COMPRESSIVE STRENGTH OF RUBBERIZED-ULTRA HIGH PERFORMANCE CONCRETE WITH DIFFERENT ELEVATED TEMPERATURE

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ABSTRAK

Kemajuan teknologi menjadikan bahan konkrit membawa kepada pembangunan jenis komposit bersaiz baru yang dikenali sebagai Ultra High Performance Concrete (UHPC). UHPC adalah sejenis konkrit yang dikenali dengan kekuatan yang sangat tinggi dan ketahanannya. Bahan buangan dikenali sebagai bahan yang boleh menyebabkan masalah kepada alam sekitar. Bahan buangan boleh dikurangkan dengan memprosesnya dalam bahan binaan seperti UHPC. Bahan sisa yang digunakan dalam kajian ini adalah sisa tisu sampah (WCT). Objektif dalam kajian ini untuk menentukan kekuatan mampatan UHPC getah pada suhu tinggi yang berbeza seperti 100˚C, 150˚C dan 200˚C dan menentukan penurunan berat getah UHPC tertakluk kepada keadaan pra pemanasan. Tayar sampah buangan diubahsuai pada rawatan permukaan dengan menggunakan NaOH dengan tempoh 20, 40 dan 60 minit. Tayar serbuk sisa digunakan sebagai pengganti agregat kasar dalam 5% daripada jumlah berat keseluruhan agregat kasar dan akan dicampur bersama untuk membuat getah UHPC dengan peratusan 5% tetap WCT. Berdasarkan hasilnya, dapat disimpulkan bahawa UHPC getah dengan rawatan permukaan 60 minit atau getah UHPC-60 adalah yang terbaik dengan kekuatan dan penurunan berat dibandingkan dengan rawatan permukaan UHPC getah lain.

ABSTRACT

Advance in technology makes the concrete material led to the development of new type of cementitious composites which known as Ultra High Performance Concrete (UHPC). UHPC is a type of concrete known by its exceptionally high strength and durability. The waste materials were determined as material that can cause problem to the environment. The waste materials can be reduced by processing them in construction materials such as UHPC. The waste material used in this study was waste crumb tyre (WCT). The objective in this study to determine the compressive strength of rubberized UHPC at different elevated temperatures such as 100˚C, 150˚C and 200˚C and determine the weight loss of rubberized UHPC subjected to pre-heating condition. The waste crumb tyre were modified on surface treatment by using NaOH with duration of 20, 40 and 60 minutes. The waste crumb tyre were used as replacement for coarse aggregate in 5% of percentage from total weight of coarse aggregate and will be mixed together to make rubberized UHPC with fixed 5% percentage of WCT. Based on the result, it can be concluded that the rubberized UHPC with surface treatment 60 minutes or rubberized UHPC-60 is the best with strength and weight loss compared to other rubberized UHPC surface treatment.

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LIST OF SYMBOLS

˚C	Celcius
°	Degree
kg/m^3	Kilogram per metre cube
kN	Kilo-Newton
MPa	Mega Pascal
µm	Micrometre
mm	Millimetre
N/mm^2	Newton per millimetre square
%	Percentage

LIST OF ABBREVIATIONS

Agg	Aggregate
OPC	Ordinary Portland cement
SF	Silica fume
NaOH	Sodium hydroxide
SP	Superplasticizer
UHPC	Ultra-High -Performance Concrete

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Advance in the technology make the concrete materials led to the development of new type of cementitious composites which known as Ultra-High Performance Concrete (UHPC). UHPC is a type of concrete known by its exceptionally high strength and durability. It was developed in Europe in the 1980s for specialized applications that need superior strength and corrosion resistance. In 2000, UHPC has become commercially available in the United States that lead to the series of research project to demonstrate the capabilities of the material as stated by (Graybeal, 2011). The properties of high strength and durability UHPC make it an optimal model for use in developing new solutions for highway infrastructure deterioration, repair and replacement. Besides that, UHPC also used as marine anchors, piers and seismic structure. UHPC also has less water-cement ratio which is 0.25 than mechanical properties of UHPC include compressive strength greater than 150 MPa and the sustained post-cracking tensile strength greater than 5 MPa as mentioned by (Graybeal, 2011). UHPC also has been used in a variety of the applications such as precast concrete piles, seismic retrofit of substandard bridge substructures and security and blast mitigation applications. The elements or materials contain for making UHPC such as Ordinary Portland Cement (OPC), sand, ground quartz, silica fume and water. However, the ground quartz as the ingredient for make this UHPC is expensive affected to the cost production compare with other materials. The new solution has been determined to replace the ground quartz that act as the aggregate with use of recycled waste tire or waste crumb tire to reduce the cost production. This material will replace the ground quartz as the aggregate and places for make UHPC.

In recent decades, the worldwide growth on automobile industry and increasing the use of cars as the main transport have been accelerates boosted on the production of tire. This has produced huge stockpiles of used tires. Besides that, more than 270 million scrap-tires are produced in United States each year (Rubber Manufacturers' Association, 2000). On the other hand, the rubber tires also used in making fuel for cement kiln, and feedstock for making carbon black. The involvement of high capital investment in it by using tires as a fuel is not economically attractive. The stockpiles are dangerous not only effect the potential environment threat but also from fire hazards and contribute breeding grounds for rats, mosquitoes and bedbugs. In addition, over 300 million tires reach their service life every year in European Union alone and become waste. (Sofi, 2017) stated that the waste tires disposal contributes to the decreasing of biodiversity because tires contain toxic and soluble components. The waste tires disposal also can cause the temperature to be high when the tires started to burn down and generates toxic fumes (Sofi, 2017).

1.2 Problem Statement

In making Ultra-High Performance Concrete (UHPC), the materials used contain such as ground quartz, Ordinary Portland Cement (OPC), sand, silica fume and water. However, the ground quartz is expensive material compared with others material thus it would increase the cost of production making UHPC. Next, in order to decrease or reduce the cost production for making UHPC, an alternative waste material can be used to replace the ground quartz which is replace it with recycle waste tire. Recently, the quantity of recycle waste tire become increases because of the production of vehicles from day to day increases. Besides that, the use of recycled waste tire provides low cost in production of UHPC. The recycled waste tire safe the environment impact. In this research study is crumb rubber from waste of by-products namely as waste crumb tire (WCT). As a comparison with previous research, UHPC was introduced and the success in the formation of superplasticizers has make the development for the new concrete family of UHPC, which has reach the compressive strength that was earlier possible only with steel as mentioned by (Randl, et al., 2014).

However, the waste crumb rubber has some problems when used as aggregate replacement. Several researchers found that, the size, proportions and surface texture of rubber particles able affect compressive strength of mixtures (Thomas & Gupta, 2015). Furthermore, the concrete mixtures that been added with crumb rubber aggregates lower compressive and splitting tensile strength than regular Ordinary Portland cement concrete (Thomas & Gupta, 2015). The crumb rubber has ability to absorb a large amount of energy under compressive and tensile loads. Thus, the previous research has determined when crumb rubber has rough surface or given a pre-treatment, the crumb rubber becomes better and improved bonding will develop with the surrounding that make the compressive strength to be higher.

1.3 Objective of Study

i. To determine the compressive strength of rubberized UHPC at different elevated temperatures.
ii. To determine the weight loss of rubberized UHPC subjected to pre-heating condition

1.4 Scope of Study

Stage 1: Preparation on The Surface Treatment of WCT

The concrete mixed with waste crumb tyre has good toughness and strength rather than traditional concrete. Besides that, it has better heat and sound insulation properties. Despite, the waste crumb tire has poor interface compatibility with inorganic materials. Moreover, the surface for WCT was hydrophobic and cement paste was hydrophilic material thus the bonding between WCT and cement paste was poor. Several researches have been done to enhance the performance through the surface treatment of WCT as mentioned by (He, et al., 2016). Before use the WCT with the concrete mixed, it will be washed by using acetone. Then, the waste crumb tire (WCT) will be immersed into sodium hydroxide solution, NaOH solution at different duration. The WCT will immersed into the solution about 0, 20, 40 and 60 minutes to strengthen the compressive strength for WCT. The main role of NaOH is to discard the tyre rubber soaked formulation additives and saturated in NaOH solution for 24 hours will not change the hydrophobic nature of rubber mentioned by (He, et al., 2016). After the WCT has been dissolved into NaOH solution, it will be washed again with the distilled water. As stated by (Eldin & Senouchi, 1993) soaked and washed crumb rubber with water used to remove contaminants. Then, it will be poured together with the concrete mix into the plastic moulds. The total specimens had been prepared were 108 cubes.

Stage 2: Preparation on Raw Materials and UHPC mix proportions

In this study, the materials will be used for making rubberized UHPC such as Portland cement, sand, silica fume, superplasticizers, aggregate, WCT and water. The silica fume that been used was 10% replacement from the total weight of Portland cement. The bonding between the cement and crumb rubber can be improved by the addition of silica fumes in the concrete which can increase the compressive strength of the rubberized concrete. Then, the aggregate will be used is 95% and the remaining for 5% was replaced by WCT. The percentage level of WCT was constant at 5% from coarse aggregate. The admixture used namely superplasticizer was used at percentage of 3.5% from the weight of the cement. The water cement ratio for this study used was 0.20. Besides that, to get the higher compressive strength and durability of UHPC, a low water cement ratio between 0.20-0.25 used in result will dense and strong structure of the hydration products that will prevent the brittle failure. The mix design contains four (4) series such as plain UHPC and three series of rubberized UHPC.

Stage 3: Curing Process for Plain UHPC and Rubberized UHPC

The specimens will be cured in water tanks for 7, 14 and 28 days before used on testing. After that, the specimens will be removed from water tank and left at room temperature for one (1) hour. The specimens which plain UHPC and three (3) series of rubberized UHPC such as UHPC20, UHPC40 and UHPC60 were tested after that.

Stage 4: Testing Method

The plain UHPC specimen was act as a control mix will be tested to compressive strength test. Then, the rubberized UHPC specimens such as UHPC20, UHPC40 and UHPC60 were tested on the heating treatment for compressive strength and weight loss. The rubberized UHPC specimens were stored in the furnaces at elevated temperature 100˚C, 150˚C and 200˚C. This process to investigate the compressive strength for series of rubberized UHPC with different pre-treatment. For the weight loss test, the sample were weighted before placed in the furnace and weight again after the sample was completed the heat treatment process.

Stage 5: Data Analysis

The data from the testing which were compressive strength test and weight loss test were collected and interpret. The results collected were analysed to determine the relationship on the compressive strength towards different duration pre-treatment WCT and elevated temperature.

1.5 Significance of Study

In this study, the cost production for making UHPC need to be reduce by replacing conventional aggregate with WCT. On other hand, the use of recycled aggregates can save natural aggregates and spend a minor quantity of cement needed. In this study, the level of percentage replacement used for WCT was constant at 5% from weight of aggregates with the pre-treatment of NaOH in 20, 40 and 60 minutes. The size of WCT used in this research was 5 mm respectively. The mix design used was 0.20 water cement ratio (w/c) constant for all mixes. The used of superplasticizer for this mix was constant at 3.5% from weight of cement. The percentage for silica fume combined with cement for this mixing was used at 10% from total weight of cement.

The rubberized UHPC would be taken out from the mould after casting in 24 hours. The samples were cured at age 7, 14 ad 28 days. In this study, the samples were tested at different elevated temperature consists of 100˚C, 150˚C and 200˚C in one (1) hour for plain UHPC and rubberized UHPC with different pre-treatment before subjected to compressive strength test. The samples were tested at two (2) testing which were compressive strength and weight loss tests. The compressive strength test was conducted for plain UHPC and rubberized UHPC with size of 100 mm x 100 mm x 100 mm. The weight loss test was weighted before and after the heat treatment process.

CHAPTER 2

LITERATURE REVIEW

2.1 General

In this chapter, the review on Introduction of UHPC, problem of waste crumb tire, effect of use waste crumb tyre in concrete, effect of heating resistance, surface treatment, effect of surface treatment on waste crumb tire, heating test, effect of heating test at different temperature, compressive strength and effect of compressive strength.

