

GAZIANTEP UNIVERSITY
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

**EFFECTS OF BINDER CONTENT AND CURING TYPE ON THE
MECHANICAL AND FRACTURE PROPERTIES OF ULTRA
HIGH STRENGTH FIBER REINFORCED CONCRETE**

M.Sc. THESIS
IN
CIVIL ENGINEERING

BY
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**Effects of Binder Content and Curing Type on the Mechanical and
Fracture properties of Ultra High Strength Fiber Reinforced
Concrete**

**M.Sc. Thesis
in
Civil Engineering
Gaziantep University**

**Supervisor
Assoc. Prof. Dr. Mehmet GESOĞLU**

**By
Avan MALA
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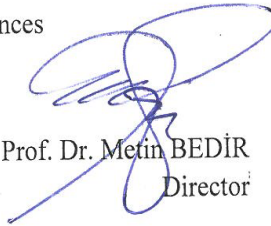
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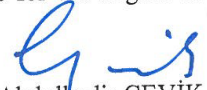
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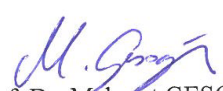
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Avan MALA

ABSTRACT

EFFECTS OF BINDER CONTENT AND CURING TYPE ON THE MECHANICAL AND FRACTURE PROPERTIES OF ULTRA HIGH STRENGTH FIBER REINFORCED CONCRETE

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M.Sc. in Civil Engineering

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An investigational study was implemented to examine the effects of the different amount of binders on the most mechanical and fracture parameters such as; compressive and tensile strengths, modulus of elasticity, bending, toughness, stiffness, brittleness and ductility of Ultra-High Performance concretes (UHPCs) reinforced with 2% of micro steel fibers for generating Ultra-High Performance Fiber Reinforced Concretes (UHPFRCs). Depending on water curing (WC) and steam curing (SC) of the same water per binder ratios (w/b) of 0.12, two sets of UHPFRCs each of containing 850, 900, 950, 1000, 1050, 1100, 1150, and 1200 kg/m³ binder (85% of cement+15% of silica fume (SF)) were produced and tested for the compressive strength, splitting tensile strength, modulus of elasticity, modulus of rupture, load versus displacement curves, fracture energy, and characteristic length. This study revealed that the mixtures with 1150 kg/m³ of total binder contents exhibited the best results for all tests measured. The results also showed that at 1200 kg/m³ of total binder content, all improvements slightly began to decrease. On the other hand, all mechanical and fractural test results showed that steam cured much preferred than corresponded curing by water.

Keywords: Ultra High Performance, Micro Steel Fiber, Binder Content, Steam Curing, Water Curing, Mechanical Properties, Fracture Parameters.

ÖZET

BAĞLAYICI MİKTARI VE KÖR TIPİNİN FİBER TAKVİYELİ ULTRA YÜKSEK DAYANIMLI BETONLARIN MEKANİK VE KIRILMA ÖZELLİKLERİNE

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Bu araştırmada, ultra yüksek performanslı lif takviyeli betonlar (UHPRFCs) üretmek için %2 mikro çelik lif içeren Yüksek performanslı betonların (UHPCs) sünekliği ve basınç ve çekme dayanımı, elastisite modülü, eğilme dayanımı, süneklik ve kırılma gibi kırılma parametreleri üzerine farklı miktarlarda bağlayıcı kullanımı ve kür tipinin etkileri incelenmiştir. 0.12 su bağlayıcı (w/b) oranına sahip, her biri 850, 900, 950, 1000, 1050, 1100, 1150 ve 1200 kg/m³ içeren (%15 silis dumanı + %85 çimento) iki grup UHPRFC üretilip su kürü (WC) ve buhar kürü (SC) uygulandıktan sonra basınç dayanımı, yarma çekme dayanımı, elastisite modülü, kırılma elastisite modülü, yük-sehim eğrileri, kırılma enerjisi ve karakteristik boy ölçülmüştür. Bu çalışma 1150 kg/m³ bağlayıcı oranının bütün testlerde en iyi sonuçları verdiğini göstermiştir. Sonuçlar aynı zamanda 1200 kg/m³ toplam bağlayıcı oranında incelenen özelliklerin azalmaya başladığını göstermiştir. Bir diğer yandan, bütün mekanik ve kırılma özellikleri, buhar kürünün su kürüne göre daha fazla tercih edilebileceğini göstermiştir.

Anahtar kelimeler: Ultra Yüksek Performans, Mikro Çelik Lif, Bağlayıcı İçeriği, Buhar Kürü, Su Kürü, Mekanik Özellikler, Kırılma Parametreleri.



To my parents

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LIST OF SYMBOLS/ ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British standard
CH	Hydroxide Calcium
C-S-H	Calcium-Silicate-Hydrate
E	Modulus of Elasticity
f_{flex}	Flexural Strength
FRC	Fiber Reinforced Concrete
F_{st}	Splitting Tensile Strength
GF	Fracture Energy
h_{cp}	Hardened Cement Paste
HPC	High Performance Concrete
HPFRC	High-Performance Fiber Reinforced Composites
ITZ	Interfacial Transition Zone
l_{ch}	Characteristic Length
LVDT	Linear Variable Displacement Transducer
RPC	Reactive Powder Concrete
SEM	Scanning Electron Microscope
SF	Silica Fume
TS	Turkish Standard
UHPC	Ultra High Performance Concrete
UHPFRC	Ultra-High Performance Fiber-Reinforced Concrete
UHS	Ultra High Strength
w/b	Water per binder ratio
w/c	Water per cement ratio

CHAPTER 1

INTRODUCTION

1.1 General

The expansion in the mechanical properties is essential in the design and construction of structures made of quantity and quality of the cementitious materials (Habel et al., 2006). In addition to superior high strength, the good concrete should exhibit greater durability characteristics. The concept of RPC was first developed by Richard and Cheyrezy (1994) and was first produced in the early 1990s by researchers at Bouygue's laboratory in France. So far, the worldwide use of ultra-high performance fiber reinforced concrete (UHPFRC) in structural implementations has suggestively increased owed to its plentiful returns, especially in European and American countries. For example, the bridge of Sherbrooke, that is the first RPC pedestrian bridge with a very low load-bearing capability and the Mars Hill Bridge in Iowa, USA, which completely constructed by using RPC named as a 'The future bridge' (Liu et al., 2009).

UHPFRC represents an ultimate strength, fracture parameter, and a durability property depends mainly on the adopted manufacturing techniques and curing conditions (water, steam or autoclave curing). Steam curing is an appropriate and a popular application not only because of enhancing the hydration of huge amounts of unhydrated cement inside UHPCs due to large quantities of binder, and also it consisting to control the moisture movement from and into the concrete (Van Tuan et al., 2011). Therefore, researchers preferred steam over water curing for the production of UHPFRCs and superior results were observed (Melekaa et al., 2013, Yu et al., 2014). For instance, Yazıcı studied the mechanical properties under different curing regimes containing mineral admixtures. They revealed that the steam and autoclave curing looked like very effective ways to improve the strengths of UHPCs (Yazıcı et al., 2009).

Concerning to the amount of UHPCs' binder, some researchers trying to produce an only skeleton of UHPC convincing by moderate results via applying modified Andreasen and Andersen's packing particle model with comparatively low amount of binder whereas the others tried to generate it with more quality and higher results using a big amount of binder. Hassan et al. (2012) show some mechanical properties on UHPC with nearby 650 kg/m^3 cement, 420 kg/m^3 of GGBFS and SF with 120 kg/m^3 . Tayeh et al (2012) used around 770 kg/m^3 cement and 200 kg/m^3 silica fume to produce UHPC as a repair material. El-Dieb (2009) produced UHPC with approximately 900 kg/m^3 cement and 135 kg/m^3 silica fume. Moreover, Melekaa et al. (2013) found big variance results between the maximum and minimum binder content when they presented their experimental study of the mechanical properties of steam cured UHPCs. The differences between 800 and 1040 kg/m^3 binder amount were 76 MPa , 3 MPa , 19.9 GPa , and 10.3 MPa , regarding the tensile strength, compressive strength, elastic modulus, and net flexural strength, respectively.

1.2 Research Significance

By reviewing the literatures and recommendations of authors, an open question coming into consideration, which is; how to find a reasonable balance between the binder amounts and aggregate volume for elevating more performance of UHPCs? To answer this, an experimental program is prepared by taking different volumes of binder ranging between 850 to 1200 kg/m^3 with an augmentation of 50 kg/m^3 for investigating strength and fracture parameters for UHPFRCs. In addition, excluding binder amounts and curing methods the other parameters such as flow, w/b, SF, and micro steel fiber content were kept constant for optimizing the results of compressive strength, tensile strength, modulus of elasticity, flexural strength, load displacement curves, fracture energy, and characteristic length.

1.3 Outline of the Thesis

In this M.S.c thesis, the whole work is demonstrated via five chapters;

Chapter 1 gives explanation about objective and the significance of the study.

Chapter 2 involves a review of the literatures and general background of the compounds as well as applications, mechanical and durability properties of UHPCs.

Chapter 3 includes the experimental tests carried out in this study. The properties of the materials used, mixture design, mixing procedures, the preparation of samples and curing types, as well as the testing procedures are mentioned.

Chapter 4 provides the experimental results and discussion of the fresh properties, compressive strength, splitting tensile strength, modulus of elasticity, flexural strengths, load–displacement behavior and fracture energy of UHPCs. Results, figures and evaluation are presented and discussed.

Chapter 5 contains conclusions of the tests.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

2.1. UHPC History

UHPC was introduced 20 years ago as an advanced concrete material with enhanced mechanical and durability properties. Most UHPC research and applications have been made outside of the United States. After being mentioned by the French in 1990, ultra-high performance concrete has been slow to hit the market in the United States. With a lack of design codes in the United States, designers and researchers are using design codes that are being enhanced across the world to embed UHPC to the United States infrastructure. However since the late 1990's more research and studies have taken place at universities within the United States, including, Iowa State Michigan Tech, Georgia Tech, and Virginia Tech Ohio University,. Through the research at these institutions, UHPC has been examined and compared to methods outside of the U.S.

20 bridges in the United States have included UHPC in construction using two primary techniques. The first is complete UHPC construction in which the bridge uses UHPC for either the bridge girders or both the bridge girders and bridge deck. The second application of UHPC has been the use of thin overlays or full depth joints between girders. The Wapello County Bridge in Iowa and the Cat Point Creek Bridge in Virginia were the first two uses of UHPC bridge girders in the United States and both utilized 45 inch deep bulb tees. The third bridge to use UHPC girders, also in Iowa, was the Jakway Park Bridge as shown in Figures.2.1, 2.2 and 2.3 respectively.



Figure 2.1 Wapello County /Mars Hill Bridge, Iowa, USA (Hoshikuma et al., 1997)

This application used an innovative pi-girder in an attempt to optimize the material performance of UHPC (Graybeal, 2013). Plenty of other applications have used ultra-high performance concrete in the U.S. Most of this work has been accomplished by the New York DOT and the Iowa DOT. Applications include {waffle (net) deck panels}, full depth joints between deck panels, full depth joints between girders, and shear connections to girders.

UHPC is also resistant to draining and erosion. Most impressively, however, is the high compressive strengths (30 ksi) and tensile strengths (7 ksi) observed after a thermal cure (Graybeal, 2005). Once UHPC is thermally treated, virtually no shrinkage and limited creep has been observed (Graybeal, 2006). UHPC is able to achieve these specific mechanical and durability properties by getting coarse aggregate off, in order to optimize the particle packing of the forms. This compact cement matrix allows very few pores. Additionally, fiber reinforcement (2-10%) is introduced into the UHPC to provide tensile strength by the bridging of cracks in the UHPC. The lack of UHPC applications in the U.S. is due to the absence of a design code, although other countries have enhanced their own codes, in France Japan (Japan, 2006) (SETRA, 2002), and Australia (UNSW, 2000).



Figure 2.2- Cat Point Creek Bridge, Virginia, USA (Graybeal, 2009)



Figure 2.3 Jakway Park Bridge, Buchanan County, Iowa USA (Rouse et al., 2011)

2.2 Material Influences on UHPC

2.2.1 Portland Cement

The widespread demanding and low cost of the limestone and other naturally materials used in Portland cement makes it commonly used and the most economic material over the last century. In order to reduce cost and improve the production of quality blended cements, blends of Portland cement clinker with mineral admixtures are being made (Singh et al., 2002). The most common mixed hydraulic cement is currently the Portland cement in combination with pozzolanic additives. A pozzolan is a siliceous material that develops hydraulic cementitious properties when it reacts with calcium hydroxide and water (Henrik et al., 2003).

Workability is affected by paste volume, because the paste grease the aggregates (Ferraris and Gaidis, 1992; Dhir et al., 2004). For a given water content, decreasing the cement content increases toughness of concrete with having poor workability (Lamond and Pielert, 2006; Mehta and Monteiro, 1993). Concrete with high cement content shows high glueyness and becomes sticky (Lamond and Pielert, 2006; Mehta and Monteiro, 1993). To prevent an adverse effect, relative cement content should be used to achieve the desired workability.

2.2.2 Silica Fume

Physically Silica fume employed as a micro-sized filler to occupy the micro pores between aggregate particles and cement to reduce deposition of portlandite as a chemical response (Schröfl et al., 2012). Y.W. Chan and S.H. Chu 2004 resolved that the optimum silica fume contented was among (20% and 30%) in terms of the bond characteristics. Other investigators established that the optimal silica fume content was (30–35%) of the cement in UHPC through strength of 200 MPa (Chan and Chu, 2004 and Yang, 2000). Addition silica fume to concrete mixtures improves the durability and increases the strength as well as reducing the cost by reducing the cement content demanded. The high level of silica dioxide enhances the pozzilanic reactions.

