FLEXURAL CAPACITY OF ULTRA HIGH PERFORMANCE FIBRE REINFORCED CONCRETE (UHPFRC) RECTANGULAR BEAM

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By

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ABSTRAK

Kajian ini dijalankan untuk mengenalpasti kandungan optimum gentian untuk mencapai kapasiti lenturan rasuk maksimum konkrit prestasi ultra tinggi bertetulang gentian (UHPFRC). Gentian keluli mikro licin yang berdiameter 0.2 mm dan panjang 20 mm digunakan dalam campuran konkrit yang telah dicadangkan Tayeh et al. (2013). Empat bancuhan konkrit telah disediakan dengan kandungan gentian sebanyak 0%, 0.8%, 1.6% dan 2.4% dalam jisim, menggantikan pasir kuarza. Kekuatan mampatan yang direka bentuk adalah 100 – 120 MPa. Lima ujian termasuk ujian aliran konkrit, ujian mampatan kiub dan silinder, ujian belah tegangan dan ujian lenturan empat-titik telah dijalankan berdasarkan BS1881. Rasuk (100 × 300 × 2000 mm) disediakan untuk ujian lenturan empat-titik. Berdasarkan keputusan, SP yang diperlukan bagi 0.8%, 1.6% dan 2.4% UHPFRC untuk mencapai aliran 600 mm adalah 1.36%, 1.25% dan 1.14%. SP yang diperlukan menurun apabila kandungan gentian meningkat. Tambahan gentian meningkatkan kekuatan mampatan UHPC. Kandungan gentian yang optimum untuk mencapai kekuatan mampatan maksimum (116.8 MPa, peningkatan sebanyak 22.6%) adalah 0.8%. Selain itu, tambahan gentian keluli meningkatkan kekuatan belah tegangan UHPC juga. Kekuatan belah tegangan maksimum (75.3 MPa) tercapai pada kandungan gentian 1.6% dengan peningkatan sebanyak 35.2%. Sementara itu, kekuatan lenturan maksimum (10.24 MPa) tercapai pada 1.6% kandungan serat dengan kenaikan sebanyak 24.4%. Kenaikan kandungan gentian berikutnya menunjukkan kesan buruk ke atas kekuatan lenturan rasuk. Kesan bebolaan telah berlaku apabila 2.4% gentian digunakan. Akhir sekali, gentian mikro keluli didapati meningkatkan kemuluran UHPFRC.

ABSTRACT

This study was done to identify the optimum fibre content to achieve maximum flexural capacity of ultra-high performance fibre-reinforced concrete (UHPFRC) beam. Smooth micro steel fibres of diameter 0.2 mm and length 20 mm were used in the mix which was proposed by Tayeh et al. (2013). Four batches of concrete were prepared with fibre content of 0%, 0.8%, 1.6% and 2.4% by mass, replacing the quartz sand. The targeted designed compressive strength is from 100 MPa to 120 MPa. A total of 5 tests were conducted on the concrete samples as in accordance to BS1881. They are flow table test, cube and cylinder compression test, tensile splitting test and four-point flexural test. Four beams of size 100 mm × 300 mm × 2000 mm were cast for the four point flexural test. Based on the results, the super-plasticizer (SP) needed for 0.8%, 1.6% and 2.4% UHPFRC to achieve flow of 600 mm is 1.36%, 1.25% and 1.14% by mass respectively. Less SP is required to achieve the same fresh concrete flow when the fibre content increases. Addition of fibre increases the compressive strength of UHPC. The optimum fibre content to achieve maximum compressive strength (116.8 MPa, 22.6% higher than UHPC) is 0.8% by mass. Besides that, adding steel fibre increases the tensile splitting strength of UHPC too. Maximum tensile splitting strength (75.3 MPa) is achieved at 1.6% fibre content with the increment of 35.2%. Meanwhile, maximum flexural strength (10.24 MPa) was achieved at 1.6% fibre content too, with the increment of 24.4% as compared to UHPC. Further increment in fibre content shows adverse effect on the beam flexural strength. Minor balling effect took place when 2.4% of fibre mass is used. Lastly, micro steel fibre is found to improve the ductility of UHPC, enhancing the crack control.

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CHAPTER 1

INTRODUCTION

1.1 Background

Ultra-high performance concrete (UHPC) refers to concrete with compressive strength of 150 – 200 MPa (Rossi et al., 2005). UHPC is applicable when the structural member size has to be limited to a smaller section. Despite its high compressive strength, UHPC without adequate reinforcement is brittle and tends to crack easily as compared to conventional concrete. Therefore, ultra-high performance fibre reinforced concrete (UHPFRC) is developed to mitigate the cracking deficiency.