2.2 Introduction of UHPC

On the introduction of UHPC, there were divided into three (3) subtopics which were definition of UHPC, development of UHPC and the application of UHPC. For each subtopic, there were discussed and study more details from previous research.

2.2.1 Definition of UHPC

Ultra-High Performance Concrete (UHPC) is a current material that provides better mechanical properties and good resistance against the environmental impact. UHPC is a cementitious composite material that composed an optimized gradation of granular components. Besides that, UHPC also has water-to-cementitious material ratio less than 0.25 as mentioned by (Graybeal, 2011). UHPC also known as high strength concrete, the adaptable material formulated by combining the Portland cement, silica fume, fine sand, quartz flour, accelerator, superplasticizer, water and steel or organic fibre as mentioned by (Graybeal & Hartmann, 2003). It also stated that this concrete contains a huge quantity of cement, cementitious materials, a large quantity of superplasticizer and a little quantity of water. For the water and accelerator to cementitious materials such as silica fume and cement water-to-cement ratio is 0.15 as stated by (Graybeal & Hartmann, 2003). The compressive strength for UHPC is greater than 150 MPa compared with High

Performance Concrete (HPC) and conventional concrete (Graybeal, 2011). Based on (Schmidt & Fehling, 2004), UHPC with steel has compressive strength up to 250 N/mm^2 and significant increase in durability compared with HPC. (Ferdosian & Camões, 2017) stated that UHPC is high-tech composite construction material with extraordinary mechanical and durability characteristics which has self-compactness, compressive strength higher than 150 MPa and remarkable resistance to aggressive environments.

2.2.2 Development of UHPC

Concrete has been used since aged times. UHPC was first known as reactive-powder concrete due to its contained very fine material (Benjamin, 2014). Besides that, (Bache, 1981) and (Richard & Cheyrezy, 1995) stated that because of the restricted grain size less than 1 mm and use of different reactive mineral additions that formed high packing density this concrete was called as "Reactive Powder Concrete (RPC)". UHPC has been developed by using local components which were cement, supplementary cementitious materials such as silica fume and fly ash, fine sand, quartz or glass powder, steel fibre and a low water cement content. The production of concrete can be competing on the market when used of local components (Vítek, et al., 2013).

The development of concrete within the UHPC group has been progressed in recent years. Based on (Graybeal, 2011), UHPC product in United States has most readily available sold in large multinational construction material supplier. This product has been subjected important of testing to show its specific characteristic. The research programs in Europe were facilitated the development of non-proprietary products produced come from local constituents mentioned by (Graybeal, 2011).

Based on European Directive, the quartz fillers that contain particles with the diameter of less than 5 micron are suspected to cause the health problems. This problem led to demanding efforts to replace with other mineral powders. As stated by (Schmidt & Fehling, 2004), the extensive research project in Germany financed by the government, the technical criteria and measures has been developed to use local available raw materials for fine or coarse grained UHPC which to reduce the cement content and used fiber mixture as well as noncorrosive high strength plastic fibers. The materials used to control the strength and ductility based on the requirements given by an individual design and construction.

2.2.3 Applications on UHPC

UHPC is well known as a concrete that has high strength concrete and durability. UHPC was used in a wide type of highway infrastructure applications. As mentioned by (Graybeal, 2011), UHCP in United States has been used in three pre-stressed concrete girder simple span bridges which for first and three were placed at Lowa and the second placed at Virginia. For the first and second, this UHPC was used as replacement for conventional concrete inside I-girder shapes. This cases for the tensile properties of UHPC were matched to allow for the removal of the mild steel reinforcement shear stirrups. As stated by (Arslan, 2007), the shear stirrups defined as shear strength composed of the increase of nominal shear strength contribute by stirrups and the nominal shear strength contribute by concrete. For the third, the UHPC was used as prestressed deck bulb double tee girder shape. The girder shape was developed to match the mechanical and durability properties of UHPC in a shape that facilitate the construction of acceleration mentioned by (Graybeal, 2011). Then, the UHPC has excellent characteristic in strength and durability, its applications gaining interests in other European countries as well mentioned by Schmidt and Fehling, (2004). As stated by (Alsalman, et al., 2017), the replacement conventional concrete to UHPC saves the materials, decrease installation and labor costs.

Besides that, The Federal Highway Administration (FHWA) at its Turner Fairbank Highway Research Center (TFHRC) was presently evaluate UHPC used in the transportation industry as mentioned by (Graybeal & Hartmann, 2003). UHPC also can be used for bridges, buildings, structural strengthening and other special applications. UHPC has been demonstrated for extraordinary performance when used as field cast closure pour or grout material in applications requiring the onsite connection of multiple prefabricated elements. As stated by (Vítek, et al., 2013), the tests of bond of steel and UHPC were carried out for anchorage length of steel bars embedded in UHPC and the results obtained clearly show the anchorage length of steel bars in UHPC can be reduced in comparison with ordinary concrete. The UHPC was investigated used on other applications such as precast concrete piles, seismic retrofit of substandard bridge substructures, thin-bonded overlays on deteriorated bridge decks and blast mitigations application as mentioned by (Graybeal, 2011). (Alsalman, et al., 2017) mentioned that the benefits of using UHPC in the design of precast and prestressed structures have been proved by number of projects in United States, Germany, Canada, France and Australia.

2.3 Factors Affecting Properties of UHPC

In this study, there were discussed about the investigation on the factors affecting properties of UHPC. The investigation mainly focused on the main raw material components in preparing UHPC that include aggregates, silica fume, chemical admixtures, cement, water and waste crumb tyres. Besides that, all the factors give the influence on the properties of UHPC.

2.3.1 Effect of Different Types of Aggregates in UHPC

The coarse aggregate was included in the production of UHPC but aggregate contribute to be relatively small and included at low proportions compared with conventional concrete. As stated by (Azevedo, et al., 2012), the dimension coarse aggregate used was 8.0 with fineness modulus was 5.9. The density for this coarse aggregate was 2620 kg/m^3. The purpose of adding the coarse aggregate was to minimize the usage of cement content in UHPC production then it reduced cost production as stated by (Arafa, et al., 2010). The introduced of aggregates into the system of UHPC to reduce the cost and burden its applications mentioned by (He, et al., 2016). The coarse aggregate more economic was used efficiency rather than other raw materials and it also makes UHPC poses a better shrinkage performance and lower hydration temperature rise which contribute to the lower binder content. The solution to reduce the cost of UHPC with used sand that has diameter of 150-600 µm or natural sand as a filler material. The use of sand that has grain sizes in range of 125-500 µm for the development of UHPC that had 28 days compressive strength up to 188 MPa as mentioned by (Alsalman, et al., 2017). The use of finer sand accelerates the compressive strength compared to natural gradation sand but minimal effect on the compressive strengths when using 5% of silica fume. Based on (Wille & Boisvert-Cotulio, 2015), the use of aggregates in design UHPC at least for type of fine aggregate smaller than 1.2 mm and coarse aggregate type smaller than 12.5 mm.

2.3.2 Effect of Silica Fume to UHPC

Silica fume is well known as micro-silica is a basic component in production of UHPC because of its small particle size and reactivity. Silica fume was selected due to median particle size, high silicon dioxide content and low carbon content. Besides that, the use of silica fume in the UHPC was required to achieve the high compressive strength and durability as mentioned by (Alsalman, et al., 2017). The use of silica fume to quicken the pozzolanic reactions that produces additional calcium silicate hydrates (C-S-H) that can fill the voids. UHPC mixture with minimum compressive strength 138 MPa at 28 days and 150 MPa for 56 days can be produced by 10% replaced of silica fume as stated by (Alsalman, et al., 2017). The researcher persistent the most efficient silica fume content with used locally available material because not only gives a suitable compressive strength but also reduces cost of UHPC. The use of 5% and 10% of silica fume had similar 90 days compressive strength in concrete mixture as stated by (Alsalman, et al., 2017). Some certain researchers stated that the compressive strength increases as silica fume content increases due to curing condition as a possible factor that contribute to this deviation. (Rostami & Behfarnia, 2017) stated that the use of silica fume in alkali activated slag concrete can reduced initial and total water absorption.

The percentage of using silica fume as replacement rates on 20% and 30% for concrete mixtures had lower compressive strength compared to concrete mixture with percentage of 10% as replacement as mentioned by (Alsalman, et al., 2017). The UHPC mixture contain 10% replacement of silica fume had good compressive strength at 1 day, 28 days, 56 days and 90 days. On the 90 days, the UHPC with 10% replacement of silica fume had higher strength compared with UHPC contains 0%, 5%, 15% and 20% as replacement mentioned by (Alsalman, et al., 2017). The typical particle size of silica fume is about 0.1 µm to 0.5 µm. The silica fume has smaller particles compared to cement thus can fill the gap between cement grains that lead to particle packing which can contribute towards increasing in compressive strength and decreased permeability. As stated by (Zhang, et al., 2016), the addition of silica fume in concrete can improve the interface bond strength between hardened paste and aggregate. The use of amounts of silica fume which ranges in 5-10% of the cement weight were used to give the considerable strength gain and produced concrete of workability with a strength level exceeding 80 MPa (Rashid & Mansur, 2009). The size and spherical geometry of silica fume particles enable them to fill effectively voids between larger and angular cement grains and reduce internal bleeding of the concrete.

2.3.3 Effect of Chemical Admixture to UHPC

Variety of chemical admixtures were used to improve the properties of construction on concrete such as workability, pumpability, setting properties, mechanical performance and durability such as freeze thaw resistance and shrinkage properties. The chemical admixtures allow the manufacture and construction of special concretes such as high fluidity concrete, high strength concrete, underwater concrete and sprayed concrete. (Plank, et al., 2009) stated that the low w/c ratio and high packaging density for UHPC demand highly effective superplasticizers to enable adequate workability. Superplasticizers (SP) are used widely nowadays to produce flowable, strong and durable Portland cement concretes and mortars. The superplasticizer authorized fluid mixes with very low water-to-cement ratio but control the workability of the concrete mix as stated by (Chen, et al., 2013). The workability agents or water reducing agents such as plasticizer and superplasticizer which the superplasticizer more consistence and adhesive even at low water-to-cement ratio as mentioned by (Dumne, 2014). It essential to reduce inter-particle friction among solids particle in concrete by using superplasticizer and reducing coarse aggregate content.

The superplasticizers affect the microstructure of cement pastes by reducing their porosity and permeability which can sustain their intensive used in concrete preparations. Moreover, the superplasticisers were added less than 5%, the water demand can be reduced about 30% while increasing the workability, mechanical and rheological performances and concretes durability as mentioned by (Mangane, et al., 2018). As stated by (de Reese, et al., 2013), in fresh concrete the superplasticizers were used to extend increase the effective contact area because they fluidity fresh concrete and enable a higher strength at the same time. Besides that, (Kim, et al., 2018) stated that the carbon nanotube (CNT) contents and superplasticizers were added to the cementitious composites correspondingly fixed on 0.5% and 1.6% by weight of the cement. Most of the researchers stated that use of chemical admixtures agreed polycarboxylate (PCE) based superplasticizers are the most effective to distribute the particles of calcined clay blended cements as mentioned by (Ferreiro, et al., 2017). Moreover, the maximum quantity specified for the superplasticizers type generally in between 1.5% to 2% of binder content depends on superplasticizers type and quantity.

2.3.4 Effect of Low Water Cement (w/c) Ratio to UHPC

The lower water-to-cement ratio (w/c) used to reduce the voids between particles. Besides that, the compressive strength and durability of UHPC can be improved by a low w/c ratio about 0.20 to 0.25 that lead to very dense and strong structure of the hydration products and minimize the capillary pores (Schmidt & Fehling, 2005). The high packaging density of fine grains will in the binder matrix reducing the water demand of the fresh mix thus increase the compressive strength as well as the brittleness of the concrete as mentioned by (Schmidt & Fehling, 2005). The ultra-high strength concrete (UHSC) is generally characterized by a high level of silica fume and low in w/c ratio. The UHSC mixtures were designed with constant low w/c ratio about 0.197 and constant silica fume contents about 13% (Gesoglu, et al., 2016).

