

## ACKNOWLEDGEMENTS

*In The Name of ALLAH swt, The Most Beneficent, The Most Merciful...*

*May ALLAH swt Guide Us All To Truth and Keep Us On The Straight Path...*

I wish to express my sincere appreciation and gratitude to my lovely supervisor, Associate Professor Dr. Norazura binti Muhamad Bunnori for her guidance since my final year project in undergraduate until now, master degree. I would also like to thank to my co-supervisor, Associate Professor Dr. Megat Azmi bin Megat Johari. No matter what happen during this journey, they still guide and accept me as their student. For that reason, I will always remember, appreciate and respect them as my teacher. My big thanks also go to both Dr. Bassam Tayeh who guided me on the repair works and Dr. Majed A.A. Aldahdooh - about the main materials for my research, GUSMRC. Also, I would like to thanks the staff of Concrete and Structural Laboratory of Universiti Sains Malaysia, Mr. Shahril, Mr. Fauzi, Mr. Aliuddin, Mr. Fadhil and Mr. Abdullah for their co-operation during my research. In addition, I would like to express my appreciation to my co-researcher, Nur Liyana as she always helps me during these one and half years of journey. Not to forget my other co-laboratory-mates, Wan Norsariza, Jafni, Mastura, Ahmed Tariq and Dr. Mustafa Juma for helping me during the lab work. My special appreciation goes to my best friend, Aktham Hatem Qasim, who now in Ana, Iraq as he always encouraged and stands beside me especially during my hard time. Not only my best friend, he also is my forever best brother. Not to forget Muwazir Mansor, Ali Siddiq and Ahmed Khaldoon. Finally I would love to thanks to my one and only family especially my beloved mother, brothers and nephew as they always make me happy during my hard time. Nobody can replace them and may *ALLAH swt* blessed and grant/guide us to *Jannatul Firdous !*

## TABLE OF CONTENTS

	Page
<b>ACKNOWLEDGEMENTS</b> .....	ii
<b>TABLE OF CONTENTS</b> .....	iii
<b>LIST OF TABLES</b> .....	viii
<b>LIST OF FIGURES</b> .....	x
<b>LIST OF SYMBOLS</b> .....	xvi
<b>LIST OF ABBREVIATIONS</b> .....	xviii
<b>ABSTRAK</b> .....	xix
<b>ABSTRACT</b> .....	xxi
<b>CHAPTER ONE: INTRODUCTION</b>	
1.1 Background.....	1
1.2 Problem statement.....	3
1.3 Research objectives.....	5
1.4 Research scope.....	6
1.5 Thesis structure.....	6
<b>CHAPTER TWO: LITERATURE REVIEW</b>	
2.1 Introduction.....	8
2.2 Ultra high performance fiber reinforced concrete (UHPFRC).....	8
2.2.1 UHPFRC application as concrete structural and repair material for rehabilitation.....	10
2.3 Green Universiti Sains Malaysia reinforced concrete (GUSMRC).....	17
2.3.1 GUSMRC materials content.....	19

2.3.1.1	Sand.....	20
2.3.1.2	Cement.....	21
2.3.1.3	Densified silica fume (DSF).....	22
2.3.1.4	Ultra-fine palm oil fuel ash (UPOFA).....	23
2.3.1.5	Steel fiber.....	25
2.3.1.6	Superplasticizer (SP).....	27
2.3.1.7	Water.....	28
2.4	Bonding between old concrete and repair material.....	29
2.4.1	Slant shear bond strength.....	31
2.4.2	Pull off strength.....	33
2.4.3	Splitting tensile strength.....	34
2.4.4	Flexural strength.....	36
2.5	Fluid transport properties.....	37
2.6	Surface treatment/roughness of concrete substrate.....	40
2.7	Summary of literature review.....	43

### **CHAPTER THREE: RESEARCH METHODOLOGY**

3.1	Introduction.....	45
3.2	Materials preparation.....	47
3.2.1	Cement.....	47
3.2.2	Coarse aggregate.....	47
3.2.3	Sand.....	48
3.2.4	Silica fume.....	48
3.2.5	Superplasticizer.....	48
3.2.6	Ultra-fine palm oil fuel ash (UPOFA).....	49