Like most concrete beam, flexural strength is one of the primary concerns in the design of UHPFRC. When a beam experiences bending, one zone of the beam will be in compression while the opposite zone will be in tension. As concrete is weak in tension, steel is incorporated into concrete to reinforce its performance. As the structural members made with UHPC are usually thin to achieve higher efficiency by eliminating unnecessary self-weight, rebar size is constrained. Therefore, steel fibre is added to enhance the tensile capacity as well as the flexural strength. Moreover, combination of steel fibre and shear reinforcement depicted slow and controlled cracking, better distribution of tensile cracks and minimized the penetration of shear crack into the compression zone of beam (Mansur et al., 1986). Hence, the effects of adding different percentages of micro smooth steel fibre to UHPC will be studied to have better understanding on the crack and bending behavior of the UHPFRC and facilitate its application in the construction industry. In addition, the flexural strength quantitatively, contributed by different percentages of smooth fibre and its limit is yet to be identified.

Workability is another key element during the casting process. The fibre content and plasticizer amount are known to have great impact on the workability and this project will take these parameters into consideration. This is to ensure suitable fresh concrete workability is achieved so that the durability of the concrete is assured without compromising concrete’s performance by eliminating the occurrence of honeycomb. Iqbal et al. (2015) stated that the concrete flow decreases as the smooth steel fibre content increases.

1.2 Problem statement

Concrete is weak in tension. Crack tends to form at the tension zone of the beam during bending. Enhancing tensile strength at that zone can delay the formation of crack at higher loading. This can be seen by adding smooth steel fibre into UHPC in conjunction with conventional steel bar reinforcement. As rectangular beam is a common structural component in a building, achieving maximum flexural capacity of UHPFRC rectangular beam at practical mixing workability by controlling the steel fibre amount is the ultimate aim in this project. On top of that, UHPFRC sections are always very thin. Therefore, UHPFRC requires steel fibre and small rebar to strengthen the beam’s flexural capacity.

On the other hand, the flexural strength contributed by smooth micro steel fibre reinforcement is yet to be determined. Whether there is a linear relationship between fibre amount and the beam flexural strength will be verified. It is known that smooth fibre induces less friction, results in poor bonding with the cement matrix, contributing towards less bridging effect. Another concern is the upper boundary of fibre content in the UHPFRC will be identified to prevent negative effect towards the concrete flexural strength by mean of the balling effect. Hence, the optimum steel fibre and plasticizer content to achieve the highest flexural strength will be determined in this project.

1.3 Objectives

1.3.1 To identify the optimum smooth micro steel fibre content for ultra-high performance concrete to achieve high flexural capacity.

1.3.2 To evaluate the effect of smooth steel fibre inclusion to the flexural strength of UHPC beam.

1.3.3 To interpret the effect of super-plasticizer in maintaining the workability of UHPFRC.

1.4 Scope of works

The project scope includes casting and identifying the flexural strength of beams of different smooth micro steel fibre percentages. At the same time, the concrete compressive strength, workability and tensile splitting strength were checked to ensure the consistency and uniformity of concrete grade and quality of the four beams. From lab test, the UHPFRC performance was analyzed and their flexural strengths were identified. In addition, super-plasticizer content used to achieve the targeted fresh concrete workability was recorded too.

1.5 Expected outcome

The beam flexural strength contributed from different percentages of smooth micro steel fibre as well as the optimum fibre content will be identified. Optimum fibre content refers to the fibre content used at which the maximum flexural strength achieved at an adequate concrete flow.

1.6 Dissertation outline

For better reading and understanding of this study, the thesis is categorized into five chapters including introduction, literature review, methodology, results and discussion and conclusions.

Chapter 1: Introduction – this chapter depicts the big picture of this study which includes the overall background of ultra-high performance fibre reinforced concrete (UHPFRC), problem statement, scope of work, objectives and the expected outcome of the research.

Chapter 2: Literature review – this chapter gives detailed explanation to the technical terms, findings and topics related to the research with reference to the research papers published earlier.

Chapter 3: Methodology – this chapter describes the methodology to obtain the expected outcomes and ways to achieve the project objectives in detailed.

Chapter 4: Results and discussion – the results were analyzed and discussed in this chapter to answer the research objectives.

Chapter 5: Conclusions – conclusions and a short summary were drawn in this chapter to cover the findings of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In the construction industry especially when dealing with mega structure, it often comes to the demand of structural member which are capable of taking high loading. As for conventional reinforced concrete beam, it usually requires a deeper section to resist the mentioned load. However, a larger section is less favourable as it exerts additional load to the whole structure and is difficult to cast. The difficulties in casting a massive concrete section include the compaction of fresh concrete. Therefore, UHPC with high compressive strength was introduced. The drawback is that UHPC, despite high compressive strength, is brittle and tends to crack easily. Adding smooth micro steel fibre as reinforcement has found to be able to improve the flexural capacity and to mitigate the crack issue. However, no specific fibre amount is specified in BS8110 for the design of UHPFRC. There are research works which have been conducted to study the properties of UHPFRC beam such as compressive strength, tensile strength and so on. However, the manipulating parameters vary over a wide range from fibre percentages, shapes, orientations to beam size. In this paper, the focus will be on the relationship between smooth micro steel fibre content and flexural capacity of the beam.