UHPC was a cementitious composite material that has low w/c ratio about less than 0.25 and makes UHPC required increased energy input compared to conventional concrete thus mixing time also increases (Graybeal, 2011). The increased energy input because of combination with reduced or eliminated coarse aggregates and low w/c ratio. Based on (Liu, et al., 2017), the addition super absorbent polymer (SAP) into the high strength cement-based materials can extremely reduce internal shrinkage for a cement mixture with low w/c ratio about 0.25. The observation on paste development and optimized aggregates size distribution for all matrices were categorized by excellent workability (spread= 265-315 mm) by using w/c ratio in between 0.21 to 0.24 and compressive strength increases about 150 MPa (Wille & Boisvert-Cotulio, 2015).

2.4 Tyre Rubber Waste

In this study, the introduction of tyre rubber waste, the definition of waste crumb tyre, the effect of rubber in concrete, application of rubberized concrete, effect of different temperature on rubberized concrete, effect of surface treatment on crumb tyre, effect of silica fume with crumb tyre, effect crumb rubber on compressive strength of concrete and weight loss at high temperature.

2.4.1 Introduction

Tyre rubber waste is an important waste that should be more concerned because of the increasing in number of vehicles. Besides that, the use of waste tyres can be used as fuel for cement kilns, feedstock for producing carbon black and reefs in marine environments as mentioned by (Hooton, et al., 2001). The classification of scrap rubber tyre usually has three broad categories such as chipped, crumb and ground rubber. (Sofi, 2017) stated that in year of 2030, the number of tyres from motor vehicles was expected to achieve 1200 million representing almost 5000 million tyres to be eliminated in a regular basis. The waste tyres disposal areas commit to the reduction of biodiversity and tyres hold toxic as well as soluble components. The common method used in Malaysia for control tyre rubber waste was landfilled disposed. (Thomas & Gupta, 2015) stated that the possible solution use of waste tyre rubber in the asphalt pavements was to incorporate into cement-based materials which to replace some of the natural aggregates and helps to dispose the waste tyres and some of the costly natural aggregates can be saved. The European Association of tyres and rubber produced estimate that 3.2 million tonnes of used tyres were eliminated in 2009 as stated by (Thomas & Gupta, 2016). The recovery ratio was 96% which on retreated or reused at 38% were recycled and 40% were used for energy production.

2.4.2 Effect of Rubber in Concrete

Crumb Rubber (CR) was been introduced and used as aggregates in plasters, mortars, concrete and asphalts. CR was good as an aggregate because it uses up impact energy and it reduced the risk of high-strength concrete (HSC) spalling with fire. Besides that, it has been observed that the replacement with 4% of level crumb rubber in Portland Pozzolana Concrete (PCC) based concrete the strength has achieved to 33 N/mm^2 as mentioned by (Bisht & Ramana, 2017). Some of authors recommended that the incorporating waste rubber into the concrete can improve the durability of concrete and provides eco-friendly way to recycle the waste rubber as mentioned by (Si, et al., 2017). The researchers investigated that the use of crumb rubber with the size from 1 mm to 4 mm can improve the freeze thaw durability of concrete when the content of rubber in concrete was limited to 10% by volume. The crumb rubber that had been recycled from crumbling tyres have size in between 1 mm to 2 mm with the specific gravity about 0.73 as mentioned by (Noaman, et al., 2015). The previous research on crumb rubber concrete materials (CRC) stated that the use of rubber in concrete can contribute its ductility, toughness, impact resistance, energy dissipation and damping ratio (Youssf, et al., 2016). Concrete mixed with crumb rubber has good toughness and impact strength than ordinary concrete and has better heat insulation as well as sound insulation properties. The toughness of concrete was noticeable improved by adding the crumb rubber due to more intense external impact only produced narrow cracks. At elevated temperatures, the voids that has been created by decomposed crumb rubber reduces the pore water pressure in steel fiber reinforced concrete specimens thus reducing crack initiation and propagation as mentioned by (Onuaguluchi & Panesar, 2014).

Furthermore, the improvement of impact strength in the rubber concrete because the elastic rubber particles that able to disperse local stress (He, et al., 2016). As stated by (Mendis, et al., 2017), the crumb rubber was a granulated rubber that has size usually less than 6 mm and can be used as replacement for sand in producing concrete. The size of rubber particles and maximum replacement ratio of 10% improved the dynamic increase factor as stated by (Noaman, et al., 2015). Crumb rubber has been used in asphaltic pavement and gives many positive effects such as good water resistance towards low absorption, low shrinkage, resistance towards acid, high impact resistance and better thermal and sound insulation (Li, et al., 2018). The performance of concrete paving blocks contains crumb rubber contribute high toughness resistance due to the energy absorbing capacity and recommended for concrete structures placed at areas of severe earthquake risk as well as production of railway sleepers (Azevedo, et al., 2012).

2.4.3 Effect of Surface Treatment on Rubber

Many researchers stated that the treating rubber aggregate with NaOH solution can improve the adhesion between rubber particles and cement paste. The air-void content of the samples with NaOH treated rubber aggregate slightly decreased compared with untreated rubber at the same rubber aggregate replacement level. It indicated the reduced porosity around NaOH treated rubber particles and tighter connection between NaOH treated rubber particles and cement paste as stated by (Si, et al., 2017). The treated rubber particles immersed in NaOH solution for 5 minutes before use in crumb rubber concrete (CRC) can reached 16% increase in compressive strength (Youssf, et al., 2016). The pre-treatment of rubber using NaOH solution can removes zinc stearate layers that can be found on the rubber surface of tyres from the manufacturing process. Moreover, by using with 10% of NaOH pre-treatment for rubber particle increases the roughness of outer surface which increase the bonding between rubber and the surrounding cement paste thus strength growth. (Youssf, et al., 2016) concluded that the best pre-treatment period using 10% NaOH solution in the range of 0.5h or 30 minutes improved higher compressive strength and tensile strength compared to other pre-treatment periods. The concrete with 5% rubber replacement ratio has higher compressive strength compared to the normal concrete as mentioned by (Guo, et al., 2017).

The previous research found that the performance of rubberized concrete processed with NaOH treated rubber makes the improvement of the compressive strength as well as moderate increase in flexural strength as stated by (He, et al., 2016). The function of NaOH was to remove the tire rubber soaked formulation additives and the saturated of NaOH solution in 24 hours cannot change the hydrophobic nature of rubber due to the water contact angle of the rubber surfaces still higher than 90˚ (He, et al., 2016).

2.4.4 Effect of Silica Fume on Rubberized Concrete

The use of silica fume increases the homogeneity and decrease the number of the large pores in cement paste which would lead to a higher strength material. The use of silica fume will denser interface between cement paste as well as coarse aggregates and might be an alternative way to increase the properties of the rubberized concrete for the structural applications as mentioned by (Guneyisi, 2004). The use of silica fume slightly increases the elastic modulus of rubberized concrete up to 15%. (Guo, et al., 2017) stated that the applied of silica fume into the concrete enhance the strength of concrete by replacing with 10% replacement of the cement content. (AbdelAleem & Hassan, 2018) mentioned that silica fume can be considered as one of the most efficient supplementary cementitious material (SCM) because of its high pozzolanic reaction and able to increase the impact resistance of the concrete.

Besides that, the incorporation of silica fume with the percentage of 10%, 15% and 20% in concrete that acts as replacement of cement weight considerably increase the compressive strength even at high temperature up to 800˚C (Mousa, 2017). Then, the researcher observed that the impact energy absorbed under rebound test for rubber fiber concrete with the replacement 5% and 10% of silica fume respectively. As stated by (Gupta, et al., 2015), the use of 10% replacement of cement by silica fume gives impact energy absorbed by control concrete increases marginally. Besides that, the increase in electrical resistivity of concrete more considerable in mixtures incorporating silica fume as mentioned by (Onuaguluchi & Panesar, 2014). The addition of silica fume influences the thickness of transition phase in mortars as well as the degree of orientation of CH crystals in it. The mechanical properties and durability increase due to improvement in interfacial or bond strength as mentioned by (Siddique, 2011).

2.4.5 Effect of Different Temperature on Rubberized Concrete

According to (Gupta, et al., 2017), the voids and crack in cement matrix with rubber fibers are responsible for decreasing in mechanical strength and durability of rubberized concrete at higher temperature and longer exposure duration which 300˚C and 120 minutes. The colour of concrete specimens changed from grey at 27˚C and becomes yellowish brown at 300˚C. Besides that, the researcher investigated the behaviour of concrete specimens containing crumb rubber, steel fiber and recycled aggregated when exposed to elevated temperature. In addition, the specimens were exposed at temperature 200˚C, 400˚C and 600˚C in 120 minutes and resulted the high quantity of crumb rubber had been considerably loss of compressive strength at elevated temperature as mentioned by (Gupta, et al., 2017). According to (Ahn, et al., 2016), when temperature was ranged from 600˚C to 800˚C, the expansion of cracks extended and reduce in compressive strength due to decarbonation of calcium carbonate of the calcareous aggregate (aggregate that composed of calcium carbonate).

Based on the previous studies conducted, the reductions in the enduring compressive strength and flexural strength after firing at temperatures 400˚C, 600˚C and 800˚C about one hour of concrete containing natural fine and coarse aggregate replacement at levels of 5%, 10% and 15% as mentioned by (Guelmine, et al., 2016). The performance of recycled crumb rubber mortar when exposure to elevated temperature at 150˚C, 200˚C, 300˚C and 400˚C has been observed where there had slight effect on the residual properties of mortar that exposed at 300˚C and strong effect when temperature reaches at 400˚C as stated by (Gupta, et al., 2017).

2.4.6 Effect of Compressive Strength on Rubberized Concrete

The reduction in compressive strength can be prevented when the replacement of crumb rubber not exceeded 20% of the total aggregate content (Thomas & Gupta, 2016). The concrete with NaOH treated rubber increased the compressive strength up to 15% at 28 days compared to non-treated rubber. As stated by (Thomas, et al., 2016) the use of silica fume with 5% in rubberized concrete helps to minimize the loss in compressive strength at elevated temperatures and temperature above 400˚C the compressive strength was related to the control concrete. (Mohammed & Adamu, 2018) stated that some researcher had investigated the increasing in the compressive strength by 5%, 7%, 9% and 10% of crumb rubber replacement and increasing in higher strength due to 10% silica fume has been used. From the previous research, by changing the other mixing parameters the similar compressive strength can be reached from different crumb rubber concrete (CRC) with different level of rubber content where for CRC of similar rubber content have different in compressive strength because of different proportions of other constituents of the mix as stated by (Mendis, et al., 2017).

Besides that, the researcher investigated that the compressive strength of rubberized concrete could be increased at elevated temperature of 150˚C by adding the microsilica up to 5% as stated by (Gupta, et al., 2017). By using pre-treated rubber, the compressive strength and modulus of elasticity increase up to 15% and 12% respectively as mentioned by (Youssf, et al., 2016). The use of cement content at 350 kg/m^3 for crumb rubber concrete (CRC) showed the highest significant improvement in concrete slump, compressive strength and tensile strength. Then, the compressive strength and tensile strength for CRC at 28 days increased by 20% and 7% with the cement content increase from 300 kg/m^3 to 350 kg/m^3 as mentioned by (Youssf, et al., 2016).

2.5 Weight Loss at High Temperature

As stated by (Mousa, 2017), the weight loss increased as the temperature of rubberized filled high strength concrete (HSC) as the significant weight loss was started at temperature of 400˚C and proceed to 800˚C. The concrete with 3% coarse and 5% fine rubber displayed smaller weight loss values compared to control concrete and the maximum weight loss for concrete without rubber and 3% fine rubber about 7.9% and 8.6% respectively at 800˚C mentioned by (Mousa, 2017). Most of the weight lost appears at the temperature in between 25-200˚C as stated by (Guo, et al., 2014). This happened because evaporation of water that lead to the weight loss of concrete specimens during heating process, appears at temperature in the range of 25-200˚C. (Topcu & Bilir, 2009) concluded that when exposed concrete to high temperature, the free water in capillary pores of the concrete such as the water in C-S-H gel and chemical bond, water in C-S-H and sulphoaluminate were evaporated. This process causes the shrinkage in concrete around 300˚C. Besides that, the initial weight of the controls had been measured after had been taken out of the water cure at 28 days where after 400˚C and 800˚C the weight was measured again and losses in their weight because of exposed to higher temperature effect as stated by (Topcu & Bilir, 2009).

