CHLORIDE RESISTANCE PENETRATION OF RUBBERIZED-ULTRA-HIGH PERFORMANCE CONCRETE (UHPC)

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ABSTRAK

Pelupusan sisa pepejal dari produk sampingan sisa adalah salah satu isu alam sekitar yang utama pada masa kini seperti pelupusan tayar. Penggunaan tayar kitar semula sebagai pengganti agregat dalam konkrit biasa dan konkrit kekuatan tinggi telah diterokai. Kini, UHPC telah menjadi terkenal kerana kekuatan mampatan tinggi yang boleh mencapai lebih daripada 100 MPa. UHPC dihasilkan dengan menggunakan nisbah simen air rendah dan menggantikan simen Portland biasa (OPC) dengan 10% silika asap yang bertambah baik dengan ketara kebolehkerjaan, kekuatan dan ketahanannya. Dalam kajian ini, satu idea untuk menggantikan jumlah agregat dengan sisa serbuk getah (WCT) dalam campuran UHPC telah dikaji. WCT diganti secara berterusan pada 5% daripada jumlah berat agregat. Zarah WCT tertakluk kepada proses pra-rawatan dengan merendam zarah WCT dalam larutan NaOH selama 20, 40 dan 60 minit. Dua (2) jenis ujian iaitu ujian ketahanan dan penembusan klorida telah dijalankan. Untuk ujian ketahanan, sampel UHPC telah direndam dalam larutan 3% NaCl selama 7, 14 dan 28 hari dan spesimen yang terdedah telah diuji dari segi kekuatan dan penurunan jisimnya. Kedalaman penembusan klorida UHPC yang terdedah juga dinilai. Keputusan menunjukkan bahawa kekuatan mampatan untuk keseluruhan getah-UHPC jauh lebih rendah dalam kekuatan berbanding dengan UHPC biasa. Kedalaman penembusan klorida untuk getah-UHPC adalah nilai yang lebih tinggi berbanding dengan UHPC biasa. Dalam getah-UHPC, UHPC-20 mempunyai nilai yang lebih tinggi untuk kedalaman penembusan klorida daripada UHPC-40 dan UHPC-60. Hasilnya menunjukkan bahawa UHPC-60 meningkatkan penembusan tahan klorida daripada UHPC-20 dan UHPC-40.

ABSTRACT

Solid waste disposal from waste by-products are one of the major environmental issue nowadays such as tires disposal. The utilization of recycled tyre as aggregate replacement in normal concrete and high strength concrete has been explored. Nowadays, UHPC has become famous due to high compressive strength that can achieved more than 100 MPa. UHPC was produced by using low water cement ratio and replacing the ordinary Portland cement (OPC) with 10% silica fume improved significantly its workability, strength and durability. In this study, an idea to replace the amount of aggregate with waste crumb tyre (WCT) in UHPC mixture was investigated. The WCT was replaced constantly at 5% from the total weight of aggregate. The WCT particle was subjected to pre-treatment process by immersing the WCT particles in NaOH solution for 20, 40 and 60 minutes. Two (2) type of testings namely durability test and chloride penetration were conducted. For durability test, the UHPC samples were immersed in 3% NaCl solution for 7, 14 and 28 days and the exposed specimens were tested in terms of its strength and weight loss. The chloride penetration depth of exposed UHPC was also evaluated. The results showed that the compressive strength for entire rubberized-UHPC significantly lowest in strength as compared to plain UHPC. The chloride penetration depth for rubberized-UHPC was higher value as compared to plain UHPC. In the rubberized-UHPC, UHPC-20 has higher value for chloride penetration depth than UHPC-40 and UHPC-60. The results revealed that UHPC-60 enhanced the chloride resistant penetration than UHPC-20 and UHPC-40.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
m^3	Meter cubic
mm	Milimeter
MPa	MegaPascal

LIST OF ABBREVIATIONS

$AgNO_3$	Silver Nitrate
HPC	High Performace Concrete
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
UHPC	Ultra-High performance Concrete
WCT	Waste Crumb Tyre

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Ultra High Performance Concrete or known as UHPC is a cementitious composite materials composed of an optimized gradation of granular constituents and water-to-cementitious materials ratio less than 0.25. The compressive strength and tensile strength of UHPC was greater than 150 MPa and the value tensile strength was greater than 5 MPa, respectively (Graybeal, 2011). UHPC is one of the latest advances in concrete technology and it addresses the shortcomings of many concretes today. The discontinuous pore structure in UHPC can reduces the liquid ingress and also increasing the durability of UHPC when compare to those of conventional concrete and high performance concrete (Graybeal, 2011).

As well known, UHPC was produced by using quartz as aggregate, therefore it become very expensive. To reduce the cost of production, the quartz can be replaced by using alternative material from waste products. In this study, the present of waste crumb tyre as aggregate replacement will be introduced. Nowadays, a millions of rubber tubes or rubber tires have been produced for human consumption every year. This excludes waste tyre that can only cause mosquito reproduction and also cause increased earth temperatures due to widespread burning of waste tyre. This causes a very high environmental pollution. In order to reduce pollution problem, the use of waste crumb tires (WCT) is one of the alternative to replace the aggregate in the UHPC.

However, previous researcher found that the bonding or the strength between the rubber particles with the cement matrix in concrete were weak (Ankit, 2016). To overcome the problem on bonding between the rubber particles with the cement matrix about to increase the strength of rubberized-UHPC there is the method that the past researchers were done. Several researchers, Ankit, (2016) and Sofi, (2016) found that the process of surface treatment by using chemical solution has been suggested. The chemical solution used for the surface treatment of WCT is sodium hydroxide (NaOH). NaOH solution is a great chemical in cleaning agent to take out the dirt and cleans the surface of rubber. Thus improves the bonding between the waste crumb tyres with cement matrix of concrete.

The modification of UHPC containing WCT needs future investigation on its durability such as chloride resistance penetration. The UHPC specimens were immersed in sodium chloride (NaCl) solution to investigate the durability of rubberized-UHPC. In this present study, the tests conducted are compressive strength and chloride penetration.

1.2 Problem Statement

Traditionally, to produce the ultra-high performance concrete (UHPC), the materials that used are Portland cement, silica fume, fine sand, ground quartz, water and superplasticizer. However, the quartz is very expensive because it is natural resources and it became limited sources in Malaysia. Therefore, to reduce the cost of the UHPC, the quartz should be replaced with other waste materials. In this study the waste material used is waste crumb tyre. In Malaysia, it is estimated that of 57,391 to 8.2 million tons production of waste tires every year where, more than 50% amount of waste tires were disposed wrongly (Thiruvangodan and Sandra, 2006). Due to increases of the waste tyres, the price of the waste tyres become cheap and easy to obtained. Several researchers were used the waste tyres as aggregate replacement material in the normal concrete (Michelle, 2006; Ankit, 2016). In Malaysia, there are many of the waste tyres were dump at the landfill of Madang, Kayu, Telipok, Sabah. The expanse of this landfill was about 0.5 hectares and it can support all the waste tyre in Telipok. However, this placed was destroyed by fired and resulting air pollution due to this incident in January 2017. Therefore, this is the opportunity to researcher to make the innovation to use the WCT as aggregate replacement in concrete.

However, Ankit (2016) has been observed that the bonding between the rubber particles in cement matix was very weak. To improve the bonding between the rubber particles with the cement matrix, the surface treatment of rubber particles should be treated. NaOH solution is perfect as cleaning agent to remove the dirt and also clear the surfaces. There are different in duration of immersion WCT into NaOH solution from the previous research. Therefore, the further investigation on the duration of immersion were be carried out. All the rubberized-UHPC specimens will be exposed into chloride to investigate the durability performance. Effect on different duration of WCT surface treatment subjected to chloride penetration was main concern in this study.

1.3 Objective of Study

i. To determine the effect of using different pre-treatment duration on surface of waste crumb tyre particles as aggregate replacement in UHPC.
ii. To determine the compressive strength of rubberized-UHPC subsequently immersed in sodium chloride (NaCl) solution.
iii. To examine the chloride penetration profiles on exposed rubberized–UHPC immersed in NaCl solution.

1.4 Scope of Study

The present study focused on the determinants of strength loss and chloride resistance penetration of rubberized-UHPC incorporated waste crumb tyre. In order to produce rubberized-UHPC the aggregate in UHPC was replaced with the waste crumb tyre (WCT). To achieve the objectives, this study was carried five (5) stages as outlined in the following sequences.

Stage 1: Pre-Treatment on Surface of Waste Crumb Tyre Particles

In order to use WCT as an aggregate replacement in UHPC production, the raw particles of WCT underwent to the pre-treatment process. Before the treatment process, the WCT particles were cleaning using acetone to remove the probable impurities on the WCT surface. Then, WCT was immersed in NaOH solution as pre-treatment. NaOH is a powerful cleansing agent removes the dirt and cleans the surface of rubber which enhances the bonding between the rubber aggregate with the other materials in concrete. There are four (4) different in duration of the immersion 0, 20, 40 and 60 minutes.

Stage 2: Preparation of Concrete Mix Proportion

In this study, there are four (4) different of mixtures where prepared consists of plain ultra-high performance concrete (UHPC) and three (3) rubberized-UHPC. Each series of rubberized-UHPC consists of different duration of pre-treatment process at 20, 40 and 60 minutes of NaOH immersion. The rubberized-UHPC may be labelled as UHPC-20, UHPC-40 and UHPC-60 respectively. In addition, the materials that been used in this rubberized-UHPC is ordinary Portland cement (OPC) which is by follow standard BS EN 197-1:200, fine sand with size 5 mm. Then 10% silica fume undensified by the weight of OPC was added. The crushed gravel was used as aggregate with size 10 mm, waste crumb tyre been doing sieve analysis to get the actual size about 20 mm, water and superplasticizer. The water cement ratio (w/c) is about 0.2 were prepared namely cube and cylinder. There two type of specimens which is the first type are 36 cube with size 100 mm x 100 mm x100 mm and the second type are 36 cylinder with size diameter about 150 mm and long 300 mm.

Stage 3: Curing and Immersion of Rubberized-UHPC Specimens in 3% Sodium Chloride (NaCl) Solution

All the were comprise of plain UHPC and rubberized-UHPC specimens were cured in water for 7 days before the entire specimens were exposed to aggressive enviroment. After 7 days of cured in water, all the specimens were immersed in 3% NaCl solution. All the specimens immersed in 3% NaCl for 7, 14 and 28 days. For the chloride penetration test, the upper and bottom surfaces of the cylindrical specimen was sealed using water-proofing membrane before the specimens immersed in 3% NaCl solution.

Stage 4: Method

In this stage, there are two (2) types of testing method were conducted. The compressive strength and tensile strength were be the strength performance in this study to be conducted. The strength test were conducted after the specimens were immersed in 3% of NaCl for the 7, 14 and 28 days. On the other hand, to measure the content of the chloride in the UHPC and rubberized-UHPC the colorimetric method ($AgNO_3$ sprayed method) was conducted to the cylinder specimens after the specimens were taken out from the 3% NaCl.

Stage 5: Data Analysis

All the data obtained was presented in graph to show the different in compressive strength and also the chloride penetration depth of UHPC and the rubberized-UHPC. The analysis was also performed by using Design Expert, to determine the possibility relationship between strength and chloride resistance penetration.

1.5 Significant of Study

The importance of this study is to. In addition, the use of waste crumb tyres in UHPC can also reduce the environmental pollution. This because nowadays many of the construction project were developed in this era. That mean the quantity of the concrete material like cement and aggregate must be in high demand and it would affect the environmental issues. So to control the environment issue, the new method or alternative must be carried out. The compressive strength of this UHPC is high about three to four than the ordinary concrete compressive strength. In this study, the replacement of the aggregate with the WCT would be the new knowledge to the industry out there and also new for me. In other word, the possibility do using WCT as aggregate replacement can reduce the chloride penetration inside rubberized-UHPC.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter was reviewed in details the definition of UHPC, comparison between high performance concrete and ultra-high performance concrete (UHPC), historical of UHPC, applications on UHPC, advantage of UHPC, compressive strength of UHPC, durability, workability, effect of curing in UHPC, mix proportion, chlorination

2.2 Definition of UHPC

Ultra High Performance Concrete (UHPC) is a cementitious composite material that compose to the optimized gradation of granular component, which is the ratio for the water to cementitious is less than 0.25. The value for the compressive strength of UHPC can achieved more than 150 MPa and the tensile strength greater than 5 MPa. UHPC has a discontinuous pore structure that decreases fluid entrance, essentially improving durability when compared with high-performance concrete and conventional concrete (Graybeal, 2011).

The material that been used in the UHPC were Portland cement, fine sand, silica fume, ground quartz, superplasticizer and water. In this era, the quartz is very expensive compared to the other material. To reduce the cost of production, the quartz can be changed by using the other material by waste products. The waste product that been used in this study is waste crumb tyre (WCT).

Before the tyre was used, the WCT should be treated first by chemical solution. The chemical that been used is sodium hydroxide (NaOH). This study is to know the durability of the rubberized-UHPC towards chloride attacks.

2.3 Comparison between High Performance Concrete and Ultra High Performance Concrete

The high performance concrete (HPC) almost same like the Ultra high performance concrete (UHPC). Regardless of actuality that up to how HPC has been practiced mainly in high strength concrete, it is unavoidable that in the consistently future HPC will be must determine and utilized for its durability other than particularly for its high compressive strength. In the United States, the definition of High Performance Concrete by the Federal Highway Administration includes eight performance characteristics: freeze-thaw durability, scaling resistance, abrasion resistance, chloride penetration, compressive strength, modulus of elasticity, shrinkage, and creep (M. Schmidt, 2004).

Clearly that, “high” is a relative term. The term “ultra-high” is more so. The Laurentienne Building in Montreal, built in 1984, used a 106 MPa high performance concrete and the Two Union Square Building in Seattle, USA, built in 1988, utilized a 145 MPa high performance concrete. Going to a UHPC with strength higher than 200 MPa certainly is another big step forward (M. Schmidt, 2004).

The water/binder ratio for the HPC must be greater than 0.30 and the compressive strength about 40 to 80 MPa. The material that been used was almost same like UHPC but the amount was different like HPC used 10% of silica fume to achieve a 100 MPa compressive strength (Sherbrooke, 1997). Then for the UHPC the water-to-cementitious materials ratio less than 0.25. The compressive strength and tensile strength of UHPC was greater than 150 MPa (Graybeal, 2011).

2.4 Historical of UHPC

In the 1960s, concrete with a compressive strength of up to 800 N/mm^2 has been produced and developed under specific laboratory conditions and it were compacted under high pressure and thermally treated. In the mid-1980s the idea was destined to grow fine grained concrete with very dense and homogeneous cement matrix. due to the use of different inert or reactive mineral additions they were called “Reactive Powder Concretes (RPC)” (Bache 1981; Richard and Cheyrezy 1995).

In other word, the term of the “Ultra-High-Performance Concrete” or in short UHPC was recognised international for concretes with a minimum of compressive strength at 150 MPa. In the mid of 1980, the first commercial applications was started. The application that been applied was security industry like strong rooms, vaults and the other things is protective defence construction in Denmark (Buitelaar 2004). Additionally, regarding to (Schmidt, 2003) the high-rise building and columns were developed by coarse grained UHPC with natural high strength aggregate which is its can sustained in good condition towards the highly loaded.

In other European nation state like Germany, UHPC is in advance increasing attention as well. In Germany, the researcher were established to use regionally raw materials in replacing the coarse or fine in UHPC to decrease content of cement and also to use fiber mixtures and noncorrosive high strength plastic fibers to control the strength and the ductility.

2.5 Applications on UHPC

In around 1985, in Denmark the first application used was conventionally reinforced UHPC precast components for bridge decks. According to Buitelaar, (2004) the worsened concrete bridge and industrial floors were applied in situ. Other than that, in Canada the first prestressed hybride pedestrian bridge was be development at Sherbrooke in 1997 and at Bourg-lès-Valence in France their bridge was built by the UHPC about 20.50m wide and 22.50 m long for the cars and trucks user. For bridges in Bourg-lès-Valence be made up of of five precast beams which are pre-tensioned (Schmidt, 2004). The replacement of steel parts also one of the application was used at Cattenom of the cooling tower (Hajar, 2004).

Breakthroughs, in Seoul and Japan their bridges was built by fine grained, fiber reinforced UHPC at the decks and the other load bearing components (Acker and Behloul, 2004). Regarding to Replendino (2004), the toll-gate of the Millau Viaduct in France show that the architectural was taking advantage of the benefits of UHPC which is the design of roof look elegant like huge twisted sheet of paper with 28 m wide and 98 m long.

For the Europe country, the first application that used UHPC as one of the element in construction was the hybrid bridge. This hybrid bridge was been constructed for the bicycles and the pedestrian with the span about 40m and the length is 135m. Furthermore this bridge deck was used maximum 2 mm of grain size material when they precast it (Fehling, 2004).

2.6 Advantage of UHPC

There are many advantage of UHPC that can be conclude. Micheal, (2016), the strength of UHPC was very high compare with the other concrete type like normal strength concrete and high performance concrete. The strength of the normal strength concrete (NSC) was 20 to 41 MPa. Meanwhile, the strength for the high performance concrete (HPC) was 41 to 96 MPa and ultra-high performance concrete was 100 to 200 MPa.

Other than that, UHPC also advantage in early strength. The time for the cure of UHPC almost same about 24 to 48 hours to archives the strength about 100 MPa to 150MPa. The duration was good enough to meet the quality required including the reinforcing bar advancement. Then the UHPC can be loaded with design load after this time.

UHPC is also very flowable and will promptly fill tight spaces, to such an extent that it is critical to firmly seal shapes, and slope pours require top framing. This ease is valuable for potential congested zones, for example, panel joints, where two arrangements of rebar and potentially even shear studs are for the most part fighting for a similar space. It can also be used to fill haunches underneath precast panel with haunch thicknesses as low as (15 mm), restricted just by the length of the steel fiber in the UHPC.

The enhanced resistance of UHPC to all types of dangerous gases and liquids, to chloride and frost or freezing and thawing attacks is linked up to the improved density both of the grain structure of the matrix and the much denser contact zone between the matrix and the coarse aggregates as well as by the denser structure of the hydration products.

For today structure, there are four types of properties that look before start the pattern of any building like strength, durability, workability, and likewise the effect curing of UHPC.

