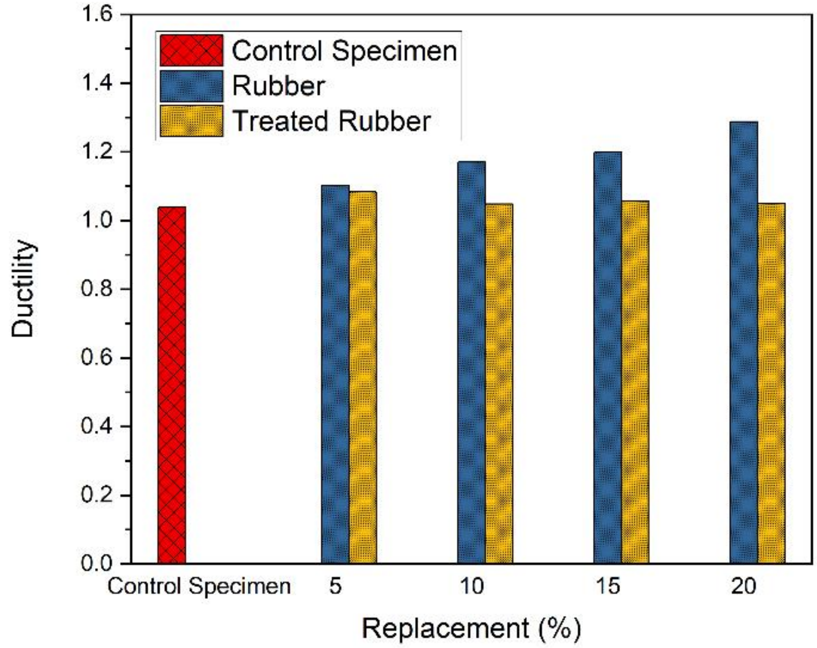

Figure 4-12: Strain ductility of all specimens.

4.7 Energy absorption and toughness index

The capacity of a material to absorb energy before rapturing called toughness of that material. Toughness of material involved strength of material and ductility of material. We can calculate the toughness of material by calculating the area under the curve using stress-strain curve. In other words, toughness is summation of pre-crack energy, crack energy and post crack energy of material. To get these energy value we should have idea of yield strain, peak strain, and ultimate strain. Pre-crack energy defined as the capacity of material to absorb energy up to yield point and calculated by area under the curve up to yield point. It is difficult to find the yield point in concrete because the peak stress and yield stress are very close to each other. To calculate the yield point (H.Muguruma 1991) invented a method using this, yield point is calculated in this research. Usually yield point is considered where first crack in specimen is observed. Crack energy absorbed in compression is calculated by area under the curve from yield point to peak point. Post crack energy is taken by evaluating the area of stress strain curve from peak point to ultimate point. For energy calculation ultimate stress is taken as the 80% of peak stress after peak point.

Total energy absorbed is calculated by area under the stress strain curve from zero to ultimate point, it should also equal to the summation of pre-crack energy, crack energy and post crack energy absorbed in compression.

4.7.1 Pre-Crack energy (PEC)

By using stress strain curve, we can find out the PEC value by using mathematics terminologies. The energy absorbed by concrete specimen from start point of curve to the yield point is called PEC. It is area under the curve and obtained by integration of stress strain curve from zero to yield point. The value of different samples are compared in below mentioned Fig. 4-13. PEC value depends upon the peak of curve as the non-treated rubber content increased in min the PEC gradually decreases. The R20 specimen showed the minimum PEC value 0.01419 because of the great strength reduction. When treated rubber is incorporated in the concrete mix, we can see the gradual increment in PEC values. The TR20 specimen showed the maximum PEC value 0.04554 among all treated sample and obtained value was almost the same of control specimen. However, it is observed from the study that pre-treatment of rubber helped to improve the pre crack energy as well as the toughness of concrete by controlling the strength reduction.