2.6 Summary

In conclusion, this chapter discussed about the previous investigation that were carried out on the production of UHPC. Besides that, the investigation on production of concrete containing waste crumb rubber particles were also been reviewed. The selection of the constituent material in making UHPC based on strength, durability and impact resistance. Moreover, there are some principles need to be considered in making UHPC. In addition, UHPC also known as concrete that have high cementitious materials content and it also has very low w/c ratio compared to high strength concrete and conventional concrete. Based on literature reviews, there are few concepts had been applied to modify the mix design proportions and selection of raw materials used. In this research, the raw materials were important for producing UHPC such as ordinary Portland cement (OPC), coarse aggregate, sand, superplasticizer (SP), silica fume (SF) and water. In this current research, it has been decided to follow the mix proportions formulations that has been described by Mohd Faizal, (2017) as a control mix proportions.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter was described in detail the procedures that carrying out on the experimental works where to achieve the objectives of study. The methodology was drawn to ensure the study based on the scope of study. The summary for experimental process flow on plain UHPC and series of rubberized UHPC is shown in Figure 3.1.

In this study, there would have three type of pre-treated rubber which known as rubberized UHPC20, rubberized UHPC40 and rubberized UHPC60 with constant percentage level 5% of WCT. Each rubberized UHPC will be subjected to heat treatment at elevated temperature on 100˚C, 150˚C and 200˚C. The purpose for this research to evaluate the properties of rubberized UHPC when using waste crumb tyre with pre-treated rubber as coarse aggregate replacement.

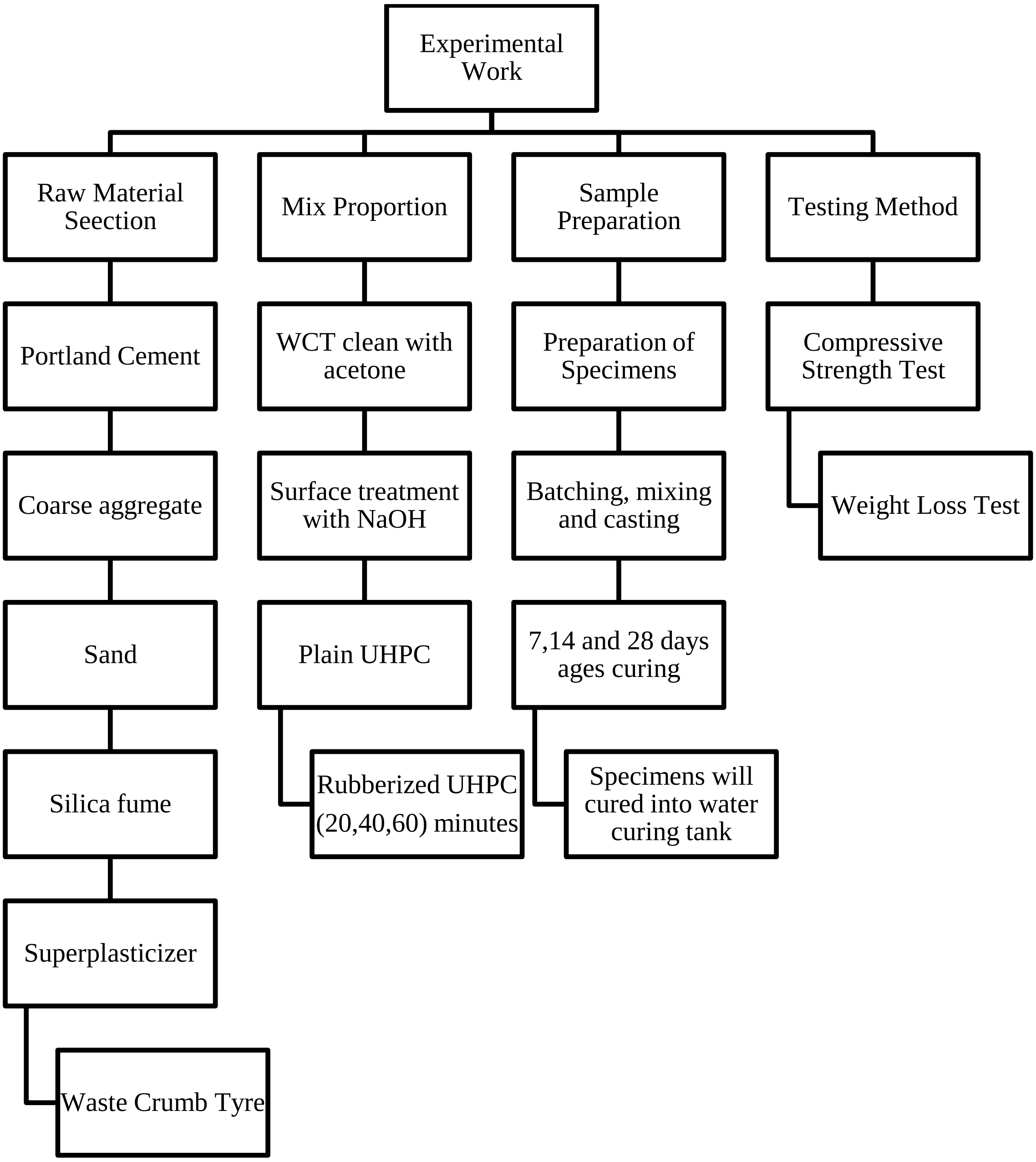

Figure 3.1 Flow chart process of experimental work

3.2 Raw Material Selection

3.2.1 Ordinary Portland Cement

In the current study, the ordinary Portland cement would be provided by local supplier was used as a binder for making plain UHPC and series of rubberized UHPC mixture. The properties of Portland cement based on standard BS EN 197-1: 2000 specifications. Besides that, the amount of cement content used for this study was constant at 720 kg/m^3 for plain UHPC and series of rubberized UHPC that contains three such as UHPC20, UHPC40 and UHPC60. The concrete produced from Portland cement was one of the most versatile construction materials used in the world because of the lowest cost materials. Then, Figure 3.2 shown the ordinary Portland cement (OPC) type 1 used in this study.

Figure 3.2 Ordinary Portland cement

3.2.2 Coarse Aggregate

Basically, aggregates are passive granular materials such as gravel, sand or crushed stone. The aggregate and sand act as inner filler for concrete mix. Aggregate was essential used for ingredient in concrete mixture. Even the preparation of UHPC was differ but the functions of aggregate would remain same as conventional concrete. Then, the performance concrete mixture will depend on the several factors such as gradation of aggregate, maximum size aggregate used, unit weight of aggregate and moisture content in aggregate. The coarse aggregates are particles greater than 4.75 mm and generally has range between 9.5 mm to 37.5 mm in diameter. The size of coarse aggregate will be used in this study was 10 mm. Before use the aggregate for concrete mixture, aggregate must be sieve first and passing through 10 mm. Then, the particle size distribution of coarse aggregate was determined when through sieve analysis. Figure 3.3 shown the size of coarse aggregate been used in this study for making UHPC mixture.

Figure 3.3 Coarse aggregate with size of 10 mm

3.2.3 Sand

Sand mining usually used as fine aggregate in concrete mixture. The sand was taken from the river and dried in temperature room. The sand would be used for this study was 3 mm and must undergo sieve to get the targeted size. The sand went through the sieve analysis according to standard BS EN 933-1: 1997 to determine the specification size of sand. The sand that passing through 3 mm will be taken for use as ingredient in concrete mixture. The sand used for concrete mix must be clean from dusk, stain clay and clear form salt ingredients. Next, Figure 3.4 displays the sand with the size of 3 mm been used for concrete mixture in UHPC.

Figure 3.4 Sand with size of 3 mm

3.2.4 Water

Water was essential for making UHPC mixture. For UHPC, the use of water was low amount of water content needed. Besides that, the water used in this study was tap water for plain UHPC and series of rubberized UHPC such as UHPC20, UHPC40 and UHPC60. The use of low amount of water in making UHPC leads to higher strength and durability but it would become difficult when to make the concrete. Then, this concrete would be added by superplasticizer for making it easy to form concrete. The use of tap water must be clean and clear from impurities. Water must clear or free from impurities to avoid effect on the process of hardening, volume stability and durability. The water also makes an important role in the mixes to form UHPC. The use of tap water will follow the standard MS 28: 1985 or BS 3148: 1959 that has been specified by the Public Work Department of Malaysia. In Figure 3.5 is shown the tap water been used in this study.

Figure 3.5 Tap water

3.2.5 Silica Fume

Silica fume (SF) or known as microsilica was an amorphous. Silica fume is one of the pozzolan material that been used in concrete mixture that contributes to pozzolanic reaction. The use of silica fume as pozzolanic material usually for high performance concrete. Besides that, silica fume was an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production industry. The reduction amount of high-purity quartz to silicon at temperature of 2000˚C will produces silicon oxide (SiO_2) vapours as mentioned by (Siddique, 2011). The silica fume was added to Portland cement concrete to increase its properties such as compressive strength, workability, bond strength and abrasion resistance. As mentioned by (Motahari Karein, et al., 2017), the silica fume was used to improve some properties of concrete such as increase in bonding strength whether aggregate to matrix or concrete to reinforcement, decrease in permeability, increase in resistivity against corrosive chemicals and increase in corrosion resistance of reinforced steel in concrete.

In this study, the constant replacement level of 10% silica fume from the total weight of cement materials was hired to produce plain UHPC and three series of rubberized UHPC mixtures. According to (Siddique, 2011), the involvement of silica fume in range between 0 to 15% as partial replacement lead to significant reductions porosity in mixtures. In addition, the reductions in porosity increases as the replacement level of 10% silica fume was used. The silica fume used in this study was shown in Figure 3.6.

Figure 3.6 Silica fume in UHPC mixtures

3.2.6 Chemical Admixture

There are several types of chemical admixtures were used to increase the construction properties of concrete such as workability, mechanical performance, durability and shrinkage properties. As mentioned by (Graybeal, 2011), chemical admixture (CA) such as accelerator, polycarboxylate-based superplasticizer and phosphonate-based superplasticizer were used in preparing UHPC. The effectiveness of chemical admixture based on several factors such as type and quantity of concrete, water content, mixing time, slump and temperature as mentioned by (Albayrak, et al., 2015). Moreover, the other various of admixtures were special chemicals that contribute corrosion inhibition, workability, bonding, shrinkage reduction, colouring and damp proofing.

The low water cement ratio was used for this study on plain UHPC and three series of rubberized UHPC at 0.20. Besides that, the dosage of superplasticizer used in concrete mixture was 3.5% from the total of cement materials for plain UHPC and three series of rubberized UHPC. The chemical admixture used in UHPC mixtures as shown in Figure 3.7.

Figure 3.7 Superplasticizer in UHPC mixtures

3.2.7 Waste Crumb Tyre

Waste crumb tyre was supplied by Jingyun Rubber Product Recycle Industries that located at Indera Mahkota, Kuantan, Pahang. The waste crumb tyre was used as partial replacement for coarse aggregate. In this study, the constant replacement level 5% was used for waste crumb tyre (WCT) from the total weight of coarse aggregate to produce plain UHPC and three series of rubberized UHPC. Besides that, the waste crumb tyre must undergo the sieve analysis to determine the specification size used in this study. The size of waste crumb tyre passing through 6 mm for added into three series of rubberized UHPC. The particle size distribution was determined according to standard BS EN 933-1: 1997. Then, in the Figure 3.8 show the size of waste crumb tyre (WCT) used in three series of rubberized concrete.