2.2.3 Superplasticizer

The workability of fresh UHPC (Tue et al., 2008) is also influenced by The addition procedure of SP. Step by step addition strangely improved the distributing impact of superplasticizer, and developed the flowability of UHPC. Suitability of cementitious materials and superplasticizer generally a problem. (Schröfl et al., 2012) researched the connection among different SP types with cement or silica fume in UHPC. From the investigations in can be concluded that methacrylat portland cement effecttively mix with cement and allylether portland cement with silica fume. The integration of the two PCs demonstrated a remarkably preferable distribution. The decent fluidity was examined in UHPC with limestone compared to metakaolin, fly ash and siliceous containing same ratio of SP. When SF replacement with cement admixture was rised from 30% to 40%, within the increasement in SF amount the SP ratio also increased from 1.43% to 2.38% (Van Tuan.et.al., 2011). (Hirschi and Wombacher, 2008) explored 8 kinds of portland cement based on SP on fresh and hardened features of Ultra High Performanace Concrete. The compressive strength is direct proportional with the flexural strength.

2.2.4 Quartz Aggregate

Aydin et al. (2010) explained the effect of aggregate type on the properties of RPC. The used types of aggregates were korund, basalt, limestone, quartz, sintered bauxite, and granite. Also the second variable used in this experiment was type of curing (standard, autoclave, and steam curing). They improved that using high-strength; rough-surface aggregate can increase the mechanical performance of RPC. However, using the low-strength aggregate (limestone) or aggregate on the smooth surface (quartz) can get very high compressive strength of 170-180 MPa even under standard processing conditions. It can increase the compressive strength of strong and rough surface textured up to 200 MPa, in accordance with the terms of the standard treatment.

2.2.5 Micro Steel Fiber

In order to reduce the fiber amounts and to attain the required performance, two or three dissimilar fibers incorporated into the UHPC matrix (Qian and Stroeven, 2000).

Park et al. (2012) claimed that tensile strain stiffening in UHPC can be observed more in 0.5% micro steel fibers than 1.0% macro steel fibers incorporation in mixture, while the tensile performance was the best in the state of UHPFRC with twisted macro-fibers, with strain capacity, post cracking strength and various micro-cracking actions of 18.6 MPa, 0.64%, and 3.8 mm, respectively, while that with the long smooth one revealed the poorest performance.

Abbas et al. (2015) studied a lot of UHPC mixtures with different length of steel fiber of (8 mm, 12) and (16 mm) and doses 1%, 3% and 6% by volume mixture. They assessed the Mechanical properties of UHPC. Furthermore, its resistance to penetration of chloride ions and mechanical degradation under several chloride expositions (i.e. 3.5% and 10%) were estimated. Their results presented that as the dose of fiber increased, mechanical properties increases. UHPFRC mixtures combined with short steel fibers offers enhancement in flexural properties in contradiction of mixtures by the same volume with the longer steel fibers.

Zheng et al. (2013) examined the influence of temperature, steel fibre content, curing time of reactive powder concrete (RPC) in the temperature range of 20–800 °C. The experimental outcome indicates that 2% steel fibres can prevent explosive spalling of RPC and considerably enhance the compressive and tensile strengths. Compressive strength for cube molds decreases at 100 °C, increases at temperatures between 200 to 500 °C, and decreases for above 600 °C. when the temperature is below 300 °C, the compressive strength for cubic molds of RPC increases as the fibre content increases and vice versa. The tensile strength of RPC with steel fibres increases at temperatures ranging from 200 to 300 °C.

2.3 RPC-Mix proportions

Dattatreya et al. (2007) studied several particle packing models to develop a mix ratio of concrete powder reaction. The optimization of the packaging of granular components is a substantial agent for enhancing the durability and mechanical possessions. Packing the granulated substances such as silica cinder, quartz dust, sand and cement were adjusted and had compared the empirical results to theoretic packing models.

Plawsky et al. (2002) discovered a modern way to disbanding cement within the sand for the production of dry mixture with best mechanical and physical properties. It has been identified the problems in the mixing of dry material and the dispersion of water. Besides of the understanding the mixing methods lead to plan the future generation gears to make intense-mortar.

Staquet and Espion (2002) developed the mechanical properties of UHPC prepared with the materials existing in Belgium. Similarly, it was recommended that (the CEM152.5) that was applied in Reactive Powder Concrete uses can be replaced by VEM 42.5 to achieve a compressive strength of 180 MPa without heat processing. The workability of the RPC prepared with the white and light grey silica fume which manufactured from Zirconium had better workability than that prepared by white and black silica fume from silicium industry.

Richard and Cheyrezy (1995) sophisticated ultra-high-strength ductile concrete with the requisite principles to encourage uniformity by excluding the coarse aggregate and consolidate the microstructure over heat treating after setting. Additionally, the tensile strength and ductility of concrete is augmented by combining small, straight, high tensile micro fibers. The development of two types of concrete set 200 RPC and RPC 800. These types of concretes had special mechanical properties, which led to reinforcement eliminations, and the reduction of material resulting in low self-weight -leading cost economy, Applications found in concrete storages, silos, nuclear wastes and industrials.

2.4 UHPC-Design Considerations

Lai and Sun (2010) used Hopkinson bars to find spalling strength of RPC. Prepared samples were exposed to impact of the projectile at the free end with dissimilar volume of steel fibers inserted with RPC. It has been recorded the reflected compressive and tensile waves. Moreover, the implementation of finite element analysis through simulation using a physical model “Johnson Holmquist Concrete”.

Almansour and Lounis (2008) carried out an UHPC with high strength or very low permeability to build bridges in the long life. And it presented the current design recommendations for the use of UHPC and designed according to the Canadian Road

Bridge Design Code. The obtained results show a substantial decrease in volume of concrete by 49%-65%.

Hoang et al. (2008) carried out mechanical properties of ultra-high performance concrete by using two aspect ratios of steel fibers, ($L_f/d_f=17/0.2$ and $L_f/d_f=35/0.5$). The hybrid steel fibers caused high flow ability, flexural strength and greater than 150 MPa of compressive strength. Moreover, it is determined that a higher strength was achieved due to adding micro-fiber by a volume higher than 1% as suggested. Besides, the ratio of silica fume and other filler powders should be about 20-25% for producing self-compacting ultra-high strength concrete with a w/b ratio of 0.2.

2.5 UHPC Properties

2.5.1 UHPC-Mechanical Properties

Wua et al. (2016) investigated the technical informations, mix design process and techniques for arranging the UHPC. UHPC has four principles while designing it: porosity decline, microstructure enhancement, homogeneity increment, and toughness increase. Additionally, materials, arrangement method and curing system significantly affect the UHPC properties. The utilization of fly ash and slag with cement and silica fume, may remarkably decrease the cost of material without losing the strength.

Gesoglu et al. (2013) tested the influence of water and steam curing on the development of compressive strength and transport properties such as the permeability of rapid chloride ion, water sorptivity, and gas permeability of concrete including various volumes of lightweight fly ash aggregate (LWA) were investigated. They used in a fixed amount of lightweight coarse (LWCA) aggregate in addition to varying amounts of lightweight fine aggregate (LWFA). Employment of LWFA was fulfilled by volumetric substitution of fine aggregate with five different substitute levels i.e., 0%, 25%, 50%, 75%, and 100%. The manufactured concretes were classified into two parts; the first part was initially steam cured and the second was directly subjected to water curing the steam cured (SC) concretes were also moved to water while waiting for testing Mechanical properties of concretes were regulated through compressive strength development more than 56

days, whereas transport properties were measured by water sorptivity method, gas and rapid chloride permeability tests governed at 28 and 56 days

Cwirzen et al. (2008) used a new Ultra high strength mortar(UHS) concrete (both treated and non-treated) and tested for frost durability properties. The result of compressive strength at 28 days changed from 170 to 202 MPa in heat cured concrete and for non-heat cured concrete the strength varied from 130-150 MPa. Other tests were carried out for creep and shrinkage, which showed improved values when compared with ordinary concrete. Several experiments were made in order to find the relation between the water need wetting time, mix design, rheological and the mechanical properties. Quartz micro-fillers were used to evolve the packing density.

Kanakubo (2006) notify the findings of JCI technical committee sponsored round robin test program on tensile characteristics of ductile FRCs (DFRCs) in which four types of uniaxial direct tension tests were evaluated using different types /dimensions of specimen and loading jigs. Flexural and split tension tests were also rated. In general, differences were spotted in the results reported according to testing method, samples parameters, shape and dimensions, boundary conditions and specimen preparation.

Habel et al. (2006) improved ultra-high performance concretes with fiber cocktail. This study detect that the small fibres were contributing the strain hardening resulting in bridging of micro cracks and long fibres were responsible for transferring of forces in localized cracks and govern the softening part. So the improved UHPFRC resulted in higher hardness and higher resistance to cracking with a stiffing modulus of more than 45 GPa preventing softening behavior.

Graybeal (2006) has mentioned direct tensile strength determination of UHPC using briquette specimens conforming to AASHTO T132, which consist of dog bone-shaped briquette is 76 mm long with 25 mm square middle length cross section. The first crack strength ranged between 6.3 MPa to 10.1 MPa while the post cracking strength ranged between 5.6 to 9.5 MPa. The hardness expressed as the ratio of post peak to pre-peak areas ranged from 2 to 5.5. In majority of the cases, strain-hardening characteristic was not evident.

Redaelli (2006) studied the mechanical manner of real scale UHPFRC ties with reinforced steel bars. It is proved that fibres improved the pliancy of concrete when the volume of fibre is more than 1.5%. However, at the ultimate limit state, even a large amount of further ordinary reinforcement cannot avoid strain localization and a brittle failure. This study detected that UHPFRC tensile members cannot be made fully ductile by introducing plain reinforcement and an alternative definition of the amount of minimum reinforcement to avoid brittle failure or UHPFRC tensile members had been proposed

Dili and Santhanam (2005) developed two RPC mixes and designated as RPC 200 and RPC 800 which could be appropriate for nuclear waste containment structures. The mixes were tested for its workability, mechanical and durability features. The test according to ASTM C 10 916 in the range of 120% -140 % and water permeability and chloride ions are very low indicating the aptness of nuclear waste containment structures. However, RPC needs to be suitable with respect to resistance to breakthrough of heavy metals and other toxic wastes emanating from nuclear plants to qualify for use in nuclear waste containment structures.

Bierwagen et al. (2005) examined the multistage project 21.64 m long RPC test beam for shear and flexural capabilities. In stage II 33.83 m long beams were cast and tested. Depended on results of test the section of web was miniature in top flange by one inch (25 mm) and bottom flange by two inches (50 mm). The design guidelines were taken from the commendation obtainable from the reports available as France .The construction was finished in 2005.

Jungwirth et al. (2004) carried out both material and structural members of RPC with reinforcement bars tested. So as to understanding the features of structural members in UHPC, largescale tests simulating the condition in real situation were achieved. Three samples with various reinforcement ratios between 1 % and 4.8 % (ribbed steel, $f_y = 556$ MPa) was examined. The sample's dimensions were 160 x 160 x 1500 mm. The strain was measured over a standard length of 1000 mm. because of the existence of fibres and their assistance, the features in tension in UHPC offer a violent variation while the compared to that of plain concrete. This has a wonderful effect on the structures designing in UHPC

Resplendino (2004) noticed that the post peak of features UHPC is very hard to describe because it rely on so much on the mixture and status procedure. Any flow during the pouring of concrete tends to fiber alignment in flow direction. Fibers near to walls are aligned parallel by nature to the formwork. This phenomena halt beyond a distance from the formwork in surplus of the fibre length. The major is the impact on the efficient tensile strength of the parts, Preferential gravitational guidance of fibres may be occasionally happen, because the natural features of fibres in the viscous liquid situation of concrete before it sets.

Reineck and Greiner (2004) made tensile tests execute on Ductal, formula can be obtained commercially from reactive powder concrete (RPC) with a 2% volume of steel fibres. The obtained compressive strength values are about 180 MPa and axial tensile strengths are about 9 to 10 MPa for RPC. These values comply well with the published results by other investigators.

Behloul and Lee (2004) informed a characteristic tensile strength of 8 MPa and a post peak strength of 5 MPa for the RPC mix (Ductal) used for the Seonyu Bridge in Seoul. Axial tensile tests have been achieved with a sample flat bones haped with cross-section of 30×90 mm. This shape is more appropriate than a prisms or cylinders to determine this important material property for use of UHPFRC in shells and tanks.

Karl-Heinz (2004) executed direct tension tests, and only a small rise of the load adduced after cracking. Often reduce of load has occurred and, in some cases, was radically so that it was clear that the sample with a weak slice where fiber directed mostly perpendicular to the direction of the load during the concrete pour. Therefore, utmost care must pay on the concrete and quality assurance in general. For tensile flexural strength of 25-40 MPa it has been reported. These values are consistent in their own tests, but the flexural tensile strength clearly reduced with the increase in the depths of the prisms, and this means that there is a "size effect" distinguished. Therefore, it must be pointed to the size of the prism is always when they are reporting such value. It was one of the main reasons for this effect size orientation of the fibers, which it leads to the preferred orientation of the fibers parallel to the surface in a row to the pouring of concrete, and this has a greater effect of small dimensions.

Teutsch et al. (2004) detected a change while comparing reinforced UHPC mixture with short fibers and UPHC unreinforced mixture in the loading and behavior breaking capacity. From the tensile tests observed a ductile fracture behavior with additional short discontinuous fibers. The loading capacity change directed to continuous load and higher service load carrying performance Because of the evolution of the crack distributed finally. Also it achieved high loads in the same displacement. Changes in the matrix composition of the UHPC mixture (ie short fibers) does not have great influence for bonding feature, thus observed no significant differences in the evolution of pregnancy displacement curves obtained by tensile tests.