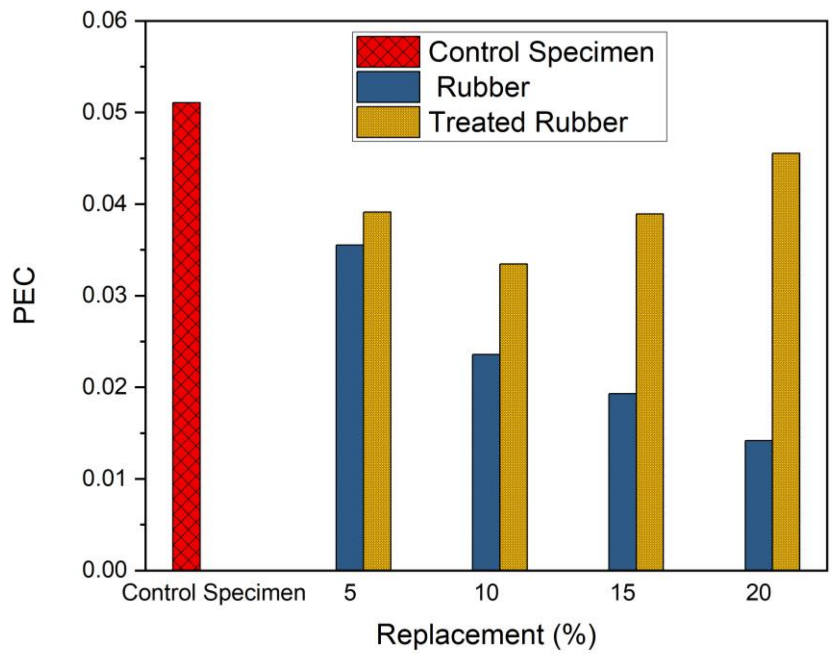

Figure 4-13: PEC results of all specimens

4.7.2 Crack energy absorbed in compression (CEC)

Crack energy is the energy absorbed by concrete specimen from yield point to peak point. It is obtained by calculating area under the stress strain curve from yield point to peak stress point. In high strength concrete it took a very small instant to reach from yield point to peak point. The below mentioned graph showed the comparison of all sample behavior towards crack energy absorption. Similar trend was found of PEC by increasing the rubber percentages the capacity of specimen to absorb the energy decreased shown in Fig. 4-14. Pre-treated sample showed better energy absorption capacity compared with non-treated specimen. The treated rubber sample showed some bridge from yield point to peak point and helped to delay the failure. R20 showed minimum crack energy 0.000319 it showed that the yield point and peak point were almost the same. Whereas TR5 sample absorbed the maximum energy, and the recorded value was 0.00197 and this value was almost equal to the control sample.