Figure 3.8 Waste crumb tyre with size of 6 mm

3.3 Mix Proportion Design

In this study, the preparation for mix proportion of plain UHPC and three series of rubberized UHPC were set up. Next, the plain UHPC was prepared as a control UHPC mix without added the waste crumb tyre (WCT). Then, the constant 5% of waste crumb tyre would be used as partial replacement of coarse aggregate. Before the waste crumb tyre added into the mix, these waste crumb tyre must be washed by acetone to remove zinc impurities and clean the dust. Then, the waste crumb tyre would be immersed into the sodium hydroxide solution, NaOH at different times which on 20, 40 and 60 minutes. Besides that, the three series of rubberized UHPC would be mixed together with the constant partial replacement of waste crumb tyre at 5%. These mixes were labelled as rubberized UHPC20, rubberized UHPC40 and rubberized UHPC60. The size use for the waste crumb tyre (WCT) was decided at 6 mm diameter. The addition of admixture namely as superplasticizer was hired into the plain UHPC and three (3) series of rubberized UHPC mixes as partial replacement of cement. In addition, the water cement ratio (w/c) was used in this study at 0.20. Table 3.1 classify the mix proportion of plain UHPC and three series of rubberized UHPC mixes. This mix proportion was adopted by Muhd Norhasri, (2014).

Table 3.1 Mix proportion of plain UHPC and series of rubberized UHPC

Mix Designation	Raw materials (kg/m^3)						
	OPC	SF	Agg	Sand	WCT	Water	SP
UHPC	720	80	433	800	0	160	25.2
UHPC20	720	80	411.4	800	21.7	160	25.2
UHPC40	720	80	411.4	800	21.7	160	25.2
UHPC60	720	80	411.4	800	21.7	160	25.2

Notes: OPC=ordinary Portland cement; SF=silica fume; Agg=aggregate; WCT=waste crumb tyre; SP=superplasticizer

3.4 Preparation of specimen

The preparation of UHPC specimens in this study required the amounts of all combining materials such as ordinary Portland cement (OPC), silica fume (SF), aggregate, sand and superplasticizer (SP) were weighed correctly based on the mix proportion that has been stated in Table 3.1. Besides that, the sieve analysis test has been completed on sand, coarse aggregate and waste crumb tyre (WCT) where to determine the specification particle size of distribution of these raw materials. The waste crumb tyre was used in this study as a partial replacement of coarse aggregate. Then, the mixing process would be used concrete pan mixer. The batching, mixing and casting process will be discussed on the subsequent sub-sections with more details. Moreover, the curing age of concrete and dimension of specimens also been discussed with more details on the following sub-sections.

3.4.1 Batching, Mixing and Casting

There are four (4) series of mix designation were prepared in this study which namely as plain UHPC and three series of rubberized UHPC with constant percentage of waste crumb tyre (WCT) as partial replacement of coarse aggregate. For this mix design, the plain UHPC act as control mix without added waste crumb tyre (WCT). Besides that, the concrete pan mixer was used for mixing process as shown in Figure 3.9.

In mixing process, the ordinary Portland cement (OPC) and silica fume (SF) were mixed together with water until consistently. The quantity of silica fume was weighted about constant 10% of ordinary Portland as partial replacement cement from the total weight of cement. Besides that, the admixture namely as superplasticizer (SP) would be added into the concrete pan mixer once mix homogenously. The superplasticizer was used at constant 3.5% for all mix designations such as plain UHPC and three series of rubberized UHPC. When the mix become cement paste, the coarse aggregate and sand would be poured into concrete pan mixer together with cement paste mixture until the mix consistently and flowable. Once the mix become flowable and consistent, the concrete mixture would be poured into the plastic moulds on (1/3) from total volume of concrete. Then, the plastic mould was placed on vibrator table to compact the fresh concrete mix. This process was repeated for two times on each plastic mould. The excess concrete mix on surface of plastic mould will be removed by using a trowel. After casting concrete, the plastic mould was kept at dry place with temperature room for 24 hours. When the concrete mix was dry, the plastic mould were removed as shown in Figure 3.10.

The series of rubberized mixture with constant level percentage of waste crumb tyre (WCT) was added together as partial replacement of coarse aggregate. The process for basic mixing procedures same as plain UHPC mixture. The mixture must include ordinary Portland cement (OPC), silica fume and water were mixed together until the mix become consistent flowable. After that, the admixture known as superplasticizer was gently added into the concrete pan mixer and mix simultaneously until become the cement paste. The coarse aggregate and sand would be added into the concrete pan mixer once the mix become flowable followed by poured the waste crumb rubber (WCT) together into the concrete pan mixer with constant level percentage WCT.

In this study, the procedure of pouring waste crumb tyre (WCT) into the concrete pan mixer was displayed in Figure 3.11. The replacement level of waste crumb tyre (WCT) was constant for three (3) series of rubberized UHPC with different pre-treatment. After the concrete mix was homogenous, the fresh concrete mix were casting on the plastic mould then were placed at vibrator table which similar casting procedure for plain UHPC mixture.

Figure 3.9 Concrete pan mixer for mixing process

Figure 3.10 Plastic mould kept at room temperature for 24 hours

Figure 3.11 Pour materials into concrete mixer pan

3.4.2 Dimensions of Specimens

The total for specimens are about 108 cubes with dimension of 100 mm x 100 mm x 100 mm were casted to be tested on the compressive strength test as shown in Figure 3.12. The cube specimens also were tested on weight loss test for initial and final weight as shown in Figure 3.13.

Figure 3.12 UHPC samples for compressive strength test

Figure 3.13 UHPC samples for weight loss test

3.4.3 Curing ages

The specimens must through the curing process. Curing is the process where concrete was conducted before it can be tested. Generally, the concrete specimens would be placed in the water and leave at certain period. In this study, the concrete specimens were stored in the water curing tank about 7, 14 and 28 days before treated to the compressive strength test and weight loss test. The plain UHPC and series of rubberized UHPC specimens in water curing tank for curing process were displayed in Figure 3.14. The method and procedure of curing based on the standard BS 1881: Parts 111: 1983 which has been specified by Public Work Department of Malaysia concrete specification. Besides that, the curing process was essential for the concrete specimens to avoid the loss of water from concrete that can lead to shrinkage problems.

Figure 3.14 Plain UHPC and rubberized UHPC were cured in water curing tank

3.5 Testing procedures

In this study, the testing method set up must focused on the strength properties of plain UHPC and three series of rubberized UHPC specimens. The strength properties can be determined by conducted the compressive strength test and weight loss test to find loss of water before and after the heat treatment. The testing that been conducted were observed to make comparison between plain UHPC and series of rubberized UHPC. The explanation about the testing were explained with more details on following sub-sections.

3.5.1 Heat Treatment

In this study, heat treatment has been used to investigate the series of rubberized UHPC specimens on the compressive strength at elevated temperature. After finish curing process at 7,14 and 28 days, the samples were left at room temperature for one (1) hour. Then, the rubberized UHPC samples were conducted to heat treatment process. The series of rubberized UHPC samples were heat up at elevated temperature such as 100˚C, 150˚C and 200˚C. The rubberized UHPC samples heated in furnaces as shown in Figure 3.15 at one (1) hour. When the rubberized samples completed the heat treatment process, the samples were left at room temperature for one (1) hour. The series of rubberized UHPC samples were subjected to compressive strength test.

Figure 3.15 Plain UHPC and rubberized UHPC were treat in furnace

3.5.2 Compressive Strength Test

Compressive strength test was carried out after completed curing ages at 7,14 and 28 days and heat treatment process. The objective of compressive strength test as carried out to investigate the strength on the specimens whether achieved the target strength at the ages 7, 14 and 28 days for plain UHPC samples and target strength on heat treatment process for series of rubberized UHPC specimens. The compressive strength test was carried out according to standard BS EN 12390-3: 2009 on specimens with dimension of 100 mm x 100 mm x 100 mm. The samples were tested by using an automatic compression testing machine with loading capacity of 1000 kN. In Figure 3.16 showed the compressive strength test machine for the samples to be tested. The maximum load and maximum strength applied to the samples were recorded. The average readings of maximum for strength tested on plain UHPC samples and series of rubberized UHPC samples were recorded as compressive strength of the specimens. Then, the compressive strength was calculated by using Equation 3.1.

$$compressive\ strength, \sigma = \frac{P}{A} \qquad 3.1$$

Where;

P= maximum load/force

A= cross section

Figure 3.16 Compressive strength testing machine

3.5.3 Weight Loss Test

In this study, the weight loss test was carried out before and after the heat treatment process. After completed curing process at the ages of 7, 14 and 28 days, the specimens were left at room temperature for one (1) hour. Before the samples being tested by heat treatment process, the specimens will be weighted first to get the initial weight of the samples before placed into the furnaces. After the samples finished the heat treatment process, then the samples were weighted to obtain the final weight of the samples. In addition, the calculation for percentage of weight of the samples were calculated by using Equation 3.2. In Figure 3.17 showed the equipment used to take the weight loss of the samples.

$$\frac{w_i - w_f}{wi} x\ 100\% \qquad 3.2$$

Where;

w_{i}= weight of sample before heat treatment

w_{f}= weight of sample after heat treatment

Figure 3.17 Weight loss measurement

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the result on the compressive strength test and weight loss test on the UHPC with the combination of pre-treated WCT in 20, 40 and 60 minutes were investigated. The WCT was used as replacement of coarse aggregate with fixed percentage which was 5% with different duration pre-treatment. The specimens were subjected to the compressive strength test and weight loss test. The experimental data that has been obtained will be shown in form of table and graph for better understanding to explain on analysis and comparison. This chapter was written in two (2) section such as Section 4.1 and 4.2. In Section 4.1, there were discussed about the result of compressive strength test and the effect using WCT as coarse aggregate replacement with different elevated temperature. For Section 4.2, there were discussed about the result of weight loss test using different elevated temperature.

4.2 Effect of Rubberized UHPC on Compressive Strength

The results of compressive strength of rubberized UHPC were obtained after curing in water for 7, 14 and 28 days and proceed to heat treatment process. The specimens were placed in a compressive machine test at concrete laboratory and the compressive strength test was conducted towards the cube specimens then be recorded. Besides that, the averages of sample were recorded for each curing days and different elevated temperature. There was sub-section in this result where to explain about effect of rubberized UHPC on compressive strength when subjected to pre-treatment WCT and effect of rubberized UHPC on compressive strength when subjected to different elevated temperature.

4.2.1 Effect of Rubberized UHPC on Compressive Strength subjected to Different Pre-Treatment WCT with Elevated Temperature

The results of compressive strength on 7 days curing period were summarized in Table 4.1. In Figure 4.1 shows the relationship of the compressive strength of fixed percentage of WCT with pre-treatment duration which were 20, 40 and 60 minutes. From the result, it was clear the compressive strength rubberized UHPC without pre-treatment WCT was reduced. At temperature 100˚C, the compressive strength reduced about 9.50% for 0% WCT. However, the 5% percentage of WCT with pre-treatment duration of 20, 40 and 60 minutes, it can be described the compressive strength slightly increase from 0 to 60 minutes. The rubberized UHPC20 on temperature 100˚ shows the compressive strength reduced about 19.70%, 14.50% for rubberized UHPC40 and 8.01% on rubberized UHPC60.

At temperature 150˚C, the strength reduced about 11.95% for 0% WCT. Then, the rubberized UHPC for UHPC20 was reduced about 23.55%, 19.19% for UHPC40 and UHPC60 reduced on 8.46%. For temperature 200˚C, the compressive strength reduced at 0% WCT about 29.93%. The rubberized UHPC20 was reduced about 28.98%, 31.28% on rubberized UHPC40 and rubberized UHPC60 strength reduced on 12.64%. From Figure 4.2, the rubberized UHPC60 had more comparable value compared to rubberized UHPC20 and UHPC40. In addition, the pre-treatment WCT at 60 minutes shows increasing compressive strength value among the others.