Dallaire et al. (1998) mentioned different mechanical properties of the use of the description materials (RPC) to build a pedestrian bridge Sherbrooke Bikeway. Ductility of RPC is enhanced by restraining the material into a steel tube or adding steel fibers, "1.8% of volume and 12 mm length". Members of the bottom chord consists of two 320X380 mm bridge beams stress with all 5 m boxes that correspond to the connection between the diagonals and beams down. A reduction in RPC structure reinforcement leads to liberty in the form and shape of organs. Reaching a point in which this substantial can be used in pressure and sewer pipe, thin walled, in ceiling panels and tunnel wall and projects extremely require strength and ductility necessities.

Collerparidi et al. (1999) made a comparison between the mechanical properties of concrete powder modification reaction (with the addition of coarse aggregate) with original concrete powder reaction. In the modified RPC graded natural aggregate (up to a maximum size of 8 mm) was used to exchange the fine sand and portion of the cement binder. The better performances had observed from both modified and original RPC in terms of low drying shrinkage and high strength or creep strain when the steam to be treated rather than be cured at room temperature. Also RPC specimens were cured by steam achieved microstructure more intense than in the cement matrix 160 °C.

Dubey et al. (1998) researched another study of the post peak energy dissipation mechanism through a crack. It came to energy dissipation due to the withdrawal of the fiber through the crack. Also the brittleness of the matrices increase in load

results with additional of pozzolanic materials like silica fume in the crush and the splitting of the matrix, which in turn limits the capability of fibers to transmit stresses, they advised that toughness of RPC can be amended by enriching high metakaolin interaction to the mix, which in turn will expand the RPC durability properties

Bonneau and Lachemi (1997) produced two Reactive powder concretes (RPC) at a precast plant in Sherbrooke University. RPC used prefabricated reinforced fiber and not in the ready-made factory. Many tests have done on those RPC specimens for, modulus of elasticity, compressive strength, freezing and thawing cycling resistance, and expand resistance deicing salts and chloride ion penetration resistance. Freeze and thaw resistance and the loss of a very low mass under test measurement of RPC observed combination. The penetration of chloride ion was less than 10 Coulomb 's RPC impregnated steel fibers

Bioizi et al. (1997) studied the effectiveness of high strength micro steel fibre on the high strength concrete on tension and compression under controlled strain over the closed - loop system. They used maximum size of aggregate which is 3mm with aggregate to binder ratio of 2, and proportion water to binder ratio was 0.2. The different doses of fiber assess the concrete impact it concluded that poly acrylic based superplasticizer gives materials with low porosity.

Mufti (1992) studied the appropriateness of concrete deck slabs fiber reinforced without steel reinforcements. For slab-girder bridges four half-scale models were formulated with fiber polypropelene completely avoid rebar and corrosion related problems. Upper flange girders must be connected in the transverse directions with steel straps to avert the curvature of the deck slab on the top surface. This was simulated through introducing stiffeners along the edges using alternative edge beams. It has been proven that slab had main flexural rigidities in horizontal plane from test results and it was suggested to provide shear connectors to confirm an efficient transmission in plane of the deck slab to the girders.

2.5.2 UHPC-Durability Properties

The durability properties of a new cement based materials with excellent micro structural properties were studied. Study of the C-S-H (behavior of hydrates) gel was studied on a pure cement and silica fume paste. The advantage of silica fume addition on calcium leaching was studied by XRD analysis from SEM observations and from the tritium diffusion and pore distribution analysis. It was found that the leaching greatly affects the microstructure especially that of the anhydrous cement grains remaining in the paste.

Harish et al. (2008) found that the choice of constituents and type of curing play a key role in improving the performance of UHPC through investigating UHPC at CSIR-SERC, Chennai. They also realized that adding silica fume lead to increase the strength of concrete because of its high pozzolanic action. Furthermore, curing regime types was hot water curing, normal water curing and hot air suggested to attain high mechanical properties. Through optimization for the volume of constituents and curing regime 193 MPa ultra-high strength concrete achieved and mix proportion has been developed.

Dattatreya et al. (2008) discussed several durability test procedures recommended by other scientists for RPC and a mix proportion for RPC concrete was developed. Also, many testing procedures identified to find the durability and mechanical properties of RPC. They found that RPC is so ticklish to heat treatment and the strength of RPC influenced even by a small change in curing regime.

Cwirzen (2007) studied nine various curing ways with different heat treatment, different in water - binder ratio, with different of filler materials such as silica fume and fine quartz to observe the influence of curing regime on the hardness of UHPC properties. The microstructure investigation of the samples was done through mercury intrusion porosimeter scan and electron microscope. The results showed that by increasing heat treatment times the hydration processes decreased and enhance the microstructure and provided higher compressive strength. Investigation scanning electron microscope discovered the formation of one hydration ridge around anhydrous particles of cement and the company of a hollow shell in all the samples studied.

Yazici (2007) combined pulverized fly ash (FA), pulverized granulated blast furnace slag (PS) and silica fume (SF) with the portland cement (PC) to develop an Ultra high performance concrete. Portland cement was replaced with PS and FA with specified ratios. He used basalt and quartz powder as an aggregate in the mixtures. Three different curing regimes are applied (Standard water curing, steam curing and autoclave), results showed that high strength concrete can be gained with a large volume of mineral admixtures. Compressive strength of the mixtures was more than 170 MPa.

Morin et al. (2002) studied ultrasonic and autogeneous shrinkage measurements for capillary network of RPC investigation. activation of different modes during hydration processes was performed and evaluated. Segmentation of sedimentary pores occurs because of the segmentation of capillary network because of chemical activity induced in C-S-H chains. This capillary network study is crucial because it provides information about the porosity evolution, which is an important parameter in the transport properties of the concrete, which are related to its durability.

Matte and Moranville (2000) conducted tests to predict the long – term durability of RPC, the hydration rate of cement minerals, pozzolanic reactivity of silica fume, pore structure and mechanism of chemical reactions. So simulation of the microstructure of RPC matrix was done first by the NIST micro structural model use. Then the transfer of Ca ions through percolating water was estimated using DIFFU-Ca, a model based on the local chemical equilibrium. The damage process related to an instantaneous dissolution of anhydrous cement silicates at the degradation from which results in a higher connected pore, space and is in good agreement with experimental results through double model validation. The study reveals that the RPC is durable matrix as long sound zone persists. Taking just the concentration of calcium in this process, and was at a depth of 1415 mm deteriorating in the 300 years of the RPC matrix, in experimental conditions from leaching. This value can be considered to determine the thickness of the high integrity containers for use in storage of type B nuclear waste without cementation.

Matte and Moranville (1999) studied the RPC, class of concrete, which owns the dust content of high silica (25% of the total material binder) and low water cement ratio (0.20) heat treatment process applied after demolding, at temperatures between 20 °C

to 400°C to promote hydration and pozzolanic reactions. Improve the mechanical and micro structural characteristics. Additional steel fibre lead to a compressive strength of 200 MPa and 800 MPa, which in turn improves the ductility of concrete.

Vodak et al. (1997)'ve done several experiments to determine the thermal characteristics of RPC concrete like thermal conductivity, thermal diffusivity and linear thermal expansion coefficient of RPC. The French nuclear power plant used concrete tested for a temperature Range of 20 °C to 200 °C, specific heat of -30 °C to 100 °C, moisture diffusivity from 0 to 75% of maximum water saturation at room temperature and water vapor diffusivity at room temperature. Other authors measurements compared with current achieved results for concretes with similar composition show a reasonable agreement for most of the parameters.

Feylessoufi et al. (1997) made a discussion for the results of specimens cured with three different heating modes. The formation of Xonolite confirmed when heat-treated and the data showed that the kinetically controlled thermal curing had a control on hydration and crystallization.

Feylessoufi et al. (1996) considered a Reactive Powder Concrete (RPC) for the proposed study with a compressive strength of 230 MPa with low temperature nitrogen adsorption–desorption volumetry by DRIFTS (Diffuse Reflectance infrared Fourier Transformed Spectroscopy). It was observed that RPC had an open network of pores of various diameters with high level durability characteristics through experimental conductions.

Zanni et al. (1996) studied the reaction of the hydration and pozzolanic through the use of two RPC specimens with two different heat treatment at 20°C and 250°C. The effect of heat on hydration level is the investigated aim of this experiment. At 250°C micro structural changes leads to the existence of Q3 peak is based on the generation of Xonolite. The heat treatment increase length of C-S-H because of silica fume and quartz powders pozzolanic activity. It was observed that the leaching greatly affects the microstructure especially that of the unhydrous cement grains remaining in the paste.

2.6 Studies Related UHPC

2.6.1 Varying UHPC Properties According to Typical Curing Methods

The hardened and toughness UHPC properties are assumed to be “lock in” after the UHPC is stripped of its molds through a thermal cure occurring. The unique properties of the UHPC will get different effects through different thermal curing treatments, including the compressive strength and the creep and shrinkage response.

The main objective of high temperature curing is to achieve early strength development. Generally, approved that there is long-term strength loss as a result of heat curing. due to the retrogression in later strength (Neville, 1996), it has been considered that the optimum curing temperature should balance the attainment of high early strength and high late strength. Hanson (1963) determined that there was little further benefit in steam curing concrete beyond a peak temperature of 150 °F (66 °C). Verbeck and Helmuth (1969) studied cement pastes to determine the cause(s) of ultimate strength reduction of Portland cement systems when cured at elevated temperatures. It is reported that the high rate of hydration at elevated temperatures causes a layer of densely packed hydration products to form around the hydrating cement particles inhibiting further hydration. Consequently, there are higher porosities and lower strengths in heat-cured cementitious systems at later ages due to the lesser quantities of C-S-H and other hydration products formed under heat treatment. The effects of heat treatment on elastic modulus and flexural strength properties of concrete are considered to be similar to its effect on compressive strength (ACI 517.2R; Radjy and Richards, 1973).

The strength of Ultra-High Performance Concrete (UHPC) can be sensitively affected by the curing method used. However, in contrast to the precast plant production of UHPC where a standard high-temperature steam curing is available, an optimum curing condition is rarely realized with cast-in-place UHPC (Park et al., 2015) experimentally investigated the strength development of UHPC, with an affirmation of early-age strength by taking the various curing conditions anticipation on site. Concrete specimens were cured under different conditions with variables including curing temperature, delay time before the initiation of curing, duration of curing, and moisture condition. Several conditions for curing are proposed that are

required when the cast-in-place UHPC should gain a specified strength at an early age. It is expected that the practical use of UHPC on construction sites can be expedited through this study.

Yanzhou et al. (2015) produced a (RPC) specimens where the the phosphorus content of the slag powder (PS) and silica fume about 50% (of binder weight) after been cured in 95 °C steam for a known period. The flexural and compressive results, freezing-thawing and confrontation of sulfate showed exceptional durability and mechanical properties. The searches of selected RPC compositions by Thermogravimetric Analysis, Mercury Intrusion Porosimetry and Scanning Electronic Microscope facilitate the understanding of their mechanical and durability properties with respect on their microstructure. Thermogravimetric Analysis and Scanning Electronic Microscope explained the successive hydration effect of cementitious composites while heat treatment. Mercury porosimetry results illustrate that RPC had very low porosity and the the most probable pore diameter was less than 10 nm. These microstructural characteristics would authorize RPC to have outstanding mechanical and durability properties.

Beglarigale et al. (2014) distinguished a different type of concrete which has well optimized micro grain, binder segment and steel micro-fibers. RPC can attain compressive strength values between 150–800 MPa, whereas traditional concrete usually has 20–50 MPa. Furthermore, the high performance of this concrete type, under flexural loads is the most important advantage in the civil engineering field. RPC can aesthetically and structurally compete with steel capabilities. To improve the strength of this compound material the autoclaving curing methods is used. Autoclave curing requires additional SiO₂ source to fill micro pores and strengthen hydration products. the influence steel micro-fibers volume fraction and silica fume amount as SiO₂ source on the mechanical properties of RPC under autoclave curing were examined.

Askar et al. (2013) showed the influence of dissimilar curing circumstances on mechanical properties of UHPFC. Test outcomes showed that steam and boil curing procedures showed an auspicious performance mainly at early age of curing matched to other style of curing. One of the latest type of concrete is a Ultra-High Performance Fiber Concrete (UHPFC). Because of its distinguished mechanical

properties, UHPFC is considered as an ideal alternative material for use in developing new structural solutions.

Yazıcı et al. (2013) illustrates that the mechanical properties such as compressive and flexural strength, of reactive powder concrete (RPC) have been examined under autoclave curing and compared with the condition of standard water curing. Test results designate that; autoclaved compressive strength of RPC significantly is higher than the standard water curing. It can be understood that, there is critical duration time for every pressure and temperature state of affairs.

Magureanu et al. (2012) indicated that effect of curing plays important role in hardened and durability properties of UHPC, for example the static and dynamic modulus of elasticity, compressive strength, the splitting and the flexural tensile strengths. The results of this influence is show that the specimens attained compressive strength of approximately 150 N/mm^2 (21,756 psi) and a modulus of elasticity greater than $50,000 \text{ N/mm}^2$ (7,251,887 psi). The flexural characteristics depended on the fiber addition and the specimen's dimensions. Overall, the flexural tensile strength displayed values between 14 and 34 N/mm^2 (2030 to 4931 psi).