2.6.1 Compressive Strength of UHPC

According to Sudha, (2014) stated that the compressive strength of UHPC can be range from 100 MPa to 200 MPa. A standout amongst the most detectable resources of UHPC is its high compressive strength. Previous researcher by Graybeal, (2011) found that the compressive strength of UHPC was about 150 MPa. Perry and Zakariasen, 2003) exhibited that UHPC is fit for achieving compressive strength of 172 MPa to 228 MPa. This was upheld by Kollmorgen, (2004) indicative that the compressive strength of UHPC is more than 193 MPa. The expansion in compressive strength, over normal strength concrete (NSC) or high performance concrete (HPC), can be credited to the molecule pressing and determination of particular constituents, and warm curing of UHPC. Table 2.1 show that the differentiate mechanical properties between NSC, HPC and UHPC

Table 2.1 Comparison of UHPC Material Properties to Other Concrete Classifications

Mechanical Properties	NSC	HPC	UHPC
Compression Strength, (ksi)	3.0-6.0	6.0-14.0	25.0-33.0
Split Cylinder Tensile Strength, (ksi)	0.36-0.45	-	1.0-3.5
Poisson's Ratio	0.11-0.21	-	0.19-0.24
Creep Coefficient, Cu	2.35	1.6-1.9	0.2-0.8
Porosity	20-25%	10-15%	2-6%
Fracture Energy, (k-in/in^2)	0.00057-0.00086	-	0.057-0.228
Young's Modulus, (ksi)	2000-6000	4500-8000	8000-9000
Modulus of Rupture 1st crack, (ksi)	0.4-0.6	0.8-1.2	2.4-3.2
Flexure Strength - ultimate, (ksi)	-	-	3.0-9.0
Shrinkage	-	Post Cure 40-80x10^{-5}	Post Cure <1x10^{-5}, No Autogenous Shrinkage After Cure
Coefficient of Thermal Expansion (per °F)	4.1-7.3x10^{-6}	-	7.5-8.6 x10^{-6}
Ductility	-	-	250 Times > NSC

Source: Theresa, 2008

2.6.2 Durability

The durability of a concrete can be conclude as the ability of a concrete to keep carrying out its design capacities while keeping up its dimensional strength in any issues. There were many issues that the durability problem can be increase like the physical attack (fire and salt crystallization) or by the chemical agents like chloride ingress. Nowadays the concrete structure damaged by the chloride attack were increasing. The injurious corrosion of the steel bars was chlorination. It's the major process that happen in the sea area.

The formation of cracks on concrete cover were causes by the corrosion of reinforcement and also the residual life of the concrete will be decrease because of that corrosion (Sanjeev, 2013). But the durability of UHPC give the longer service life and slender element even under the harsh environment because its dense microstructures, which prevent the growth of rust crystals (Sukhoon, 2017). Table 2.2 shows the different in durability characteristics between normal strength concrete (NSC), high performance concrete (HPC) and also the ultra-high performance concrete (UHPC).

Table 2.2 Comparison of UHPC Material Properties to Other Concrete Classifications

Durability Characteristics	NSC	HPC	UHPC
Freeze/Thaw Resistance	10% Durable	90% Durable	100% Durable
Chloride Penetration (coulombs passing)	> 2000	500-2000	< 100
Air Permeability (k) at 24 hrs and 40°C, (in^2)	$4.65x10^{-14}$	0	0
Water Absorption at 225 hours, (lb/in^2)	$4x10^{-3}$	$5x10^{-4}$	$7.1x10^{-5}$
Chloride ion diffusion coefficient (by steady state diffusion), (in^2/s)	$1.55x10^{-9}$	$7.75x10^{-10}$	$3.1x10^{-11}$
Penetration of Carbon / Sulfates	-	-	None
Scaling Resistance, (lb/ft^2)	Mass Removal >0.205	Mass Removal 0.016	Mass Removal 0.002

Source: Theresa, 2008

2.6.3 Workability

The other researchers finding that the possibilities for corrosion of steel fibers and for corrosion-induced matrix cracking are inconsequential in UHPC even if chloride ions penetrate into UHPC (Sukhoon, 2017). Furthermore, the workability and durability can be increased by reducing the amount of water necessary to produce a fluid mix, and therefore permeability, the polycarboxylate superplasticizer also contributes in the UHPC (Theresa, 2008). The UHPC has a good workability and could be satisfactorily handles during consolidation using external or infernal vibrators (Arafa, 2010).

2.6.4 Effect of Curing in UHPC

Curing process is one of the factor that can increase the strength of the concrete. The strength of the concrete can increase by the duration of the curing. In other word, the concretes moist cured for only two days show significant improvement in strength, and other characteristics, as compared with the concretes without any curing. The continuous moist curing of concrete is essential to achieve the highest strength, lowest porosity and highest resistance to the penetration of chloride ions (Ramezanianpour, 1995). For the good performance in strength on UHPC the water curing must be done.

2.7 Mix Proportion

There are a series of experiments were designed to study the effects of chloride content in UHPC. In this UHPC, the materials that been used were cement, aggregate, sand, silica fume, superplasticizer and water. For the rubberized-UHPC the material also same with the plain UHPC but just the aggregate were replaced by the waste crumb tyre.

2.7.1 Silica Fume

The strength of the UHPC increase by the material that been used is silica fume. The silica fume plays a very important role with physical (filler, lubrication) and pozzolanic effect because it is very fine and high amorphous silica (Nguyen, 2010). The increasing of silica fume satisfies a few parts including particle packing, increasing in flowability because of circular nature, and pozzalonic reactivity (response with the weaker hydration product calcium-hydroxide) prompting the increasing of extra calcium-silicates (Theresa, 2008).

From the previous researcher by Nguyen (2010) noted that the high compressive strength of UHPC was achieved with 20% cement replacement by silica fume. Replacing the conventional cement with the silica fume from 10% to 20% at 28 days can increase the compressive strength of UHPC. However increases of silica fume more than 20% show the decrease value of compressive strength (Nguyen, 2010). The percentage of cement replacement by silica fume is 10% as the optimum in this case because the cost of silica fume was three time than Portland cement (Nguyen, 2010). Figure 2.1 shows that the result of the amount on the effect of different silica fume with respect to compressive strength of UHPC.

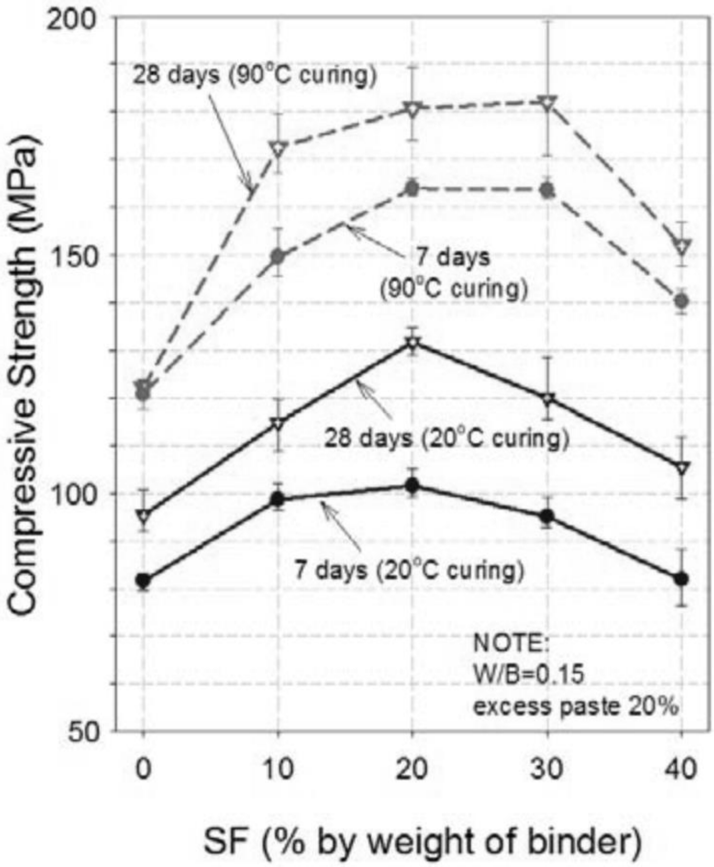

Figure 2.1 Compressive Strength of UHPC vs. % Silica Fume. (By Weight of Binder), W/B Ratio = 0.15, 28 Days, at 20°C and 90°C Curing (Nguyen, 2010)

2.7.2 Waste Tyre

European Association of Tires and Rubber Producers gauges that about 3.2 million metric tonnes of useable tyres were dismissed in 2009. The recovery proportion was 96% of which 18% were withdrawn or utilize once more, 38% were reused and 40% were utilized for vitality generation (Bravo, 2012). The harmful by-product like gases, leachate can be eliminate by use the wastage tyre in the construction. The importance of use waste crumb tyre (WCT) is to reduce the pollution and also to reduce the cost of making UHPC.

The particles grading can be define by the crumb tyre should be sieved. Regarding to previous researcher, about 94.9% of source rubber crumb particles size were between 1.16 and 2.36 mm, with 5% being finer than size of 1.16 mm and no material passing the 0.43 mm pan sieve (Richardson, 2010). The data of the sieved was shown in the Table 2.3. Ankit (2016) found that the maximum size of the crumb tyre used for the concrete was 20 mm and it can be about replaced 5%, 7.5% and 10% by weight of the coarse aggregate used. The compressive strength result of concrete with containing waste crumb rubber were less than normal concrete and it decreases about 18.21%, 32.25% and 40.55%. In this study the percentage of waste crumb tyre was been used is 5% and the size is 6mm. Table 2.4 showing compressive strength of concrete with different percentage of WCT at different curing age (Ankit, 2016).

Table 2.3 Results of Rubber Crumb Sieve Test (Richardson, 2010)

Sieve Size (mm)	Sieve Weight (g)	Sieve and Crumb Weight (g)	Rubber crumb-weight retained (g)	Percentage of Sample (%) (kg)
2.36	482.0	482.0	0.0	100
1.16	443.0	443.0	473.5	5.1
0.43	381.5	855.0	25.5	0
Base Pan	248.0	273.5	0	0
Total	1554.5	20553.5	499.0	-

Table 2.4 Compressive Strength of Concrete with Different Percentage of WCT at Different Curing Age (Ankit, 2016)

S.No	Sample	Percentage of Rubber Aggregate	7 Days Compressive strength (N/mm^2)	28 Days Compressive strength (N/mm^2)
1	S1	0	17.33	25.92
2	S2	5	16.30	21.20
3	S3	7.5	13.63	17.56
4	S4	10	12.22	15.41

2.7.3 Surface Treatment of Waste Crumb Tyre

Regarding the previous researcher, the bonding between waste crumb tyre and the cement paste is very weak (Michelle, 2006).The bonding of WCT can be increase by surface treatment. The chemical of surface treatment used was sodium hydroxide (NaOH) solution (Ankit, 2016). NaOH is a powerful cleaning agent to eliminate the dirt and cleans the surface of rubber which improves the strength between the rubber aggregate and the other material in UHPC. The rubber aggregate must be immersed in the NaOH solution. The duration of the immersed is about 24 hours (Ankit, 2016). The pH number for the NaOH was pH 10 (Miguel, 2011). But research by the Michelle (2006) found that the duration for the immersion is about 20 minutes by the saturated aqueous NaOH solution then wash with water and let it dry in room temperature. The crumb tyre also immersed about one hour in NaOH solution (Elchalakani, 2016). In this study the duration for the treatment were 0, 20, 40 and 60 minutes. Figure 2.2 shows that the compressive strength of concrete with no treatment and with treatment versus curing age (Michelle, 2006).

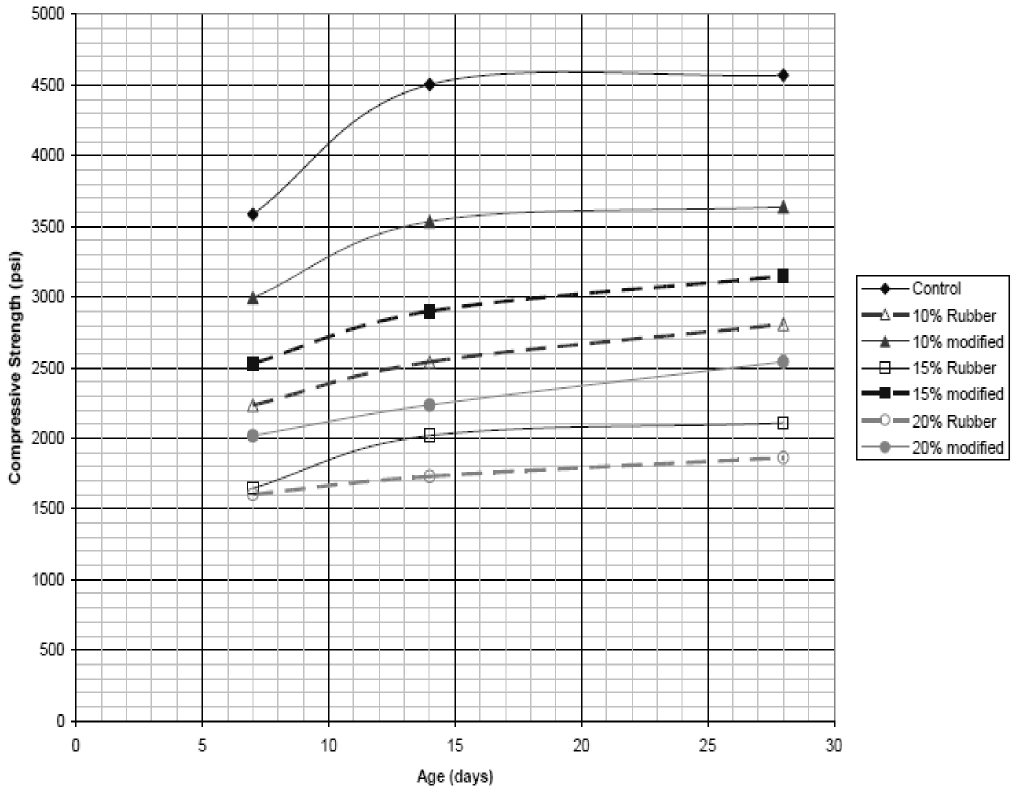

Figure 2.2 The Compressive Strength of Concrete with No Treatment and With Treatment Versus Curing Age (Michelle, 2006).

2.7.4 Superplasticizer

The function of the polycarboxylate is to reduce the amount of water to produce a fluid mix and permeability. The better slump result will be produced. Other that that the superplasticizer also can improve the durability and workability of UHPC Theresa (2008). The new chemistry is being mentioned to as comb polymers in light of the fact that their structure which includes a backbone consisting of a polycarboxylate polymer to which has been united polyoxyalkylene pedant group Kassel (2004). So according to the Richard and Cheyrezy (1995) the superplasticizer was used 1.6% optimum for the mix in the UHPC. Then 3% of optimum dosage of the high range water agent reducing according (Khalil, 2012) to increase the workability of the concrete. The water/binder ratio was 0.20, and 2% superplasticizer in reverence to the binder was used (Kaufmann, 2004)

2.8 Chlorination

The one factor that the durability of concrete structures decrease because of the steel corrosion by the chloride penetration. Diffusion of chlorides in concrete has been evaluated by Fick’s 2nd law of diffusion (Li, 2011). Zhang (2009) observed that in aggressive chloride-laden environment increasing concrete cover is more effective than using corrosion resistant steel, it is necessary to use both high performance concrete and corrosion resistant steel, a relative decrease in the concrete cover has to be compensated by a much greater increase in the corrosion resistance of steel, and values of critical chloride content and concrete cover are governed by chloride diffusion coefficient

2.8.1 Chloride Penetration

The resistance in the UHPC towards chloride ion was very high and the compressive strength become small when the days of curing become higher. In previous researcher Sukhoon (2017) found that the 3.0% NaCl was expose to the normal mortar (NM), high strength mortar (HSM) and ultra-high performance concrete (UHPC) and the strength loss was detected about 33.1%, 21.9% and 4.0% at 91 days of curing. The strength loss of UHPC was the lower that can be detected than the NM and HSM. Special effects of chloride ions on concrete durability, range from 0.3 to 2.0% of chloride per binder weight is recognized to be a critical value affecting beginning of corrosion of reinforcement in conventional concrete structures (Mcdonald, 1998).

Sukhoon (2017) found that increases in number and area of rust spots were not found when the NaCl content was increased from 1.5% to 3%. For the HSM series, only limited numbers of rust spots were found on the surfaces; these were smaller than those of the NM series. Some of the fibers projecting from the specimen surface were corroded for the specimens with NaCl. However, for the cases of UHPC, no rust spots were found on the surface of specimens, regardless of NaCl content, and only the fibers projecting were corroded. Therefore, the percentage of the NaCl that been used was 3% in this study. Figure 2.3 shows relationship between compressive strength and percentage expose of NaCl to UHPC.

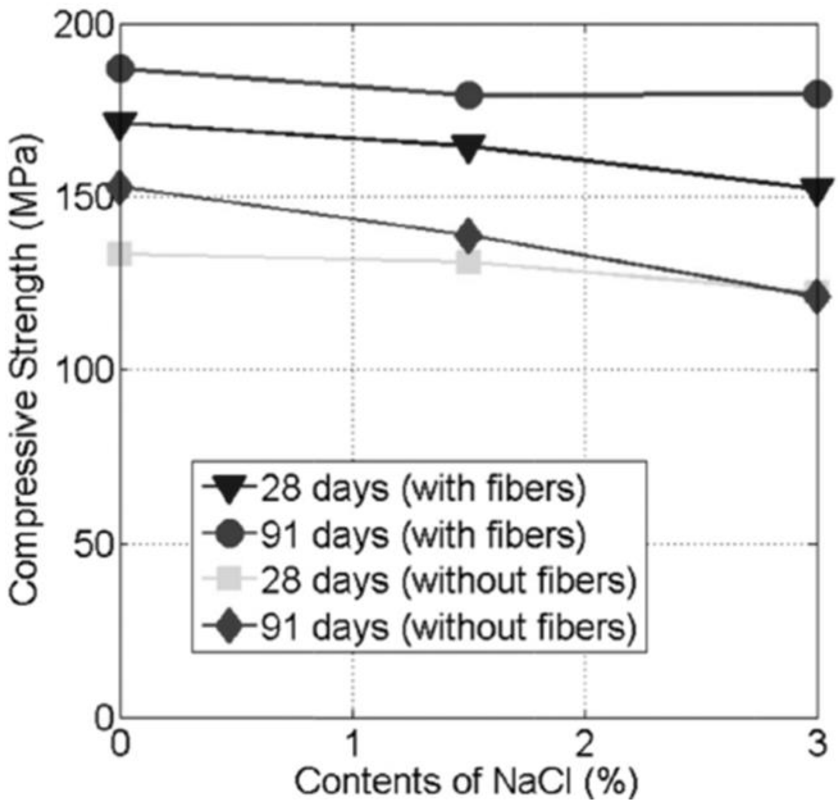

Figure 2.3 Relationship between Compressive Strength and Percentage Expose Of Nacl to UHPC (Sukhoon, 2017)

2.8.2 Chloride Penetration Depth Profile

The method to determine the chloride penetration depth by using colorimetric method (AgNO3 sprayed method). This method is to investigate the chloride penetration depth profile. The chloride ion penetration depth increase gradually with increase the time of exposure. But when the time of exposure more than 365 days, the chloride ion penetration depth become decreased regarding to (Mohd Faizal et al., 2017). According to Faizal (2017) the chloride penetration depth for UHPC was at range 0-6 mm at 7 to 28 days. The 0.1N aqueous solution of silver nitrate was observed as the most evident of colour change 0.05, 0.1, 0.2, 0.3 and 0.4N after spraying them (Nobuaki, 1993). The increasing of the chloride penetration depth was defined by the increase of the pore size distribution of the concrete. Other than that, the silica fume giving the effect of the reducing of chloride penetration depth because pozzolanic and micro-filler effect. Figure 2.4 shows chloride penetration depth in NPC, HPC, UHPC and nano metaclayed-UHPC concretes.