Table 4.1 Compressive strength for 7 days curing period

Temperature (℃)	0% WCT of Compressive Strength(MPa)	5% WCT of Compressive Strength(MPa) (20 min)	5% WCT of Compressive Strength(MPa) (40 min)	5% WCT of Compressive Strength(MPa) (60 min)
Control	84.1	49.55	59.4	63.33
100	76.11	39.79	50.79	58.26
150	74.05	37.88	48	57.97
200	58.93	35.19	40.82	55.32

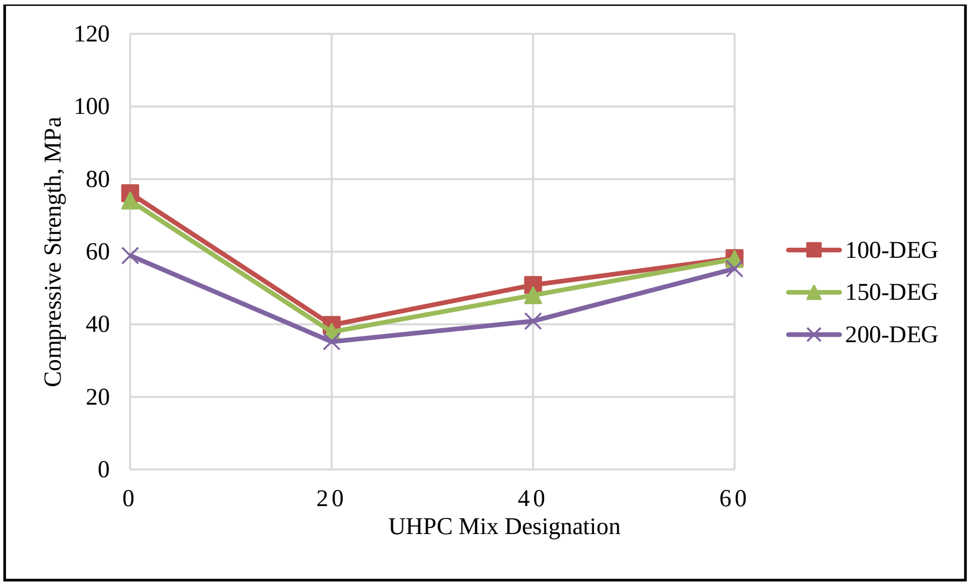

Figure 4.1 Compressive strength at 7 days subjected to pre-treatment WCT

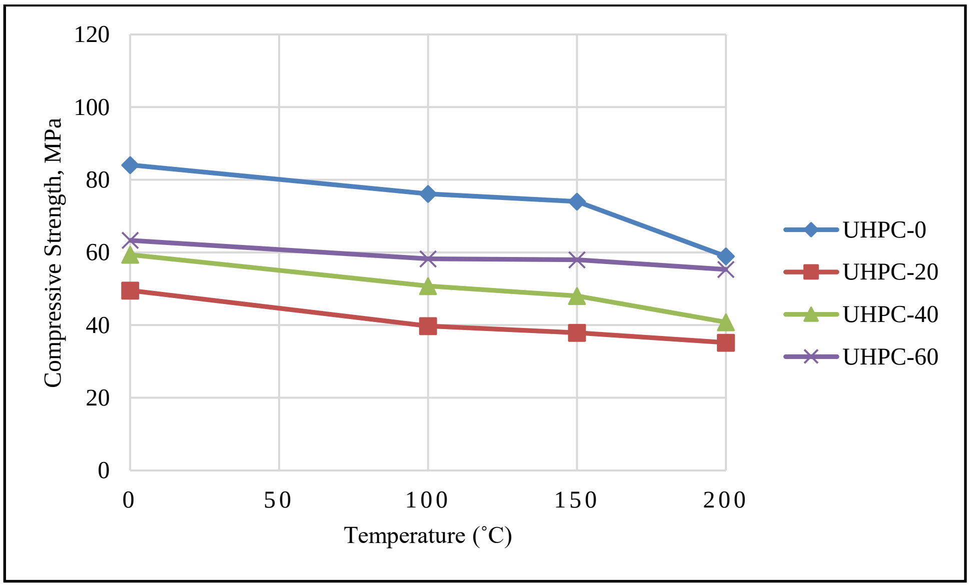

Figure 4.2 Compressive strength at 7 days subjected to elevated temperature

The compressive strength result for 14 days curing period were illustrated in Table 4.2. The results of compressive strength also had been evaluated in Figure 4.3. Based on the result, the compressive strength of the rubberized UHPC reduced from the control mix.

From Figure 4.3, when the temperature at 100˚C, the strength reduces about 5.95% for 0% WCT. However, the rubberized UHPC with different duration pre-treatment WCT has illustrated different value from UHPC20 to UHPC60. At temperature 100˚C, the UHPC20 was reduced in strength about 25.84%, 6.44% for rubberized UHPC40 and UHPC60 was reduced on 5.75%. At temperature 150˚C, the 0% WCT was reduced in strength about 14.05%. For rubberized UHPC20, the strength reduced about 27.43%, UHPC was reduced on 6.69% and 7.21% on rubberized UHPC60. At temperature 200˚C, the strength reduced about 24.53% for 0% WCT. For rubberized UHPC20, the strength reduced on 33.14%, 17.11% for rubberized UHPC40 and UHCP60 was reduced in strength on 11.25%. Based on the result, the UHPC60 has more comparable value in compressive strength among the others as shown in Figure 4.4.

Table 4.2 Compressive strength for 14 days curing period

Temperature (°C)	0% WCT of Compressive Strength(MPa)	5% WCT of Compressive Strength(MPa) (20 min)	5% WCT of Compressive Strength(MPa) (40 min)	5% WCT of Compressive Strength(MPa) (60 min)
Control	91.56	57.92	69.48	75.69
100	86.11	41.71	59.28	60.15
150	78.7	40.82	59.12	59.22
200	69.1	37.61	52.52	56.64

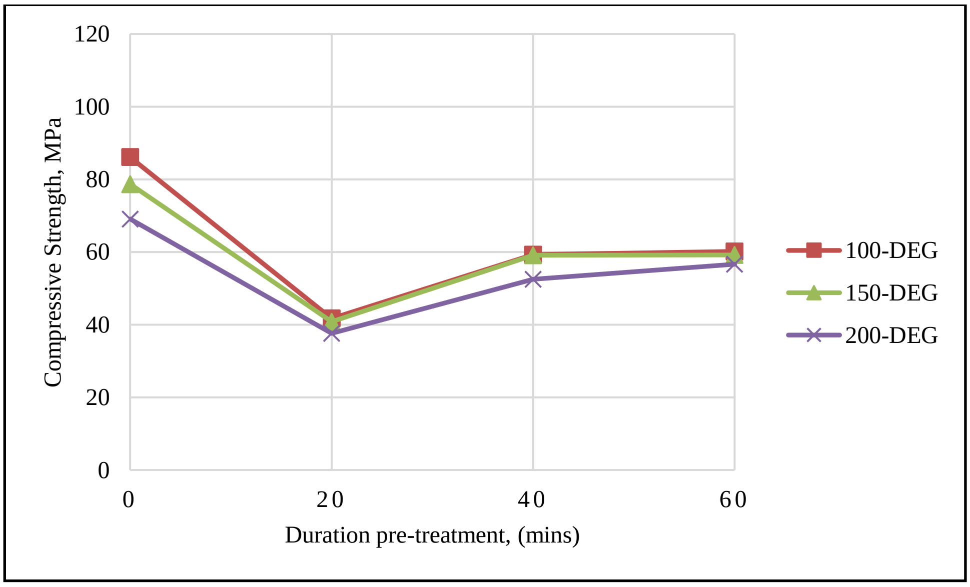

Figure 4.3 Compressive strength at 14 days subjected to pre-treatment WCT

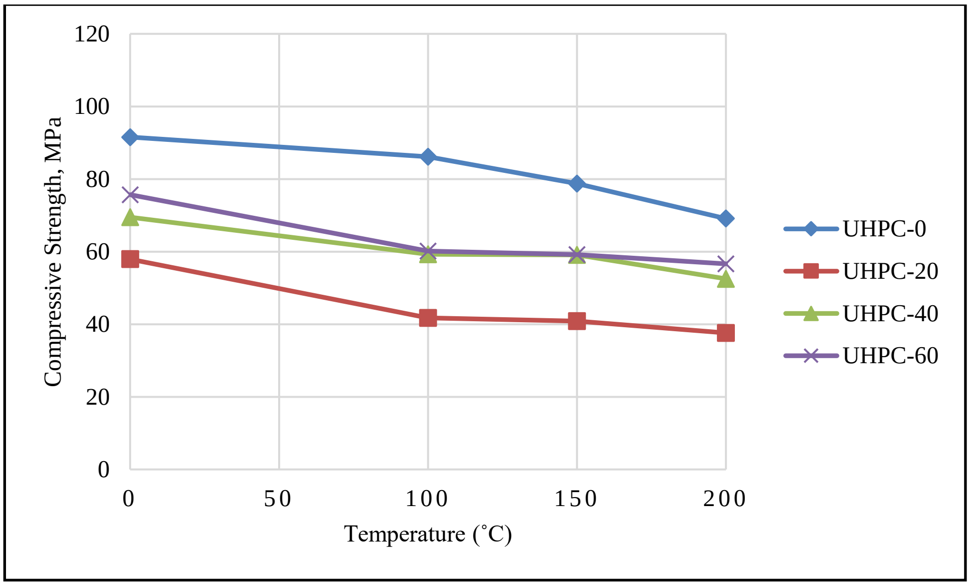

Figure 4.4 Compressive strength at 14 days subjected to elevated temperature

The compressive strength result for 28 days curing period were illustrated in Table 4.3. The results of compressive strength also had been evaluated in Figure 4.5. Based on the result, the compressive strength of the rubberized UHPC reduced from the control mix.

According to Figure 4.5, the temperature at 100˚C gives the result for 0% WCT on reduced in strength at 12.70%. However, the rubberized UHPC with pre-treatment duration shows different value from UHPC20 to UHPC60. The strength reduced for rubberized UHPC20 was 7.70%, 14.55% for rubberized UHPC40 and strength reduced on rubberized UHPC60 was 19.34%. At temperature 150˚C, the strength reduced for 0% WCT was 18.44%. for rubberized UHPC20, the strength reduced was 12.68%, 15.18% for rubberized UHPC40 and rubberized UHPC60 was reduced on 20.42%. Then, at temperature 200˚C, the compressive strength reduced on 31.41%, rubberized UHPC20 reduced in strength on 28.75%, 22.59% on rubberized UHPC40 and rubberized UHPC60 reduced at 26.43%. Based on the result, the rubberized UHPC60 had more comparable value compressive strength among the others as shown in Figure 4.6.

Table 4.3 Compressive strength for 28 days curing period

Temperature (°C)	0% WCT of Compressive Strength(MPa)	5% WCT of Compressive Strength(MPa) (20 min)	5% WCT of Compressive Strength(MPa) (40 min)	5% WCT of Compressive Strength(MPa) (60 min)
Control	111.8	61.05	75.09	83.75
100	97.6	56.35	59.32	62.69
150	89.55	53.31	58.88	61.87
200	75.31	43.5	53.74	57.2