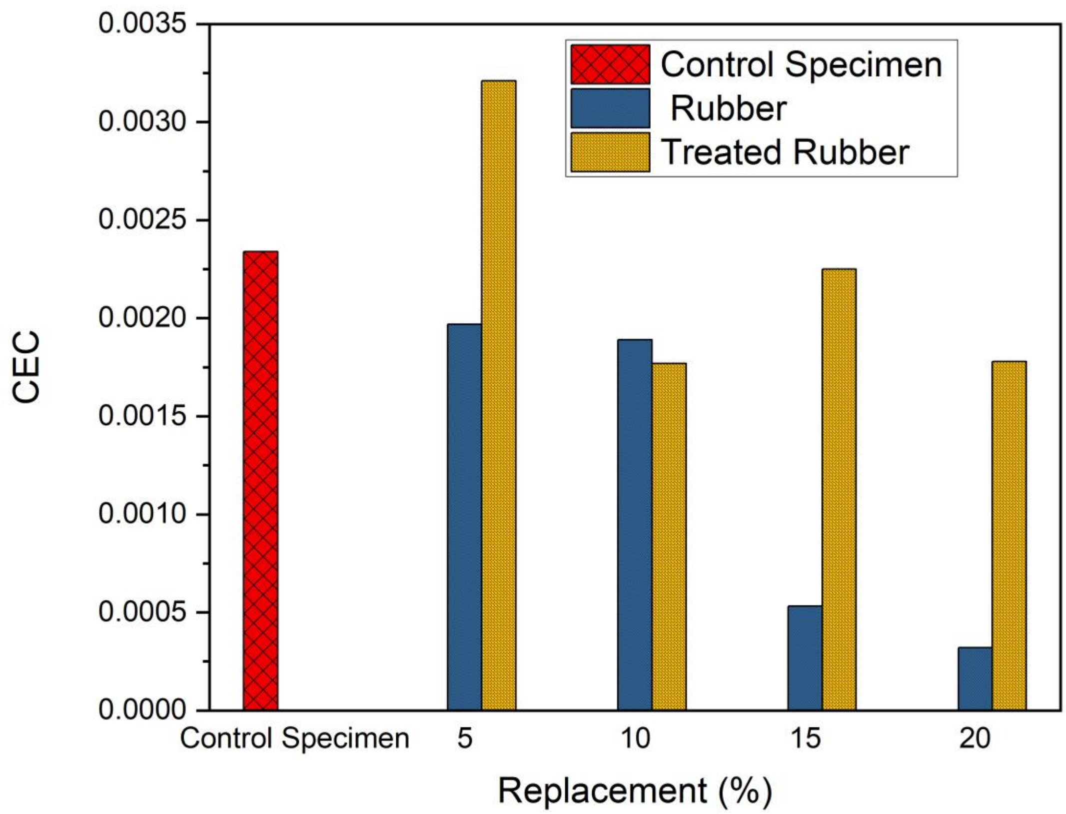

Figure 4-14: CEC results of all specimens

4.7.3 Post crack energy absorbed in compression (PCEC)

The energy absorbed by specimen from peak stress to the ultimate point. The ultimate point is taken at 20% drop of peak stress. High strength concrete showed Fig. 4-15. very small capacity of energy absorption after peak point. The PCEC of control specimen R0 noted only 0.0019 because the sudden drop occurred after peak stress due to brittle nature of concrete. The important part of this study is to capture the post peak behavior while using rubber because of its quality to improve the post peak behavior. The non-treated rubber specimen show the continuous improvement in post peak behavior. The post energy absorption capacity of sample increases by increasing the rubber percentage. The R20 specimen show the maximum energy absorption and value obtained was 0.00874 as shown in below graph. The R20 specimen absorbed 430% more energy as compared to control sample R0.

The treated specimen also show improvement in post peak behavior. Although the improvement in post peak behavior of treated sample was not enough good compared with non-treated sample but they showed improved behavior compared with control specimen R0. The TR20 specimen absorbed 76% more energy compared with control specimen R0. The reduction in energy absorption of same percentage of treated specimen compared with non-treated happened due to WQD. The coating of WQD on rubber minimize the elastic nature of rubber.