2.2 Ultra high performance concrete (UHPC)

Ultra-high performance concrete (UHPC) refers to concrete with compressive strength of 150 – 200 MPa (Rossi et al., 2005). Unlike conventional concrete, there is no fixed design form given by British Standard to design UHPC. The materials needed are different, too and requires strict filtering and monitoring. The typical materials used are ordinary Portland cement (OPC), quartz sand, silica flour and silica fumes. Based on

Tayeh et al. (2013), a mix proportion is proposed and will be implemented in preparing samples in this project. The expected compressive strength of concrete prepared adopting the recommended mix proportion is from 100 to 120 MPa. Coarse aggregate is not used in the mix. UHPC is applicable when the structural member size has to be limited to a smaller section. Despite its high compressive strength, UHPC without adequate reinforcement is brittle and tends to crack easily as compared to conventional concrete. Therefore, ultra-high performance fibre reinforced concrete (UHPFRC) is developed to mitigate the cracking deficiency.

2.3 Ultra high performance steel fibre-reinforced concrete (UHPFRC)

UHPFRC refers to UHPC with the addition of steel fibre as reinforcement. The typical diameter of the micro fibre is 0.15 to 0.20 mm and average length of 20 mm (Mahmud et al., 2013). Flexural strength is one of the primary concerns in the design of UHPFRC. Without fibre, formation of inclined shear cracking might lead to direct critical failure without any advanced warning (Lim and Hong, 2016). Moreover, thin beam cross section has restrained the use of reinforcement bar with large diameter. In contrast, using steel fibre as reinforcement can solve this problem. To achieve high flexural strength, the deficiency of concrete poor tensile strength has to be resolved. This is to avoid early failure of beam at the tension zone. Therefore, steel with high tensile strength is used to resist the tension force instead of concrete. In addition, steel fibre is able to hold the crack, increasing the strain at peak load and providing a great deal of energy absorption (Chanh, 2004). Although higher flexural strength can be achieved using higher fibre content, there exists a limit before the balling effect occurs during the casting process. The drawbacks of balling effect will be discussed in Section *2.9*. Furthermore, increasing the fibre content would increase the cost in manufacturing the beam and this is unfavourable.

2.4 Steel fibre

Steel fibre can vary in shape, size, length and orientation. Manipulating these parameters will affect the performance of UHPFRC. In term of size, steel fibre can be categorized to micro fibre and macro fibre. The five common macro steel fibre shapes found in the industry (*Figure 2.1*) are long smooth steel fibre (LS), short smooth steel fibre (SS), hooked fibre A (HA), hooked fibre B (HB) and twisted steel fibre (TF). Different percentages of the fibre blended into the concrete induce different impact on the UHPC flexural strength, so does the shape. The enhancements in modulus of rupture, deflection capacity and energy absorption capacity were different according to the types of macro fibre and their amount. The ascending order of flexural performance of UHPFRC according to macro fibre types is as follows: HB, TF, LS, SS and HA (Kim et al., 2011).

On the other hand, the influence of straight smooth fibre of different lengths on UHPFRC was studied too. In a study conducted by Yoo et al. (2017), straight fibre of lengths 13 mm (short), 19.5 mm (medium) and 30 mm (long) were used. The fibre content was altered too. The results indicated that the hybrid use of long and medium-length fibers effectively improved the flexural performance in terms of post-cracking strength, deflection capacity, toughness, and cracking behavior, whereas the hybrid use of long and short fibres generally decreased the performance. In this project, medium length straight fibre is used.

Nondestructive electrical resistivity technique can be used to qualitatively assess the orientation of fibres in UHPFRC panels. Meanwhile, computed tomography imagining was used to observe the orientation of fibre in the hardened concrete directly. Based on Barnett et al. (2010), the steel fibres tended to align perpendicular to the direction of flow during the pouring of concrete. As a result, panels poured from the centre were significantly stronger than panels poured by other methods because the alignment of fibres led to more fibres bridging the radial cracks formed during mechanical testing. In short, orientation of fibre is important as it can maximize the efficiency and concrete strength by providing adequate bridging effect on the crack.