Loukili et al. (1998) observed thermal treatment of reactive powder concrete (RPC) developed by the Scientific Division of Bouygues. Which provide benefits in both shrinkage and creep of the RPC. When the RPC was not thermally treated, observed a shrinkage of 58% and 2 to 3 times the creep of high performance concrete. During the standard thermal cure, autogenous shrinkage can be eliminated, due to an increase in cement hydration reactions which consume the free water within the cementitious matrix. The standard thermal cure can also reduce the creep of concrete specimens by complete drying of the concrete. Loukili et al. (1998) also observed that having the complete drying of the concrete causes the collapse of interlayer space within the C-S-H hydration product leading to significant reduction in creep. Ambient curing of UHPC would typically be seen in cast-in-place applications, where applying a thermal treatment is not possible. Ambient conditions will vary with different field applications. In this research, this type of curing condition will be referred to as "ambient cure," and conditions were held at constant laboratory conditions with a temperature range of $73.5^\circ \text{F} \pm 3.5^\circ \text{F}$, and relative humidity range of $50\% \pm 4\%$ (ASTM, 2010). With this ambient cure condition, the UHPC has to

lock in all of the mechanical and durability properties as seen with a thermal cure. Graybeal (2005) tested with lower temperature thermal curing which was termed a “tempered cure”. In many precast/prestress plants, standard U.S. practice is to apply a steam treatment to accelerate the curing of the concrete, in order to clear the concrete casting beds quickly to produce more precast elements. Because mimicking what would be expected of precast/prestressed plant is the objective of this research, a “pre-steam cure” was implemented as a curing method to accelerate the early-age compressive strength of UHPC. The pre-steam cure follows Graybeal’s tempered cure procedures, which used a temperature of 140 °F (60 °C) at a relative humidity of 95%, and falls into the range of steam curing used by U.S. precast/prestressed plants. A curing process which delays the start of thermal curing was implemented by Graybeal (2005) and Peuse (2008). The delay allowed for more ambient curing time between the casting of the UHPC and the start of the thermal treatment process. Their research each presented that by delaying the thermal treatment no obvious changes in compressive strength of thermally treated UHPC and the delayed thermally treated UHPC was observed. In the research reported herein, the UHPC specimens were subjected to a continuous compressive load before undergoing a standard thermal cure. By delaying the onset of the standard thermal cure, significant creep and shrinkage of the specimens was expected. Other than the manufacturer’s thermal treatment curing method, all additional curing methods investigated in this study are scenarios with realistic curing conditions for UHPC field applications

2.6.2 Effect of Binder Content on UHPC

Zdeba (2015) Studied mechanical properties and microstructure of reactive powder concretes RPC manufactured with the use of three different industrial Portland cements diversified in terms of the strength class (42.5 and 52.5), chemical and mineral composition as well as specific surface area. All developed materials were subjected to three different hydrothermal curing conditions. The test results confirm that the factors most influencing the consistency of the concrete mixture are the chemical and mineralogical composition of the binder. However, it appears that when it comes to mechanical properties, the factor which plays the crucial role is the specific surface area of cement. For one of the analyzed cement, due to its favorable chemical and mineralogical composition, it was possible to limit the value of W/B

ratio up to 0.17, without adversely affecting the properties of the concrete mixture. Nevertheless, it has not contributed to any spectacular increase in strength as compared to materials based on the cement with the largest surface area, where the minimum realizable W/B ratio was 0.20.

Gesoglu et al. (2015) developed large amount of gypsum, so the gypsum has big role in pollute aggregates especially sand. Therefore it has effect on the compressive strength and expansion of ultra-high performance fiber reinforced cementitious composites (UHPERCCs). The cementitious composites can be classified to two groups to design with binary and ternary cementitious blends of Portland cement, silica fume, and ground granulated blast furnace slag, each of this two groups consist of five mix with different SO_3 contents of between 0.11% and 4.5% by weight of natural sand. The samples of each mixes need water cured or steam cured for 48hr period. The microstructure of the cementitious composites was also studied by the SEM–EDX. Besides, some findings of UHPFRCCs were compared to those of Portland cement mortars. Test results indicated that UHPFRCCs showed a strength gain, particularly under steam curing and an insignificant expansion even in the presence of excess sulfates, in contrast to the mortars.

Ahmad et al. (2015) studied mixtures of RPC by considering three grades of the three main factors such as: water-to-binder ratio, cement content and silica fume content, consistent with a 33 factorial experiment design. The implementation of the selected mixtures of RPC was measured in terms of compressive strength, modulus of rupture and modulus of elasticity. Statistical examination of the experimental data indicated the obvious effect of sand grading, water-to binder ratio, cement content and silica fume content on flowability and mechanical properties of RPC.

Ng et al. (2010) classified ultra-high performance in mechanical properties like compressive strength. Concrete produced from high-performance concrete and reactive powder concrete is experimentally managed and compared. They used main ingredients which are Portland cement, very low quantity water/binder ratio which contains cement and silica fume, a high amount of superplasticizer and company of very fine quartz sand and silica fume. The results revealed that the compressive strength, static modulus of elasticity and splitting tensile strength are institute to be considerably greater than that of high performance concrete employing the similar

(water/binder) ratio. The difference in strength by the time is even greater. The compressive strength of around 200 MPa might also be concluded in three days for reactive powder concrete specimens

2.6.3 Effect of Water-to-Cement Ratio on UHPC Properties

The ratio of the mass of the water to the mass of the cement in concrete is defined Water-to-cement ratio. Water cementitious water to cement ratio is the single most influential parameter in mix design of concrete. A lower water-cementitious ratio yields a better engineering properties in concrete. To ensure adequate durability, w/c ratios not exceeding 0.40 to 0.45 are typically used in the precast concrete industry.

Heinz et al. (1989) studied mortars of 0.33, 0.4, 0.5 and 0.7 w/c cured at temperatures 80 to 100 °C. Founding that mortar mixtures of the higher 0.7 w/c expanded earlier than those of the lower 0.4 w/c. Also, Ludwig (1991) arrived at similar conclusions

Because the w/c is very small, it's impact on UHSC shrinkage property is important. Neville (1997) stated that the autogenous shrinkage is high (700 microstrain) for concrete with (w/c) ratio of 0.17. Zhang et al. (2003) stated that the autogenous shrinkage is significant if the water-to-cement ratio is low and particularly if the concrete contains silica fume. The authors (Zhang et al., 2003) observed an increase in autogenous shrinkage from 40 to 180 microstrain at 98 days due to a reduction in w/c from 0.35 to 0.30. Nevertheless, more decrease w/c from 0.35 to 0.26 resulted in a marginal increase of autogenous shrinkage up to 197 microstrain.

Abadi et al. (2014) showed in their results that suitable water/binder ratio and super plasticizer amount, higher temperature and pre-setting pressure increase the workability, density and compressive strength of composition.

2.7 UHPC-Applications

Liu and Huang (2008) revealed a Reactive powder mortar (RPM) of compressive strength of 75 MPa and flow value 200% for rehabilitation and repair. Many tests such as, tensile tests, rebar pull-out, slant shear conducted and the test results compared

with the repaired cylinders with epoxy resins. The strength of cylinders with RPM was higher, whereas the slant shear strength is almost equal to that of epoxy resin.

Tsung et al. (2007) proposed a Reactive powder mortar (RPM) of flow value 200% and compressive strength of 75MPa for repair and rehabilitation. Series of tests were performed such as, slant shear, rebar pull- out, tensile tests and the results compared with the cylinders repaired with epoxy resins. The strength of cylinders with RPM mortar was higher while the slant shear strength is almost equal to that of epoxy resin.

Zhang et al. (2006) found a new-engineered cementitious composite incorporated via poly vinyl alcohol which had a high ductility property that can be utilized in modify and repair of existing structures. The mixtures were tested for high early strength gain rate with different mixtures of a binder system. The micro mechanical model discovered that the quick deterioration in strain capacity, which was because of rapid drop of complementary energy and continuous rise of crack tip toughness.

Lee et al. (2005) evaluated bond and durability properties of RPC concrete through the study of its usage also as repair material with existing High strength (HSM) and reinforced concrete (RC). The bond strength, compressive strength, steel pull out strength and relative dynamic modulus of elasticity (NDT) tests were carried out. The test result verified the superiority of RPC with respect to other concretes. The mechanical properties are 200% more, when associated with regular concrete. The results of slant shear tests show that the bond strength of RC/RC, HSM/RC and RPC/RC decreased significantly more with freeze – thaw cycles as compared with that of RPC/RC.

2.8 Reports and Books

Markovic (2006) Established a new way to add fiber to concrete in his Ph.D. thesis project, thus improving the ductile and tensile properties. The fresh mixes were combined with straight short (13 mm) and hooked long (30 mm) steel fibers. All characteristics such as pullout tests for single fibers, compressive tests, uniaxial tensile tests, and flexural tests were showed for different combination of steel fibers. A novel analytical model for cracks of bridges through fibers was developed and applied for tensile softening reaction of HPC. Moreover, the application of HPC in

the engineering practice was discussed, containing a case study on light prestressed long-span beams made of HPC.

Lee and Chisholm (2005) investigated the effect of quantity of superplasticizer, w/c, utilization of SF, curing regime and the quartz powder via the compressive and tensile strength of RPC produced study. The observed mechanical properties directly correlated to the particle packing of the fine reactive powders added to the concrete. The RPC tested had a flexural strength of 15 to 20 MPa and a compressive strength of 200 MPa.

Graybeal (2005) For UHPC investigated the mechanical and durability properties in order to use them in construction of bridge structures. This type of material was utilized in order to cast prestressed highway bridge beams and they were tested under flexural and shear loadings. Based on this investigation, a fundamental girder constructive design model was suggested. JianXin Ma and Orgass (2004) Studied two UHPC's with and without Coarse Aggregate in their project report for autogeneous shrinkage and other mechanical properties. The autogeneous shrinkage of UHPC with coarse aggregates is about 60% of the RPC. In addition, the compressive strength indicated no difference between the RPC with and without coarse aggregate.

Voo et al. (2003) suggested a Variable Engagement Model established in order to define the performance of randomly oriented discontinuous which was applied to uniaxial tension. Experimental verification concluded that the model beside capability of capturing the stress vs crack behavior of both plain and deformed steel fibres in the pre and post-peak ranges, also can be used to describe the tensile behavior of micro-synthetic fibre-concrete where the fibres fracture under load.

Voo et al. (2003) reported the effect of large-range beams failed by stress. The beams casted by RPC with a compressive strength between 150 to 170 MPa, pregnant with steel fibers in order to carry shear stresses. Comparisons were made for crack patterns for the beams with regard to quantity, types and mixture of concrete and fibers. Moreover, the shear beams were modeled using the finite-element method with a good correlation for the non-linear numerical model against the experimental data.

ACI 544. 1R-96 (2002) made a report on Fiber-Reinforced Concrete (FRC). Which was contained an essential principles comprehensive review of FRC like description of fiber type, a glossary of terms, mix proportioning and mixing methods, manufacturing method, physical practices, installation practices, design considerations, durability, research needs, and applications.

ACI 544-3R (1993) provides the notification on the existing technology in proportioning, specifying, mixing, placing, and finishing of steel fiber reinforced concrete. For this, various mixture proportions were tested then tabulated. The report also gives the recommendations for techniques of the mixing to reach the uniform mixes, placement techniques to confirm sufficient compaction, and finishing techniques to guarantee satisfactory surface textures.

Roy et al. (1993) On UHPC particularly dealing with RPC prepared a review paper which conducted on various headings, on all phases of RPC beginning from mixture of considerations to design and applications of RPC. Many conclusions were directed from this study. The optimization of binary, tertiary, quaternary and multi-component mixtures with appropriate combinations increases the packing density. An improvement of 20% to 30% of compressive strength is achieved because of the optimization causing in a denser RPC mixes. The performance of silica sand is restricted. Silica particles in the mixes were responsible for deciding the strength of the designated mixture. Also noticing a requirement for microstructural investigations for thorough studies in the area of leaching properties, pozzolanic reaction, autogenous shrinkage, and quantification of the products formed due to cement hydration.

ACI 544-2R (1988) wrote a report on preparation of specimens and its testing for workability, flexural strength, energy consumption, and toughness. Recently developed test methods were illustrated for the mechanical properties, creep, yield unit weight, air content freeze-thaw resistance, cavitation, abrasion resistance, and erosion.

ACI 544-4R (1988) on design practices for fiber reinforced concrete and mortar using steel fibers made a report. Mechanical properties were discussed, design methods were presented, and typical applications are listed.

CHAPTER 3

EXPERIMENTAL STUDY

3.1. Raw Materials

In the present work (CEM I 42.5 R) Portland cement (PC) and Silica fume (SF) were used as accompanying cementitious materials. Chemical composition, physical and mechanical properties of them are prearranged in Table 3.1. UHPC including SP, aggregate as well as micro steel fibers to provide fiber reinforcement were utilized. Crushed quartz sand with a specific gravity of 2.65 used as fine aggregates.

3.1.1 Portland Cement (PC)

A CEM I 42.5 R Portland cement was used in the current study. It had a specific gravity of 3.15 and a blaine fineness of 394 m²/kg

3.1.2 Silica Fume

In the current study, SF was used as supplementary cementitious material. Specific gravity and specific surface area of the silica fume were 2.2 and 21.80 m²/kg, respectively.