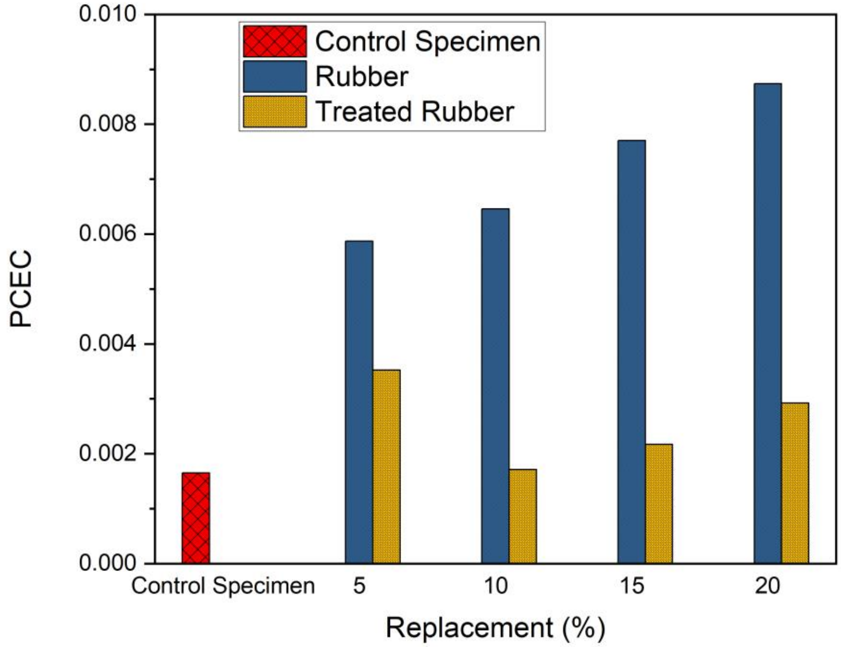

Figure 4-15: PCEC results of all specimens

4.7.4 Total energy absorption in compression

Total absorbed energy obtained by integration the stress train curve from zero to the ultima point of the curve as shown in Fig.4-16. Ultimate point is taken at the 20% drop of peak load. It is also the summation of all energies recorded above. The achieved value of control specimen R0 was 0.05506. Although the post peak energy and crack energy was not enough but pre crack energy was enough to contribute to total energy absorption of R0. The graph showed the reduction in TEC when the amount of non-treated rubber increased. The post crack energy value of rubberized concrete was greater but the pre crack and crack energies were less resulted in the reduction of total energy absorption capacity of rubberized sample. Minimum total energy absorption was recorded 0.0232 of R20. The treated sample showed improvement in total energy absorption although their post crack energies were less but the pre crack energies helped them to absorb enough energy. TR20 achieved maximum energy value of 0.05024 among all rubberized sample. The novel technique of pre-treatment help the rubberized sample to attain good result of pre-crack energy which help to improve the capacity of total energy absorption of specimens.

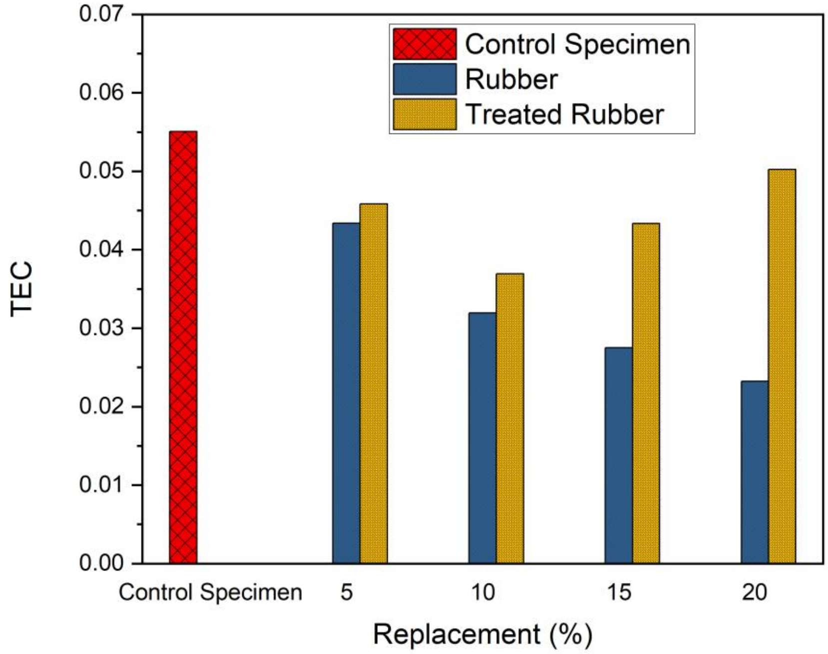

Figure 4-16: TEC of all specimens

4.8 Toughness index (TI)

The capacity of material to absorb energy before reputing is defined as toughness of that material. Toughness of any material depends upon the strength as well as the ductile behavior. The value of toughness can be obtained by calculating the area under the curve from start of curve to ultimate point of curve, ultimate point is taken at the 20% drop after peak stress point. Similarly TI can be calculated by dividing the total energy absorbed in compression to the pre crack energy absorbed in compression(Khan, Cao et al. 2018). The below Fig. 4-17. show the TI of different specimen. The control specimen R0 show the minimum toughness index of 1.078. The non-treated rubberized concrete achieved maximum toughness index as value increased by increasing the rubber content. R20 achieved maximum toughness index value of 1.63 and it was 52% greater than the control specimen R0.