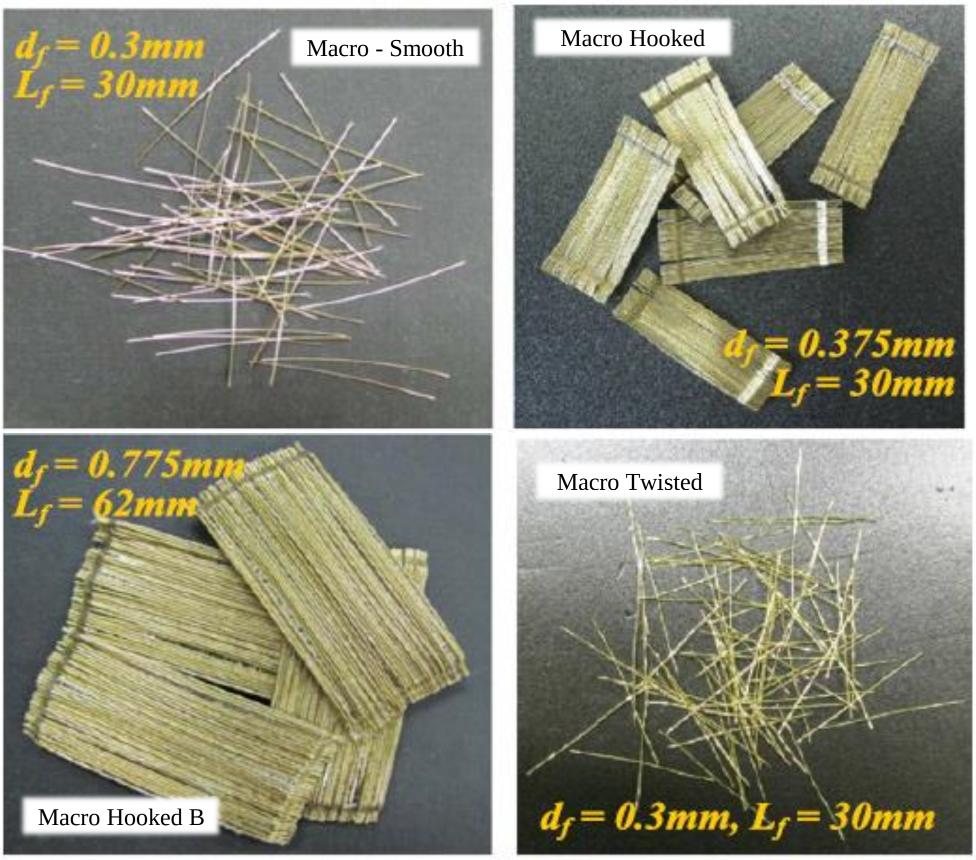

Figure 2.1: Different types of steel fibre

2.5 Influence of beam size

With the same amount of fibre content, UHPFRC beams of different sizes have different flexural strength. As the size of the specimen decreased, the flexural strength, normalized deflection and normalized energy absorption capacity of UHPFRC increased significantly, while the average crack spacing on the bottom surface of the specimen was noticeably decreased (Nguyen et al., 2013). To compare the deflection of each beam, the four point loading flexural test configuration should made constant.

Another finding from the paper is that beam of lower tensile ductility (strain capacity of range 0.5% to 0.6%) is more sensitive to the specimen size in term of flexural strength.

2.6 Shear capacity

The shear strength of UHPFRC is contributed from shear link, fibre reinforcement, reinforcement bar and concrete itself. Ordinary shear reinforcement can be designed in accordance to *BS8110 Clause 3.4*. The arrangement of shear reinforcement whether vertical or inclined, will affect the concrete shear strength. However to ease the casting at site, links are usually arrange vertically. Addition of steel fibre can increase beam shear capacity by holding the crack, allowing shear failure to occur at higher loading. According to Mansur et al. (1986), combination of steel fibre and shear reinforcement depicted slow and controlled cracking, better distribution of tensile cracks and minimized the penetration of shear crack into the compression zone of beam. However, too much fibre amount will have adverse effect on concrete strength. This is the result of balling effect which practically making the fresh concrete difficult to be placed and moulded. Besides that, previous research shows that the shear strength of UHPFRC is greater than current design code. In accordance to Lim and Hong (2016), UHPFRC can take higher load without failure even if the link spacing exceeds the limit specified in *BS8110*.

2.7 Tensile strength

The tensile strength of concrete can be determined by direct uniaxial tension test. Strain hardening is used to represent the tensile strength of UHPFRC. Tensile strength will then influence the flexural capacity of concrete. Blending steel fibre in can increases the tensile strength of brittle UHPC but the extent of increment is highly depending on the fibre shape and size (Park et al., 2012). With controlled fibre volume (1% for macro fibre and 0 – 1.5% or micro fibre), the overall shape of tensile stress–strain curves of

UHPFRC is primarily dependent upon the type of macro-fiber. Meanwhile, the addition of micro-fibers favorably affects the strain hardening and multiple cracking behaviors.

Aligned with Kim et al.'s (2011) findings on flexural performance, UHPFRC produced from macro-fibers with twisted geometry provides the best performance with respect to post cracking strength, strain capacity and multiple micro-cracking behavior, whereas UHPFRC produced with long, smooth macro-fibers exhibits the worst performance (Park et al., 2012). However, it is difficult to achieve strain capacity more than 0.5% and tensile post-cracking strength more than 15 MPa using a single type of fibre. First, there is a limit in the amount of fibre volume content that can be mixed, especially for deformed steel macro-fibres with an aspect ratio (length to width) more than 80 and length longer than 30 mm. Secondly, the bond strength of short micro-fibre is much weaker than that of deformed steel macro-fibre. Hence, hybrid use of micro and macro fibre is encouraged.

On the other hand, Wille et al. (2011) managed to produce strain hardening behavior, with 14.2 MPa post-cracking strength and 0.24% strain capacity, by using only 2.5% short smooth steel fibres (d = 0.2 mm, L = 13 mm) in an UHPC matrix. However, 2% deformed steel fibres such as hooked and twisted steel fibres showed better tensile performance.