3.1.3 Superplasticizer

Even though well known as a high range water reducing (HRWR) admixtures, is a chemical admixture required where well-divided particle suspension is important. Often pointed to as super-plasticizers, help in increasing the workability of concrete without additional amount of water. It is a polymer material used as dispersants to

Table 3.1 Properties of Portland cement and silica fume

Constituent (%)	Cement	Silica fume
CaO	57.87	0.45
SiO ₂	17.99	90.36
Al ₂ O ₃	3.88	0.71
Fe ₂ O ₃	3.36	1.31
MgO	1.49	-
SO ₃	2.47	0.41
K ₂ O	-	1.52
Na ₂ O	-	0.45
Cl	0.005	-
Loss of Ignition	3.37	3.11
Insoluble Residue	0.34	-
Free CaO	2.18	-
Specific surface (m ² /kg)	394 ^a	21,080 ^b
Specific gravity	3.15	2.2

a Blaine specific surface area.

b BET specific surface area.

prevent particle isolation, and to increase the flux characteristics of fresh state of different types of concrete. Their addition to concrete allows the reduction of the water added to concrete (w/c), and enables the production of ultra-high achievement and self-compacting concretes (Ramachandran, 1995). The used super-plasticizer in this study complies with ASTM C494-Type F and ESS 1899-1

3.1.4 Quartz Aggregate

Quartz is the crystal composition, which consists of unremitting framework of silicon and oxygen tetrahedral (SiO₄), in which the formation of the chemical formula SiO₂ obtained from one oxygen and two tetrahedral. Commercial Quartz sand utilized having specific gravity of 2.65. The maximum size of the fine aggregate which is quartz sand ranged from 0 to 0.4, 0.6-1.2, and 1.2 to 2.5 mm to be a substitute for the coarse aggregates.

3.1.5 Micro Steel Fiber

Brass-coated steel fibers with a length of 6 mm and a diameter of 0.16 mm were used to supply fiber reinforcement as (see Figure 3.1). As shown in Table 3.1 the manufacturer reported that the aspect ratio; specific gravity and tensile strength of the fibers were 37.5, 7.17 and 2250 MPa, respectively.

In as much it is satisfactorily identified that the reduction in w/b ratio lower the porosity and enhance the strength (Nallathambi et al., 1984; Foy et al., 1988), typical water/binder ratio (w/b) for UHPFRC is taken as 0.12.

Table 3.2 Physical, mechanical properties and aspect ratios of micro steel fibers

Name of Fiber	Length (L) (mm)	Diameter (d) (mm)	Aspect ratio (L/d)	Density (g/cm ³)	Tensile strength (N/mm ²)
Micro steel Brass coated	6	0.16	37.5	7.17	2250

3.2. Concrete Mixture Proportioning, Casting and Sample Preparation

The mixture proportioning consisted of eight concrete mixes as shown in Table 3.3, the same w/b of 0.12, accounting for 850, 900, 950, 1000, 1050, 1100, 1150, and 1200 kg/m³ of total binder. The silica fume was used about 15% of the binder by weight in all the mixes. Superplasticizer was used in varying amounts to adjust the workability. Two curing regimes, water and steam were applied. The mixtures were labeled according to the binder content and curing types. For example, 950SC indicates the mixture containing 950 kg/m³ of binder and cured by steam.

Adequate mixing is needed to attain desired performance of concrete and homogeneity. In UHPC mixes, mixing time is important to fully discrete the silica fume, breaking any agglomerated particles, and to permit the super-plasticizing go-

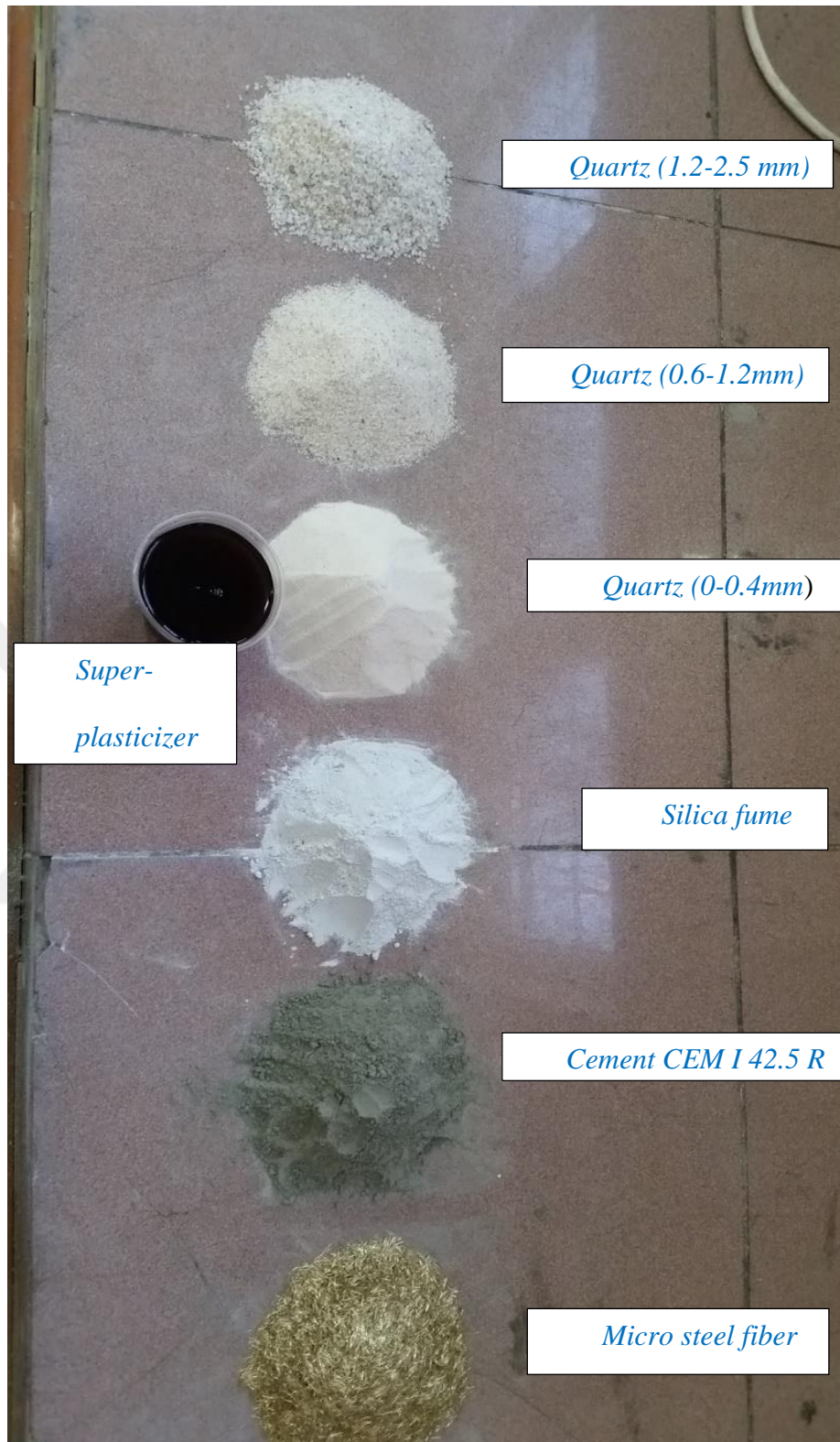


Figure 3.1 materials used in this study

between to improve its full potential. The mixes were set by a singular designed, high speed mixer, which has mixing speed as high as 470 rpm. Dry constituents and aggregates were mixed with the speed of 100 rpm for about three min. After addition of water, mixture was remixed for another five min with the speed of 100 rpm. Later, SP was added to premix material and mixing was resumed at 470 rpm for around five

Table 3.3 Mixture proportion of UHPFRC

Binder Content (kg/m ³)	w/b	Cement (kg/m ³)	SF (kg/m ³)	Water (kg/m ³)	SP (kg/m ³)	Micro Steel fiber (%)	Quartz aggregate (kg/m ³)
850	0.12	722.5	127.5	102	69.7	2	1365.8
900	0.12	765	135	108	66.6	2	1312.6
950	0.12	807.5	142.5	114	65.55	2	1254.4
1000	0.12	850	150	120	63.0	2	1199.9
1050	0.12	892.5	157.5	126	57.75	2	1145.9
1100	0.12	935	165	132	57.2	2	1092.5
1150	0.12	977.5	172.5	138	55.2	2	1036.6
1200	0.12	1020	180	144	56.4	2	972.9

min. (See Figure 3.2). Subsequently, 2% of micro steel fibers were added at the low speeds for two min. Finally, the mixing resumed for the last two min at high speed. A usual mixture consists of three 50-mm cubes, six 70-mm cubes, and three 150-mm cubes to determine compressive strength, splitting tensile strength, and modulus of elasticity, respectively. Furthermore, flexural strength and fracture energy were measured on three prisms of 70 x70x280 mm dimensions. Fresh UHPFRC was then poured into the molds and compacted by using a vibrating table. The samples were then insured with polyethylene sheets and kept in room temperature of 22 ± 2 °C. After demolding, the samples for compressive strength, splitting tensile strength, and expansion tests were subjected to either water curing or steam curing. The first group specimens were directly stored in normal water curing basin at 20 ± 2 °C until testing date and samples for the second group were cured by steam at 90 ± 2 °C for 48hrs later put in standard water up to the testing day.



Figure 3.2 Mixing of UHPFRC, (a) dry mix, (b) water addition, (c) superplasticizer addition with low speed, (d) superplasticizer addition with high speed

3.3. Slump Flow Test

By using the mini- slump test qualified by EFNARC (2002), the flow of UHPFRC was measured as illustrated in Figure 3.3. After pouring fresh UHPCC in a small cone full capacity , raising the cone directly up to allow the free flow of new sample on the plate. The designed UHPFRC's flow value was calculated by taking an average of two diameters measured from the mixture (D1 & D2). Many researchers, including Yu et al. (2014) and Wille et al. (2012) used flow cone test to find the workability of UHPFRC. In fact, the cone test is one of the simple and widely used test method for high flowable concrete. All mixtures had a flow value of 18 ± 1 cm, which was carried out by using an appropriate amount of superplasticizer. Moreover, it was revealed any season for all the mixes by visual examination.

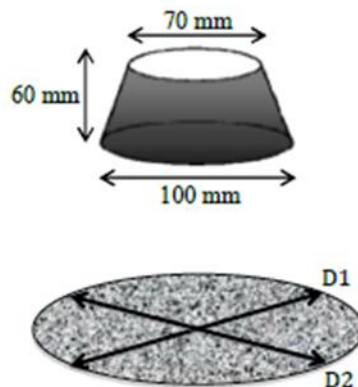


Figure 3.3 Slump flow test

3.4. Testing Methods

Compression test was conducted on 50 mm cubes at 7, 14 and 28 days with respect to ASTM C39 (2012).at a rate load of 0.9 kN/s using a digital testing machine of 3000 kN capacity. Each result presented in this study is the average of three samples. (Figure 3.4).



Figure 3.4 Compressive strength instrument with specimen during test

Splitting test was performed on 70 mm cubes ASTM C496 (2011) at a rate load of 0.2 kN/s. The test was conducted on three cubical samples for each mix at 28 days (Figure 3.5).

Static modulus of elasticity was determined on 150 mm cubes at 28 days in accordance with ASTM C469 (2014) (Figure 3.6). For this, the cube specimens were loaded and unloaded three times up to 40% of the ultimate load specified from the compression test. The first set of readings from each cube was thrown out and the modulus of elasticity was described as the average of the other two reading sets.



Figure 3.5 Sample during splitting tensile strength



Figure 3.6 Sample during Modulus of elasticity test

Fracture energy, labeled as a work of fracture, is an indirect surface energy quantity of cementitious materials (1976). The test was performed according to RILEM 50-FMC/198(1985) (Figure 3.7).

The displacement was measured instantaneously using a linear variable displacement transducer (LVDT) at mid-span. As shown in Fig. 3.9a, Instron 5500R

closed-loop testing machine with a maximum capacity of 250 kN was used to apply the load. Figure 3.8b shows the prepared beam for the fracture energy tests. The opening notch was achieved through reducing the effective cross section to 42×70 mm via a diamond saw to accommodate large aggregates in more abundance. Therefore, samples notch to depth ratio (a/W) was determined as 0.4.