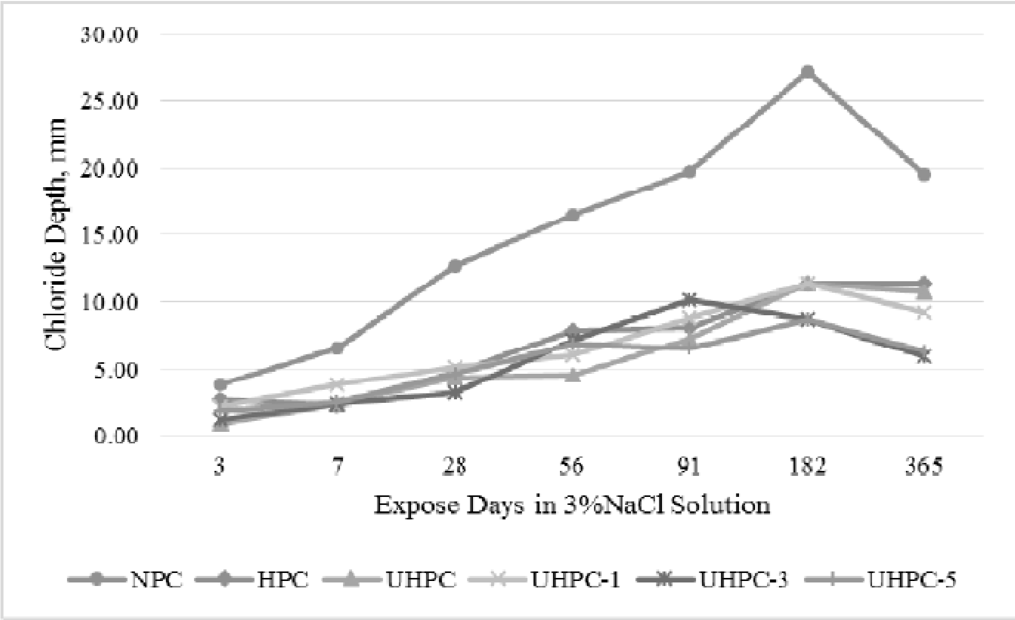

Figure 2.4 Chloride Penetration Depth in NPC, HPC, UHPC And Nano Metaclayed-UHPC Concretes (Mohd Faizal, 2017)

2.8.3 Visual observation

Due to the previous study (Nobuaki, 1993), the zone that be penetrated by Cl^- will be form white precipitate of silver chloride. Then brown precipitate were found on the surface when the area not penetrated by Cl^- but it reacts with OH^- to form silver oxide. Figure 2.5 shows evaluation of the chloride combination.

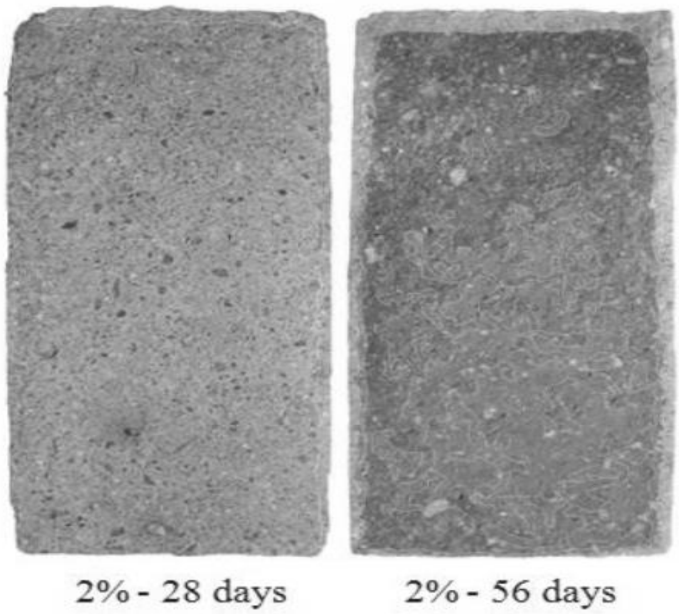

Figure 2.5 Evaluation of the Chloride Combination (Mota, 2011)

CHAPTER 3

METHODOLOGY

3.1 Introduction

The literature review guided aided in having a well understanding of Ultra-High Performance Concrete. The first objective is to determine the effect of using different pre-treatment duration on surface of waste crumb tyre particles as replacement of aggregate in UHPC. Second objective is to determine the compressive strength of rubberized-UHPC subsequently immersed in sodium chloride (NaCl) solution and last objective is to examine the chloride penetration profiles on exposed rubberized–UHPC immersed in NaCl solution.

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. To determine the strength and chloride penetration profile of rubberized-UHPC, the specimens will tasted using the chloride attacks.

Therefore, for the determination of successfully accomplishing the objective of this research, a suitable methodology is compulsory. This chapter consist explanation of test method and material used.

3.2 Experimental Program

The experimental process-flow of the strength and chloride penetration profile using Waste Crumb Tyre (WCT) as course aggregate replacement is outlined in Figure 3.1.

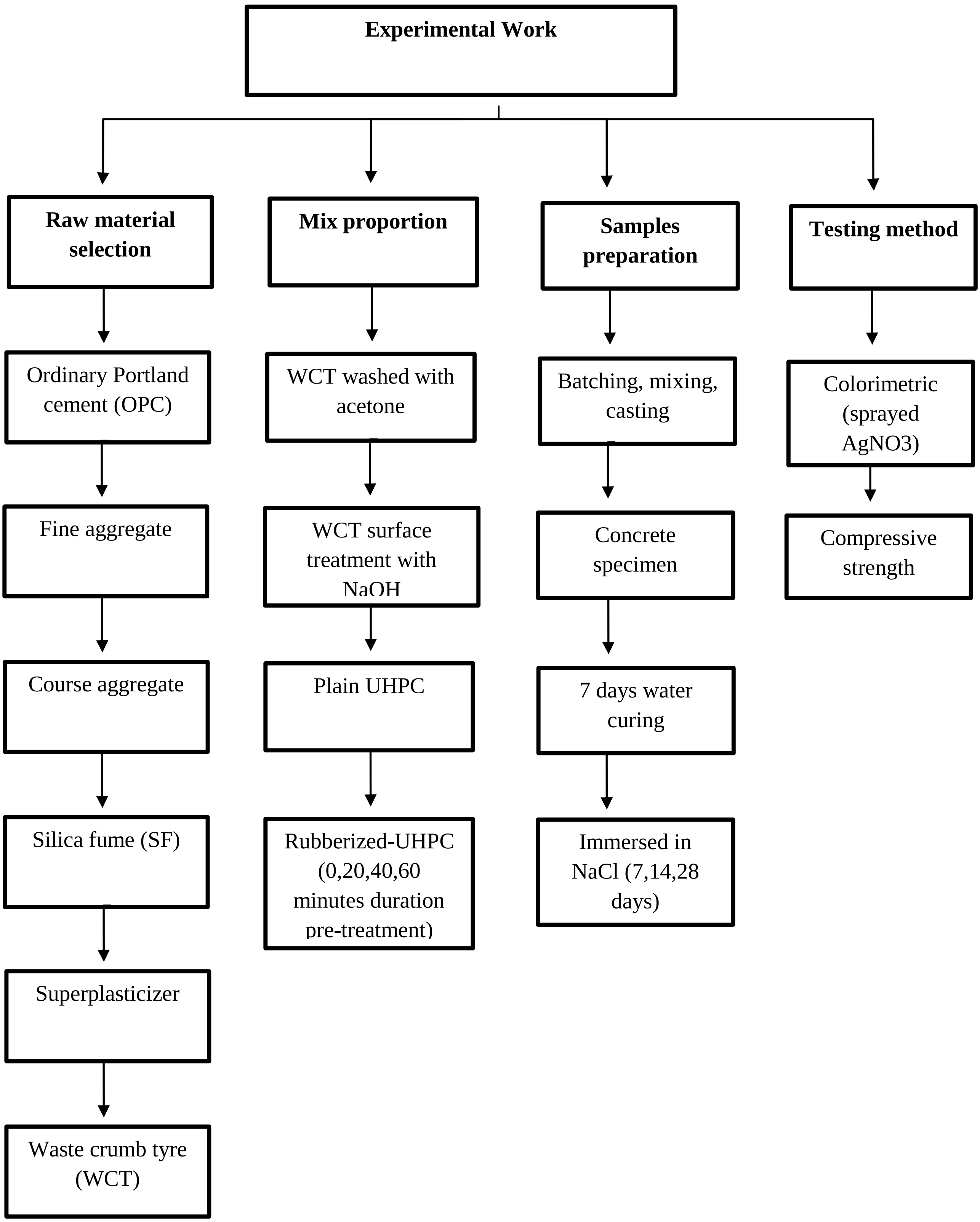

Figure 3.1 The Process Flow in This Study

3.3 Material Selection

The raw material that will be used in this study are:

i. Cement – Ordinary Portland Cement (OPC)

ii. Fine aggregate and course aggregate

iii. Silica fumes (SF)

iv. Superplasticizer (SP)

v. Waste crumb tyre

3.3.1 Cement

Normally, cement paste is act as a binder in UHPC that holds the aggregates and other raw materials and react together with other material such as silica fumes. Cement is a hard material, if mixed with water. Figure 3.2 shows the cement that been used.

Figure 3.2 Ordinary Portland Cement

Accordingly, these substances should be given great care before they are utilized or after utilize particularly while on location. For small projects, cement does not need to be stored in a large store. It is easy to store in the open space based on the following methods:

i. Set up the planks and make sure they are dry.
ii. Plane floors with ground level should be raised at least 150 – 230 mm to avoid moisture or wet.
iii. 300 mm from the warehouse wall.
iv. Create cement bags closely.
v. The cement bar shall be composed of not more than 12 layers to facilitate the preparation and taking of cement during work.
vi. The edges are arranged lower than the middle ones.
vii. Ensure that cements are used immediately for small projects to avoid damage.
viii. If the storage area is not covered, the cement should be covered with plastic cloth.

3.3.2 Sand

Sand in this study composed of grains ranging from 0.10 to 0.25 mm in diameter. It is available at sand mining, quarry or river. The quantity of sand that needs to be used is 800 kg/m^3 and it will take from river or sand mining. It is the best type of sand as it has undergone the natural distribution process through the flow of river water. This process indirectly removes the weak materials. To keep sand does not need a complicated place. Sand can be placed anywhere that as long as not block the route or easy to researcher to use the sand. Figure 3.3 shows the sand that been used.

Figure 3.3 Sand

Sand will test using sieve sand test. Apparatus and materials needed are sample of sand, sieve sizes 4.75 mm, 2.36 mm, 600 µm and 150 µm and sieve machine. The sand was sieved through 5 mm.

Procedure:

i. Sand samples are taken randomly and weighed as much as 1000 grams.

ii. The weighted sand samples are heated in the oven for 24 hours

iii. The sieve is weighed to gain initial weight.

iv. The sieve is arranged according to the desired size on the sieve machine and sand samples are put into sieve.

v. The sieve machine is switched on and left to vibrate for ten minutes.

vi. Then, the weight of each sieve containing a sand sample is retained weighed.

vii. The grading graph of the grading sand is plotted and the experiment is repeated for three different samples.

3.3.3 Course aggregate

Aggregate is the most used material that will be used in the concrete mixture. Aggregates comprise as much as 60% to 80% of a typical concrete mix, so they must be properly selected to be durable, blended for optimum efficiency, and properly controlled to produce consistent concrete strength, workability, finish ability, and durability. Aggregate size is range 5 – 10 mm. Figure 3.4 show the course aggregate that been used.

Figure 3.4 Aggregate

Good-quality aggregate for concrete activities need to be check to make sure that aggregate are followed the requirement which are: texture and grain shape. To obtain a good-quality aggregate, it must be clean, hard, strong, have durable particles, and be free of absorbed harmful chemicals, coatings of clay, or other contaminates that can affect hydration of cement or reduce the paste-aggregate bond. Monitor moisture contents of coarse and fine aggregates on a regular basis to promote batch-to-batch consistency and uniformity. Moisture probes in aggregate bins should be calibrated according to manufacturers' recommendations.

The aggregate will test using sieve analysis. After the material has been sieved, remove each tray, weigh each size, and record each weight to the nearest 0.1 g. Be sure to remove any aggregate trapped within the sieve openings by gently working from either or both sides with a trowel or piece of flat metal until the aggregate is freed. Banging the sieve on the floor or hitting the sieve with a hammer will damage the sieve. The final total of the weights retained on each sieve should be within 0.3% of the original weight of the sample prior to grading. Particles larger than 3 in. (75 mm) should be hand sieved. When passing large stones through sieves, do not force the aggregate through the sieve openings. The aggregate that been used in this study is 411.35 kg/m^3.

3.3.4 Water

The role of water in the concrete mix is to carry out cement and active ingredient reactions as well as the main factors affecting working standards. BS 3148 "Test for water for making concrete" state that the types of water used in the concrete mix are need to:

- Taken from a source of guaranteed sanitation such as water used to drink such as tap water.

- Taken from roots that are free of mineral and organic materials such as salt, alkali and others.

Water need to be used in this research is about 160 kg/m^3. Materials such as silt and ground can be separated by tasting test.

3.3.5 Silica fume (SF)

Silica fume is accessible form providers of concrete admixture and when indicated is basically included amid concrete production. These changes result two different but have same important processes. The first is physical aspect of silica fume. Adding silica fume can brings million very small particles to a concrete mixture. Silica fume can brings about significant improvement in the nature of the concrete. It is because silica fume has very high amorphous silicon dioxide content. The researcher will buy the silica fume from Sika Malaysia. Silica fume that will be used in this research is 10% of cement which is about 80 kg/m^3. Silica fume should be stored in a closed and non-exposed area with any other material. Figure 3.5 shows the silica fume that been used.

Figure 3.5 Silica Fume

3.3.6 Superplasticizer (SP)

The chemical admixture used is superplasticizer and retarding admixture, which is a modified polycarboxylate type. It is manufactured from Sika Malaysia and the appearance is dark-brown liquid. When added to concrete mix, it will improve the plasticizing effect and improve the workability of the UHPC. It is because, superplasticizer can reduce the amount of water in the concrete. The percentage of the superplasticizer that been used was 2%. Figure 3.6 shows the superplasticizer that been used.

Figure 3.6 Superplasticizer

3.3.7 Waste Crumb Tyre (WCT)

The waste crumb tyre was used 5% to be replaced with the coarse aggregate and the size is 6mm. The waste crumb tyre were store in the close place. Waste crumb tyre was be sieved to get the actual size. After get the actual size, the WCT were washed by the acetone to remove the probable impurities on the surface and let it dry in the room temperature. Figure 3.7 shows the waste crumb tyre that been used.

Figure 3.7 Waste Crumb Tyre

3.3.8 Pre treatment

When the WCT were dried, WCT must be immersed into the sodium hydroxide (NaOH) to ensure that the bonding between WCT and cement matrix were strong. The duration for the immersion is about 0, 20, 40 and 60 minute. After the duration of immersion completed, the WCT were taken out and let it dried. Next is the WCT can be mix with the other material.

3.3.9 Sodium Chloride, NaCl

Sodium Chloride, NaCl is metal halide composed of sodium and chloride with sodium and chloride replacement capabilities. 3% of NaCl was used in this study. Figure 3.8 shows the sodium chloride that been used.

$Na + Cl2 = NaCl$

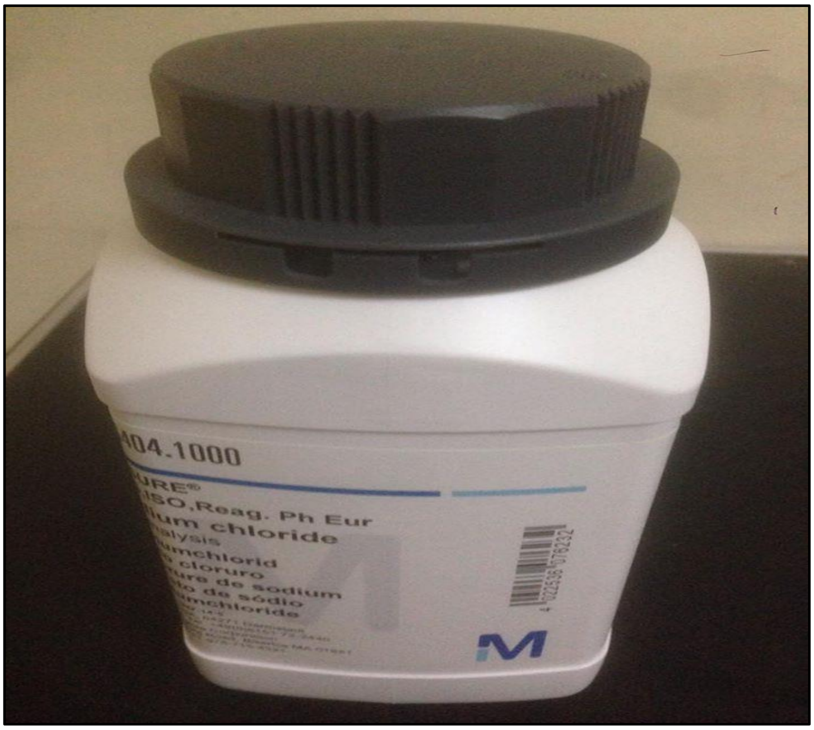

Figure 3.8 Sodium Chloride

3.4 Preparation of specimens

In this section, the detail explanation on preparing of rubberized-UHPC will be discussed. The preparation were subjected to batching, mixing, casting and curing the specimens for 7, 14 and 28 days curing age meanwhile the duration for test the specimens is 7 days of curing age was used.

3.4.1 Mix Proportion

The proportion used in preparing rubberized-UHPC for one cubic meter for 0.001 cubic meter for mixes and 150 diameter, 300 length for cylinder are shown in Table 3.1.

Table 3.1 Mix proportion of rubberized-UHPC

Raw Material (kg/m³)								
Cement	SF	Aggregate	Sand	WCT	Water	SP (%)	SP	W/C ratio
720	80	433	800	0	160	3.5	14.4	0.2
720	80	411.35	800	21.65	160	3.5	14.4	0.2
720	80	411.35	800	21.65	160	3.5	14.4	0.2
720	80	411.35	800	21.65	160	3.5	14.4	0.2

Note: SF=silica fume; WCT= waste crumb tyre; SP=superplasticizer

3.4.2 Number of specimen

Minimum three (3) number of specimens were prepared for each parameter to be tested. The table below shown the number of specimens prepared.

- Plain UHPC WCT for 0 minutes
- UHPC20- WCT for 20 minutes
- UHPC40- WCT for 40 minutes
- UHPC60- WCT for 60 minutes

In this study, there are two different type of specimen will used, which are cubic and cylinder that show in Table 3.2 and Table 3.3.

Table 3.2 Compression Test Specimens for Cubic Curing Age Duration 7 Days

Mix Designation	Duration Pre-Treatment (minutes)	Numbers of Specimens
Plain UHPC	0	9
UHPC-20	20	9
UHPC-40	40	9
UHPC-60	60	9

Table 3.3 Durability Test Specimens for Cubic and Cylinder Chloride Attacks

Mix Designation	Duration Pre-Treatment	Numbers of Specimens		
		7 Days	14 Days	28 Days
Plain UHPC	0	3	3	3
UHPC-20	20	3	3	3
UHPC-40	40	3	3	3
UHPC-60	60	3	3	3

3.4.3 Size of Specimen

This experiment will used cube and cylinder specimens. The size of cube and cylinder specimens are standard. For cube, standard size is 100 mm x 100 mm 100 mm, and for cylinder, it is 150 mm for diameter and 300 mm for length. Figure 3.9 and 3.10 shows the standard size of cube and cylinder.