3.2.7	Steel fiber.....	51
3.2.8	Water.....	52
3.3	Concrete mix design for NC substrate and GUSMRC.....	52
3.3.1	Normal concrete substrate.....	52
3.3.2	GUSMRC.....	55
3.4	Surface treatment/roughness of NC substrate.....	58
3.4.1	Grinding surface treatment preparation.....	58
3.4.2	Sand blasting surface treatment preparation.....	59
3.5	Engineering properties of monolithic samples (NC substrate and GUSMRC) and composite samples of NC substrate/GUSMRC.....	61
3.5.1	Mechanical properties of monolithic samples of NC substrate and GUSMRC.....	61
3.5.1.1	Compressive strength test.....	61
3.5.1.2	Modulus of elasticity test.....	63
3.5.1.3	Splitting tensile test.....	64
3.5.1.4	Flexural strength test.....	65
3.5.2	Bonding properties of monolithic samples of NC substrate and GUSMRC.....	66
3.5.2.1	Slant shear test of composite NC substrate/GUSMRC.....	66
3.5.2.2	Splitting tensile test of composite NC substrate/GUSMRC.....	68
3.5.2.3	Pull off test of composite NC substrate/GUSMRC.....	70
3.5.2.4	Flexural strength test of composite NC substrate/GUSMRC.....	73
3.6	Fluid transport properties of monolithic samples (NC substrate and	

GUSMRC) and composite samples of NC substrate/GUSMRC.....	74
3.6.1 Initial surface absorption test (ISAT).....	74
3.6.2 Porosity and water absorption test.....	75
3.6.3 Gas permeability test.....	77
3.6.4 Water permeability test.....	79
3.6.5 Rapid chloride permeability test (RCPT).....	80
3.6.6 Chloride penetration resistance test.....	83
3.7 Summary.....	84

## **CHAPTER FOUR: RESULTS AND DISCUSSION**

4.1 Introduction.....	86
4.2 The mechanical properties of NC substrate and GUSMRC.....	86
4.2.1 Compressive strength.....	86
4.2.1.1 Compressive strength of NC substrate and GUSMRC.....	87
4.2.2 Modulus of elasticity.....	89
4.2.3 Splitting tensile strength.....	89
4.2.4 Flexural strength.....	90
4.3 Mechanical properties of composite NC substrate/GUSMRC.....	91
4.3.1 Slant shear bond strength.....	92
4.3.2 Splitting tensile strength .....	95
4.3.3 Pull-off bond strength.....	98
4.3.4 Flexural strength of composite NC substrate/GUSMRC specimens.....	102
4.4 Fluid transport properties of NC substrate, GUSMRC and composite NC	

substrate/GUSMRC.....	104
4.4.1 Initial surface absorption (ISA).....	104
4.4.2 Porosity and water absorption.....	108
4.4.2.1 Relationship between porosity and compressive strength of NC substrate and GUSMRC.....	111
4.4.3 Gas permeability.....	112
4.4.3.1 Relationship between gas permeability and porosity of NC and GUSMRC.....	116
4.4.4 Water permeability.....	117
4.4.5 Rapid chloride permeability (RCPT).....	120
4.4.6 Chloride penetration resistance.....	125
4.6 Summary.....	127