2.8 Flexural capacity

Flexural strength is the primary study scope in this project. To study the flexural strength contributed from fibre, minimum reinforcement bar was used. Since steel is good in tensile strength, the tension force generated during bending is expected to be resisted by the fibre. Theoretically, increasing the fibre content will enhance the flexural performance. However, there exists a limit in the use of fibre content considering its cost and workability. In this project, the relationship between smooth steel fibre content and the beam flexural strength will be investigated.

2.9 Balling effect and workability

Workability is a key element in concrete casting process. Adequate fresh concrete workability is vital to ensure that the concrete is well compacted to remove void and air in the concrete. This will eventually improve the concrete durability and strength. The fibre content and super plasticizer amount are known to have great impact on the workability. Excess fibre will result in balling effect (*Figure 2.2*). Balling effect refers to the phenomenon where the concrete mix crumbs together to form several huge spheres where the mix is no longer suitable for casting. This happens when steel fibres are congested and hooked to each other. It can be caused by improper dispersion of fibre during concrete mixing and excess fibre used. Therefore, the fibre limit is one of the study scopes in this study.

There are results showing that there is strong influence on workability of self-compacted concrete (SCC) with steel fibre content of 1% by volume or more (Iqbal et al., 2015). As the fibre content increases, the slump flow decreases especially above 0.75% steel fibre content. On the other hand, there is around 18% and 70% increment in tensile splitting strength and flexural strength respectively, with increase of steel fibre content from 0.5 % to 1.25%, while the modulus of elasticity remains almost the same.

Figure 2.2: Balling effect

2.10 Factors influencing UHPC compressive strength

The compressive strength of UHPC depends on many factors. Here, the water/cement ratio, air content and the degree of compaction will be discussed. Based on Wille, Naaman, et al. (2011), the three parameters are proven to have strong influence on UHPC compressive strength. The findings show that UHPC compressive strength increases when the water/cement ratio and the air content decreases. The earlier component shows greater magnitude of influence as compared to the latter component. This is depicted in *Figure 2.3*. Meanwhile, the workability or flow of the fresh concrete is important in minimizing the air content in the concrete (*Figure 2.4*). In other words, maximizing the concrete compaction is essential to improve the compressive strength of the concrete and this can be done by increasing concrete workability. Ironically, increasing water content which is needed for better flows will impair the compressive strength. Hence, super-plasticizer is introduced.

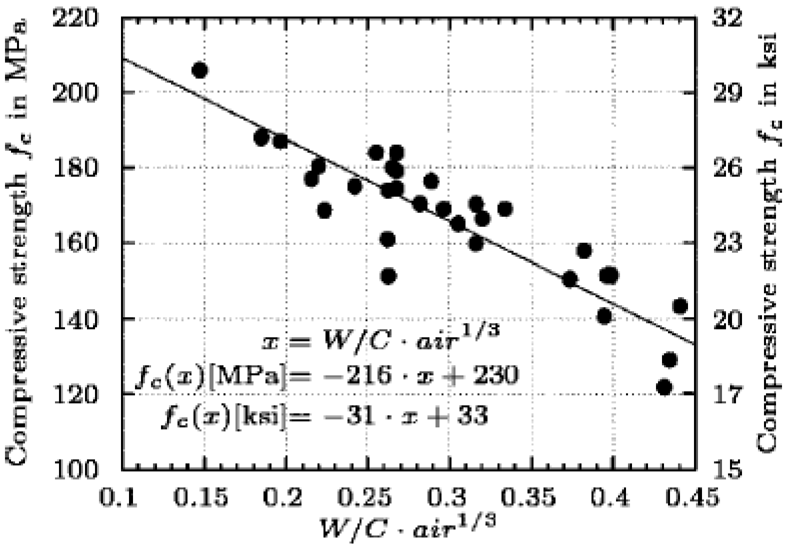

Figure 2.3: Relationship between water/cement ratio, air content and compressive strength, (Wille, Naaman, et al., 2011)

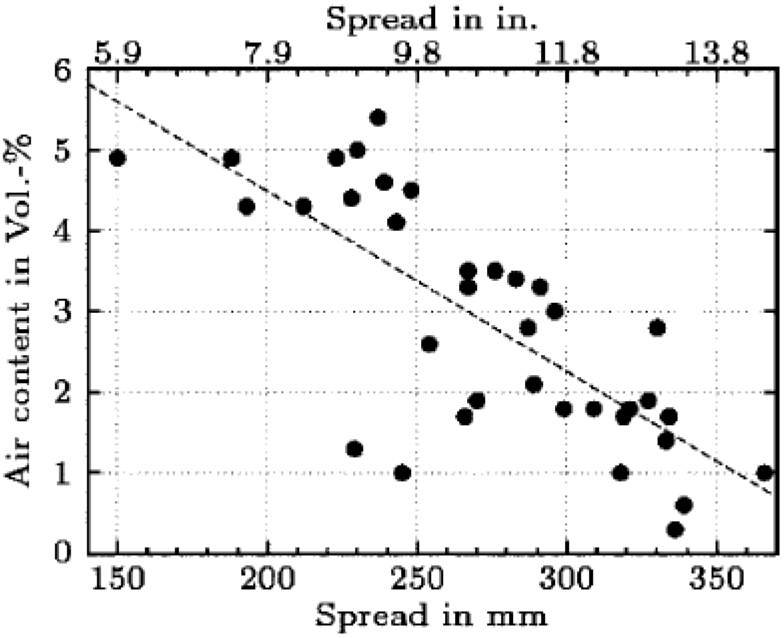

Figure 2.4: Relationship between flow and concrete air content (Wille, Naaman, et al., 2011)