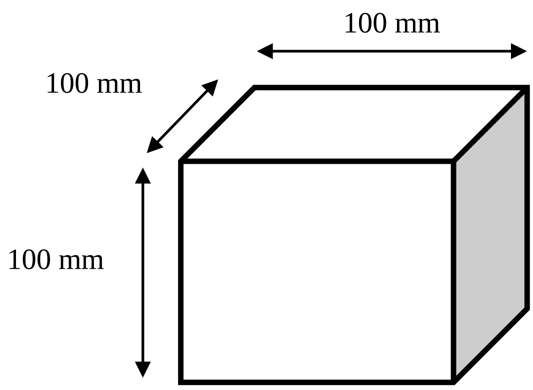

Figure 3.9 Dimension of cubic specimen

The total usage of concrete cube specimens are approximately 0.036 meter cubic.

Volume = 36 cubes x (0.1 x 0.1 x 0.1)

= 36 cubes x 0.001

= 0.036 m^3

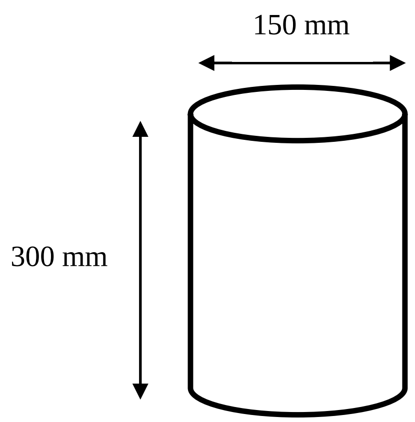

Figure 3.10 Dimension of cylinder specimen

The total usage of concrete cube specimens are approximately 0.0792 meter cubic.

Volume = 24 cylinder x (0.147x0.075x0.3)

= 24 cylinder x 0.0033

= 0.0792 m^3

3.4.4 Cube mould

The dimension of cube specimens are 100 mm x 100 mm x 100 mm made from plastic. Figure 3.11 shows the concrete mould that have been use.

Figure 3.11 Cube Specimens

3.4.5 Cylinder mould

The dimension of cylinder specimens is 150 mm diameter x 300 mm length made from plastic. Figure 3.12 shown the concrete mould that have been use.

Figure 3.12 Cylinder Specimens

3.4.6 Batching, Mixing and Casting

Preparation of the rubberized-UHPC specimens are made in the Laboratory of Civil & Environmental Engineering, University of Malaysia Pahang. The first step is required amount of material need to weight properly. After that, all the material need to mix with each other. The goal of mixing is aggregate particles must be surrounded by the silica fume and cement paste and all material need to distributed consistently in the concrete mass.

The procedure of mixing rubberized-UHPC are:

i. Placing all cementitious materials (cement and silica fume) in the mixer and blend for 2 minutes.

ii. Add water and ½ of the superplasticizer to the cementitious materials gently and blend for 2 minutes.

iii. Wait for 1 minutes, then insert the remaining superplasticizer to the cementitious materials for 1 minutes.

iv. Locating all material left in the mixer and blend for 3 minutes. (Sand, aggregate and WCT)

v. Finally, pour the mixture into the respective mould.

3.4.7 Curing

Curing is process of concrete are treated before it can be tested. This process is involve the concrete specimens to be place into the water tank and leave for a certain period. The purpose of curing is to make sure the concrete have proper process of hardened. After 24 hours, concrete that in the mould will be take out from the mould and the concrete will continue in the water tank for curing for 7 days. After it done 7 days, the concrete will curing in the chloride

3.5 Testing method

Testing method for this study were divided into two part. First is colorimetric method and the second is compressive strength method.

3.5.1 Colorimetric method

To study the influence of waste crumb tyre as a replacement of coarse aggregate in UHPC, the content of the chloride in the UHPC was investigated. All the specimens were immersed in 3% NaCl solution. Before the specimens were immersed, the surface of the specimens must be sealed on top and bottom by using water-proofing membrane to avoid the entrance chloride ion at the both parts. The time of the immersion tooks for 7, 14 and 28 days before the chloride content and the penetration were measured. All the specimens were bring out after exposure from the NaCl solution and the specimens were washed and cleaned by using tap water and let it dry in the room temperature.

After the specimens were dried, the cylinder samples were split vertical into two parts by using compression machine. Figure 3.13 show the split tensile strength.

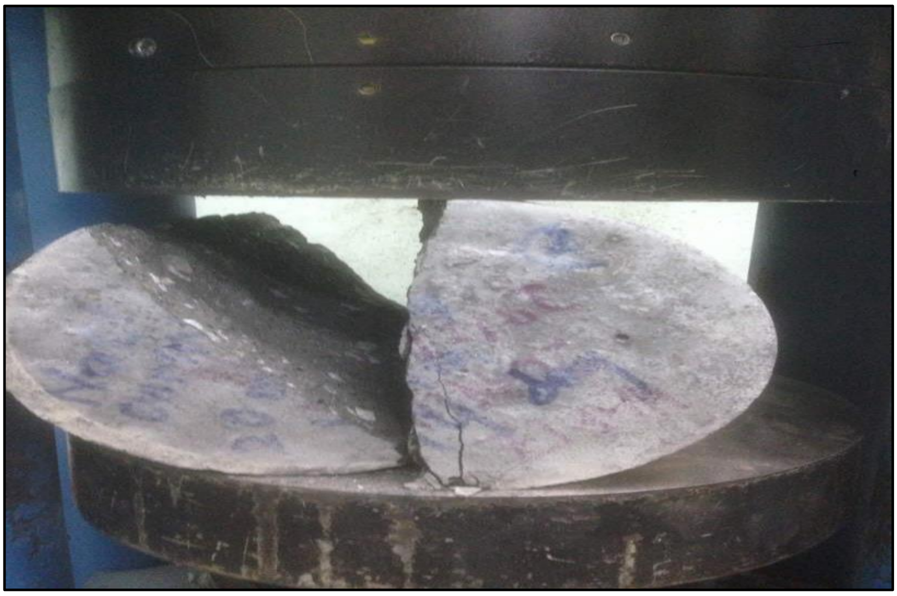

Figure 3.13 Split Tensile Strength

After that the surface of the split were sprayed by 0.1M silver nitrate ($AgNO_3$) and left the specimens in the room temperature till the sprayed solution were dried. Then is after the surface sprayed dried, the colour of white silver chloride precipitation on the surface were obvious appear and the area that not affected of chloride ion stay natural or brown in colour. Figure 3.14 shows spray silver nitrate (AgNO3).

Figure 3.14 Spray Silver Nitrate (AgNO3)

Then is line alongside the surface that cover chloride was drawn to measure the depth of the chloride precipitation. Next is measure the depth by using digital caliper. Figure 3.15 shows the measuring depth of chloride.

Figure 3.15 Measuring Depth of Chloride

3.5.2 Compressive method

For the compressive strength test, the 100mm cubic specimen was been test according to the BS EN 12390-3:2009 which is the value were be averaged for at least three specimens for each series. Figure 3.16 shows the compressive strength test.

Figure 3.16 Compressive Strength Test

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In Chapter 4, the effect of different duration pre-treatment for waste crumb tyres (WCT) as aggregate replacement in Ultra-High Performance Concrete (UHPC) are presented. This chapter deals with the presentation of results on compressive strength and durability performance of rubberized-UHPC incorporating WCT. An experimental programme was created in which the various duration of immersion WCT in sodium hydroxide (NaOH) solution as a pre-treatment process. Four (4) series of UHPC were prepared namely Plain UHPC (control mix) and a series of rubberized-UHPC containing treated WCT as aggregate. The pre-treatment duration process for WCT was soaked for 20, 40 and 60 minutes. Two (2) type of testings were conducted namely compressive strength and durability performance on Plain UHPC and a series of rubberized-UHPC. The compressive strength test was conducted on 36 cube with size 100x100x100mm. For durability test, the Plain UHPC and rubberized-UHPC specimens were immersed in 3% NaCl solution for chloride penetration resistant test. In this testing, the chloride depth, chloride profile on splitted specimens were also investigated. All the testings were conducted for 7, 14 and 28 days. All the data obtained were presented in the form of table and graph.

4.2 Waste Crumb Tyre Properties

In general, waste crumb tyre (WCT) particles were used in a variety of civil and non-civil engineering applications. Some properties of waste crumb tyre resulting after the pre-treatment process was conducted. In this study, three (3) types of properties was conducted physically which are size of WCT particles, colour of WCT particles and WCT particles surface. The WCT particles were sieved to retained size 5 mm before was immersed in sodium hydroxide (NaOH) solution. The immersion duration of 20, 40 and 60 minutes were conducted for pre-treatment process. After pre-treatment process, it was showed that the size of WCT particles changed to small after immersed in NaOH solution.

It is found the increases the duration process resulting the size of WCT particles become small. Next, the colour on the surface of WCT particles after pre-treatment was changed from black colour to whitish colour. On the other hand, the texture of WCT particles was also transformed from soft (flexible) to stiff (inflexible). It was found that prolong the duration of immersion, the texture become stiffer. Figure 4.1 shows the appearance of WCT particles before subjected to the pre-treatment process. Figure 4.2 shows the appearance of WCT after soaked into NaOH solution for the pre-treatment process. Therefore, it is noted that the WCT particles underwent the pre-treatment was significantly affect the changed its size, colour and texture of WCT particles.

Figure 4.1 Appearance of Waste Crumb Tyre Particles before Treatment Subjected to Pre-Treatment Process.

Figure 4.2 Appearance of Waste Crumb Tyre Particles After subjected to Pre-Treatment Process

4.3 Mechanical Properties of Rubberized-UHPC

In this mechanical properties of rubberized-UHPC contains effect of curing age on compressive strength of rubberized-UHPC, effect of treated-WCT as aggregate replacement on compressive strength of rubberized-UHPC, effect of curing age on tensile strength of rubberized-UHPC and effect of treated-WCT as aggregate replacement on tensile strength of rubberized-UHPC

4.3.1 Effect of Curing Age on Compressive Strength of Rubberized-UHPC

The results on compressive strength of the ultra-high performance concrete (UHPC) and rubberized-ultra high performance concrete (rubberized-UHPC) cured in water are presented. The different duration of treatment of WCT for each mix consists of 0, 20, 40 and 60 minutes of immersion in NaOH solution. Each mix was labelled as Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 respectively. Table 4.1 and Figure 4.3 shows the compressive strength of Plain UHPC as a control mix cured in water with respect to ages.

Table 4.1 Compressive Strength of Plain UHPC at Different age of Curing

Mix Designation	Age (Days)	Compressive Strength (MPa)
Plain UHPC	7	76.11
Plain UHPC	14	86.11
Plain UHPC	28	109.80

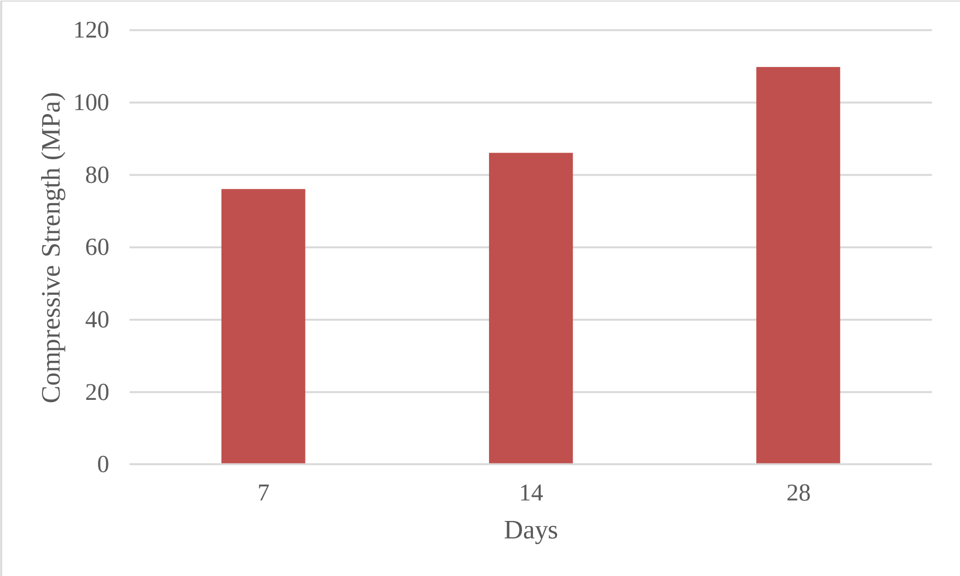

Figure 4.3 Compressive Strength of Plain UHPC Cured in Water for 7, 14 and 28 Days

From the Figure 4.3, the compressive strength of Plain UHPC increased significantly from day 7 to day 28. The highest compressive strength obtained is109.8 MPa at 28 days of curing. Meanwhile the lowest compressive strength was recorded at day 7 with strength of 76.11 MPa. It can be found that the strength of Plain UHPC increases when the duration of curing increased. Table 4.2 and Figure 4.4 shows the compressive strength of UHPC-20 cured in water with respect to ages.

Table 4.2 Compressive Strength of Rubberized-UHPC (UHPC-20)

Mix Designation	Age (Days)	Compressive Strength (MPa)
UHPC-20	7	49.55
UHPC-20	14	56.25
UHPC-20	28	61.05

On the other hand, Figure 4.4 illustrates the compressive strength of rubberized-UHPC (UHPC-20) containing 5% WCT particles immersed for 20 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of curing days.

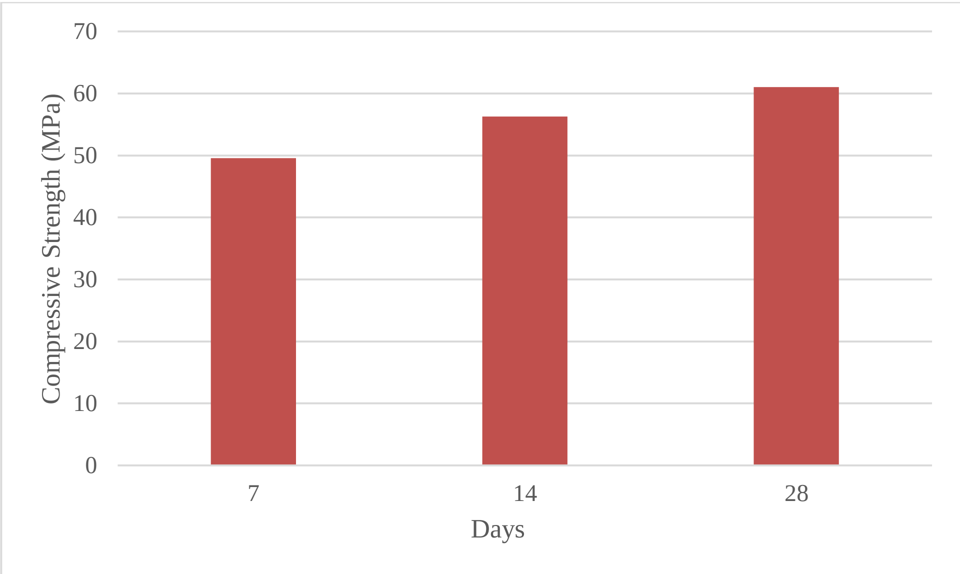

Figure 4.4 Compressive Strength of UHPC-20 Cured in Water for 7, 14 and 28 Days

Figure 4.4 indicates that, the compressive strength values for UHPC-20 was also increased starting day 7 to day 28. The result shows that the highest compressive strength is 61.05 MPa and the lowest value is 49.55 MPa at day 28 and day 7, respectively. The compressive strength at 28 days was increased about 23.21% when compared to the strength recorded at 7 days. It is reveals that the compressive strength of UHPC-20 specimen significantly increased when the duration of the curing age increases. Table 4.3 and Figure 4.5 shows the compressive strength of UHPC-40 cured in water with respect to ages.

Table 4.3	Compressive Strength of Rubberized-UHPC (UHPC-40)	
Mix Designation	Age (Days)	Compressive Strength (MPa)
UHPC-40	7	57.40
UHPC-40	14	63.82
UHPC-40	28	69.42

On the other hand, Figure 4.5 illustrates the compressive strength of rubberized-UHPC (UHPC-40) containing 5% WCT particles immersed for 40 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of curing days.

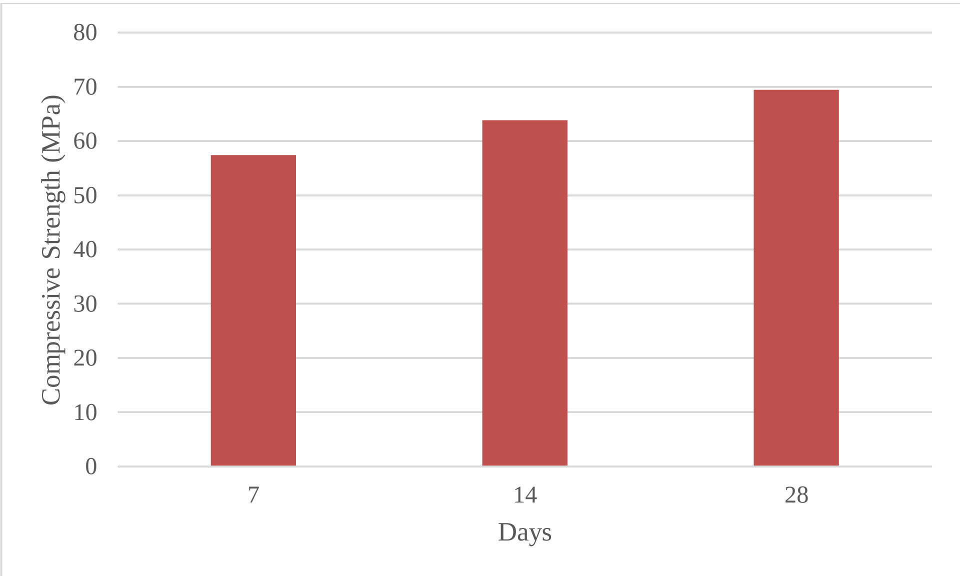

Figure 4.5 Compressive Strength of UHPC-40 Cured in Water for 7, 14 and 28 Days.

Figure 4.5 indicates that, the compressive strength values for UHPC-40 was also increased starting day 7 to day 28. The result shows that the highest compressive strength is 69.42 MPa and the lowest value is 57.40 MPa at day 28 and day 7, respectively. The compressive strength at 28 days was increased about 20.63% when compared to the strength recorded at 7 days. It is reveals that the compressive strength of UHPC-40 specimen significantly increased when the duration of the curing age increases.

Table 4.4 and Figure 4.6 shows the compressive strength of UHPC-60 cured in water with respect to ages.

Table 4.4 Compressive Strength of Rubberized-UHPC (UHPC-60)

Mix Designation	Age (Days)	Compressive Strength (MPa)
UHPC-60	7	63.33
UHPC-60	14	63.36
UHPC-60	28	77.75

On the other hand, Figure 4.6 illustrates the compressive strength of rubberized-UHPC (UHPC-60) containing 5% WCT particles immersed for 60 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of curing days.