The toughness index of non-treated sample improved due to smaller value of pre-crack energies. The treated specimen achieved not enough TI compared with same percentage of non-treated sample, as the pre-crack energies improved due to the WQD treatment. All treated specimen achieved greater TI compared with control specimen R0.

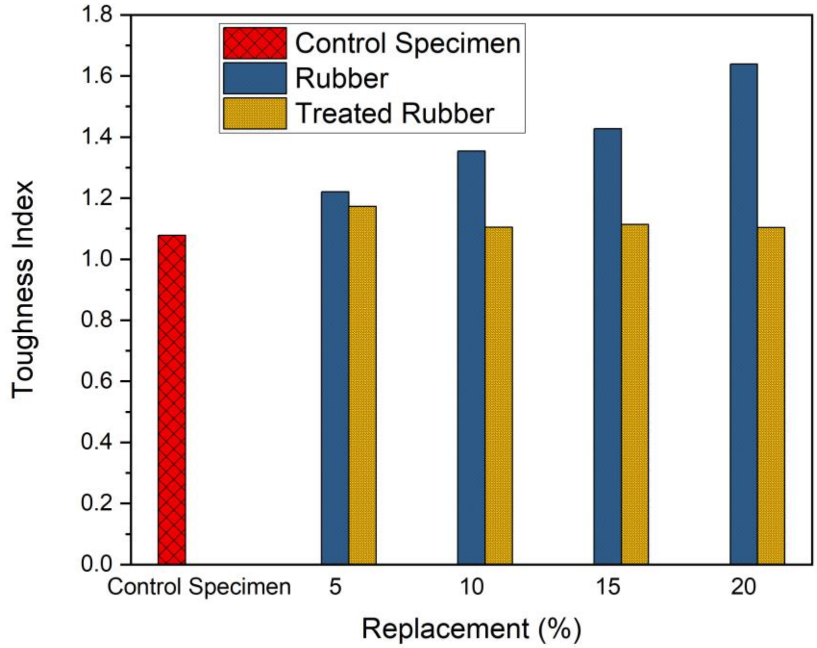

Figure 4-17: Toughness Index of all specimens

4.9 Indirect tensile strength

The below graph show the result of different specimen of indirect tensile strength. Similar behavior was found to that of compressive strength. The non-treated specimens show in Fig. 4-18. the continuous trend of split tensile strength reduction as the rubber percentages increased. The control specimen achieved maximum value 4.67 MPa at 28 days. The reduction in split tensile strength was noted 23%, 42%, 47% and 52%. The reason behind the strength loss probably same the compressive strength. The treated specimen show improvement in split tensile strength.

The TR20 specimen achieved the highest strength among all treated and non-treated specimen. The reduction in value was recorded 20%, 32%, 22%, and 12%. The TR20 specimen show minimum loss of split tensile strength and achieved 4.08 MPa tensile strength.

The improvement in strength achieved due to bond between cement paste and rubber happened by the treatment of rubber with WQD. The calculated value of the ratio between compressive strength to split tensile strength were 9.08%, 8.7%, 8.2%, 8.54% and 9.10% for R0, R5, R10, R15, and R20. Whereas the treated specimen obtained value were 8.53%, 8.32%, 8.47% and 8.45% of TR5, TR10, TR15 and TR20.