2.11 Curing of UHPC

UHPC usually requires special treatment or curing such as heat curing, blanket curing (*Figure 2.5*), pressure and/or extensive vibration in order to achieve compressive strength up to 150 MPa. The expected compressive strength is from 100 MPa to 120 MPa. The advantage of not using special treatment is cost and time saving. Using heat curing or curing blanket will impose additional cost and is less convenient to implement at site.

Wille et al. (2012) has proven that high compressive strength of UHPC can still be achieved without special treatment. Enhanced concrete performance was accomplished by optimizing the packing density of the cementitious matrix, using very high strength steel fibres, tailoring the geometry of the fibre and optimizing the matrix fibre interface properties. In other words, adding steel fibre increases the concrete compressive strength, patching the adverse effect caused by lacking of special treatment.

Figure 2.5: Curing blanket used at site

2.12 Summary of literature review

In previous studies on UHPFRC, many parameters were altered and this lead to a wide range of combinations of results. Based on the findings, all studies show that addition of steel fibre into the UHPC improves the compressive strength, tensile strength and flexural capacity of UHPFRC. Besides that, there are many findings showing that steel fibre is able to hold the crack, increasing the strain at peak load and providing a great deal of energy absorption (Chanh, 2004). However, the improvements quantitatively are different with different types and amount of fibre used. The manipulating variables in previous studies include the shape of the steel fibre (Kim et al., 2011), fibre surface, fibre aspect ratio (Park et al., 2012), fibres' direction (Barnett et al., 2010) and water/cement ratio. However, there is lack in the focus on the optimum fibre content to achieve maximum beam flexural strength. Therefore, different amounts of smooth micro steel fibre were tested in this dissertation to identify its impact on the flexural strength. This is important as the fibre content needs to be controlled to avoid the occurrence of balling effect as well as to optimize the material usage.

On the other hand, the workability of the UHPFRC is known to have influences on the air content and its compressive strength (Wille, Naaman, et al., 2011). However, there is no study focusing on the relationship among fibre content, SP content and the workability of UHPFRC. Hence, this research took SP content into consideration to produce UHPFRC with suitable workability.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the methodology in achieving the research objectives in detail. The tests on concrete are all conducted following the specification in British Standard and the respective codes referred are stated in *Sections 3.6* and *3.7*.

3.2 Overview

The experiment was started by adopting and revising the steel fibre amount proposed by Tayeh et al. (2013). The fibre amounts were then decided to be (0%, 0.8%, 1.6% and 2.4% in mass) by replacing the quartz sand. Trial mixes were then carried out until the targeted compressive strength (100 MPa to 120 MPa) and workability were achieved by altering the super plasticizer content. Then, 4 beams of size 100 mm × 300 mm × 2000 mm were cast based on the mix proportions which achieved the mentioned compressive strength and workability. A total of 5 tests were conducted on the concrete samples. All tests were conducted in accordance to BS1881. They are flow table test to ensure the concrete workability is within the desirable range (600 ± 50 mm), cube and cylinder compression test to identify the concrete compressive strength, the tensile splitting test to identify the concrete tensile strength and four-point flexural test to identify the flexural capacity of the samples. Further description of the tests will be discussed in *Sections 3.6, 3.7* and *3.8*. Lastly, the flexural strength contributed by the steel fibre can be obtained using *Equation 4.1*.

3.3 Flow chart of methodology

The flow chart of methodology is summarized in *Figure 3.1*.

