MECHANICAL PROPERTIES AND DETERIORATION SEVERITY OF FIBRE REINFORCED CONCRETE EXPOSED TO ELEVATED TEMPERATURE

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To Umi, Dear, Insyi and families, for the loves and patience

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ABSTRACT

Fibre reinforced concrete (FRC) has been proven in enhancing the strength, ductility and durability of concrete structures. However, when encountered with temperature exposure, there is limited information regarding the impact towards the mechanical properties of FRC. In this study, two different types of fibres namely the steel (SF) and polypropylene (PPF) were combined and mixed in concrete. The deterioration severity is the main concerned due to the variability of temperature exposure on the FRC. Therefore, the main aim of this study was to investigate the fundamental behaviour on the mechanical properties of FRC when exposed to elevated temperature. The temperature variations varied between 27°C (room temperature) and 800°C, with an increment of every 200°C i.e. 27°C, 200°C, 400°C, 600°C and 800°C. Altogether, there were 5 proportions for the combined fibre mix percentage at volume fraction of 1.5%, which are SF-PPF (100-0%), SF-PPF (75-25%), SF-PPF (50-50%), SF-PPF (25-75%) and SF-PPF (0-100%). Several tests were carried out in determining the mechanical properties of FRC which include compression test, flexural test, splitting tensile test, Young's Modulus test, Poisson's ratio test, toughness test and residual flexural tensile strength test. Morphology analysis using Scanning Electron Microscopy (SEM) was also carried out on the FRC after the temperature exposure and mechanical testing. In general, the experimental results show that the strength of FRC decreases as the temperature variation increases. The FRC encountered small declining strength when exposed to temperature below 400°C. However, when it was exposed above 400°C, significant impact on the FRC strength was observed. The study also suggested that the optimum dosage of the fibres percentage proportion is SF-PPF (75-25). With the addition of PPF, the explosive spalling effect was reduced due to the existence of tiny channel created by the PPF when it melted. Meanwhile, the existence of SF provided better post-cracking behaviour on the FRC. Addition of SF and PPF were very effective in minimizing the deterioration and spalling effect when FRC exposed to elevated temperature.

ABSTRAK

Konkrit bertetulang gentian (FRC) telah dibuktikan mampu meningkatkan kekuatan, kemuluran dan ketahanan struktur konkrit. Walaubagaimanapun, apabila terdedah kepada suhu, terdapat maklumat yang terhad mengenai kesan terhadap sifat mekanikal FRC. Dalam kajian ini, dua jenis gentian yang berbeza iaitu besi (SF) dan polipropilena (PPF) digabung dan dicampurkan ke dalam konkrit. Keterukan kemerosotan adalah pemerhatian utama disebabkan kepelbagaian pendedahan suhu ke atas FRC. Oleh itu, matlamat utama kajian ini adalah untuk mengkaji tingkah laku asas sifat-sifat mekanikal FRC apabila terdedah kepada kepelbagaian suhu yang tinggi. Variasi suhu adalah berbeza di antara 27°C (suhu bilik) dan 800°C, dengan kenaikan setiap 200°C, iaitu 27°C, 200°C, 400°C, 600°C dan 800°C. Secara keseluruhan, terdapat 5 peratus perkadaran untuk gabungan gentian tersebut pada kadar isipadu 1.5%, iaitu SF-PPF (100-0%), SF-PPF (75-25%), SF-PPF (50-50%) , SF-PPF (25-75%) dan SF-PPF (0-100%). Beberapa ujian dijalankan dalam menentukan sifat mekanikal FRC yang merangkumi ujian kekuatan mampatan, ujian kekuatan lenturan, ujian tegangan pemisah, ujian Modulus Young, ujian nisbah Poisson, ujian ketahanan dan ujian kekuatan tegangan lenturan. Analisis morfologi menggunakan Mikroskopi Pengimbasan Elektron (SEM) juga dijalankan pada FRC selepas pendedahan suhu dan ujian mekanikal. Secara umumnya, keputusan eksperimen menunjukkan bahawa kekuatan FRC menurun apabila peningkatan suhu meningkat. FRC menghadapi sedikit penurunan dalam kekuatan ketika terdedah kepada suhu di bawah 400°C. Walau bagaimanapun, apabila terdedah di atas 400°C, kesan yang ketara ke atas kekuatan FRC dapat diperhatikan. Kajian ini juga mencadangkan bahawa dos optimum untuk peratus perkadaran gentian adalah SF-PPF (75-25). Dengan penambahan PPF, kesan letupan *spalling* adalah berkurangan disebabkan oleh kewujudan saluran kecil yang dicipta oleh PPF apabila ia cair. Sementara itu, penambahan SF dapat menyediakan perilaku pasca-retak yang lebih baik untuk FRC. Penambahan SF dan PPF sangat berkesan dalam mengurangkan kerosakan dan kesan *spalling* apabila FRC terdedah kepada peningkatan suhu.