According to RILEM (1985), the fracture energy, G_F , of a single edge notched beam can be calculated under three point bending as:

$$G_F = \frac{W_0 + mg\delta_s U}{B(W-a)} \quad (3.1)$$

Where W_0 is the area under the load-deflection curve; m is the mass of the beam; g is the acceleration due to gravity; δ_s is the specified deflection of the beam, while S , U , B , W , abbreviated as span length, width, depth, and notch depth of the beam, respectively. For each mixture at least three specimens were tested at 28 days. Loading ratio for all specimens were 0.02 mm/minute. In according to the literature, the net flexural strength, f_{flex} , was calculated via Equation (3.2) where the P_{max} being the ultimate load by assuming no notch sensitivity (Ravindra and Henderson, 1999, Akcay et al., 2012). Moreover, the characteristic length (l_{ch}) as a measure of ductility was computed using Equation (3.3) (Hillerborg, 1985).

$$f_{flex} = \frac{3P_{max}S}{2B(W-a)^2} \quad (3.2)$$

$$l_{ch} = \frac{EG_F}{f_{st}^2} \quad (3.3)$$



Figure 3.7 Photographic view of universal testing devices and three point flexural testing fixture

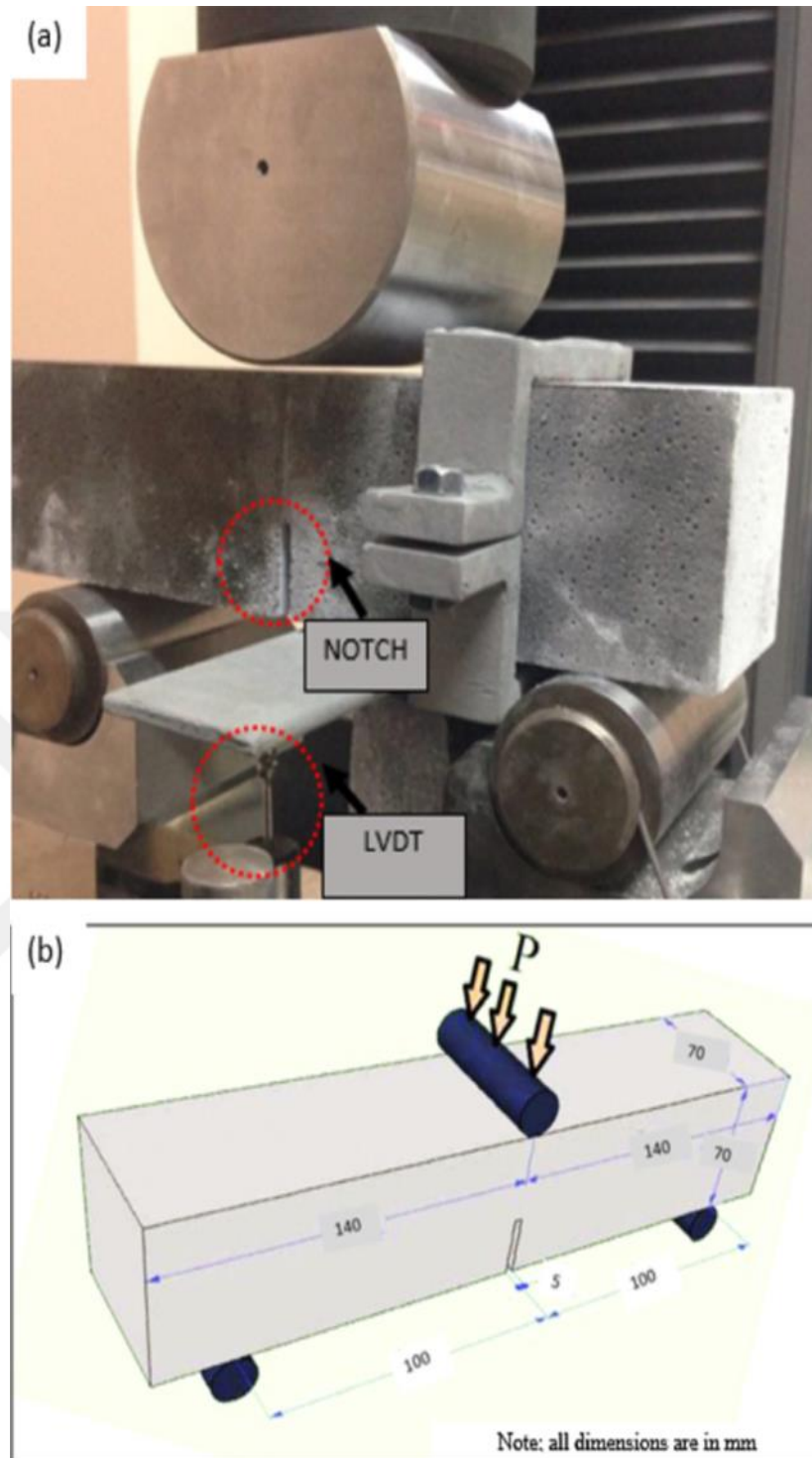


Figure 3.8.(a) Photographic view of notched beam specimen, and (b) dimensions of the notched beam specimen.

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1. Fresh Properties of UHPFRC

Assortment and utilization of SP is crucial in order to create good quality UHPC. The desired flowability for all mixtures was attained as fixed as 18 ± 1 by using different amount of superplasticizer. The relation between increasing in the amount of binder versus corresponding decrease in super plasticizer used is drawn in Figure 4.1. This inverse relationship may be because of huge surface area of silica fume and high surface energy, and this kind of fine particle is in a thermo dynamically unstable state. Thus, due to their ultra-fine sizes, small spherical silica particles may have helped to increase flowability not decrease.

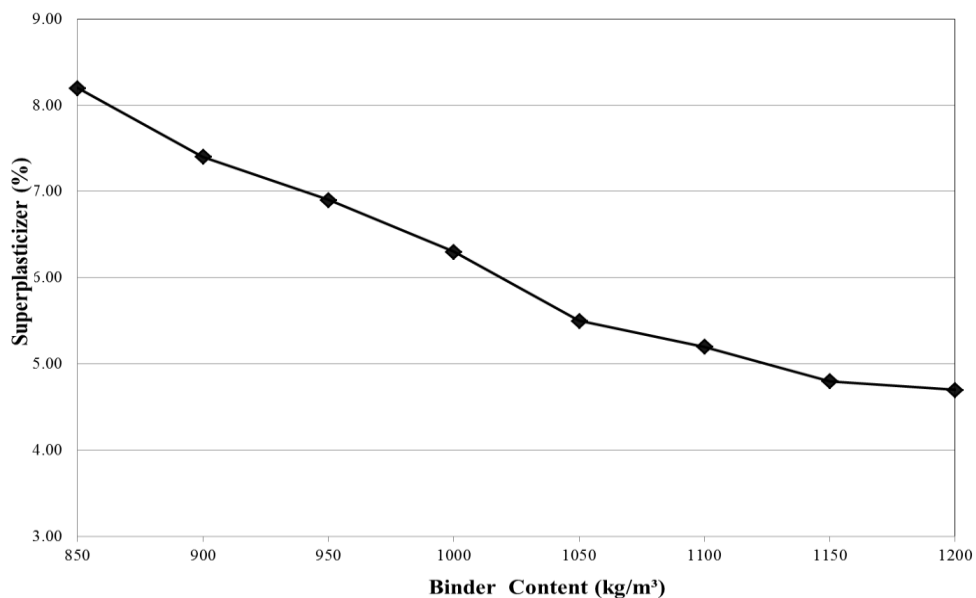


Figure 4.1. Superplasticizer demand versus binder content

4.2. Compressive Strength

Figures. 4.2 and 4.3 show the values of compressive strength of the UHPFRC subjected to water and steam curing, correspondingly. A significant growth in compressive strength occurred with increasing the level of binder up to 1150 kg/m³ then began to decrease. The compressive strength values of SC concrete were very close to each other, while greater differences were observed for WC cured concretes. At 28-day, the highest compressive strengths of 149 MPa and 192 MPa were observed for the UHPFRC cured by water and steam, respectively, while the lowest were observed for WC-UHPFRC and SC-UHPFRC at 850 kg/m³ of binder content as 129 MPa and 165.5 MPa, consequently. In addition to generally superior steam over water cured related with increasing binder content, the former showed higher enhancement in compressive strength development than the latter as the curing time prolonged. For instance, at the age of 28 days, 1150WC mixture had 21.4 % increase in compressive strength while the 1150SC had 6.3% increments, comparing to 7 days' results of water and steam curing of UHPFRC. The preferable SC than WC is may be because of congestions of high hydration and pozzolanically reactions resulting from the ingredients of the ultra-amount of binder (850-1200 kg/m³) and silica fume (127.5-180 kg/m³) that activated energetically by the high moisture and temperature of curing.

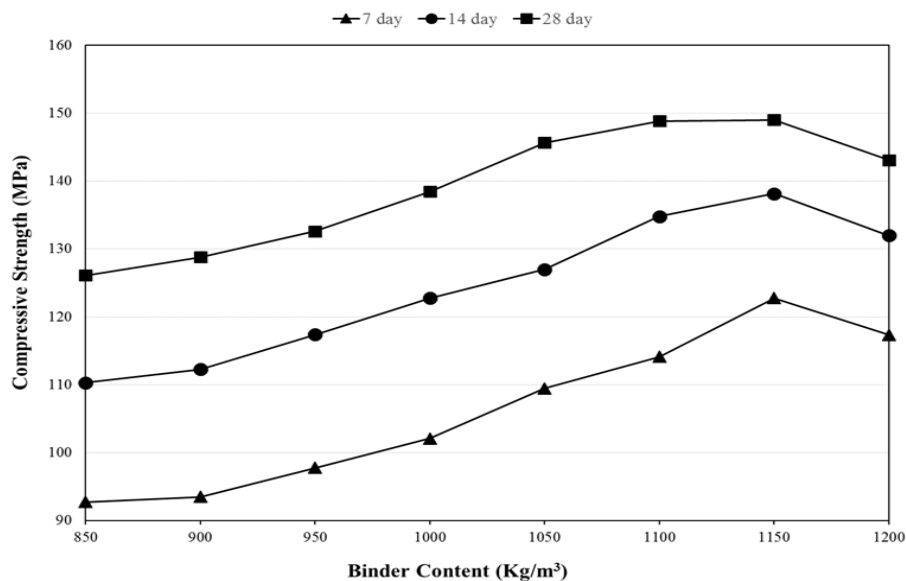


Figure 4.2. Compressive strength development versus binder content: water curing group

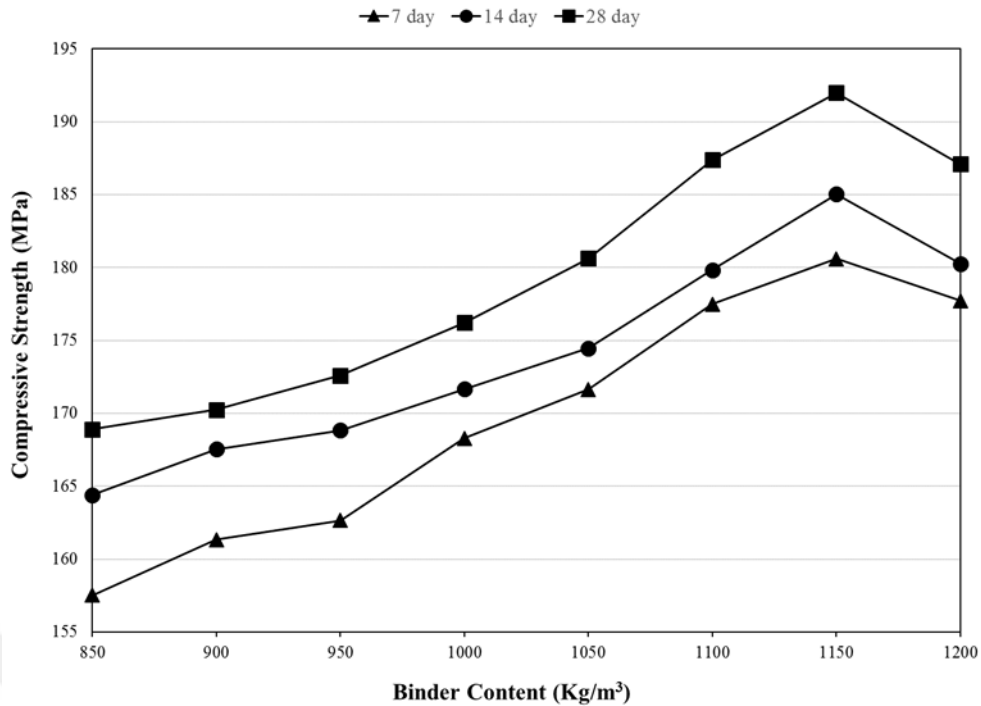


Figure 4.3 Compressive strength development versus binder content: Steam curing group

The faintly lower compressive strength of UHPFRC containing 1200 kg/m³ binder may be referred to improper dispersion of silica micro particles in the mixture due to their small sizes. The disagglomeration of particles is crucial to achieve the ideal composite materials, and the amount of silica in the mixture can also have been exceeded the quantity for consuming the CH compounds to form C–S–H gel. Therefore, it did not contribute to improve the strength of UHPFRC more (Gesoglu et al., 2016).

4.3. Splitting Tensile Strength

The variations of tensile strength of UHPFRC with the different amount of binders and two curing conditions are given in Figure 4.4. It can be noticed that the variations of tensile strength values were dominated by curing types as well as binder content. Interesting, after a jump of the results seen in converting WC to SC at 850 kg/m³ (9.6 to 11.5 MPa), adding more binders will not make a big sense comparing to tensile values gain from cured by water. This may be because of any increment in tensile values due to the relatively small amounts of binders (50 kg/m³) after completing hydration and consuming most Ca(OH)₂ of the greatest part of binder

(850 kg/m³) by assisting each of temperature and humidity. In addition, in water cured, the totally enhancement of strength distributed to all mixtures but in the steam cured, most of the improvement accumulated in 850SC mixture. For example, increasing of binder with increments of 50 kg/m³ over 850 kg/m³ caused a systematic growth in tensile strength of concretes at 28 days by; 3.7%, 10.6%, 12%, 15%, 16.8%, 19.4%, and 17.2% for the water cured group and 1.9%, 3.3%, 7%, 8.6%, 9.2%, 12.2%, and 11% for the steam cured group.