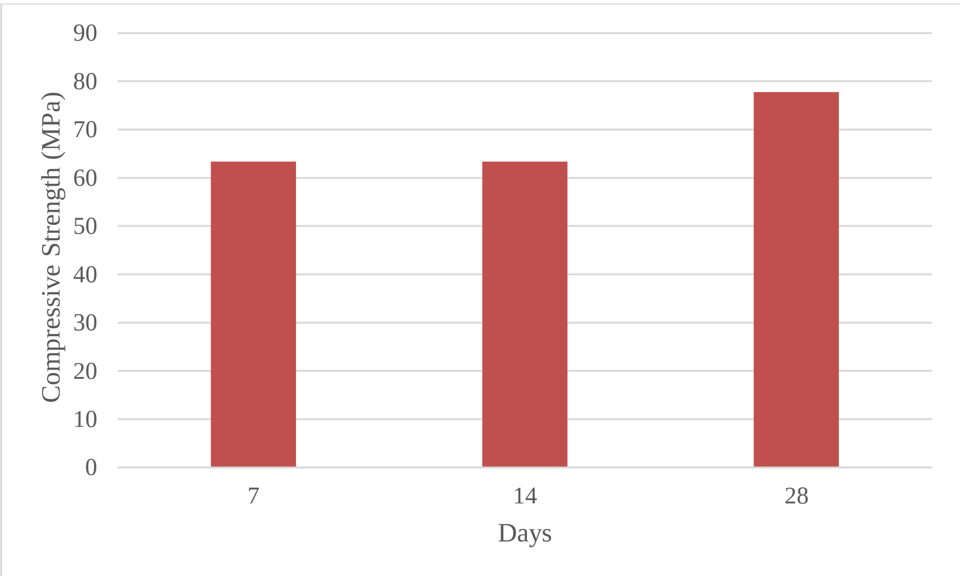

Figure 4.6 Compressive Strength of UHPC-60 Cured in Water for 7, 14 and 28 Days.

Figure 4.6 indicates that, the compressive strength values for UHPC-60 was also increased starting day 7 to day 28. The result shows that the highest compressive strength is 77.75 MPa and the lowest value is 63.33 MPa at day 28 and day 7, respectively. The compressive strength at 28 days was increased about 22.77% when compared to the strength recorded at 7 days. It is reveals that the compressive strength of UHPC-60 specimen significantly increased when the duration of the curing age increases.

4.3.2 Effect of Treated-WCT as Aggregate Replacement on Compressive Strength of Rubberized-UHPC

Table 4.5 and Figure 4.7 shows the compressive strength of Plain UHPC and a series of rubberized-UHPC for 7, 14 and 28 days cured in water.

Table 4.5 Compressive Strength of Plain UHPC and a Series of Rubberized-UHPC for 7, 14 And 28 Days Cured In Water

Mix Designation	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Plain UHPC	76.11	86.11	109.8
UHPC-20	49.55	56.25	61.05
UHPC-40	57.40	63.82	69.42
UHPC-60	63.33	63.36	77.75

On the other hand, Figure 4.7 illustrates the compressive strength of Plain UHPC and rubberized-UHPC containing 5% WCT particles immersed for 20 ,40 and 60 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of curing days.

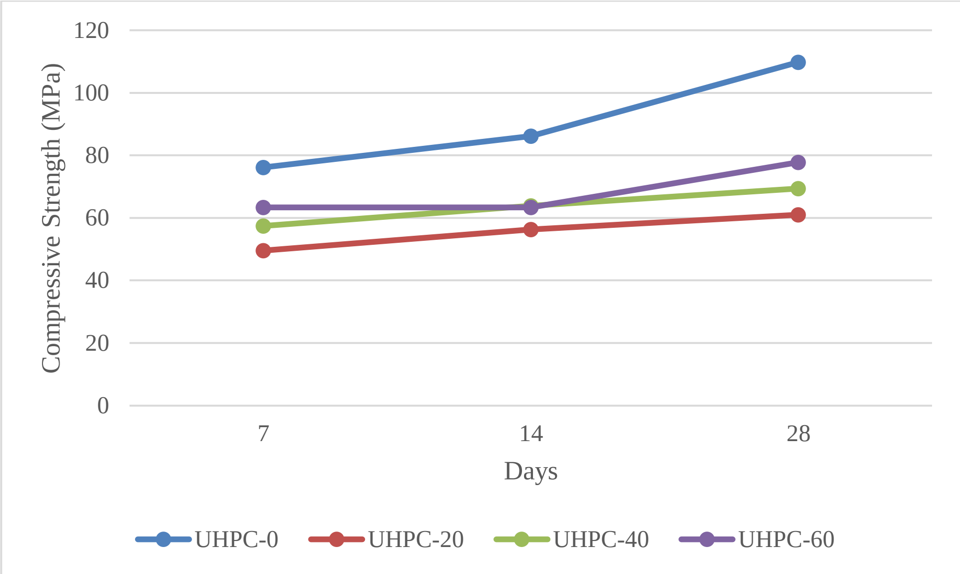

Figure 4.7 Compressive Strength of Plain UHPC and a Series of Rubberized-UHPC for 7, 14 And 28 Days Cured In Water.

From Figure 4.7, the compressive strength shows that the UHPC strength is the higher strength compare with rubberized-UHPC. The highest strength is about at days 28 with value 109.8 MPa for UHPC. For the rubberized-UHPC with namely Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 which is the UHPC-60 give high strength compare to the UHPC-20 and UHPC-40. At the 28 days, the compressive strength for UHPC loss about 29.18% after mix with the WCT particle for 60 minutes pre-treatment. Then compressive strength loss for 37.77% after mix with the WCT particles for 40 minutes pre-treatment and the compressive strength loss 44.40% after mix with WCT particles for 20 minutes. It can be conclude that the strength of UHPC increase when the duration of the curing water increase and it also same with the rubberized-UHPC that the strength increase when the duration of the curing water increase.

4.3.3 Effect of Curing Age on Tensile Strength of Rubberized-UHPC

The results on tensile strength of the ultra-high performance concrete (UHPC) and rubberized-ultra high performance concrete (rubberized-UHPC) cured in water are presented. The different duration of treatment of WCT for each mix consists of 0, 20, 40 and 60 minutes of immersion in NaOH solution. Each mix was labelled as Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 respectively. Table 4.6 shows that the tensile strength of UHPC reacted on the duration of curing water based on the pre-treatment of the waste crumb tyre.

Table 4.6 Tensile Strength of Plain UHPC

Mix Designation	Age (Days)	Tensile Strength (MPa)
Plain UHPC	7	5.12
Plain UHPC	14	5.47
Plain UHPC	28	5.87

On the other hand, Figure 4.8 illustrates the compressive strength of Plain UHPC on compressive strength was obtained for 7, 14 and 28 days of curing days.

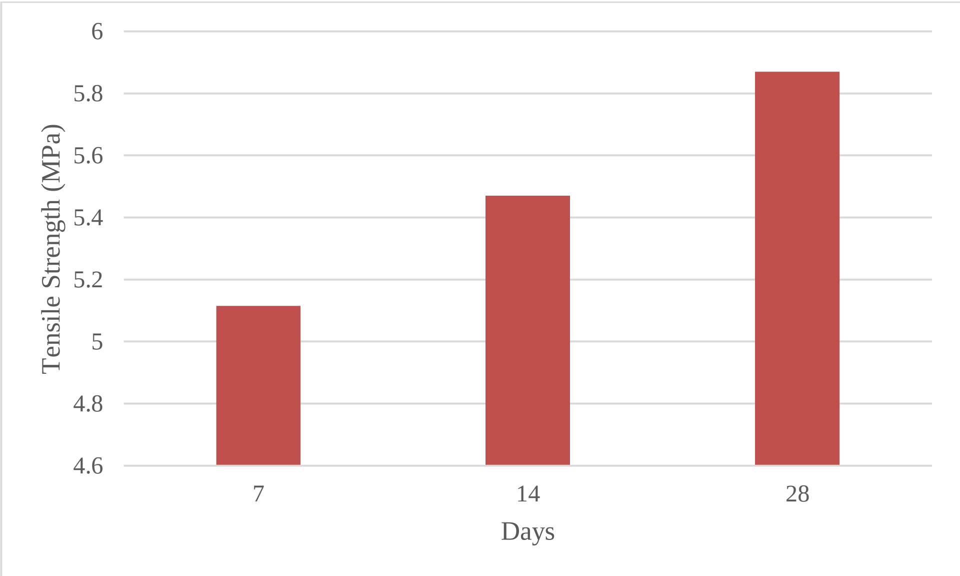

Figure 4.8 Tensile Strength of Plain UHPC Cured in Water for 7, 14 and 28 Days.

Figure 4.8 indicates that, the tensile strength values for Plain UHPC was also increased starting day 7 to day 28. The result shows that the highest tensile strength is 5.87 MPa and the lowest value is 5.12 MPa at day 28 and day 7, respectively. The tensile strength at 28 days was increased about 14.65% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of Plain UHPC specimen significantly increased when the duration of the curing age increases. Table 4.7 and Figure 4.9 shows the tensile strength of UHPC-20 cured in water with respect to ages.

Table 4.7	Tensile Strength of Rubberized-UHPC (UHPC-20)	
Mix Designation	Age (Days)	Tensile Strength (MPa)
UHPC-20	7	3.09
UHPC-20	14	3.35
UHPC-20	28	3.6

Futhermore, Figure 4.9 illustrates the tensile strength of rubberized-UHPC (UHPC-20) containing 5% WCT particles immersed for 40 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of curing days.

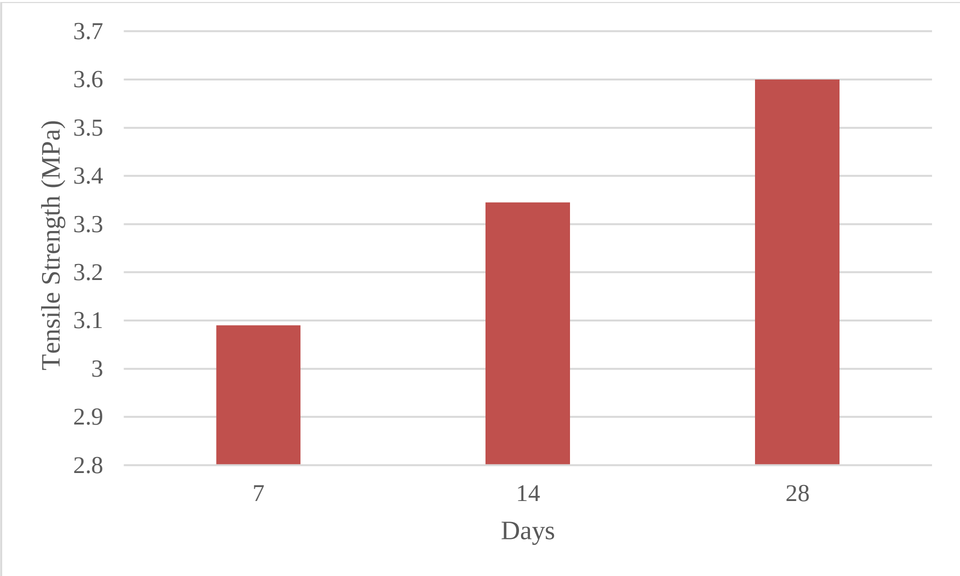

Figure 4.9 Tensile Strength UHPC-20 on Curing Water for 7, 14 and 28 Days.

Figure 4.9 indicates that, the tensile strength values for UHPC-20 was also increased starting day 7 to day 28. The result shows that the highest tensile strength is 3.6 MPa and the lowest value is 3.09 MPa at day 28 and day 7, respectively. The tensile strength at 28 days was increased about 14.65% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of UHPC-20 specimen significantly increased when the duration of the curing age increases. Table 4.8 and Figure 4.10 shows the tensile strength of UHPC-40 cured in water with respect to ages.

Table 4.8 Tensile Strength of Rubberized-UHPC (UHPC-40)

Mix Designation	Age (Days)	Tensile Strength (MPa)
UHPC-40	7	4.17
UHPC-40	14	3.62
UHPC-40	28	4.42

Besides that, Figure 4.10 illustrates the tensile strength of rubberized-UHPC (UHPC-40) containing 5% WCT particles immersed for 40 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of curing days.

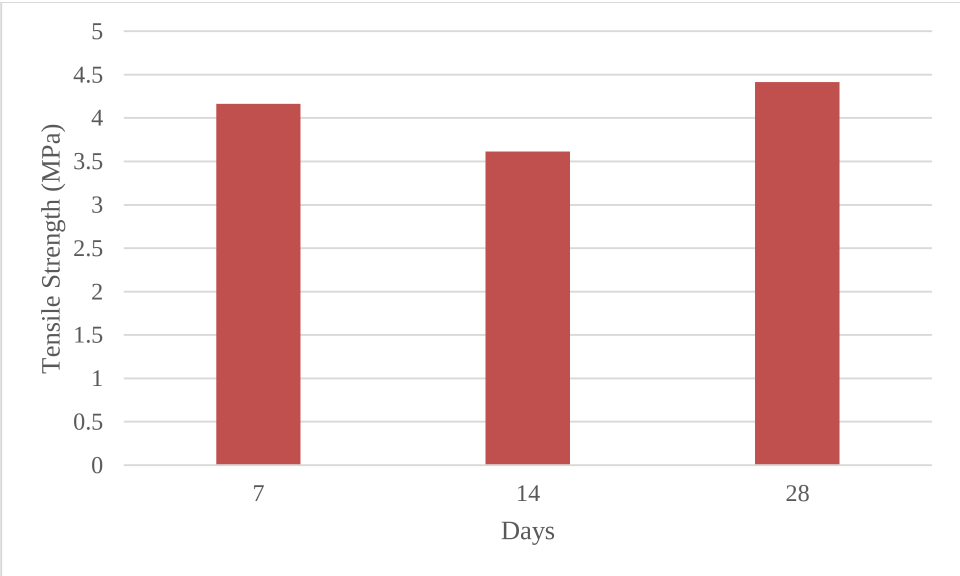

Figure 4.10 Tensile Strength UHPC-40 on Curing Water for 7, 14 and 28 Days.

Figure 4.10 indicates that, the tensile strength values for UHPC-40 was increased starting day 7 then drop at day 14 and increase at day 28. The result shows that the highest tensile strength is 4.42 MPa and the lowest value is 3.62 MPa at day 28 and day 14, respectively. The tensile strength at 28 days was increased about 6.00% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of UHPC-40 specimen significantly increased when the duration of the curing age increases. Table 4.9 and Figure 4.11 shows the tensile strength of UHPC-60 cured in water with respect to ages.

Table 4.9 Tensile Strength of Rubberized-UHPC (UHPC-60)

Mix Designation	Age (Days)	Tensile Strength (MPa)
UHPC-60	7	4.41
UHPC-60	14	5.08
UHPC-60	28	5.58

Meanwhile, Figure 4.11 illustrates the tensile strength of rubberized-UHPC (UHPC-60) containing 5% WCT particles immersed for 60 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of curing days.

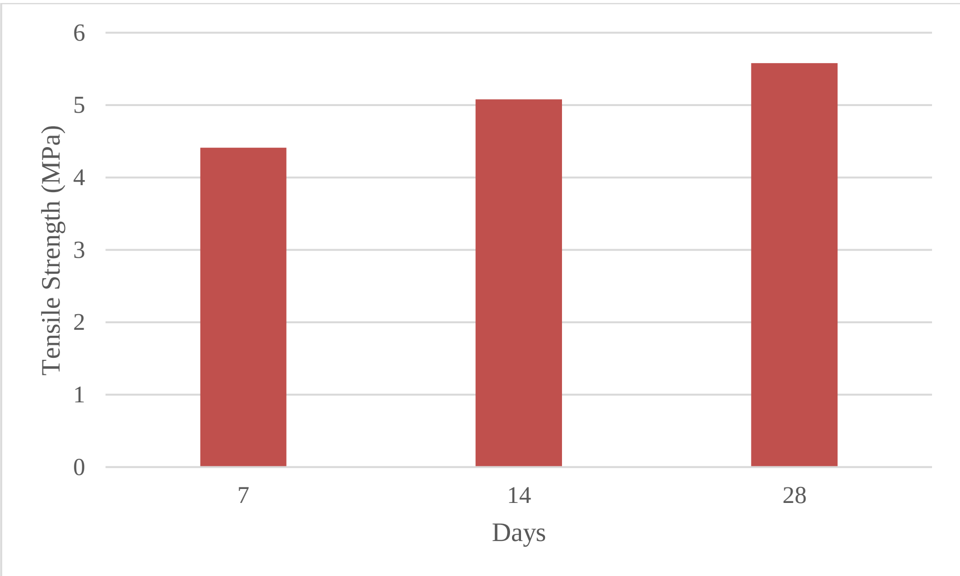

Figure 4.11 Tensile Strength UHPC-60 on Curing Water for 7, 14 and 28 Days.

Figure 4.11 indicates that, the tensile strength values for UHPC-60 was also increased starting day 7 to day 28. The result shows that the highest tensile strength is 5.58 MPa and the lowest value is 4.41 MPa at day 28 and day 7, respectively. The tensile strength at 28 days was increased about 26.53% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of UHPC-60 specimen significantly increased when the duration of the curing age increases.

4.3.4 Effect of Treated-WCT as Aggregate Replacement on Tensile Strength of Rubberized-UHPC

Table 4.10 and Figure 4.12 shows the tensile strength UHPC, UHPC-20, UHPC-40 and UHPC-60 on curing water for 7, 14 and 28 days cured in water with respect to ages.

Table 4.10 Tensile Strength of Plain UHPC, UHPC-20, UHPC-40 and UHPC-60

Mix Designation	Tensile Strength (MPa)		
	7 Days	14 Days	28 Days
Plain UHPC	5.12	5.47	5.87
UHPC-20	3.09	3.35	3.60
UHPC-40	4.17	3.62	4.42
UHPC-60	4.41	5.08	5.58

Meanwhile, Figure 4.14 illustrates the tensile strength of Plain UHPC and rubberized-UHPC (UHPC-20, UHPC-40, UHPC-60) containing 5% WCT particles immersed for 20, 40 and 60 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of curing days.

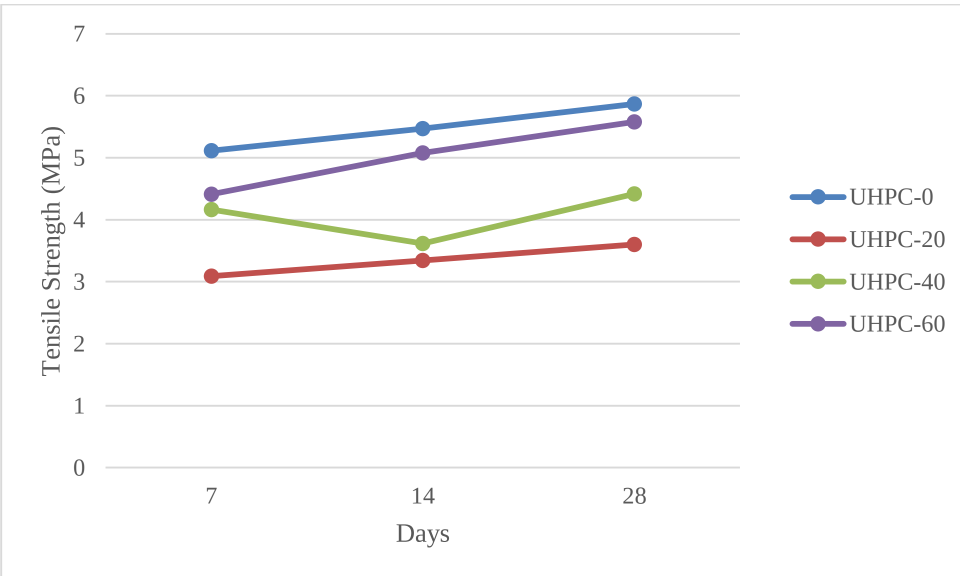

Figure 4.12 Tensile Strength Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 on Curing Water for 7, 14 and 28 Days

From Figure 4.12, the tensile strength shows that the UHPC strength is the higher strength compare with rubberized-UHPC. The highest strength is about at days 28 with value 5.87 MPa for Plain UHPC. For the rubberized-UHPC with namely, UHPC-20, UHPC-40 and UHPC-60 which is the UHPC-60 give high strength compare to the UHPC-20 and UHPC-40. At the 28 days, the tensile strength for Plain UHPC loss about 4.94% after mix with the WCT particle for 60 minutes pre-treatment. Then tensile strength loss for 24.70% after mix with the WCT particles for 40 minutes pre-treatment and the tensile strength loss 38.67% after mix with WCT particles for 20 minutes. It can be conclude that the strength of UHPC increase when the duration of the curing water increase and it also same with the rubberized-UHPC that the strength increase when the duration of the curing water increase.