## **CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS**

5.1 General.....	128
5.2 Conclusions.....	128
5.3 Recommendations for future research.....	130

<b>REFERENCES.....</b>	<b>132</b>
------------------------	------------

## **APPENDICES**

## **LIST OF PUBLICATIONS**

## LIST OF TABLES

		<b>Page</b>
Table 2.1	Summary of mechanical properties of GUSMRC	19
Table 2.2	GUSMRC mix design proportion	20
Table 3.1	Physical properties of OPC, DSF and UPOFA	50
Table 3.2	Chemical composition of OPC, DSF and UPOFA	52
Table 3.3	NC substrate mix proportions	54
Table 3.4	Mix design proportions for GUSMRC	55
Table 3.5	Compressive strength test total samples for monolithic NC substrate and GUSMRC	62
Table 3.6	Modulus of elasticity test total samples for monolithic NC substrate and GUSMRC	64
Table 3.7	Splitting tensile test total samples for monolithic NC substrate and GUSMRC	65
Table 3.8	Flexural strength test total samples for monolithic NC substrate and GUSMRC	65
Table 3.9	Chloride ion permeability based on total charge passed	82
Table 4.1	Average compressive strength of NC substrate and GUSMRC	87
Table 4.2	Slant shear strength and failure modes of composite NC substrate/GUSMRC specimens	92
Table 4.3	Acceptable bond strength range for slant shear test (ACI Concrete Repair Guide)	93
Table 4.4	Splitting tensile strength and failure modes of composite NC substrate/GUSMRC specimens	96

Table 4.5	Quantitative bond quality in term of bond strength	97
Table 4.6	Pull-off bond strength and failure modes of composite NC substrate/GUSMRC specimens	99
Table 4.7	Failure modes of pull-off bond strength	101
Table 4.8	Acceptable bond strength range for Direct Tensile Bond or Pull-Off test	102
Table 4.9	Flexural strength and failure modes of composite NC substrate/GUSMRC specimens	103
Table 4.10	Average ISAT results at different time intervals (ml/m <sup>2</sup> /s)	105
Table 4.11	Average gas permeability coefficient results (×10 <sup>-17</sup> m <sup>2</sup> )	113
Table 4.12	Average water permeability coefficient results (×10 <sup>-11</sup> m/s)	118
Table 4.13	Chloride ion permeability based on total charge passed (ASTM, 1997b)	120
Table 4.14	Test conditions for the chloride penetration test (AASHTO, 2003)	121
Table 4.15	Average total charge passed (coulombs)	121
Table 4.16	Chloride depth penetration (mm) of NC substrate, GUSMRC and composite of overlay samples	125



## LIST OF FIGURES

		<b>Page</b>
Figure 2.1	UHPFRC Pedestrian Bridge, Sherbrooke, Quebec, Canada	11
Figure 2.2	The completed Kampung Ulu Geroh Bridge, Daerah Kinta, Perak	12
Figure 2.3	Kampung Linsum Bridge, Rantau, Negeri Sembilan	12
Figure 2.4	UHPFRC portal frame during the construction	13
Figure 2.5	Completed Wilson Hall taken in year 2012	13
Figure 2.6	UHPFRC Post-tensioning arch of Second Penang Bridge	14
Figure 2.7	Cross section (A) and general view (B) of the rehabilitated bridge pier	15
Figure 2.8	Rehabilitation of the RC 712d bridge at Lavey: projected lane configuration with UHPFRC strengthened areas	16
Figure 2.9	Rehabilitation of the RC 712d bridge at Lavey: detail of the border and pavement	17
Figure 2.10	Natural river sand (A) and quartz sand / mining sand (B)	21
Figure 2.11	Compressive strength development of GUSMRC using 50 % UPOFA replacement	25
Figure 2.12	GUSMRC brass-coated micro steel fibers; (A) 6mm and (B) 13 mm	27
Figure 2.13	Predicted age-strength curves under various water to binder (w/b) ratios	29
Figure 2.14	Basic configurations for composite structural elements combining UHPFRC and conventional structural concrete by overlay technique	30

Figure 2.15	Five types of basic bond strength tests	30
Figure 2.16	Slant shear bond strength testing	32
Figure 2.17	Failures mode of composite section	32
Figure 2.18	Overlay condition of pull off sample	34
Figure 2.19	Pull-off test set-up according to ASTM C1583	34
Figure 2.20	Half-half condition of old concrete or substrate	35
Figure 2.21	Splitting tensile strength test of repair concrete; NC is old concrete/substrate and UHPFC is repair material	35
Figure 2.22	(a) Specimen arrangement; (b) Third point load beam test	36
Figure 2.23	Skeletal view of flexural strength test on the repair concrete sample	37
Figure 2.24	Durability properties of UHPC and HPC versus Normal Concrete; The lowest values shows the greater the samples	39
Figure 2.25	Slant shear specimens with different types of surface treatment	42
Figure 3.1	Flowchart of the research methodology	46
Figure 3.2	Procedures of UPOFA treatment	50
Figure 3.3	Different types NC substrate samples that left for two months to simulate the old concrete	54
Figure 3.4	Ball shapes of GUSMRC mixture	57
Figure 3.5	Steam curing of GUSMRC monolithic and composite of NC substrate/GUSMRC samples	57
Figure 3.6	Grinding surface treatment preparation using angle grinder for creating gridline	59
Figure 3.7	Sand blasting machine (A) and the nozzle (B)	60