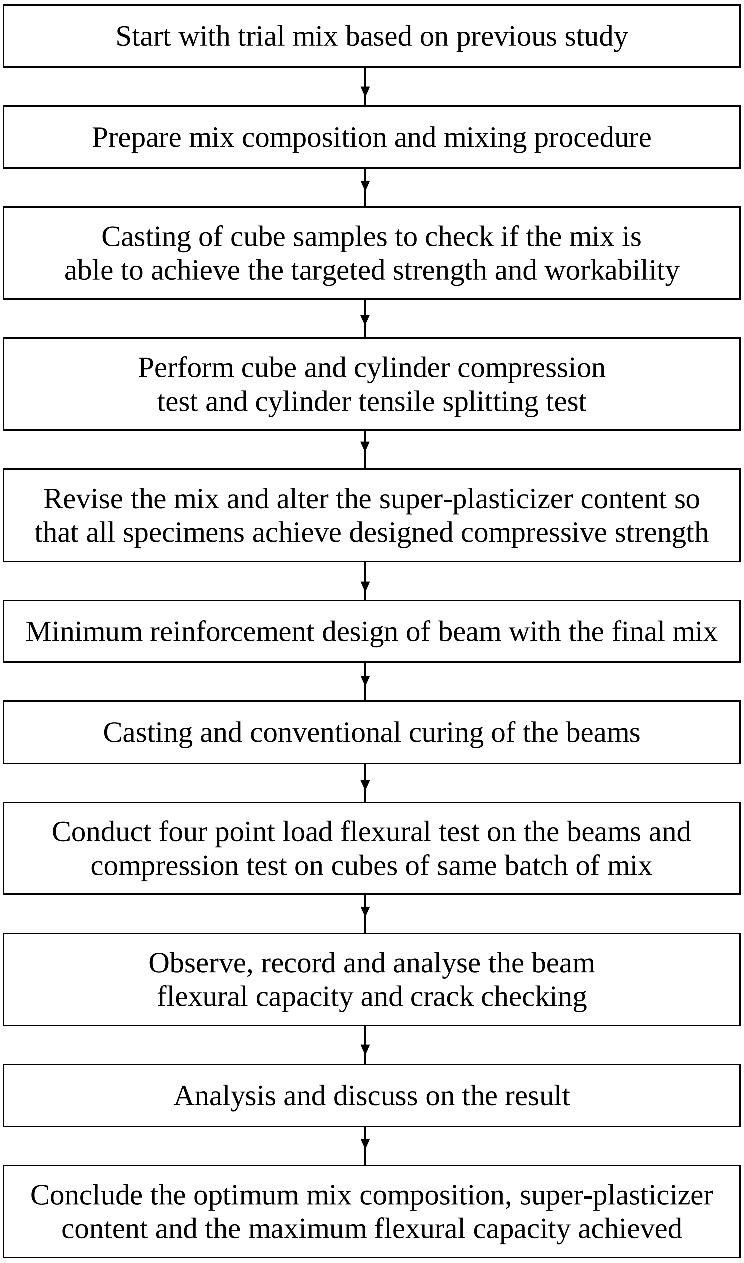

Figure 3.1: Flow chart of experimental work

3.4 Beam configuration, dimension and reinforcement

To attain significant difference in the test result, the beam's dimension was set to be thin and long which reflects the actual function of an ultra-high performance concrete.

Minimum reinforcement (reinforcement bar and shear link) were used. The detailing of the beam is shown in *Figure 3.2* while the beam geometry is tabulated in *Table 3.1* . Meanwhile, the reinforcements used are depicted in *Figures 3.3* to *3.7*.

Table 3.1: Geometry of beam and materials

Parameter	**Value**
Dimension b × h × L (mm)	100 × 300 × 2000
Concrete Cover (mm)	25
Concrete Grade (MPa)	120
Maximum Link Spacing (mm)	150
Rebar Diameter (mm)	6
Link Diameter (mm)	6

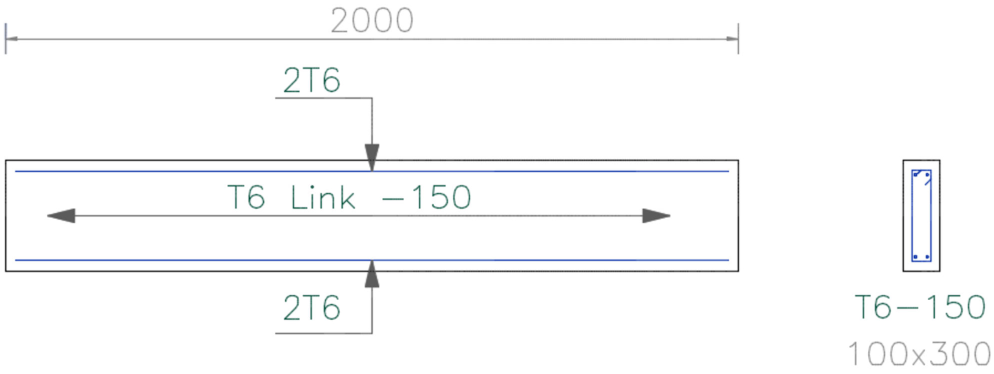

Figure 3.2: Beam detailing

Figure 3.3: Beam reinforcement setup

Figure 3.4: Beam reinforcement

Figure 3.5: T6 Shear link

Figure 3.6: T6 reinforcement bar

Figure 3.7: Beam formwork

3.5 Concrete mix proportion and mixing procedure

The beams to be tested consist of 4 steel fibre percentages which are 0% (control), 0.8%, 1.6% and 2.4% by mass respectively. The mentioned values were adopted and modified based on the one proposed by Tayeh et al. (2013). The detailed mix proportions are listed in *Table 3.2*.