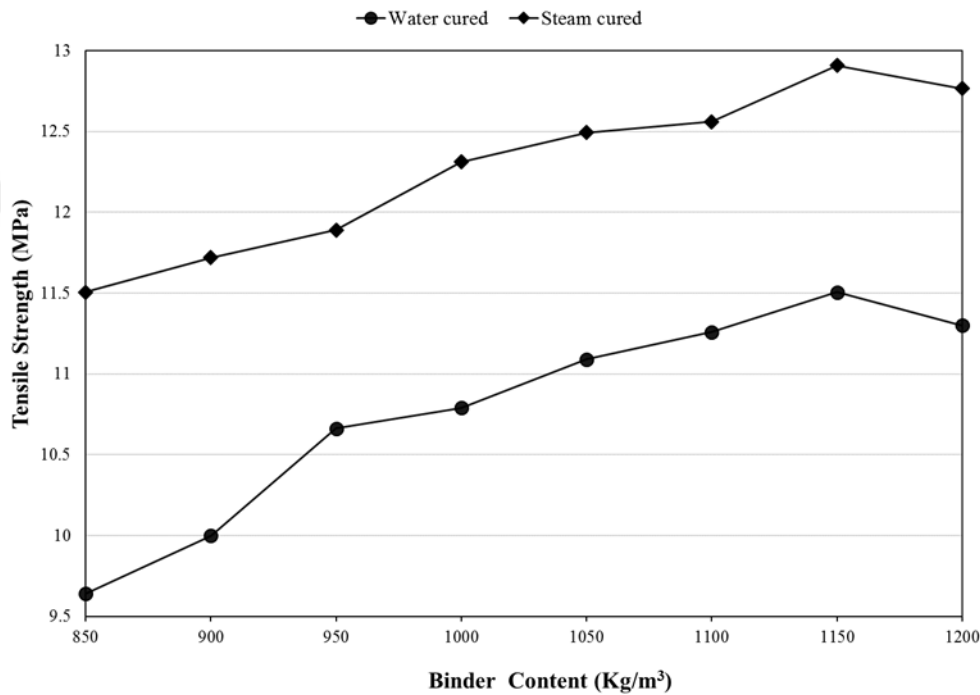


Figure 4.4. Tensile strength development versus binder content

The improvement of tensile strength limited after adding 1200 kg/m³ of binder. This may be because of the amount of NS particles that is greater than the amount necessary to combine with the other cementitious material particles during the process of hydration. For instance, depending on the specific surface area that given in Table 1, the 15% percent of micro silica of the mixture 1200 kg/m³ covered nearly an area of 3.8 km², which is greater than a totally covered area of 0.4 km² by Portland cement (85%) and all other concrete constituents. Thus, additional silica will leach out and cause dispersion of particles and weak zones formed within the system, consequently, cause shortage in the tensile value (Mukharjee and Barai, 2014).

4.4. Modulus of Elasticity

Young modulus is one of the most significant material properties applied to concrete design structures since it provides valuable information about the ability of concrete to deform in the elastic limit. Researchers investigated that a partial amount of binders giving a sharper slope in the σ - ϵ relationship curve by rearrangement stress and reduced the localized strain (Gencil et al., 2011). This meant that UHPFRC with an optimized content of binder had better stiffness due to the compactness of the paste bond with aggregates being better (Saloma et al., 2013).

Figure 4.5 showed the 28-day static elastic modulus of UHPFRC for two curing types and various binder contents. The behavior herein was similar to that seen in the strength results. It was detected that the effect of increase binder resulted in growth the static elastic moduli of the concretes. The increasing tendency nonstop until 1150 kg/m^3 content after which a drop began. When 1150 kg/m^3 was used, the concretes had higher elastic moduli by 35% and 21.1% for the water and steam groups, correspondingly, when compared to their controls (850 kg/m^3). Moreover, test results suggested that the effect of 1150 kg/m^3 water cured (1150WC) on the modulus of elasticity was almost equal to 950 kg/m^3 of that binder that cured by steam (950SC). This may have attributed the chemical and physical changes due to temperature and humidity effects on potential for the stress transfer.

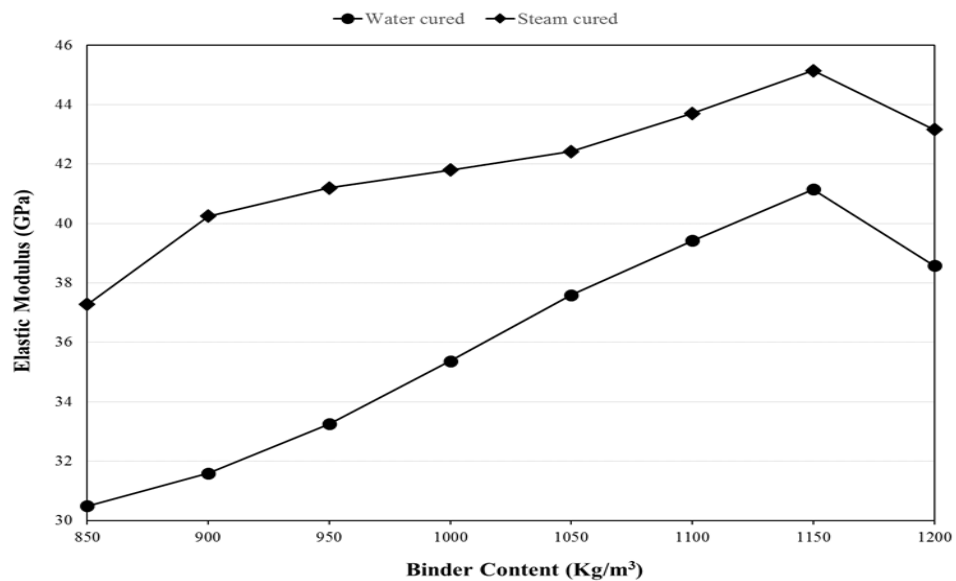


Figure 4.5. Elastic modulus development versus binder content

It has been well-known that the crystallinity of the hydration products has a great effect on the mechanical property of cement-based materials and a suitable ratio of the crystals to the non-crystals is favorable to yield a higher value (Feldman and Beaudoin, 1976). Due to this, an optimum amount of binder can attain an appropriate crystal-to-non crystal ratio to obtain a greater elastic modulus, and this could be attributed to the fact that a huge binder content is disadvantageous to the modulus of elasticity achievement of cement based materials as observed with the mixtures contained 1200 kg/m^3 of binder.

4.5. Modulus of Rupture

Effects of binder content on the flexural strength of the UHPCs reinforced with 2% of micro steel fiber are presented in Figure 4.6. It was observed that the modulus of rupture of concretes continuously increased up to 1150 kg/m^3 of binder contained, irrespective to the curing types. Beyond that the flexural strength began to decrease so that adding 1200 kg/m^3 of binder lessened the 28-day net flexural strength. Precisely, for the water and steam cured groups respectively, UHPFRC with 1150 kg/m^3 had the highest flexural strength of 12.7 MPa and 16.2 MPa, which reduced to 12.2 MPa and 15.3 MPa, when the total binder reached 1200 kg/m^3 .

The preference steam over curing by water as noticed in Figure 4.6, is probably because of high steam have motivated the pozzolanic reaction of the calcium hydroxide formed during the hydration of cement. In addition, the reaction may take place between unwanted Ca(OH)_2 and very fine quartz aggregates as well as SF due to hot steam curing conditions (Alaee, 2002). Furthermore, these pozzolanic reactions may reasons of a denser C-S-H microstructure that results in an earlier development of gaining strength. Moreover, the purpose of lessening flexural strength results is may be because the quantity of binder particles is more than needed quantity so, the strength reduction can be observer. Additionally, it may be because of the defects caused in a dispersion of binders that causes weak zones.

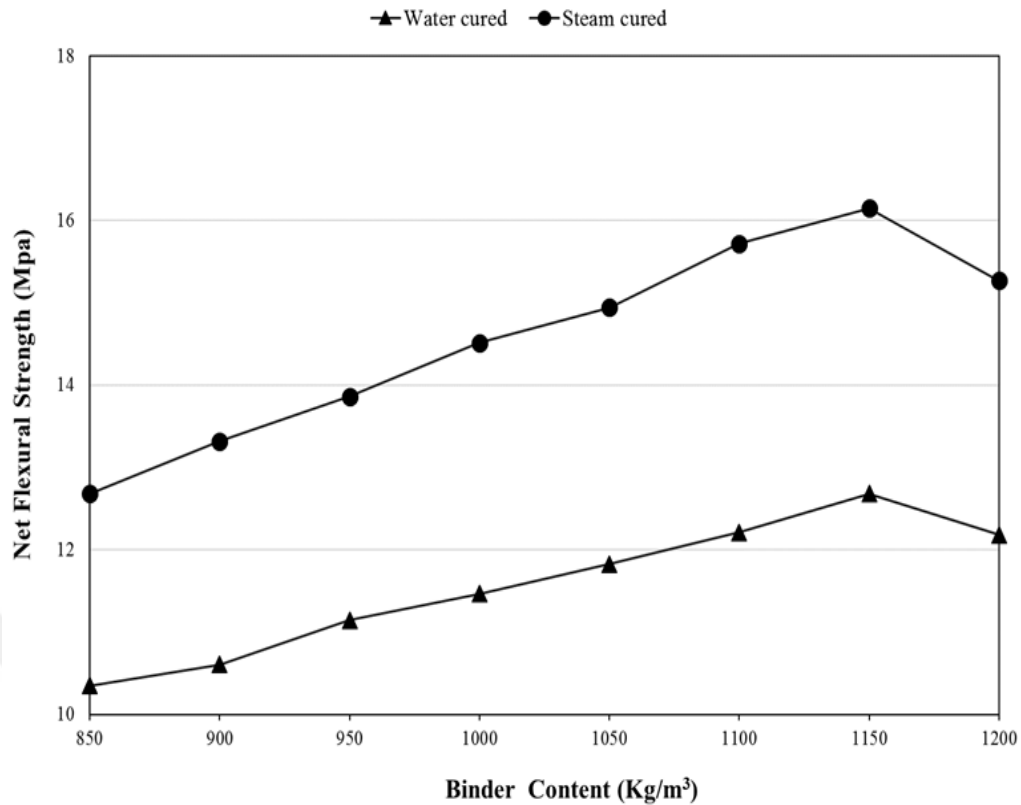


Figure 4.6. Flexural strength development versus binder content

4.6. Load-Displacement Curves

The load versus deflections measured at each loading step by the LVDTs installed at the mid-span of various binder amounts of UHPFRC under two different curing conditions of water and steam curing are given in Figures. 4.7 and 4.8. Regardless of curing types; the stiffness and toughness are improved via the addition of 2% of micro steel fibers in the UHPC matrix. It can be noted that when the crack started directly, i.e. at post peak loads, the curves have been in the zigzag form. This may be due to obstructing of micro cracks as a result of bridging process by micro steel fibers when thousands of fibers will stand to most insistence trial of loads to enlargement of cracks. It can see also that the peak load that denotes the maximum load, remarkably depends on the quantity of binder. Moreover, the slope of the prepeak and early postpeak region of the curve exposed to some extent, related to binder content. The load-displacement curves for the beam incorporating higher

binder contained demonstrated a steady drop in load carrying capacity after the peak load compared to steeper drop in the mixes with the lower amount of binders. This may be due to increasing of energy required for debonding UHPFRC components that contained high volume of binders. Furthermore, the prepeak and the early postpeak regions in the curves essentially influenced on the microcracks and their expansion, but the declining slope at the end of the softening branch is greatly related to mechanisms causing from the aggregate interlock and fiber contents (Beygi et al., 2013), where the binder amounts relatively have a significant role on both phenomena. On the other hand, Irrespective to the binder content; It can be seen from abovementioned figures that UHPFRC cured by hot steam showed higher performance than curing by water, including all important parameters found via load displacement curves as shown in Table 4. This probably referred to the high-temperature (90°C) of steam curing regime provided a shorter curing period compared with the water curing conditions.