4.4 Durability of Rubberized-UHPC Exposed in 3% NaCl Solution

In this section, the durability of the UHPC and Rubberized-UHPC with different duration on treatment on waste crumb tyre (WCT) is presented. All the specimens were immersed in 3% of sodium chloride (NaCl) solution after the entire specimens were cured in water for 7 days. All the exposed specimens were tested to determine the strength loss namely compressive strength and tensile strength, and weight loss. On other hand, the chloride penetration characteristics namely chloride penetration depth and chloride profile were also examined. The data obtained after the specimens were exposed in 3% NaCl solution for 7, 14 and 28 days.

4.4.1 Strength Loss of Exposed Rubberized-UHPC

In this section, the strength loss of exposed rubberized-UHPC was divided into two (2) part with namely compressive strength and tensile strength. From the Table 4.11 and Figure 4.13 show that the result of the compressive strength Plain UHPC on chloride attack. The result show the strength of cube after the 7, 14 and 28 days exposed in 3% NaCl solution.

Table 4.11 Compressive Strength of Plain UHPC on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Compressive Strength (MPa)
Plain UHPC	7	76.42
Plain UHPC	14	72.89
Plain UHPC	28	69.23

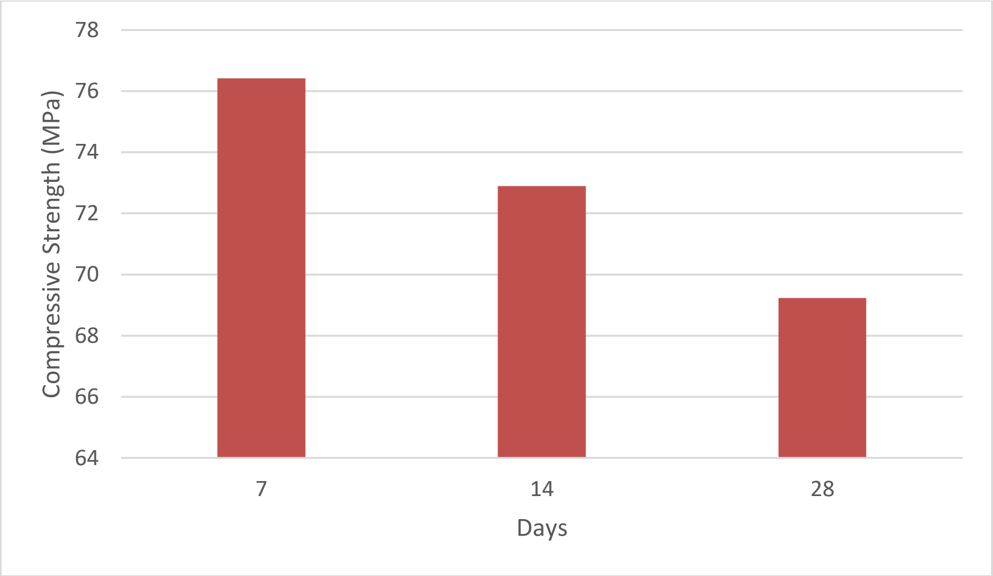

Figure 4.13 Compressive Strength of Plain UHPC Exposed in 3% NaCl Solution for 7, 14 and 28 Days

From the Figure 4.13, the compressive strength of Plain UHPC decreased significantly from day 7 to day 28. The highest compressive strength obtained is 76.42 MPa at 7 days of exposed. Meanwhile the lowest compressive strength was recorded at day 28 with strength of 69.23 MPa. The percentage of strength loss between 7 days to 28 days is about 9.41%. It can be found that the strength of Plain UHPC decreased when the duration of curing increased. Table 4.12 and Figure 4.14 shows the compressive strength of UHPC-20 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.12 Compressive Strength of UHPC-20 on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Compressive Strength (MPa)
UHPC-20	7	61.07
UHPC-20	14	59.27
UHPC-20	28	48.63

On the other hand, Figure 4.14 illustrate the compressive strength of rubberized-UHPC (UHPC-20) containing 5% WCT particles immersed for 20 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

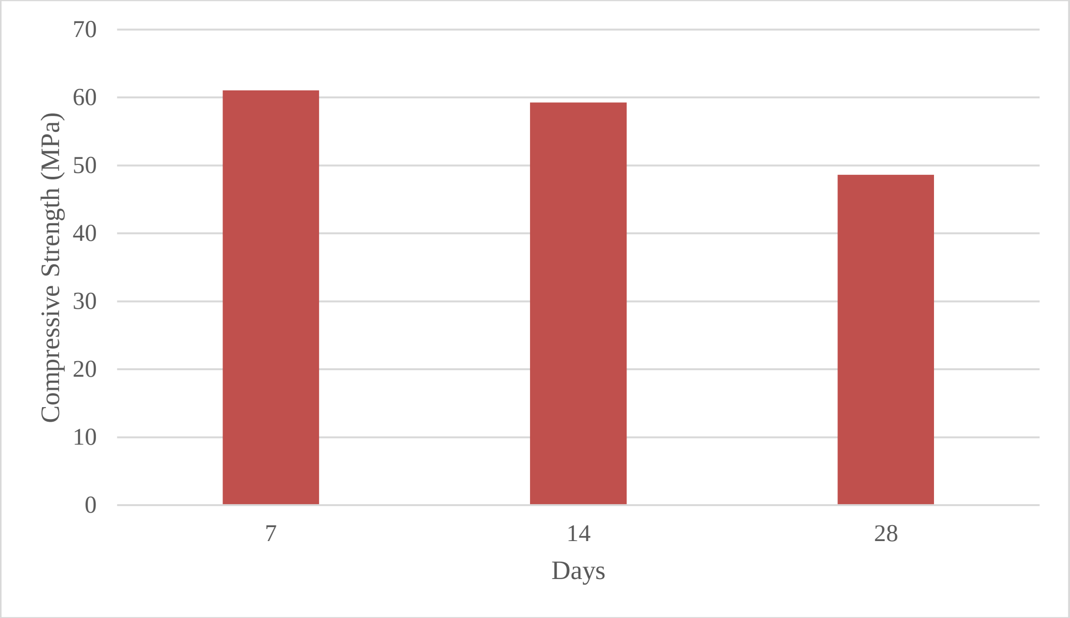

Figure 4.14 Compressive Strength of UHPC-20 Exposed in 3% NaCl Solution for 7, 14 and 28 Days

Figure 4.14 indicates that, the compressive strength values for UHPC-20 was decreased starting day 7 to day 28. The result shows that the highest compressive strength is 61.07 MPa and the lowest value is 48.63 MPa at day 7 and day 28, respectively. The compressive strength at 28 days was decreased about 20.37% when compared to the strength recorded at 7 days. It is reveals that the compressive strength of UHPC-20 specimen significantly decreased when the duration of the curing age increases. Table 4.13 and Figure 4.15 shows the compressive strength of UHPC-40 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.13 Compressive Strength of UHPC-40 on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Compressive Strength (MPa)
UHPC-40	7	68.68
UHPC-40	14	64.62
UHPC-40	28	62.59

On the other hand, Figure 4.15 illustrate the compressive strength of rubberized-UHPC (UHPC-40) containing 5% WCT particles immersed for 40 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

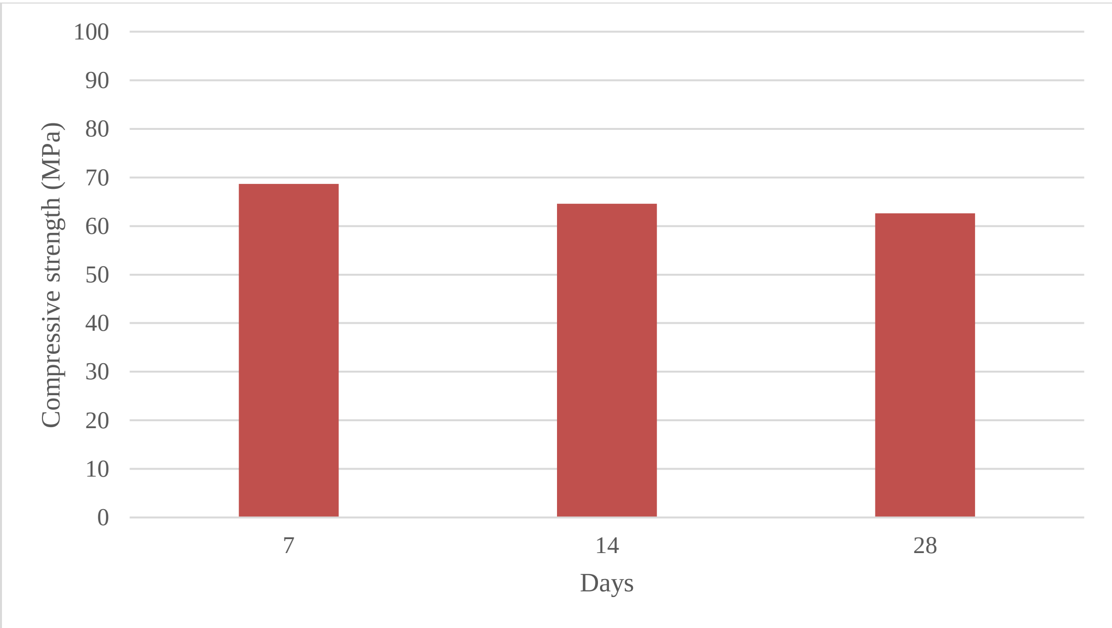

Figure 4.15 Compressive Strength of UHPC-40 Exposed in 3% NaCl Solution for 7, 14 and 28 Days.

Generally Figure 4.15 indicates that, the compressive strength values for UHPC-40 was decreased starting day 7 to day 28. The result shows that the highest compressive strength is 68.68 MPa and the lowest value is 62.59 MPa at day 7 and day 28, respectively. The compressive strength at 28 days was decreased about 8.87% when compared to the strength recorded at 7 days. It is reveals that the compressive strength of UHPC-40 specimen significantly decreased when the duration of the curing age increases. Table 4.14 and Figure 4.16 shows the compressive strength of UHPC-60 exposed in 3% NaCl solution for 7, 14 and 28 days

Table 4.14 Compressive Strength of UHPC-60 on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Compressive Strength (MPa)
UHPC-60	7	72.93
UHPC-60	14	67.83
UHPC-60	28	66.17

On the other hand, Figure 4.16 illustrate the compressive strength of rubberized-UHPC (UHPC-60) containing 5% WCT particles immersed for 60 minutes in NaOH solution. The results on compressive strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

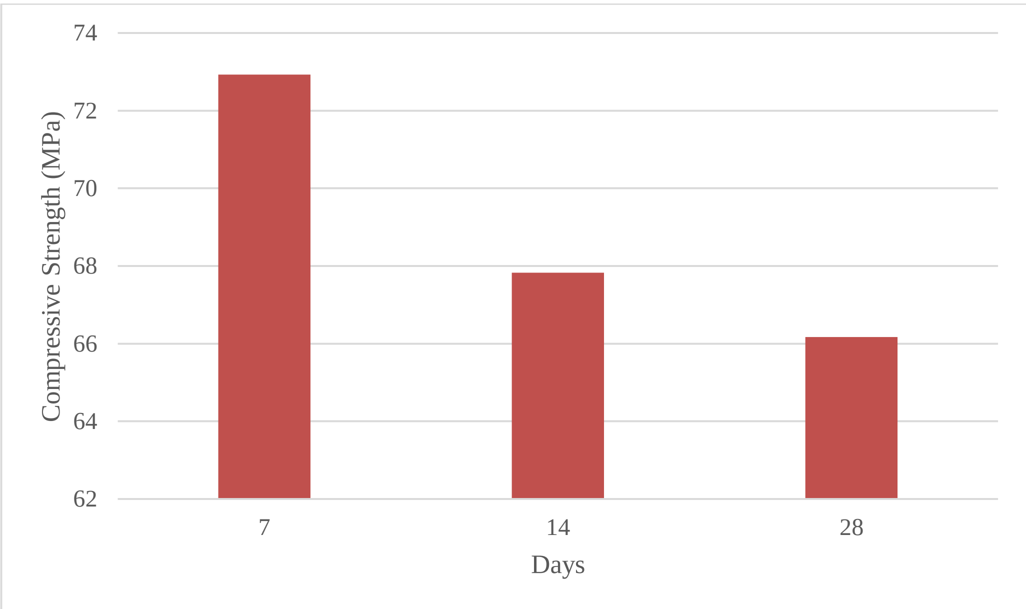

Figure 4.16 Compressive Strength of UHPC-60 Exposed in 3% NaCl Solution for 7, 14 and 28 Days

Figure 4.16 indicates that, the compressive strength values for UHPC-60 was decreased starting day 7 to day 28. The result shows that the highest compressive strength is 72.93 MPa and the lowest value is 66.17 MPa at day 7 and day 28, respectively.

The compressive strength at 28 days was decreased about 9.27% when compared to the strength recorded at 7 days. It is reveals that the compressive strength of UHPC-60 specimen significantly decreased when the duration of the curing age increases. Table 4.15 and Figure 4.17 shows the compressive strength of UHPC-0, UHPC-20, UHPC-40 and UHPC-60 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.15 Compressive Strength of Plain UHPC and a Series of Rubberized-UHPC for 7, 14 And 28 Days Exposed in 3% NaCl Solution

Mix Designation	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
Plain UHPC	76.42	72.89	69.23
UHPC-20	61.07	59.27	48.63
UHPC-40	68.68	64.62	62.59
UHPC-60	72.93	67.83	66.17

Meanwhile, Figure 4.17 illustrate the compressive strength of Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 with respect to three duration of immersion 7, 14 and 28 days on 3% NaCl solution.

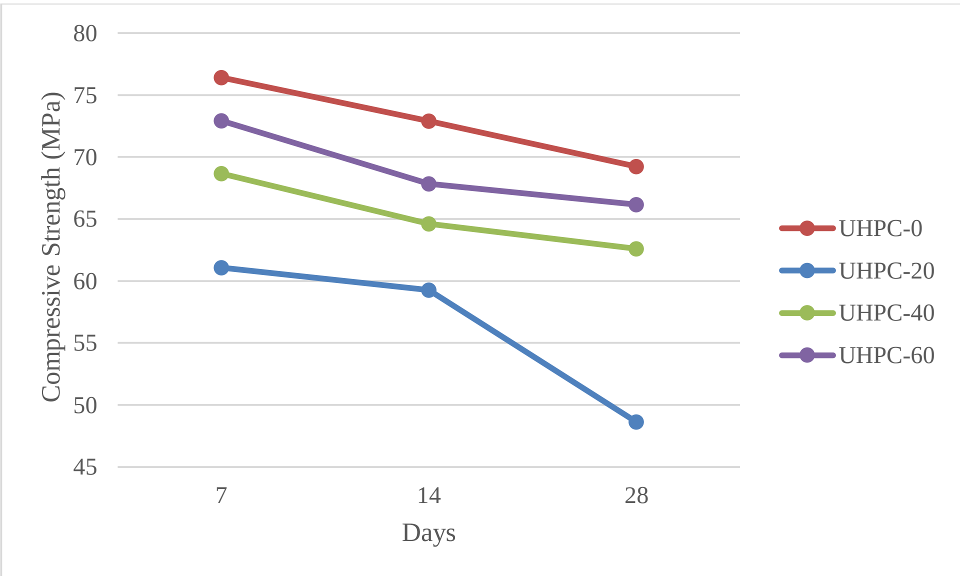

Figure 4.17 Compressive Strength of Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 with Respect to Three Duration of Immersion 7, 14 and 28 Days on 3 % NaCl Solution

Generally from Figure 4.17, the compressive strength shows that the Plain UHPC strength is the higher strength compare with rubberized-UHPC. The highest strength is about at days 7 with value 76.42 MPa for Plain UHPC. For the rubberized-UHPC with namely UHPC, UHPC-20, UHPC-40 and UHPC-60 which is the UHPC-60 give high strength compare to the UHPC-20 and UHPC-40. At the 7 days, the compressive strength for Plain UHPC loss about 4.57% after UHPC mix with the WCT particle for 60 minutes pre-treatment. Then compressive strength loss for 10.13% after UHPC mix with the WCT particles for 40 minutes pre-treatment and the compressive strength loss 20.09% after UHPC mix with WCT particles for 20 minutes. Previous finding also, Sukhoon (2017) found that the 3.0% NaCl was expose to the normal mortar (NM), high strength mortar (HSM) and ultra-high performance concrete (UHPC) will loss the strength. It can be conclude that the strength of UHPC decrease when the duration of the exposed in 3% NaCl increase and it also same with the series rubberized-UHPC that the strength decrease when the duration of the curing water increase.

In other thing to determine the development of strength UHPC and Rubberized-UHPC the tensile strength test be conducted by follow BS EN 12390-6:2009. The test was conducted to the all specimens after 7, 14 and 28 days exposed in 3% NaCl solution. The Table 4.16 and Figure 4.18 shows that the tensile strength of Plain UHPC on exposed in 3% NaCl solution for different ages.

Table 4.16 Tensile Strength of Plain UHPC on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Tensile Strength (MPa)
Plain UHPC	7	6.65
Plain UHPC	14	5.98
Plain UHPC	28	4.60

Meanwhile, Figure 4.18 illustrate the tensile strength of Plain UHPC with respect to three duration of immersion 7, 14 and 28 days on 3% NaCl solution.