Table 3.2: Mix proportion

MATERIAL	**PERCENTAGE BY MASS (%)**			
	Beam A (control)	**Beam B**	**Beam C**	**Beam D**
OPC	49.24	49.24	49.24	49.24
Quartz Sand	27.14	26.34	25.54	24.74
Silica Flour	4.14	4.14	4.14	4.14
Silica Fume	5.74	5.74	5.74	5.74
Sika Viscocrete 2192	Varies	Varies	Varies	Varies
Steel Fibre	0	0.8	1.6	2.4
Water	12.24	12.24	12.24	12.24

The casting steps start by mixing the dry material (*Figure 3.12* to *Figure 3.19*) in the following sequence: quartz sand, silica flour, silica fume followed by ordinary Portland cement (OPC). The mixture was mixed for 5 minutes every time each subsequent dry material was added. Then with the mixer operating (*Figure 3.9*), the fibre was added and distributed evenly into the mixture and mixed for 5 minutes. Water premixed with the super plasticizer (SP) was then added portion by portion and mixed for another 20 minutes. Then, flow table test was performed. Proceed to casting if the flow is within 600 ± 50 mm. If the flow is less than 550 mm, add super plasticizer and mix the materials for another 5 minutes. The steps were repeated until the targeted flow is achieved. Any ball mass (*Figure 3.8*) was removed and the fibres inside were re-dispersed into the mix. The fresh concrete was then moulded and cured (*Figure 3.10* and *Figure 3.11*) in accordance to *BS1881: Part 3: 1983*.

Figure 3.8: Ball mass of fibre

Figure 3.9: Mixing of dry material

Figure 3.10: Curing room

Figure 3.11: Moist curing

Figure 3.12: Ordinary Portland cement

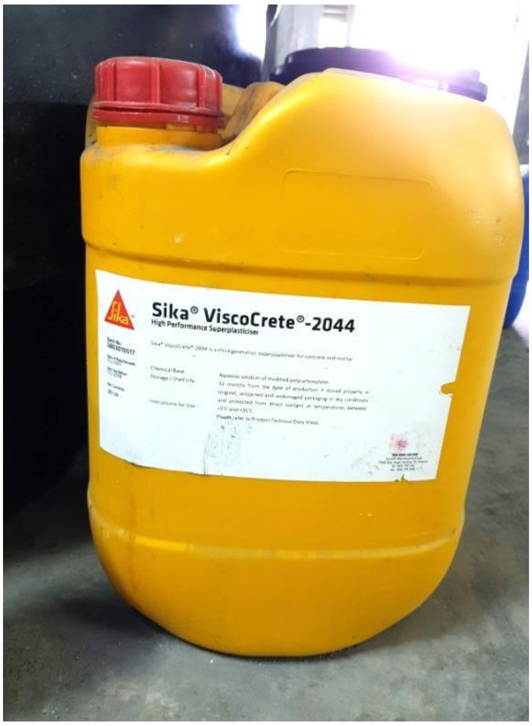

Figure 3.13: Super plasticizer

Figure 3.14: Densified silica fume

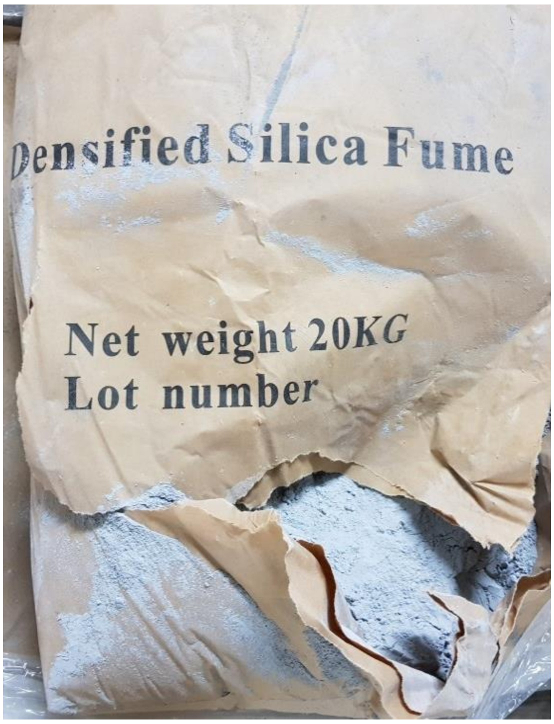

Figure 3.15: Silica fume

Figure 3.16: Smooth micro steel fibre

Figure 3.17: 20 mm (L) fibre

Figure 3.18: Quartz sand

Figure 3.19: Silica flour

3.6 Concrete flow table test

The flow table test was conducted on fresh concrete in accordance to *BS EN12350: Part 5*. The targeted flow is 600 ±50 mm.

3.7 Concrete physical strength test

The concrete physical strength tests commenced and their respective codes referred are listed in *Table 3.3*. The apparatus used are shown in *Figure 3.20* and *Figure 3.21*.

Table 3.3: Lab test and codes referred

TEST	**CODE**
Cube Compression Test	*BS1881: Part 116: 1983*
Cylinder Compression Test	*BS1881: Part 110: 1983*
Tensile Splitting Test	*BS1881: Part 117: 1983*
Four Point Flexural Test	*BS1881: Part 118: 1983*

Figure 3.20: Cube compression test