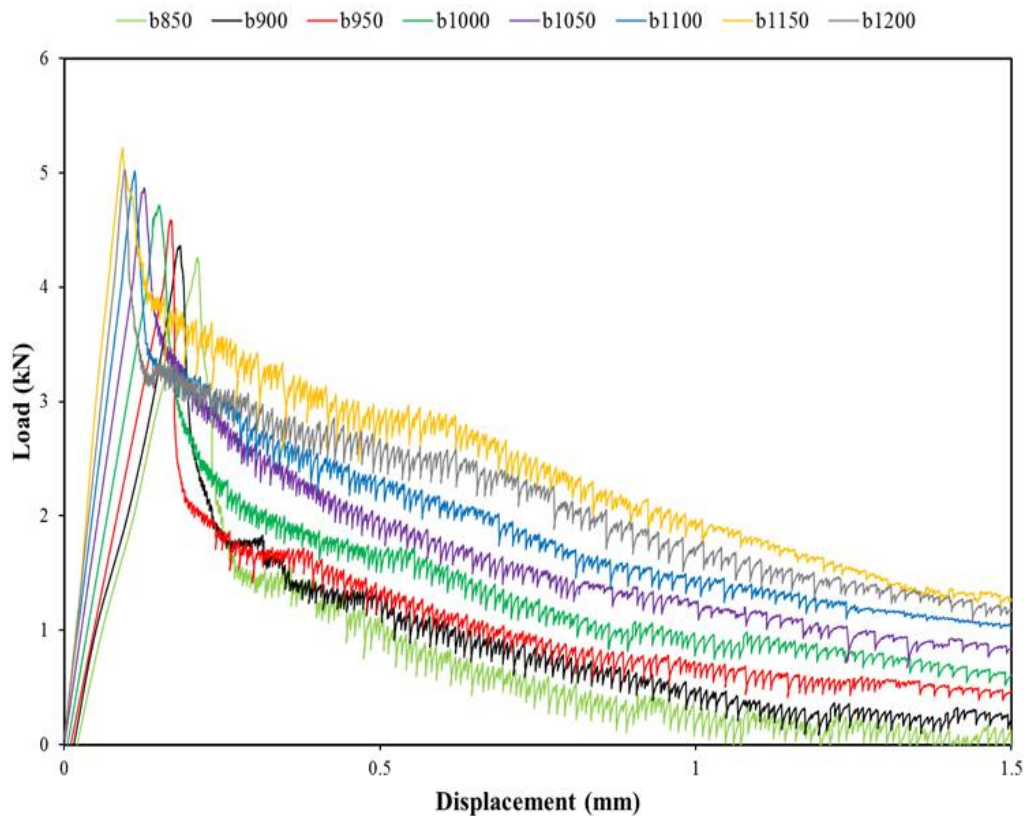


Figure 4.7. Load versus displacement curves of UHPFRC cured by water

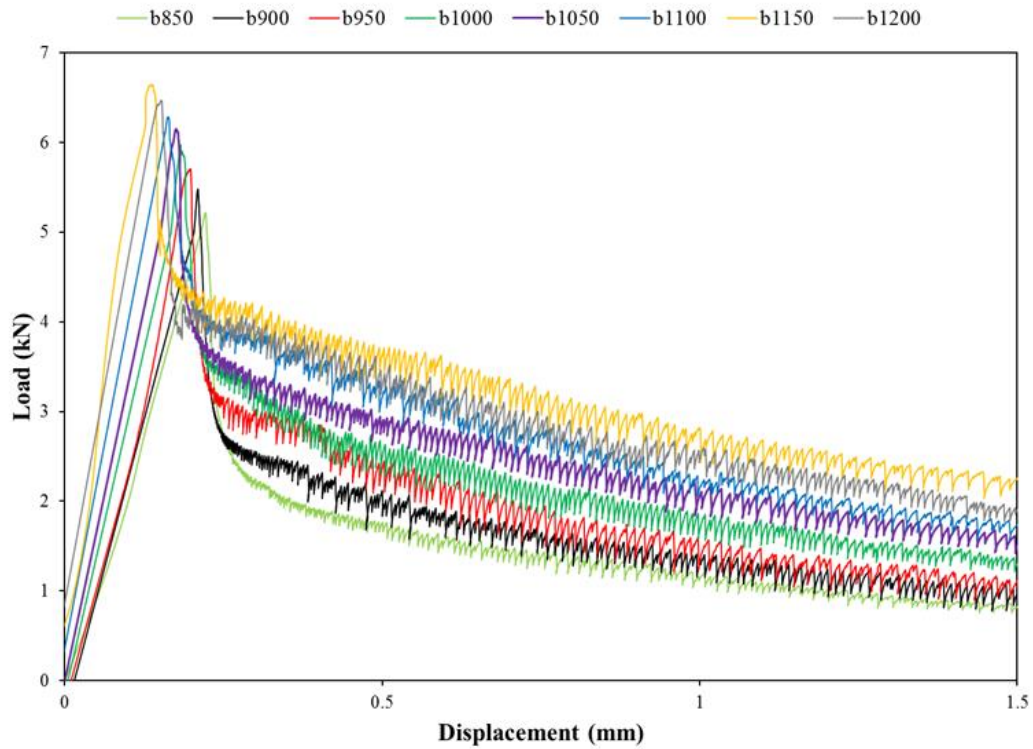


Figure 4.8. Load versus displacement curves of UHPFRC cured by steam

4.7. Fracture Energy

Fracture energy (GF) that is well known as specific energy or total energy, is essentially an energy necessary to generate a crack with unit surface area. In calculating the specific energy, the area under load against displacement curve and the weight of the beam was engaged as the energy provided by the individual weight of the prism. In this study, as presented in Figure 4.9, the total energy of UHPFRC was reliant on the amount of binders existing in concrete mixtures. It was estimated similar to the other aforementioned mechanical property tests that the UHPFRC with 1150 kg/m^3 binder gave the maximum value of the total energy regardless of the curing groups. The fracture energy improved by 9.3, 20.5, 25.6, 32.1, 45.3, 67.7, and 58.5 % as well as 8.2, 11.9, 25, 29.9, 40.4, 66.8, and 55.5 % for the water and steam cured groups respectively, compared to their reference mixtures (850 kg/m^3) at 28 days, when 900, 1000, 1050, 1100, 1150 and 1200 kg/m^3 of binder were combined. The main reason behind this enhancement in fracture energy may be attributed to the filling properties of silica fume, when their amount increased from 127.5 to 180 kg/m^3 responding to change in the binder from 850 to 1200 kg/m^3 . Consequently, the

ITZ zone and cement paste would have a significant strengthen then cracks were desired to pass across the aggregates than ITZ zone and cement paste. Furthermore, because of steam curing motivates the pozzolanic reaction, improved the microstructure of the compounds, and consumed $\text{Ca}(\text{OH})_2$ rapidly, it enhanced the fracture energy greatly compared to the results of water cured groups. On the other hand, the reason behind adversely affecting of UHPFRC after 1150 kg/m^3 (at 1200 kg/m^3) is may be referred to; there is a necessity appoint of silica inside concrete, and extra silica will leach out and weak zones formed within the system

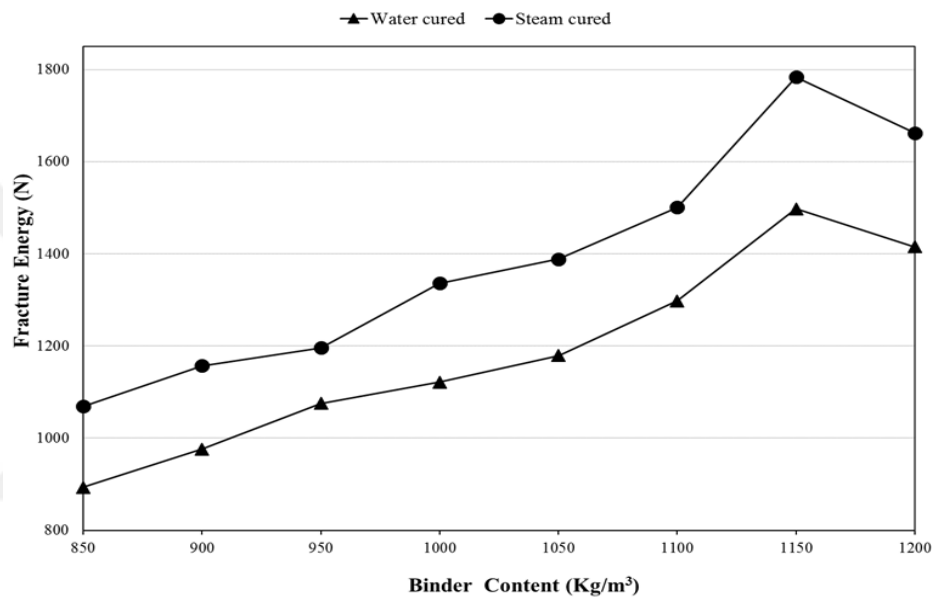


Figure 4.9. Fracture energy development versus binder content

4.8. Characteristic Length, l_{ch}

Characteristic length is a convenient parameter to evaluate the concrete brittleness, how much l_{ch} smaller, expects the more brittleness of the materials. As seen in Eq. 3, the characteristic length of concrete is mainly influenced by fracture energy with modulus of elasticity as directly proportional and inversely diversely by tensile strength.

The variation in the characteristic length of the UHPCs with addition of 2% of micro steel fibers is shown in Figure 4.10 with respect to the different replacement levels of

binders that divided into two curing groups of water and steam. The effects of increasing binder from 850 kg/m³ up to 1150 kg/m³ seemed to be significant on increasing ductility 'decreasing brittleness' of such concretes as the characteristic length ranging between 293-465.5 mm and 301.1-483.2 mm for the water and steam curing groups, respectively, then adding more binders (1200 kg/m³) led to the tendency to brittleness. This behavior of enhancement of ductility was may be attributed to the combined effect of the high cementitious materials of silica fume and cement accompanying with the very low w/b of 0.12, thus leading to converting material to be more ductile. There is a lack of study on the characteristic length of UHPC while many reports have been provided on normal concretes. The reason of inclination concrete towards brittleness at 1200 kg/m³ is may be because of any extra amount of silica fume more than 172.5 kg/m³, which contribute 15% weight of the total binder of 1150 kg/m³, may work as lubricant area to slippage the other concrete constituents over each other. On the other hand, it can be noticed from the above-mentioned figure that ductility of steam cured specimen was higher than that of cured by water. These occurred due to that the hydration process probably activated and continued for a long time in the steam curing condition. In addition, pozzolanic reaction resulting from the ingredients of silica fume in the UHPFRC mixtures will be motivated energetically by the high moisture and temperature of curing, and it may directly effect on the ductility.

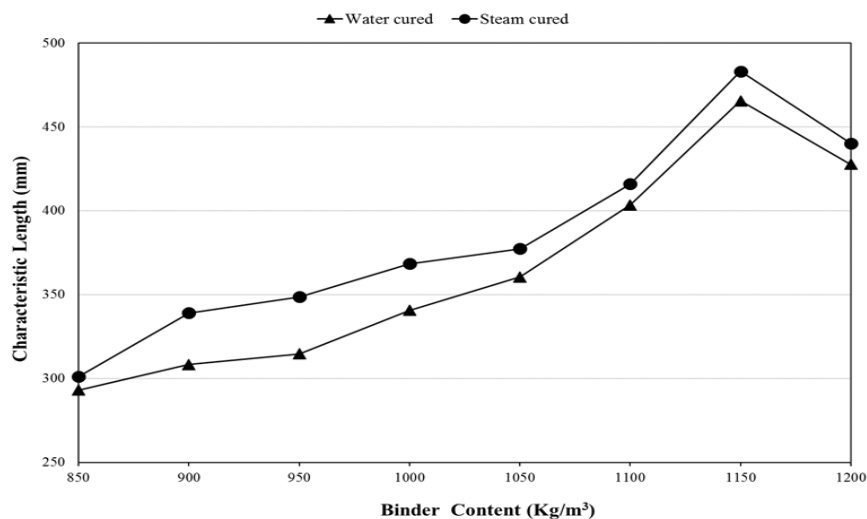


Figure 4.10. Characteristic length development versus binder content

CHAPTER 5

CONCLUSIONS

1. The preferable steam curing over water curing is may be because of congestions of high hydration and pozzolanically reactions resulting from the ingredients of the ultra-amount of binder ($850\text{-}1200\text{ kg/m}^3$) and silica fume ($127.5\text{-}180\text{ kg/m}^3$) that activated energetically by the high moisture and temperature of curing.
2. The faintly lower results of UHPFRCs containing 1200 kg/m^3 of binder content may be referred to improper dispersion of silica micro particles in the mixture due to their small sizes. The disagglomeration of particles is crucial to achieve the ideal composite materials, and the amount of silica in the mixture can also have been exceeded the quantity required for consuming the Ca(OH)_2 compounds to form more C–S–H gel.
3. The highest compressive strength observed at 1150 kg/m^3 of binder content as 149 MPa and 192 MPa, while the lowest were 129 MPa and 165.5 MPa at 850 kg/m^3 of the binder amount for the UHPFRC cured by water and steam conditions, respectively.
4. Increasing binder with an increment of 50 kg/m^3 over 850 kg/m^3 caused a systematic growth in tensile strength of concrete by; 3.7%, 10.6%, 12%, 15%, 16.8%, 19.4%, and 17.2% for the water cured group and 1.9%, 3.3%, 7%, 8.6%, 9.2%, 12.2%, and 11% for the steam cured group.
5. Test results suggested that the effect of 1150 kg/m^3 of binder that by water cured (1150WC) on the modulus of elasticity was almost equal to 950 kg/m^3 of that binder which cured by steam (950SC).

6. For the water and steam cured groups respectively, UHPFRC with 1150 kg/m³ binder had the highest flexural strength of 12.7 MPa, and 16.2 MPa then reduced to 12.2 MPa and 15.3 MPa, when the total binder increased to 1200 kg/m³.
7. At post peak at load-displacement curves, the curves have been in the zigzag form. This may be due to obstructing of micro cracks as a result of bridging process by micro steel fibers, which thousands of fibers will stand to most insistence trial of loads to enlargement of cracks.
8. The load–displacement curves for the beams incorporating higher binder contained demonstrated a steady drop in load carrying capacity after the peak load compared to steeper drop in the mixes with the lower amount of binders.
9. It can be seen that UHPFRC cured by steam showed higher performance than water cured including all important parameters in load displacement curves. This probably referred to the high-temperature steam curing regime provided a shorter curing period compared with the water curing conditions.
10. The fracture energy improved by 9.3, 20.5, 25.6, 32.1, 45.3, 67.7, and 58.5 % as well as 8.2, 11.9, 25, 29.9, 40.4, 66.8, and 55.5 % for the water and steam cured groups respectively, compared to their reference mixtures (850 kg/m³), when 900, 1000, 1050, 1100, 1150 and 1200 kg/m³ of binder were combined.
11. The characteristic length of UHPFRC ranging between 293-465.5 mm and 301.1-483.2 mm for the water and steam curing groups respectively, then adding more binders (1200 kg/m³) led to the tendency to brittleness.

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Appendix



Figure A1 Photographic view of materials used for UHPC production



Figure A2 Photographic view of Hobart mixer

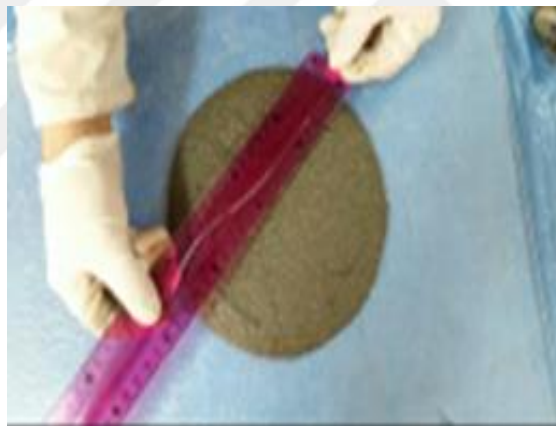


Figure A3 Photographic view of using mini cone and measuring flow



Figure A4 Setting the prisms on the testing machine