Figure 3.8	Different types of samples were arranged before the sand blasting process by facing up the surface treatment area	60
Figure 3.9	3000 kN Automatic Concrete Compression Machine	62
Figure 3.10	Modulus of elasticity test was performed onto the NC substrate sample	63
Figure 3.11	Dimensions of composites half NC substrate (red) and half GUSMRC (green)	67
Figure 3.12	The half slant shear samples of NC substrate after grinding (A) and sand blasting (B) surface treatment	68
Figure 3.13	Grinding process of NC substrate samples for splitting tensile test samples	69
Figure 3.14	Surface treatment differences between sand blasting and grinding of NC substrate on the samples of splitting tensile test	70
Figure 3.15	Cored composite NC substrate/GUSMRC	72
Figure 3.16	Gluing of GUSMRC cored surface with circular steel disc using epoxy glue	72
Figure 3.17	Initial surface absorption test onto GUSMRC sample at 28 days	75
Figure 3.18	Vacuum desiccator apparatus used to evaluate porosity and water absorption	77
Figure 3.19	Gas and water permeability apparatus	80
Figure 3.20	Coring process of RCPT overlay samples from slab	83
Figure 3.21	RCPT cells were connected to the power supply	83
Figure 4.1	Average compressive strength development of NC substrate	87

Figure 4.2	Average compressive strength development of GUSMRC	88
Figure 4.3	Average modulus of elasticity of NC substrate and GUSMRC	89
Figure 4.4	Average splitting tensile strength of NC substrate and GUSMRC	90
Figure 4.5	Average flexural strength of NC substrate and GUSMRC	91
Figure 4.6	Average slant shear strength for the different type of substrate surface at different ages	94
Figure 4.7	Failure mode D: Substratum failure with good interface at the NC substrate (A: GUSMRC, B: NC substrate)	94
Figure 4.8	Average splitting tensile strength for different types of substrate surface roughness at different ages	97
Figure 4.9	Substratum failure with good interface (A: GUSMRC; B: NC substrate)	98
Figure 4.10	Types of failure; (A) Substrate failure, (B) Bond failure, (C) Overlay failure	100
Figure 4.11	Substrate failure at NC substrate (A: GUSMRC; B: NC substrate)	101
Figure 4.12	Failure mode of substrate (at NC substrate) [A: GUSMRC; B: NC substrate]	103
Figure 4.13	Initial surface absorption results of NC substrate and GUSMRC at 10 minutes of time intervals	105
Figure 4.14	Initial surface absorption results of NC substrate and GUSMRC at 30 minutes of time intervals	106
Figure 4.15	Initial surface absorption results of NC substrate and GUSMRC at 1 hour of time intervals	106

Figure 4.16	Initial surface absorption results of NC substrate and GUSMRC at 2 hours of time intervals	107
Figure 4.17	Comparison of the average porosity test results (%) between NC, GUSMRC, grinding composite and sand blasting composite	109
Figure 4.18	Comparison of the average water absorption test results (%) between NC, GUSMRC, grinding composite and sand blasting composite	109
Figure 4.19	Relationship between porosity (%) and compressive strength of NC substrate and GUSMRC (MPa)	112
Figure 4.20	Comparison of the gas permeability test results between NC substrate, GUSMRC and composite GUSMRC/NC substrate with different surface treatment (Half-half)	115
Figure 4.21	Comparison of the gas permeability test results between NC substrate, GUSMRC and composite GUSMRC/NC substrate with different surface treatment (Overlay)substrate/GUSMRC samples	115
Figure 4.22	Relationship between average gas permeability ( $\times 10^{-17} \text{m}^2$ ) and average porosity (%) of NC and GUSMRC	117
Figure 4.23	Comparison of the water permeability test results between NC substrate, GUSMRC and composite GUSMRC/NC substrate (Half-Half)	118
Figure 4.24	Comparison of the water permeability test results between NC substrate, GUSMRC and composite GUSMRC/NC substrate (Overlay)	119