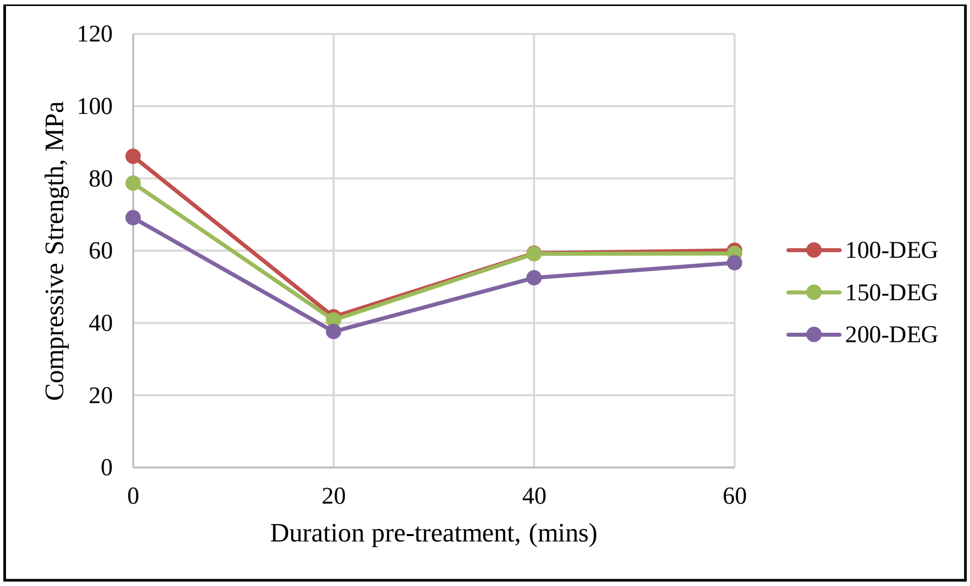

Figure 4.5 Compressive strength at 28 days subjected to pre-treatment WCT

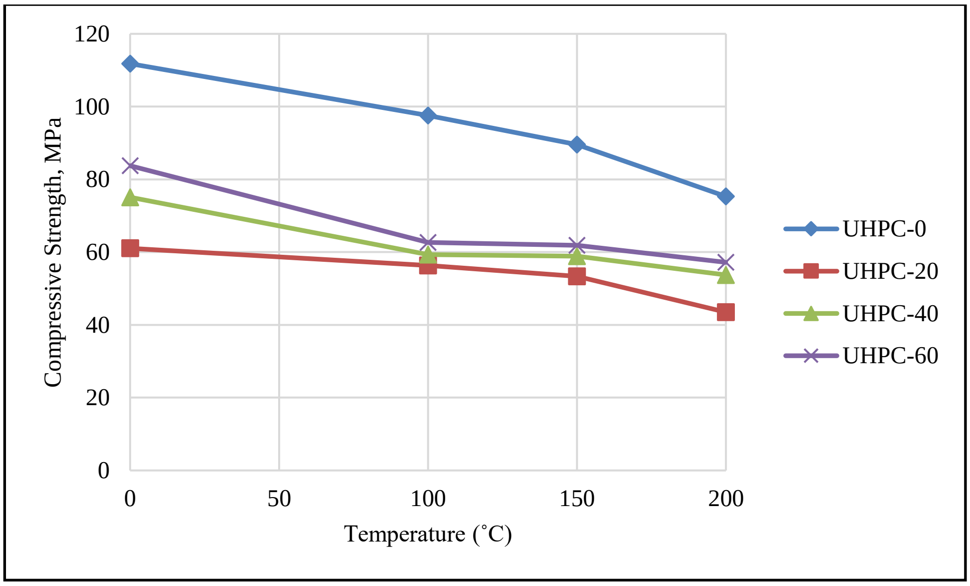

Figure 4.6 Compressive strength at 28 days subjected to elevated temperature

4.3 Effect of Rubberized UHPC with Different Pre-Treatment WCT on Weight Loss

The result of the weight loss of rubberized UHPC was obtained before and after heat treatment process. After curing process for 7, 14 and 28 days, the rubberized UHPC was weighted before proceed to the heat treatment process. The samples need to be left about one hour at room temperature before weighted. Then, the plain UHPC and rubberized UHPC with pre-treatment WCT were undergo heat treatment process for one hour in the furnace and after that the plain UHPC and rubberized UHPC with pre-treatment WCT were weighted again. The weight loss of plain UHPC and rubberized UHPC with pre-treatment WCT were calculated based on equation 3.2. The average of three samples were calculated and recorded for each curing days with different duration of pre-treatment WCT at elevated temperature. The weight loss of the samples showed how much water from the cube samples had been removed. In this study, there were relationship between the weight loss of plain UHPC and rubberized UHPC with pre-treatment WCT at the elevated temperature which were 100˚C, 150˚C and 200˚C.

The results of weight loss for 7 days curing period were summarized in Table 4.4. The results also illustrate in Figure 4.7. In Figure 4.7, the weight loss was decreased as the rubberized UHPC with pre-treatment WCT from 20 to 60 minutes. Moreover, the rubberized UHPC also decreased due to elevated temperature where the temperature increases as the percentage of weight loss also increases. The result in Table 4.4

illustrated the percentage of weight loss from 0% WCT to series of rubberized UHPC with pre-treatment WCT which were UHPC20, UHPC40 and UHPC60 at different elevated temperature.

At temperature 100˚C, the weight loss for 0% rubberized UHPC was 0.12% as control mix for 5% WCT of UHPC20, UHPC-0 and UHPC60. The rubberized UHPC20 value about 1.56%, UHPC40 was 0.86% and UHPC60 was 0.41% respectively. Then, the temperature of 150˚C where the 0% rubberized UHPC gives 0.21%. The rubberized UHPC20 was 1.85%, rubberized UHPC40 on 0.97% and 0.43% for rubberized UHPC60. For temperature 200˚C, the value of weight loss for 0% rubberized UHPC was 0.97%. The rubberized UHPC20 has value of weight loss at 3.42%, rubberized UHPC40 was 1.11% and 0.62% for rubberized UHPC60.

Based on this result, at temperature 100˚C, the weight loss of rubberized UHPC with pre-treatment WCT shows the increasing percentage over the percentage of 0% rubberized UHPC as control mix. In addition, the lowest percentage of weight loss for rubberized UHPC with pre-treatment WCT was UHPC60 at 0.41%. At temperature 150˚C, the percentage of weight loss for rubberized UHPC60 was lowest compared to UHPC20 and UHPC40 which were 1.85% and 0.97%. The percentage weight loss of 0% rubberized UHPC was 0.21%. The temperature of 200˚C gives the percentage of weight loss for rubberized UHPC60 at 0.62% which was the lowest among the others.

According to Figure 4.8, the percentage weight loss for 0% rubberized UHPC was 0.12% which has the lowest value compared to temperature at 150˚C and 200˚C on 0.21% and 0.97%. At 5% rubberized UHPC with pre-treatment, the UHPC20 was 1.56% has the lowest percentage of weight loss compared to 150˚C and 200˚C which on 1.85% and 3.42%. For UHPC40, the percentage weight loss at temperature 100˚C gives 0.86% that was lowest compared to 150˚C and 200˚C which were 0.97% and 1.11%. The percentage weight loss of rubberized UHPC60 on 100˚C was 0.41% which lowest compared to 150˚C and 200˚C at 0.43% and 0.62%. Based on the results, the rubberized UHPC60 has the lowest percentage of weight loss compared to rubberized UHPC20 and UHPC40 which contribute the pre-treatment WCT at 60 minutes was optimum as shown in Figure 4.8.

Table 4.4 Weight loss for 7 days curing period

Temperature (℃)	0% WCT of Weight Loss (%)	5% WCT of Weight Loss (%) (20 min)	5% WCT of Weight Loss (%) (40 min)	5% WCT of Weight Loss (%) (60 min)
Control	0	0	0	0
100	0.12	1.56	0.86	0.41
150	0.21	1.85	0.97	0.43
200	0.97	3.42	1.11	0.62

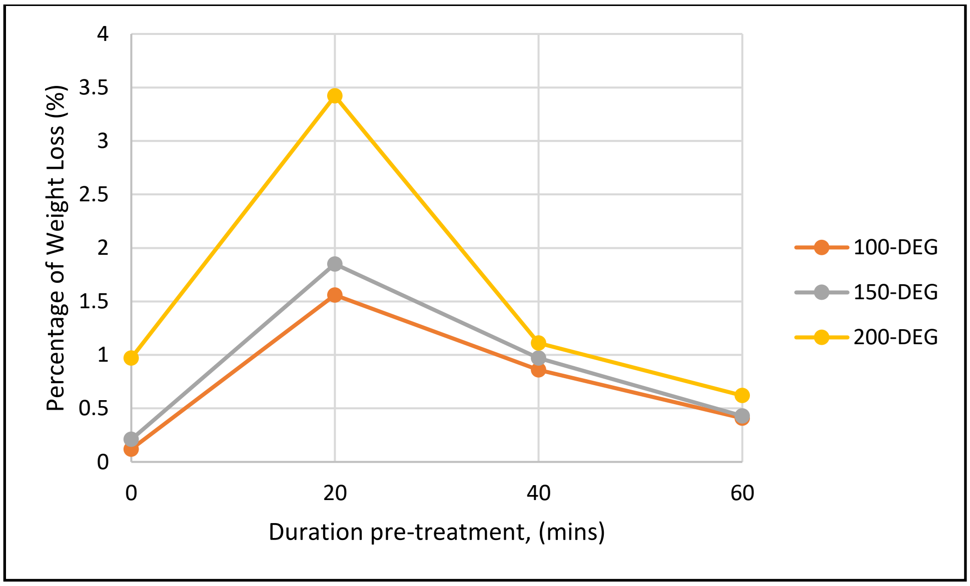

Figure 4.7 Weight loss at 7 days on UHPC and rubberized UHPC with pre-treatment WCT

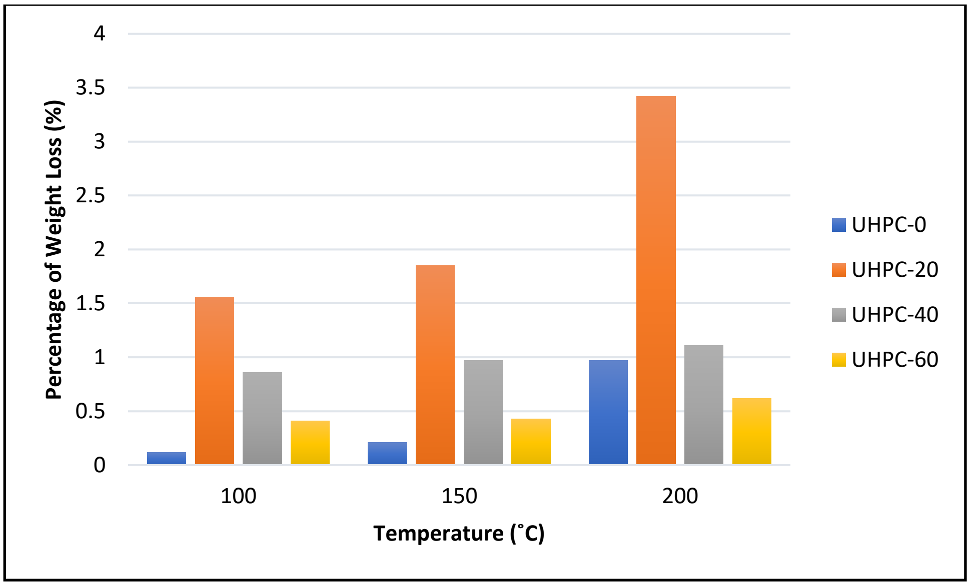

Figure 4.8 Weight loss at 7 days on UHPC and rubberized UHPC towards elevated temperature

In Figure 4.9, the relationship of the weight loss at 14 days using fixed 5% percentage of WCT with pre-treatment. There was less percentage of weight loss as the duration of pre-treatment WCT increases. The weight loss increases as the temperature increases based on result at Table 4.5.

At 100˚C, the percentage of weight loss for 0% rubberized UHPC was 0.54% as control mix for rubberized UHPC with pre-treatment WCT which known as UHPC20, UHPC40 and UHPC60. For UHPC20, the percentage of weight loss was 0.96%, 0.63% on rubberized UHPC40 and UHPC60 about 0.33%. The result shows the rubberized UHPC60 has the lowest value on percentage of weight loss compared to UHPC20 and UHPC40 at temperature 100˚C. At temperature 150˚C, the weight loss for 0% rubberized UHPC was 0.83% as control mix. The rubberized UHPC20 has the value of weight loss on 1.58%, rubberized UHPC40 was 0.70% and the weight loss for rubberized UHPC60 about 0.49%. From the temperature 150˚C, the result shows the percentage of weight loss for rubberized UHPC-60 was the lowest among the others. At temperature 200˚C, the weight loss for 0% rubberized UHPC was 0.84%. The rubberized UHPC20, the percentage weight loss was 2.20%, 0.84% for rubberized UHPC40 and UHPC60 about 0.57%. The result shows the lowest percentage of weight loss was obtained by rubberized UHPC60.

According to Figure 4.10, the percentage weight loss for 0% rubberized concrete was 0.54% which has the lowest compared to 150˚C and 200˚C at 0.83% and 0.84%. For 5% rubberized UHPC with pre-treatment, the rubberized UHPC20 has the lowest value on 100˚C at 0.96% compared to 150˚C and 200˚C which had 1.58% and 2.20%. For 5% rubberized UHPC40, at temperature 100˚C has the lowest value of percentage weight loss on 0.63% compared to 150˚C and 200˚C which contribute to 0.70% and 0.84%. Then, the 5% rubberized UHPC60, the lowest value for percentage weight loss was 0.33% compared to 150˚C and 200˚C.