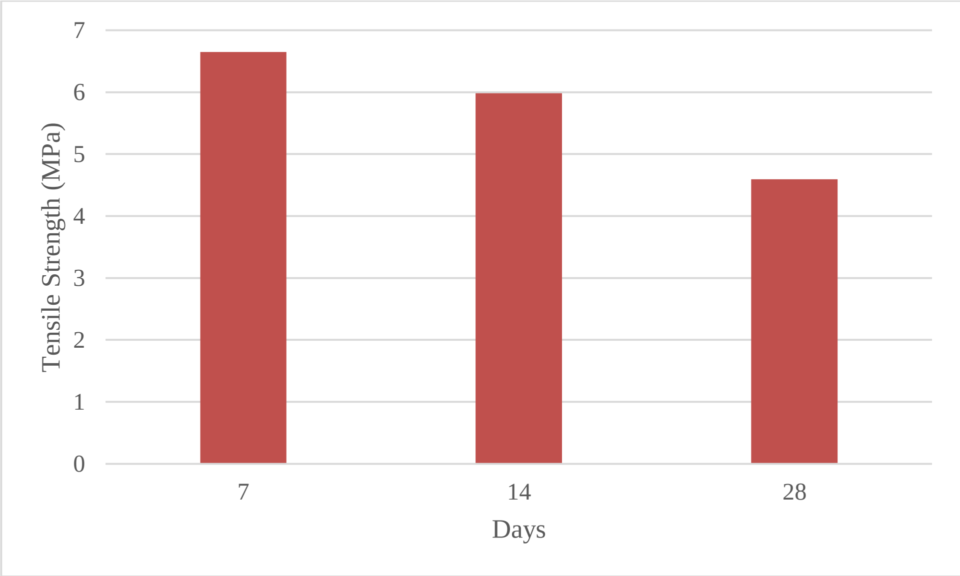

Figure 4.18 Tensile Strength of Plain UHPC with Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% Nacl Solution

Figure 4.18 indicates that, the tensile strength values for Plain UHPC was decreased starting day 7 to day 28. The result shows that the highest tensile strength is 6.65 MPa and the lowest value is 4.60 MPa at day 7 and day 28, respectively. The tensile strength at 28 days was decreased about 30.83% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of Plain UHPC specimen significantly decreased when the duration of the exposed age increases. Table 4.17 and Figure 4.19 shows the tensile strength of UHPC-20 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.17 Tensile Strength of UHPC-20 on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Tensile Strength (MPa)
UHPC-20	7	3.55
UHPC-20	14	3.84
UHPC-20	28	3.63

On the other hand, Figure 4.19 illustrate the tensile strength of rubberized-UHPC (UHPC-20) containing 5% WCT particles immersed for 20 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

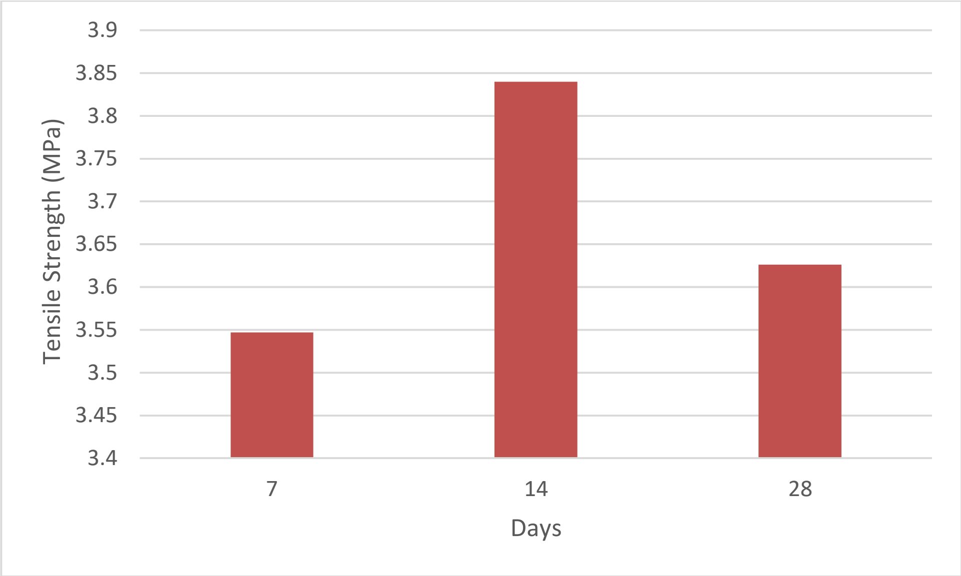

Figure 4.19 Tensile Strength of UHPC-20 with Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% Nacl Solution

Generally from Figure 4.19, the tensile strength of UHPC-20 that been immersed in NaCl can be conclude that the highest strength at day 14 which is the value is 3.84 MPa. For the lowest strength is at day 7 with value 3.55 MPa and for the median strength at day 28 with value 3.63 MPa. It can be conclude that the tensile strength small at early cured and increase at mid immersed then decrease lower than day 14 but upper than day 7 after immersed in 3% NaCl solution. Table 4.18 and Figure 4.20 show the result of the tensile strength of UHPC-40 on exposed in 3% NaCl solution.

Table 4.18 Tensile Strength of UHPC-40 on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Tensile Strength (MPa)
UHPC-40	7	4.76
UHPC-40	14	4.08
UHPC-40	28	3.86

On the other hand, Figure 4.20 illustrate the tensile strength of rubberized-UHPC (UHPC-40) containing 5% WCT particles immersed for 40 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

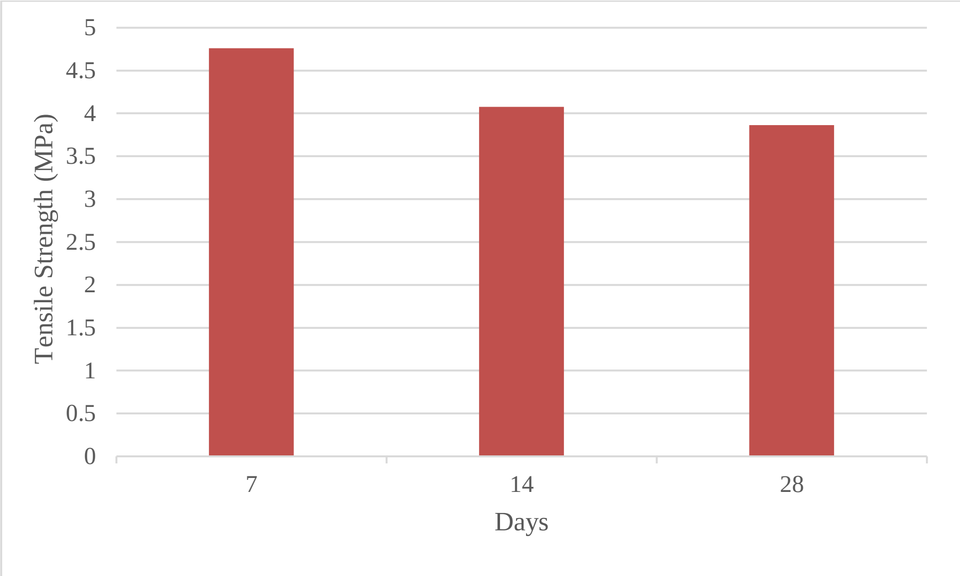

Figure 4.20 Tensile Strength of UHPC-40 with Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% Nacl Solution

Figure 4.20 indicates that, the tensile strength values for UHPC-40 was decreased starting day 7 to day 28. The result shows that the highest tensile strength is 4.76 MPa and the lowest value is 3.86 MPa at day 7 and day 28, respectively. The tensile strength at 28 days was decreased about 18.91% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of UHPC-40 specimen significantly decreased when the duration of the exposed age increases. Table 4.19 and Figure 4.21 shows the tensile strength of UHPC-60 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.19 Tensile Strength of UHPC-60 on Exposed in 3% NaCl solution

Mix Designation	Age (Days)	Tensile Strength (MPa)
UHPC-60	7	4.89
UHPC-60	14	4.75
UHPC-60	28	4.47

On the other hand, Figure 4.21 illustrate the tensile strength of rubberized-UHPC (UHPC-60) containing 5% WCT particles immersed for 60 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

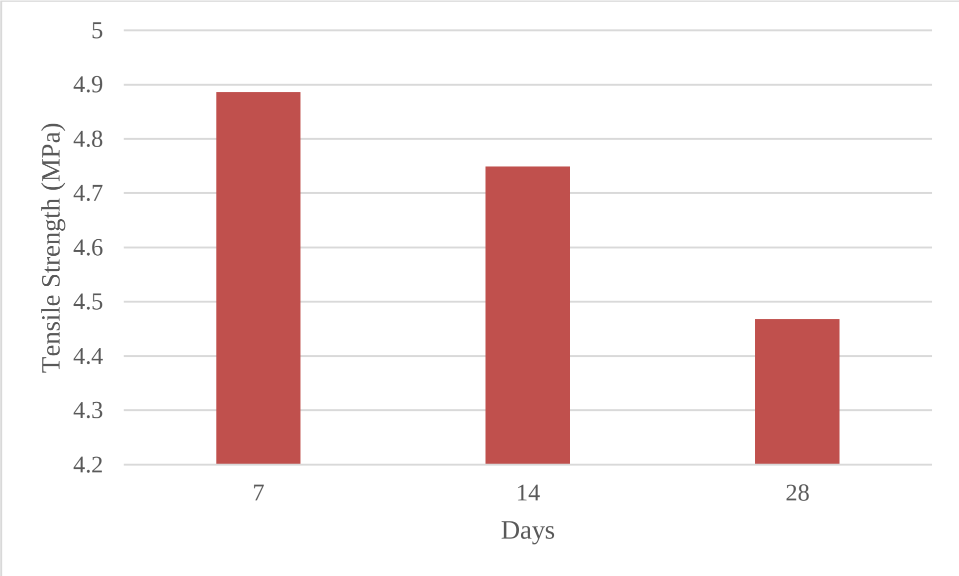

Figure 4.21 Tensile Strength of UHPC-60 with Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% Nacl Solution

Figure 4.21 indicates that, the tensile strength values for UHPC-60 was decreased starting day 7 to day 28. The result shows that the highest tensile strength is 4.89 MPa and the lowest value is 4.47 MPa at day 7 and day 28, respectively. The tensile strength at 28 days was decreased about 8.59% when compared to the strength recorded at 7 days. It is reveals that the tensile strength of UHPC-60 specimen significantly decreased when the duration of the exposed age increases. Table 4.20 and Figure 4.22 shows the tensile strength of UHPC-0, UHPC-20, UHPC-40 and UHPC-60 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.20 Tensile Strength of UHPC-0, UHPC-20, UHPC-40 and UHPC-60 Exposed on 3% NaCl Solution

Mix Designation	Tensile Strength (MPa)		
	7 Days	14 Days	28 Days
Plain UHPC	6.65	5.98	4.60
UHPC-20	3.55	3.84	3.63
UHPC-40	4.76	4.08	3.86
UHPC-60	4.89	4.75	4.47

On the other hand, Figure 4.22 illustrate the tensile strength of Plain UHPC and rubberized-UHPC (UHPC-20, UHPC-40, UHPC-60) containing 5% WCT particles immersed for 20, 40 and 60 minutes in NaOH solution. The results on tensile strength was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

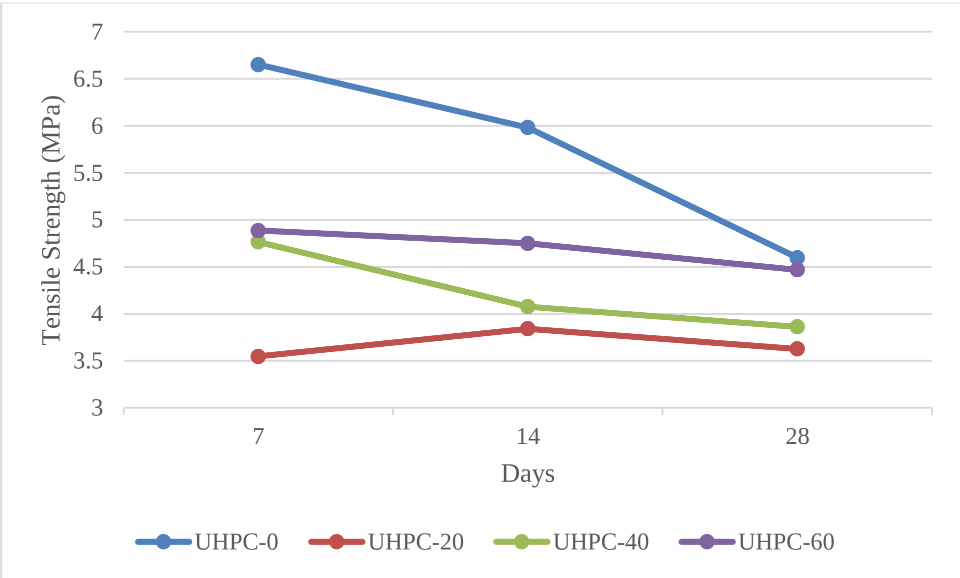

Figure 4.22 Tensile Strength of Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 with Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% NaCl Solution.

Generally from Figure 4.22, the tensile strength shows that the UHPC strength is the higher strength compare with rubberized-UHPC. The highest strength is about at days 7 with value 6.65 MPa for Plain UHPC. For the rubberized-UHPC with namely, UHPC-20, UHPC-40 and UHPC-60 which is the UHPC-60 give high strength compare to the UHPC-20 and UHPC-40. At the 7 days, the tensile strength for UHPC loss about 26.54% after UHPC mix with the WCT particle for 60 minutes pre-treatment. Then tensile strength loss for 28.07% after UHPC mix with the WCT particles for 40 minutes pre-treatment and the tensile strength loss 46.67% after UHPC mix with WCT particles for 20 minutes. Previous finding also, Sukhoon (2017) found that the 3.0% NaCl was expose to the normal mortar (NM), high strength mortar (HSM) and ultra-high performance concrete (UHPC) will loss the strength. It can be conclude that the strength of UHPC decrease when the duration of the exposed in 3% NaCl increase and it also same with the series rubberized-UHPC that the strength decrease when the duration of the curing water increase.

4.4.2 Weight Loss of Exposed Rubberized-UHPC

The other things were the weight loss on the all cube specimens were taken. The weight was taken before and after the cured in the 3% NaCl solution. The Table 4.21 show the result of the weight loss of the 36 cube that been cured in NaCl.

Table 4.21 Result Weight Loss of the 36 Cube

Mix Designation	Weight Loss (%)		
	7 Days	14 Days	28 Days
Plain UHPC	0	-0.001	-0.209
UHPC-20	0	-0.123	-0.338
UHPC-40	0	-0.108	-0.306
UHPC-60	0	-0.016	-0.258

Generally, Figure 4.23 illustrate the weight loss of Plain UHPC and rubberized-UHPC (UHPC-20, UHPC-40, UHPC-60) containing 5% WCT particles immersed for 20, 40 and 60 minutes in NaOH solution. The results on weight loss was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

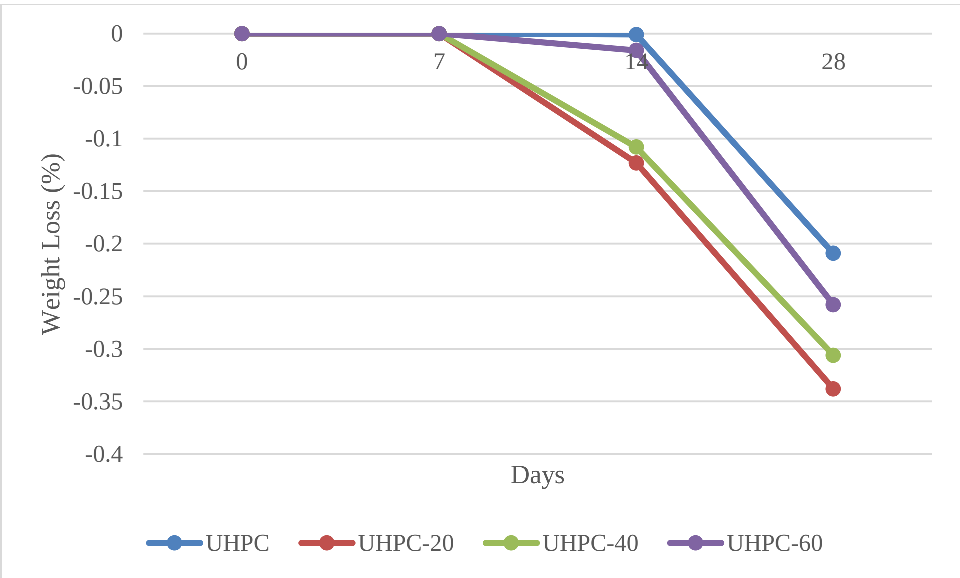

Figure 4.23 Weight Loss of UHPC and Rubberized-UHPC

The weight of the Plain UHPC and rubberized UHPC increase when exposed on 7, 14 and 28 days in 3% NaCl solution because the NaCl penetrate into the concrete but the value was different between Plain UHPC and rubberized-UHPC and Figure 4.23 indicates that, the weight loss values for Plain UHPC was the highest percentage compare to the rubberized-UHPC on 7, 14, and 28 days exposed in 3% NaCl solution. The NaCl was difficult to penetrate in the Plain UHPC compare to the rubberized-UHPC because of the micro-filler affect. For the rubberized-UHPC the replacement of the aggregate with WCT make the capillary pore increase and it is easy to NaCl penetrate into concrete. In the rubberized-UHPC, UHPC-60 was the highest weight loss compare to the UHPC-40 and UHPC-20. This because the 60 minutes of waste crumb tyre (WCT) pre-treatment change the surface of the WCT effectively than 40 and 20 minutes.

4.5 Chloride Penetration Characteristics of Rubberized-UHPC

In this section, there are two (2) chloride penetration characteristics of rubberized-UHPC which is include chloride penetration depth of rubberized-UHPC and chloride profile of rubberized-UHPC. The test was conducted by using colorimetric method to the all specimens after 7, 14 and 28 days exposed in 3% NaCl solution.

4.5.1 Chloride Penetration Depth of Rubberized-UHPC

In this study, the result that been focused is influence of pre-treatment waste crumb tyre (WCT) in producing rubberized-UHPC to chloride penetration by using colorimetric method. This method was conducted to all cylinder of UHPC and rubberized-UHPC. Table 4.22 and Figure 4.2 show that the result of chloride penetration depth for UHPC on exposed in 3% NaCl solution.

Table 4.22 Chloride Penetration Depth of Plain UHPC on Exposed in 3% NaCl Solution

Mix Designation	Age (Days)	Chloride Penetration Depth (mm)
Plain UHPC	7	3.53
Plain UHPC	14	4.17
Plain UHPC	28	4.5

Meanwhile, Figure 4.24 illustrates the chloride penetration depth of Plain UHPC on 7, 14 and 28 days of exposed 3% NaCl solution.