Figure 4.25	Comparison of the rapid chloride permeability test results between NC substrate, GUSMRC and composite GUSMRC/NC substrate with different surface treatment (Half-half)	124
Figure 4.26	Comparison of the rapid chloride permeability test results between NC substrate, GUSMRC and composite GUSMRC/NC substrate with different surface treatment (Overlay)	124

## LIST OF SYMBOLS

$A$	Cross-sectional area of sample
$A$	The water absorption of concrete samples
$A_f$	Area of the fracture surface
$A_L$	Area of slant shear;
$A_T$	Area of bond plane
$D$	Number of scale divisions during the period
$D$	Depth of penetration
$F$	Flow
$F_T$	Tensile (pull off) force at failure
$h$	Applied pressure
$K_w$	Water permeability coefficient
$L$	Sample thickness
$M$	Gain in mass
$P$	Maximum force;
$P$	The porosity of concrete samples
$P_{in}$	Pressure at inlet
$P_{out}$	Outlet pressure equal
$Q$	Volume flow rate
$Q$	Density of water
$S$	Bond strength;
$S_{po}$	Pull off bond strength
$T$	Splitting tensile strength
$T$	Test point time period

T	Time of penetration
V	Total porosity, fraction
V	Applied voltage
$W_d$	Mass after oven dry
$W_{ssd}$	Mass of sample in saturated surface dry condition in air
$W_{ssw}$	Mass of saturated sample in water
$\mu$	Viscosity of the gas



## LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS EN	British European Standards Specifications
Ca(OH <sub>2</sub> ) or CH	Calcium hydroxide
COV	Coefficient of variation
C-S-H	Calcium-Silicate-Hydrate
DSF	Densified silica fume
GPOFA	Ground-POFA
GUSMRC	Green - Universiti Sains Malaysia - Reinforced Concrete
ISAT	Initial surface absorption test
OPC	Ordinary Portland cement
POFA	Palm oil fuel ash
RSM	Response surface methodology
RCPT	Rapid chloride penetration test
SiO <sub>2</sub>	Silicon dioxide
SP	Superplasticizer
TPOFA	Treated-POFA
UHPRFC	Ultra-High performance fiber reinforced concrete
UHPRCC	Ultra-High performance fiber reinforced cementitious composites
UPOFA	Ultra-fine POFA
V	DC voltage
W/B	Water/binder ratio
W/C	Water/cement ratio

**CIRI IKATAN ANTARAMUKA DAN SIFAT-SIFAT KEJURUTERAAN  
SERTA PENGANGKUTAN BENDALIR ANTARA KONKRIT BIASA  
DENGAN KOMPOSIT BERSIMEN BERTETULANG GENTIAN  
BERPRESTASI ULTRA TINGGI HIJAU**

**ABSTRAK**

Pemulihan struktur konkrit pada masa kini digunakan secara meluas dan dipertingkatkan kerana sering terdedah kepada muatan mekanikal dan persekitaran. Diatas kebimbangan itu, kaedah dan cara kerja pemulihan dititik beratkan atas sebab untuk menghasilkan cara yang berkesan bagi menguatkan sifat struktur asal. Penggunaan komposit bersimen bertetulang gentian berprestasi ultra tinggi (UHPFRCC) sebagai bahan baik pulih dimasa kini menunjukkan keputusan yang memberangsangkan dimana ia tinggi dalam sifat mekanikal dan sifat ketahananlasakan. Walaubagaimanapun, produk ini dianggap sebagai tidak ekonomik dan kurang mesra alam disebabkan tinggi kandungan simen bagi mencapai kekuatan mekanikal ultra tinggi. Sebagai penyelesaian, UHPFRCC hijau baru yang mana telah dipatenkan sebagai Universiti Sains Malaysia konkrit hijau bertetulang (GUSMRC) telah dicipta. Konkrit ini diklasifikasikan sebagai bahan bina mesra alam atas sebab ia menggantikan 50 peratus jumlah simen dengan bahan pozolanik, iaitu POFA ultra halus (UPOFA). Berdasarkan objektif kajian ini iaitu untuk menyiasat ikatan anatar muka dan sifat kejuruteraan bendalir antara konkrit lama dan bahan baikpulihan baru, GUSMRC telah digunakan sebagai bahan baikpulihan baru dimana dua jenis kekasaran permukaan digunakan iaitu letupan pasir dan berlurah manakala konkrit normal digunakan sebagai konkrit lama. Kekuatan ciri sifat ikatan antara kedua-dua