Table 4.5 Weight loss for 14 days curing period

Temperature (℃)	0% WCT of Weight Loss (%)	5% WCT of Weight Loss (%) (20 min)	5% WCT of Weight Loss (%) (40 min)	5% WCT of Weight Loss (%) (60 min)
Control	0	0	0	0
100	0.54	0.96	0.63	0.33
150	0.83	1.58	0.7	0.49
200	0.84	2.2	0.84	0.57

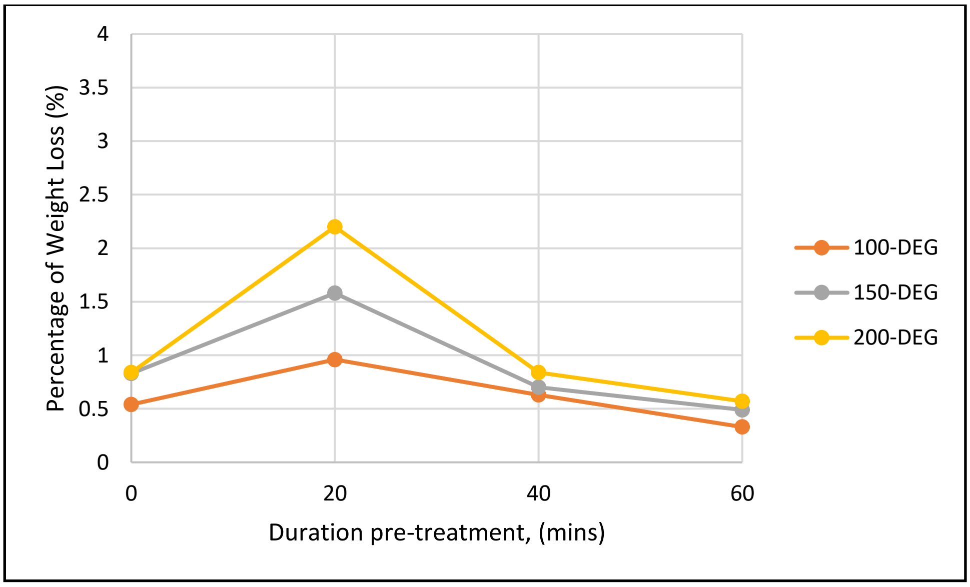

Figure 4.9 Weight loss at 14 days on UHPC and rubberized UHPC with pre-treatment WCT

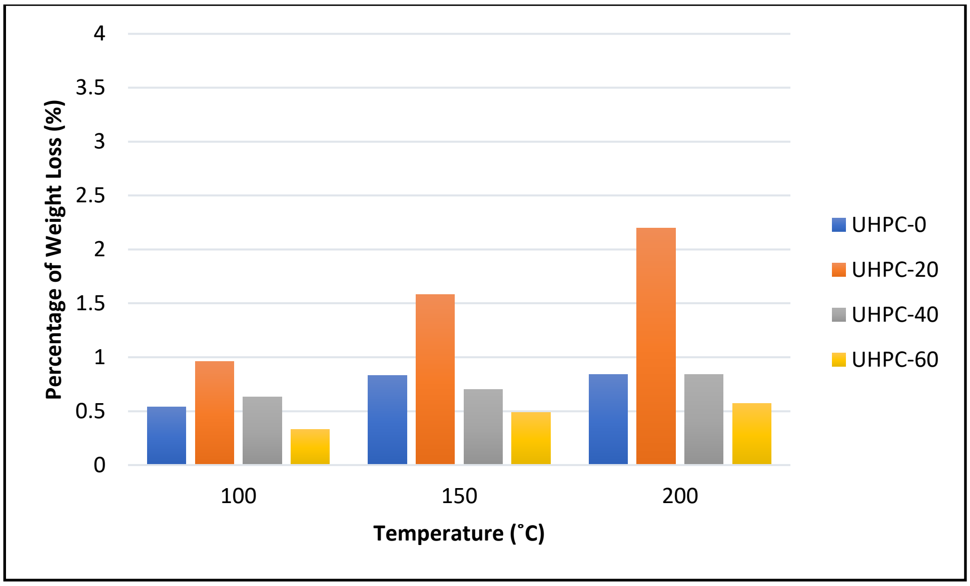

Figure 4.10 Weight loss at 14 days on UHPC and rubberized UHPC towards elevated temperature

In Figure 4.11, the relationship of the weight loss at 28 days using fixed 5% percentage of WCT with pre-treatment WCT. There was less percentage of weight loss as the duration of pre-treatment WCT increases. The weight loss increases as the temperature increases based on Table 4.6.

At temperature 100˚C, the weight loss for 0% rubberized UHPC was 0.10% as control mix for 5% WCT of UHPC20, UHPC40 and UHPC60. The rubberized UHPC20 value about 0.98%, UHPC40 was 0.68% and UHPC60 was 0.10% respectively. Then, the temperature of 150˚C where the 0% rubberized UHPC gives 0.13%. The rubberized UHPC20 was 1.37%, rubberized UHPC40 on 0.77% and 0.34% for rubberized UHPC60. At temperature 200˚C, the value of weight loss for 0% rubberized UHPC was 0.97%. The rubberized UHPC20 has value of weight loss at 2.78%, rubberized UHPC40 was 0.84% and 0.44% for rubberized UHPC60.

Based on Figure 4.12, the result for percentage weight loss for 0% rubberized UHPC at 100˚C was 0.10% which has the lowest value compared to 150˚C and 200˚C which were 0.13% and 0.68%. Then, the 5% rubberized UHPC20 was obtained at 0.98% compared to temperature at 150˚C and 200˚C on 1.37% and 2.78%. For 5% rubberized UHPC40, the value at 100˚C for percentage weight loss was 0.68% which the lowest value among the 150˚C and 200˚C which at 0.77% and 0.84%. At 5% rubberized

UHPC60, the percentage weight loss was 0.10% compared to 150˚C and 200˚C which at 0.34% and 0.44%. From the result that has been obtained, the 5% rubberized UHPC60 has the lowest value among the others.

Table 4.6 Weight loss for 28 days curing period

Temperature (℃)	0% WCT of Weight Loss (%)	5% WCT of Weight Loss (%) (20 min)	5% WCT of Weight Loss (%) (40 min)	5% WCT of Weight Loss (%) (60 min)
Control	0	0	0	0
100	0.1	0.98	0.68	0.10
150	0.13	1.37	0.77	0.34
200	0.68	2.78	0.84	0.44

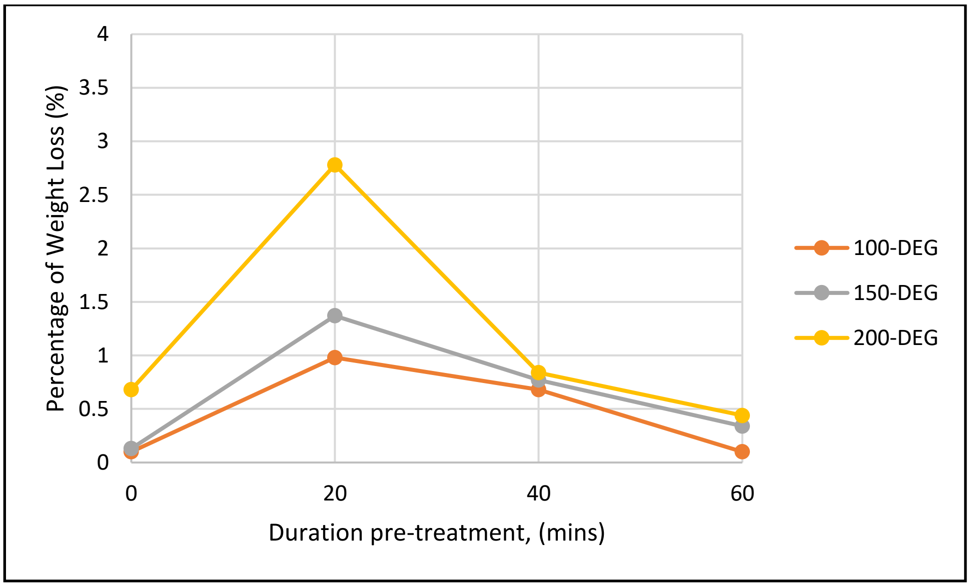

Figure 4.11 Weight loss at 28 days on UHPC and rubberized UHPC with pre-treatment WCT

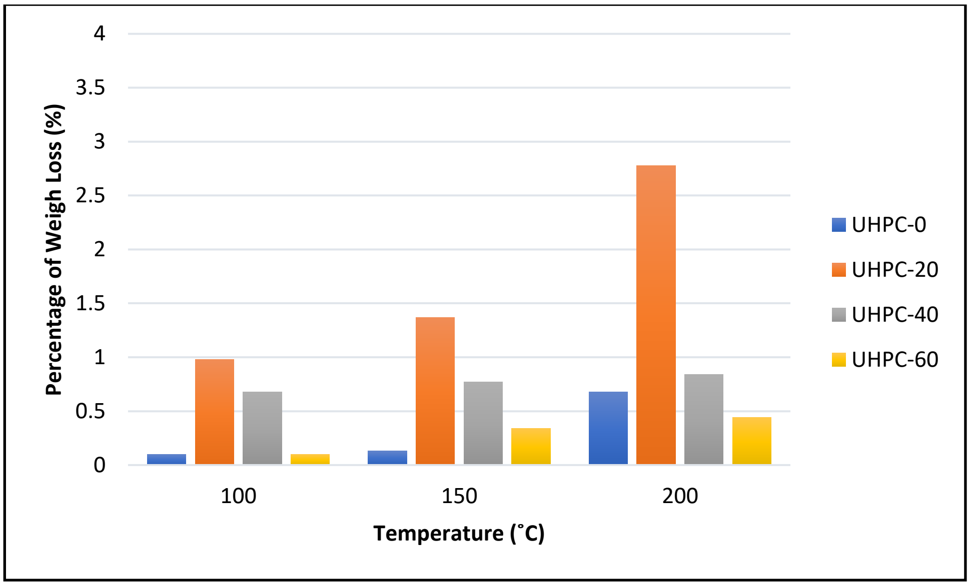

Figure 4.12 Weight loss at 28 days on UHPC and rubberized UHPC towards elevated temperature

CHAPTER 5

CONCLUSION

5.1 Introduction

The main objective in this study were to determine the compressive strength of rubberized UHPC at different elevated temperature. Then, the second objective to determine the effect on weight loss of rubberized UHPC when subjected at different elevated temperature. The analysis has been carried out to obtain the result to be conclude towards achieving the objectives of study.

5.2 Conclusion

In this study, there are four different series of mixture. There are 0, 20, 40 and 60 minutes duration of pre-treatment. There are represent UHPC, UHPC-20, UHPC-40 and UHPC-60. The UHPC and rubberized-UHPC were conducted at different elevated temperature which are 100˚C, 150˚C and 200˚C based on curing ages at 7, 14 and 28 days. From the result, the conclusion can be drawn as following:

i. It is found that the pre-treatment WCT contribute the higher compressive strength of rubberized-UHPC from duration treatment 20, 40 and 60 minutes is at 60 minutes but the WCT replacement was lower than plain UHPC.

ii. The plain UHPC contributes higher compressive strength compared to rubberized UHPC with pre-treatment WCT when exposed to different elevated temperature. Among the rubberized-UHPC samples, UHPC-60 exhibits lowest compressive strength towards the different elevated temperature.

iii. The higher the temperature of heat treatment, the lowest compressive strength for UHPC and three (3) rubberized UHPC were recorded.

5.3 Recommendation

In utilizing of Waste Crumb Tyre (WCT) could contributes in manufacturing and construction industry. In other hand, regarding to this study, there are some improvements could be done to investigate the potential of WCT in UHPC.

i. The specimen must be fully matured before test with heat treatment at different elevated temperature since the compressive strength was reduced after exposed to elevated temperature.

ii. Waste crumb tyre (WCT) need to be treated precisely before mix with the UHPC to ensure WCT can withstand when exposed to elevated temperature.

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