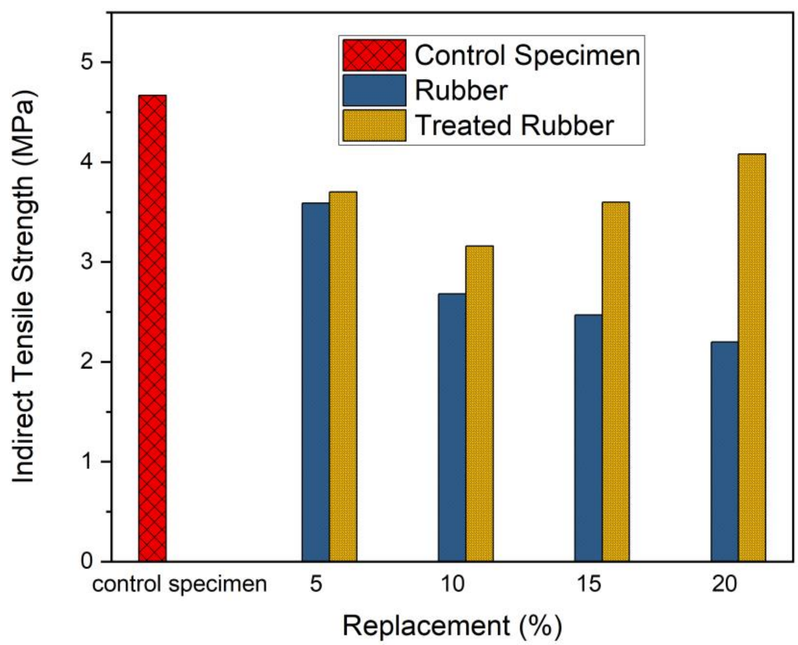

Figure 4-18: Indirect tensile strength of all specimens

Chapter 5: Conclusions and Recommendations

5.1 Conclusion

This study includes the awareness of the reuse of waste material like tire rubber and waste quarry dust in concrete industry to make eco-friendly high strength concrete. Crumb rubber was utilized to partially replace the fine aggregate by 5%, 10%, 15% and 20% of volume in this experimental study to investigate the characteristics of high strength concrete including tire rubber as partial substitution. The following results were obtained by the experimental work of above-mentioned study.

The yield strain and peak strain values of non-treated rubberized concrete decrease by increasing the rubber content. However, the ultimate strain increased by replacing more percentage of rubber with fine aggregate.

Treated rubber show improved value of yield and peak strain compared with same percentages of rubber but slightly reduction in ultimate strain observed. Coating of WQD on crumb rubber minimize the elastic behavior of rubber and curves showed the sudden drop of strength after peak stress point.

The compressive strength of non-treated rubber decreases with the increment of rubber. R20 recorded maximum reduction of around 50% compared with control specimen. There was no specific change seen after 5% replacement of crumb rubber with sand. The 10% replacement of treated rubber showed reduction in compressive strength. The treated specimen improved trend of compressive strength started after 10% replacement of crumb rubber with sand. The compressive strength of treated specimen TR20 recorded same to the control specimen.

Elastic modulus of non-treated rubber decreases with the increases in rubber content. The R20 showed maximum reduction of 45% compared with control specimen. The replaced treated rubber up to 10% showed reduction in elastic modulus whereas, after 10% the increment in elastic modulus was seen. The treated specimen TR20 achieved almost same value of modulus of elasticity as control specimen achieved.

Similar trend of compressive strength and elastic modulus was recorded in split tensile test. The treated sample TR20 achieved highest tensile strength of 4.08 MPa which was nearer to the control specimen R0.

Non-treated specimen showed good ductility and ductility improved by increasing rubber content. Treated specimen showed less ductile behavior compared with non-treated due to their treatment with WQD which caused change in their ductile property.

Energy absorption capacity of rubberized concrete decreases although their post absorption capacity was greater compared with control specimen, but their pre crack energy absorption reduces by increasing rubber content.

Non treated specimen achieved grater toughness index compared with treated sample because pre crack energy reduces in non-treated sample which helped to increase toughness values. R20 achieved maximum toughness Index of 1.63 and it was 52% greater than the value of control sample.

5.2 Recommendations

The experiments were done on limited size specimens, and the research was restricted to evaluating low densities of rubber as a partial replacement for fine aggregate. The effect of WQD on larger particle size of crumb rubber can be studied under the umbrella of stress strain curve. In addition, the effect of this treatment can be applied on structural member to check their mechanical properties.

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