kekasaran permukaan dikaji. Tambahan lagi, sifat kejuruteraan bendalir bahan baikpulih dikaji keatas sampel tunggal dan komposit (bahan baikpulih). Bagi sampel komposit, dua jenis keadaan penuangan digunakan iaitu lapisan dan separuh-separuh. Keputusan akhir menunjukkan GUSMRC diterima sebagai bahan baikpulih kerana ia mengurangkan nilai kadar sifat kejuruteraan bendalir. Sifat ikatan juga turut berjaya dimana kekuatan ikatan tertinggi telah dicapai. Tekstur letupan pasir mendahului kesemua sifat ikatan antaramuka sebagai tekstur terkasar dan paling berkesan sebagai baikpulih permukaan berbanding dengan jenis berlurah.

**INTERFACIAL BONDING CHARACTERISTIC AND FLUID TRANSPORT  
PROPERTIES BETWEEN NORMAL CONCRETE SUBSTRATE  
AND GREEN ULTRA-HIGH PERFORMANCE FIBER REINFORCED  
CEMENTITIOUS COMPOSITES**

**ABSTRACT**

Rehabilitation of concrete structure has been widely used and upgraded nowadays as the existing structures exposed to the severe mechanical loading and environment. Based on the concerns stated, the method and procedure of rehabilitation works are taking into consideration in order to produce an effective way to strengthen the properties of existing structure. The application of ultra-high performance fiber reinforced cementitious composites (UHPFRCC) as rehabilitation or repair material nowadays show an excellent feedback as it is high in mechanical and durability properties. However, this product is considered as uneconomical and less environmental-friendly as the requirement of total volume of cement is high in order to achieve the ultra-high mechanical strength. As a solution, a patented green UHPFRCC, which has been known as green Universiti Sains Malaysia Reinforced Concrete (GUSMRC) was developed. This concrete is classified as eco-friendly construction material as it replaced 50 % of cement total volume by pozzolanic material, ultra-fine POFA (UPOFA). As the objectives of this study were to investigate the interfacial bonding and fluid transport properties between the old concrete and newly repair material, GUSMRC was applied as the new repair material with two different types of surface treatment/roughness; sand blasting and grinding, where as the normal concrete substrate acted as an old concrete. Interfacial bond

strength characteristic were evaluated between these two surface textures. In addition, the fluid transport properties of repair material was also assessed on the monolithic samples and the composite samples (repair material). For composite samples, two types of layering condition were applied; overlay and half-half condition. The final results showed that GUSMRC was successfully accepted as a repair material to reduce the fluid transport values of old concrete. The bonding properties were also successfully accepted with an excellent quality of bond strength. The sand blasting surface treatment led all the bonding properties results; the roughest and more effective surface treatment compared to grinding.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background

Concrete is the single most widely used material in the world since the ancient times as it has been applied in the construction of buildings, bridges, highways, retaining walls and so on. However, the quality, safety, maintenance and cost are the main issues that have been highlighted by the structural engineering expertise. For example, world is facing unexpected aggressive environment attacks or natural disasters that may damage or fully destroy the concrete structures. This situation is a tremendous challenge to any government since it jeopardizes human life and country's economic planning.