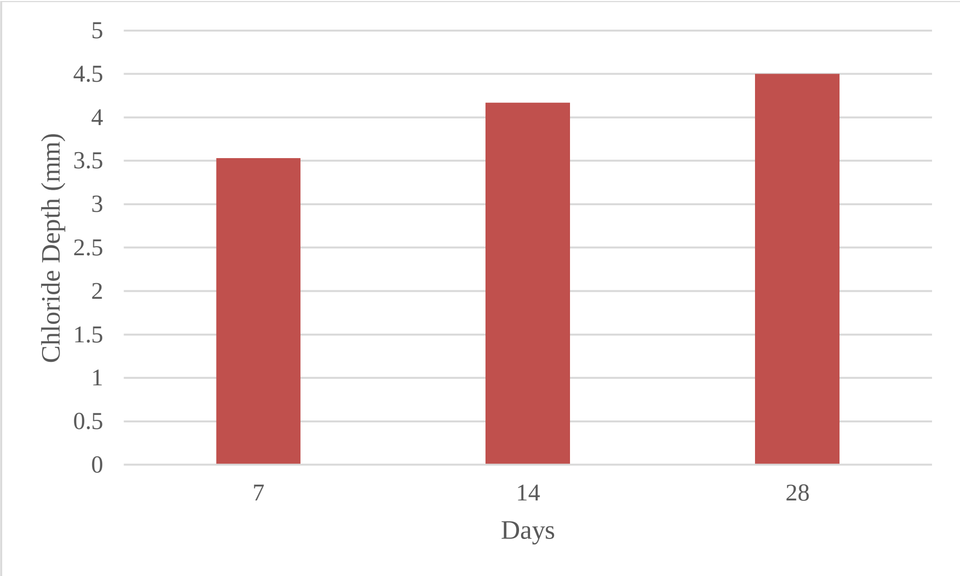

Figure 4.24 Result of Chloride Penetration Depth for Plain UHPC Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% NaCl Solution

From Figure 4.24 show that the differentiate result of chloride penetration depth for UHPC-0 with different ages after exposed in 3% NaCl solution. In this figure show that the higher chloride depth is at day 28 with value 4.5 mm. After that the lowest chloride depth is at day 7 with 3.53 mm. The chloride penetration depth at 28 days was increase about 27.48% when compared to the strength recorded at 7 days. It is reveals that the chloride penetration depth of UHPC-0 specimen significantly increase when the duration of the exposed age increases. Table 4.23 and Figure 4.25 shows the chloride penetration depth of UHPC-20 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.23 Chloride Penetration Depth of UHPC-20 on Exposed in 3% NaCl Solution

Mix Designation	Age (Days)	Chloride Penetration Depth (mm)
UHPC-20	7	3.82
UHPC-20	14	4.85
UHPC-20	28	5.96

On the other hand, Figure 4.25 illustrate the chloride penetration depth of rubberized-UHPC (UHPC-20) containing 5% WCT particles immersed for 20 minutes in NaOH solution. The results on chloride penetration depth was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

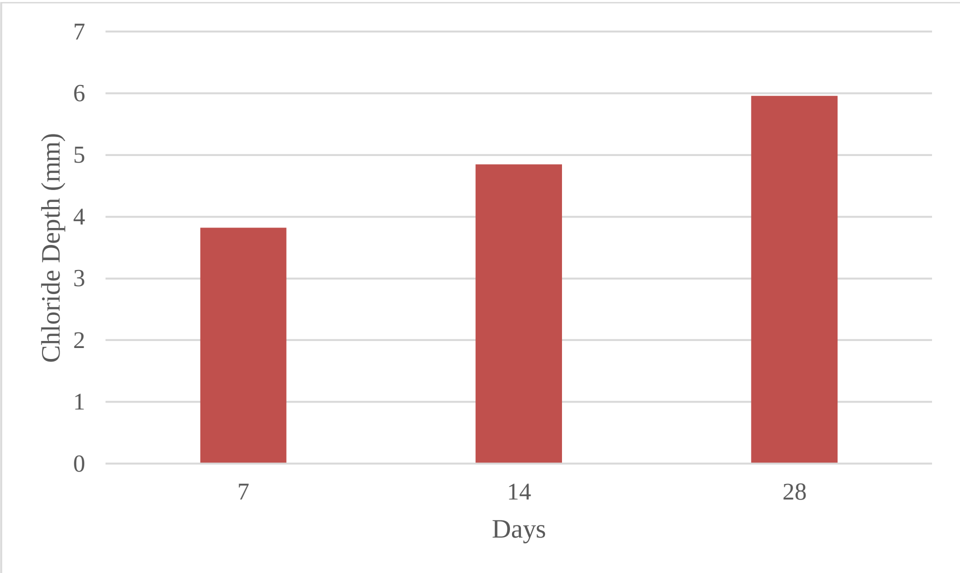

Figure 4.25 Result of Chloride Penetration Depth for UHPC-20 Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% NaCl Solution

From Figure 4.25 show that the differentiate result of chloride penetration depth for UHPC-20 with different ages after exposed in 3% NaCl solution. In this figure show that the higher chloride depth is at day 28 with value 5.96 mm. After that the lowest chloride depth is at day 7 with 3.82 mm. The chloride penetration depth at 28 days was increase about 56.02% when compared to the strength recorded at 7 days. It is reveals that the chloride penetration depth of UHPC-20 specimen significantly increase when the duration of the exposed age increases. Table 4.24 and Figure 4.26 shows the chloride penetration depth of UHPC-40 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.24 Chloride Penetration Depth of UHPC-40 on Exposed in 3% NaCl Solution

Mix Designation	Age (Days)	Chloride Penetration Depth (mm)
UHPC-40	7	3.64
UHPC-40	14	4.73
UHPC-40	28	5.82

On the other hand, Figure 4.26 illustrate the chloride penetration depth of rubberized-UHPC (UHPC-40) containing 5% WCT particles immersed for 40 minutes in NaOH solution. The results on chloride penetration depth was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

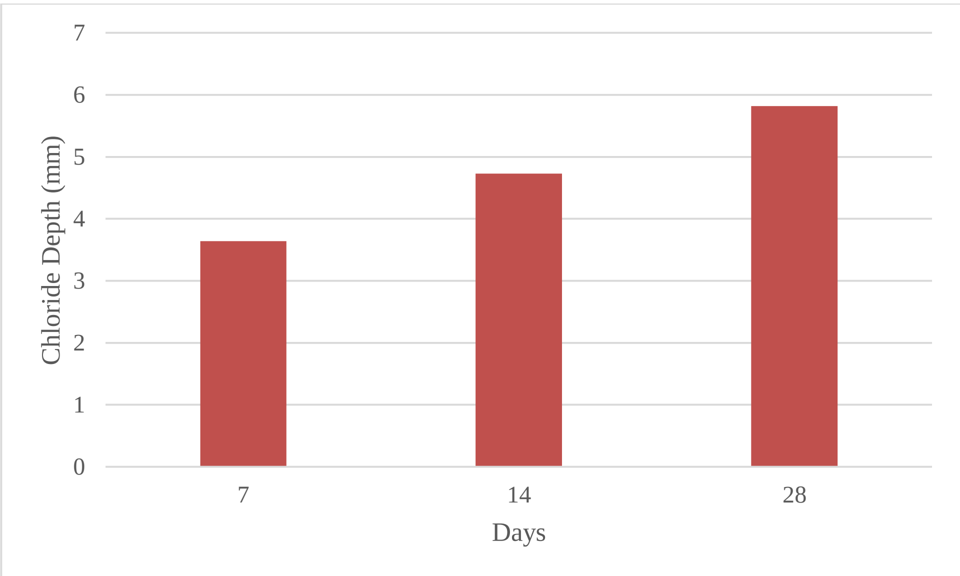

Figure 4.26 Result of Chloride Penetration Depth for UHPC-40 Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% NaCl Solution

From Figure 4.26 show that the differentiate result of chloride penetration depth for UHPC-40 with different ages after exposed in 3% NaCl solution. In this figure show that the higher chloride depth is at day 28 with value 5.82 mm. After that the lowest chloride depth is at day 7 with 3.64 mm. The chloride penetration depth at 28 days was increase about 59.89% when compared to the strength recorded at 7 days. It is reveals that the chloride penetration depth of UHPC-40 specimen significantly increase when the duration of the exposed age increases. Table 4.25 and Figure 4.27 shows the chloride penetration depth of UHPC-60 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.25 Chloride Penetration Depth of UHPC-60 on Exposed in 3% NaCl Solution

Mix Designation	Age (Days)	Chloride Penetration Depth (mm)
UHPC-60	7	3.52
UHPC-60	14	4.28
UHPC-60	28	5.50

On the other hand, Figure 4.27 illustrate the chloride penetration depth of rubberized-UHPC (UHPC-60) containing 5% WCT particles immersed for 60 minutes in NaOH solution. The results on chloride penetration depth was obtained for 7, 14 and 28 days of exposed in 3% NaCl solution.

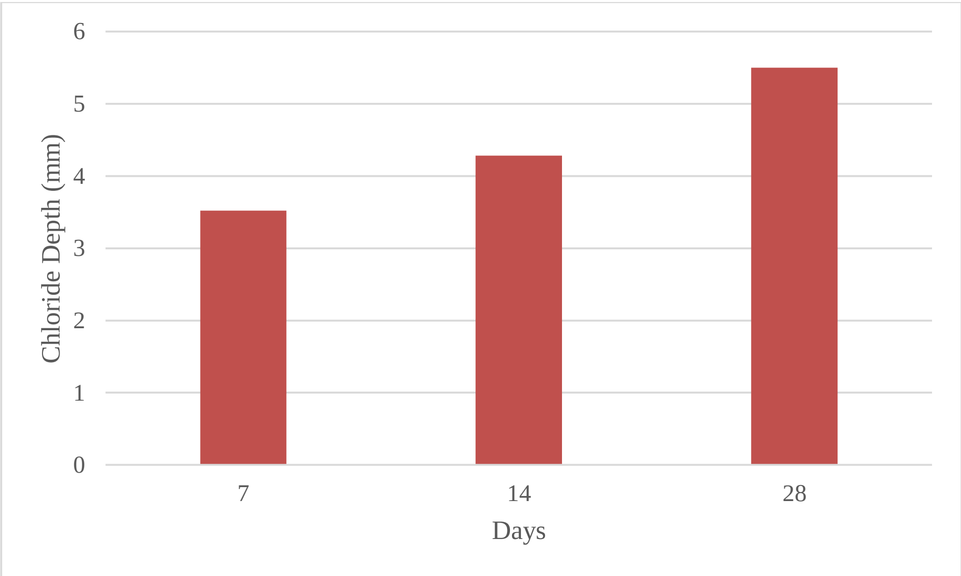

Figure 4.27 Result of Chloride Penetration Depth for UHPC-60 Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% NaCl Solution

From Figure 4.27 show that the differentiate result of chloride penetration depth for UHPC-40 with different ages after exposed in 3% NaCl solution. In this figure show that the higher chloride depth is at day 28 with value 5.50 mm. After that the lowest chloride depth is at day 7 with 3.52 mm. The chloride penetration depth at 28 days was increase about 56.25% when compared to the strength recorded at 7 days. It is reveals that the chloride penetration depth of UHPC-60 specimen significantly increase when the duration of the exposed age increases. Table 4.26 and Figure 4.28 shows the chloride penetration depth of UHPC-60 exposed in 3% NaCl solution for 7, 14 and 28 days.

Table 4.26 Chloride Penetration Depth of Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 on Exposed in 3% NaCl Solution

Mix Designation	Chloride Penetration Depth (mm)		
	7 Days	14 Days	28 Days
Plain UHPC	3.53	4.17	4.50
UHPC-20	3.82	4.85	5.96
UHPC-40	3.64	4.73	5.82
UHPC-60	3.52	4.28	5.50

Meanwhile, Figure 4.28 illustrate the result of chloride penetration depth for Plain UHPC, UHPC-20, UHPC-40 and UHPC-60 with respect to three duration of immersion 7, 14 and 28 days on 3% NaCl solution.

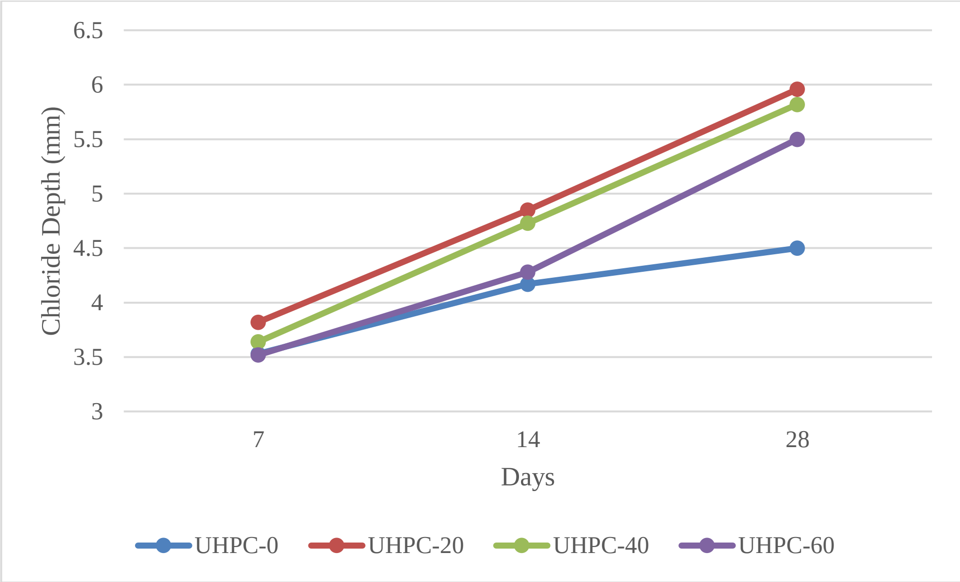

Figure 4.28 Result of Chloride Penetration Depth for Plain UHPC, UHPC-20, UHPC-40 andUHPC-60 Respect to Three Duration of Immersion 7, 14 and 28 Days on 3% NaCl Solution

From Figure 4.28 show that the differentiate result of chloride penetration depth for Plain UHPC and rubberized-UHPC (UHPC-20, UHPC-40, UHPC 60) with different ages after exposed in 3% NaCl solution. In this figure show that the lowest chloride depth at day 28 was UHPC-0 with value 4.5 mm. After that the highest chloride depth at day 28 was UHPC-20 with value 5.96 mm. The chloride penetration depth at 28 days was increase about 22.22% between Plain UHPC and UHPC-60. Then the chloride penetration depth at 28 days was increase about 29.33% between Plain UHPC and UHPC-40. For Plain UHPC and UHPC-20 the chloride depth penetration was increase at day 28 about 32.44%. The NaCl was difficult to penetrate in the Plain UHPC compare to the rubberized-UHPC because of the micro-filler affect. For the rubberized-UHPC the replacement of the aggregate with WCT make the capillary pore increase and it is easy to NaCl penetrate in the concrete. In the rubberized-UHPC, UHPC-60 was the highest weight loss compare to the UHPC-40 and UHPC-20. Previous finding also found that the chloride penetration depth UHPC range was about range 3.0-5.0 mm for 3, 7 and 28 days (Faizal, 2017). This because the 60 minutes of waste crumb tyre (WCT) pre-treatment change the surface of the WCT effectively than 40 and 20 minutes. It is reveals that the chloride penetration depth of Plain UHPC and rubberized-UHPC specimen significantly increase when the duration of the exposed age increases.

4.5.2 Chloride Profile of Rubberized-UHPC

In this section was discuss on the chloride profile of rubberized-UHPC on the colour change at the surface splitting after colorimetric method was conducted. Colorimetric method also known as silver nitrate ($AgNO_3$) spray method to know the depth of the chloride penetrate. Figure 4.29 show that the visual appearance of the splitting surface cylinder after ($AgNO_3$) spray method was conducted.

Figure 4.29 Visual Appearance of the Splitting Surface Cylinder after $AgNO_3$ Spray Method for Plain UHPC at 28 days

From Figure 4.29 shows that the visual appearance of the splitting surface cylinder after $AgNO_3$ spray method by the colour change. The penetration of the chloride show by the colour boundary between brown and white precipitate when spraying for silver nitrate. The percentage of chloride penetration depth at Plain UHPC was 6%. The colour of white silver chloride precipitation on the surface were obvious appear and the area that not affected of chloride ion stay natural or brown in colour. This finding also agreed Mota (2011) also indicated the penetration of chlorides throughout the time. Figure 4.30 shows visual appearance of the splitting surface cylinder after $AgNO_3$ spray method for UHPC-20 at 28 days

Figure 4.30 Visual Appearance of the Splitting Surface Cylinder after $AgNO_3$ Spray Method for UHPC-20 at 28 days

From Figure 4.30 shows that the visual appearance of the splitting surface cylinder after $AgNO_3$ spray method by the colour change. The penetration of the chloride show by the colour boundary between brown and white precipitate when spraying for silver nitrate. The percentage of chloride penetration depth at UHPC-20 was 7.95%. The colour of white silver chloride precipitation on the surface were obvious appear and the area that not affected of chloride ion stay natural or brown in colour. This finding also agreed Mota (2011) also indicated the penetration of chlorides throughout the time. Figure 4.30 shows visual appearance of the splitting surface cylinder after $AgNO_3$ spray method for UHPC-40 at 28 days

Figure 4.31 Visual Appearance of the Splitting Surface Cylinder after $AgNO_3$ Spray Method for UHPC-40 at 28 days

From Figure 4.31 shows that the visual appearance of the splitting surface cylinder after $AgNO_3$ spray method by the colour change. The penetration of the chloride show by the colour boundary between brown and white precipitate when spraying for silver nitrate. The percentage of chloride penetration depth at UHPC-40 was 7.76%. The colour of white silver chloride precipitation on the surface were obvious appear and the area that not affected of chloride ion stay natural or brown in colour. This finding also agreed Mota (2011) also indicated the penetration of chlorides throughout the time. Figure 4.30 shows visual appearance of the splitting surface cylinder after $AgNO_3$ spray method for UHPC-60 at 28 days

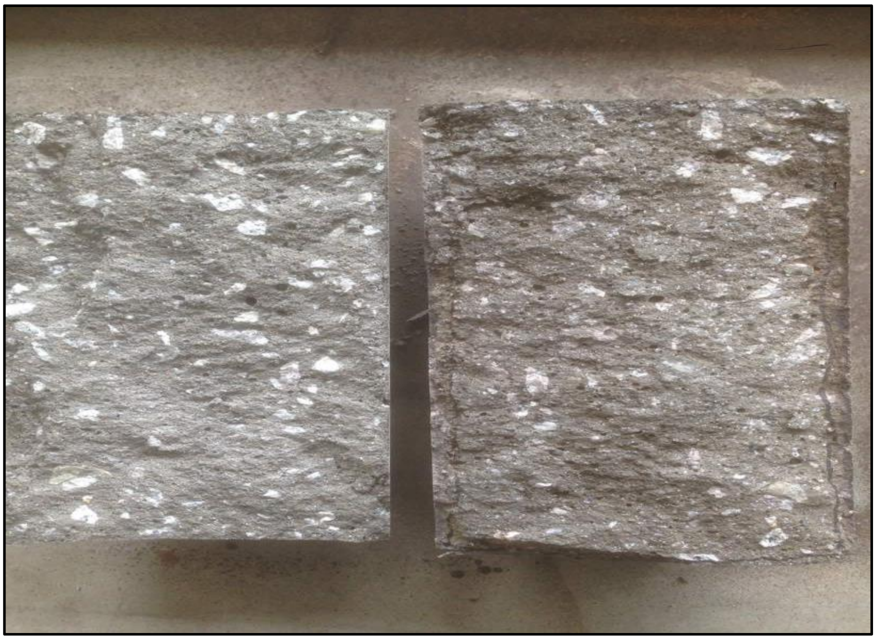

Figure 4.32 Visual Appearance of the Splitting Surface Cylinder after $AgNO_3$ Spray Method for UHPC-60 at 28 days

From Figure 4.32 shows that the visual appearance of the splitting surface cylinder after $AgNO_3$ spray method by the colour change. The penetration of the chloride show by the colour boundary between brown and white precipitate when spraying for silver nitrate. The percentage of chloride penetration depth at UHPC-60 was 7.33%. The colour of white silver chloride precipitation on the surface were obvious appear and the area that not affected of chloride ion stay natural or brown in colour. This finding also agreed Mota (2011) also indicated the penetration of chlorides throughout the time.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Introduction

The main objective of this study are to determine the effect of using different pre-treatment duration on surface of waste crumb tyre particles as aggregate replacement in UHPC and determine the compressive strength of rubberized-UHPC exposed in sodium chloride (NaCl) solution. Other than that, this study is to examine the chloride penetration profiles on exposed rubberized-UHPC in NaCl solution.

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 was immersed in the 3% NaCl solution for 7, 14 and 28 days. From the findings obtained, the conclusions can be drawn as follow:

i. It is found that the pre-treatment on the 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 depth of chloride ion penetration for UHPC shows lowest in chloride depth when compare to those of rubberized-UHPC. Among the rubberized-UHPC samples, UHPC-60 exhibit lowest chloride penetration depth.

iii. The higher in compressive strength, the lowest of chloride penetration depth was recorded.

5.3 Recommendation

In utilizing of Waste Crumb Tyre (WCT) could contribute 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 chloride attack exposure since the strength and tensile was reduced after exposed.

ii. Waste crumb tyre (WCT) need to be treated precisely before mix with the UHPC since it was defect by the chloride attack.

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