Since concrete is acknowledged as a non-everlasting construction material, the rehabilitation of it is widely applied on the old and damage heritage structures (Bruhwiler *et al.*, 2008; Voo *et al.*, 2012; Tayeh, 2013; Zmetra, 2015). Raupach (2006) concluded that the increasing number of concrete structures worldwide contributes to the development of new materials and methods of rehabilitation in producing the highest quality and also to cure the old / damage structures. In rehabilitation, the main aspects that have been highlighted before newly material and method are applied on structures are the mechanical properties of repair material, the durability properties of repair material and the properties of bonding agent / surface treatment chosen between the old structures and newly repair material (Bruhwiler *et al.*, 2008; Momayez *et al.*, 2005; Pattnaik, 2015).

Ultra-high performance fiber reinforced concrete (UHPFRC) is designed and widely used nowadays in replacing and upgrading the conventional concrete such as normal reinforced concrete. This type of concrete is chosen because it is extremely high in mechanical strength and durability properties (Graybeal, 2011; Fardis, 2012; Nabaei and Nendaz, 2015), which helps to reduce the maintenance in the future (Habel *et al.*, 2007; Bruhwiler *et al.*, 2008; Nabaei and Nendaz, 2015). On the other hand, the production of this type of concrete requires a high volume of cement in order to achieve the ultra-high strength requirement; up to 700 to 1000 kg/m<sup>3</sup> (Larrard and Serdan, 2002; Spasojevic, 2008; Tayeh, 2013). Therefore, it is claimed as an uneconomical concrete (Larrard and Serdan, 2002; Spasojevic, 2008; Zeyad, 2013; Aldahdooh, 2014). The high demand of cement in developing this material could increase the greenhouse gases emission (Zainurul, 2013). In year 2008, the cement production was recorded almost 2.8 billion tons worldwide (Zeyad, 2013). Based on that concern, many researchers suggest to use pozzolanic reactive properties of agro waste to reduce the cement usage (Kou and Xing, 2012; Zainurul, 2013; Aldahdooh, 2014; Aktham, 2015).

In year 2011, Malaysia produced 18.9 million tons of palm oil, which was the world's second largest producer after Indonesia (MPOB, 2011). As a result, this agro waste material, palm oil fuel ash or POFA, was disposed in the landfills. The unstoppable disposal of this agro waste material contributes to the high environmental pollution due to the emission of CO<sub>2</sub> gas (Tangchirapat *et al.*, 2007; Vande *et al.*, 2008; Zainurul, 2015). Therefore, many researchers investigate the potential of this agro waste to be applied on new sustainable products in the future (Rukzon and Chindaprasirt, 2009; Sata *et al.*, 2007; Tangchirapat *et al.*, 2009; Megat Johari *et al.*, 2012a; Altwair *et al.*, 2012).

## 1.2 Problem statement

When concrete structure is considered damaged or even worse over its entire life cycle, the rehabilitation process such as extracting, processing, construction, operation, demolition and recycling is carried out to keep the sustainability and the heritage of the structure. The application of repair treatment between the interfacial zone of substrate and repair material is considered as the most important mechanism in rehabilitation works, where the newly repair material should strengthen the existing structure in mechanical and fluid transport properties. According to Mather and Warner (2003), half of the rehabilitation works or specifically the repair structures are considered as “fail” where old concrete and repair concrete separated after the composite process. Meanwhile, for the durability performance, statistics show that nearly 75% of the repair material properties were weak in durability (Vaysburn *et al.*, 2000; Naderi, 2008). As a result, different considerations are studied by researchers around the world and the focus are the surface treatment/roughness between the composite samples and the layering technique for rehabilitation works (Russel, 2004; Momayez *et al.*, 2005; Tayeh, 2013).

Ultra-high performance fiber reinforced concrete (UHPFRC) is invented as an alternative to replace and upgrade the existing conventional concrete that has been used such as normal reinforced concrete. With the compressive strength achieved more than 150 MPa at 28 days of age, UHPFRC is considered as the most suitable concrete to be adapted as high load receiver structure such as skyscraper building and the bridges (Damtoft *et al.*, 2008; Scrivener and Kirkpatrick, 2008). In addition, UHPFRC is also high in durability and fluid transport properties; almost impermeable type of concrete that is suitable to be adapted in aggressive environment attack and also for rehabilitation works. UHPFRC applications have