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LIST OF ABBREVIAVATIONS

ASTM	-	American Society for Testing and Materials
Avg	-	Average
BS	-	British Standard
BSI	-	British Standard Institution
CMOD	-	Crack-mouth opening displacement
DoE	-	Department of Environment
EN	-	European Standard
FRC	-	Fibre reinforced concrete
OPC	-	Ordinary Portland cement
PPF	-	Polypropylene fibres
RILEM	-	International Union of Laboratories and Experts in Construction Materials, Systems and Structures
SEM	-	Scanning electron microscopy
SF	-	Steel fibres

LIST OF SYMBOLS

b	-	Width of specimen
C	-	Celcius
$D^{f}_{BZ,j}$	-	Toughness value
E	-	Young's modulus value
f_{ct}	-	Tensile strength
f_{cu}	-	Compressive strength of cube
$f_{cu.cy}$	-	Compressive strength of cylinder
F_j	-	Load of CMOD
$f_{R,j}$	-	residual flexural tensile strength
f_t	-	Flexural strength
F_t	-	Flexural load
h_{sp}	-	Distance between the top of the notch and the top of the specimen
l	-	Length of span
v	-	Poisson's ratio
x_{sf}	-	Percentage of SF
x_{ppf}	-	Percentage of PPF
δ	-	Deflection
σ	-	Stress
ε	-	Strain

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CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is a compound made from cement, water and aggregates. As cement combined with water, they react and the hydration process begins. During the hydration process, the compound is then rapidly hardens and at the same time, binds the aggregates. Concrete had been used widely for development throughout the human civilization. From the Egyptian pyramids, to the Great Wall of China until the Roman's Colosseum and Pantheon, concrete materials had been found in these buildings.

As time changes, researches have been done for the evolution of concrete. New technologies are continuously discovered to be applied in concrete. In the 18th century, Portland cement was discovered in Portland, England by Joseph Aspdin and it is now commonly used in construction for concrete structures. By the 19th century, there are many more new technologies being discovered especially on blended cement and admixtures in concrete. Admixtures, either mineral or chemical is function to achieve some characteristics that plain concrete does not have. Some types of admixtures include air entraining agent, water reducer and plasticizer, fly ash and many more.

During the past four decades, there has been rapid development in concrete technology. Fibre reinforcement concrete was first introduced in construction in 1970. History shows that the Roman had applied fibres by putting horse hair in concrete to resist cracks during the hardening process. Nowadays, there are many types of fibres that is normally added in concrete such as discrete steel, polypropylene, glass, natural and many more. The addition of fibres in concrete can improve the tensile strength and brittleness which is a common weakness characteristics for plain concrete. The application of fibres in concrete are also very popular in minimising crack growth such as shrinkage crack during the hardening process.

Most of previous researchers only discuss the effect of adding single type of fibre in plain concrete (Ghugal, 2005; Park et al., 2010). However, in the current research, two different types of fibre i.e. polypropylene (PPF) and discrete steel (SF) are added in plain concrete. Both fibres have difference characteristics and adding them together in plain concrete is known as hybrid fibre reinforced concrete. The study focused on the effect on its mechanical properties when exposing the fibre reinforced concrete (FRC) under elevated temperature and also the impact on its deterioration at failure.

Fire or exposing at high temperature are some of the most severe problems occurred in concrete structures. The spalling effect caused by high temperature will deteriorate concrete structure over time. In recent years, many researchers carried out investigation on concrete exposed directly to elevated temperature (Arioz, 2007; Kong and Sanjayan, 2010; Mindeguia et al., 2010). This is important in terms of its safety measure on the effect of high temperature on the development of concrete strength (Kong and Sanjayan, 2010; Lau and Anson, 2006). Furthermore, previous study normally exposed plain concrete or FRC with single type of fibre under elevated temperature (Chan et al., 2000; Kalifa et al., 2001; Lau and Anson, 2006). Others researchers on hybrid FRC does not relate the mechanical or engineering properties with the increase in temperature (Banthia, 2004; Jameran et al., 2015). This research used hybrid FRC and exposed them under elevated temperature in order to evaluate the strength development. Previous researchers also show that the application of fibres into concrete can minimise spalling effect caused by continuous exposed to high temperature (Chan et al., 2000; Lau and Anson, 2006).

1.2 Problem Statement and Gaps of the Research

Most of the previous researches did not exposed the plain concrete or FRC to elevated temperature (Celik et al., 2015; Jiang et al., 2014). There are several risks that might be occurred when FRC exposed to elevated temperature. The mechanical properties of FRC may be affected when exposed to continuous heat. Explosive spalling which was observed by many researchers which resulted in serious deterioration of the concrete structures also might be occured (Phan and Carino, 2002; Suhaendi and Horiguchi, 2005). High temperature causes dramatic physical and chemical changes, resulting in the deterioration of plain concrete (Heikal, 2000; Xu et al., 2001). Thus, the research will find the answer regarding the effect occurred on the FRC after continuous exposed to elevated temperatures.

Hybrid fibre concrete is a combination of two or more fibres added into the concrete. SF and PPF have different characteristics and therefore have its own weaknesses. For example, PPF has very low melting point between 130°C and 170°C, while in the current study, the temperature was increased from 27°C to 800°C. SF on the other hand is a type of fibre that is not very flexible to fill up the voids and pores in the concrete constituents. Thus, PPF will support SF in filling up the voids, while SF itself increases the tensile strength of concrete. This research will evaluate the interaction between the two fibres in improving their weaknesses in resisting the exposure to elevated temperature.

There are some gaps found from the previous studies. The gaps are as follows:

i. Most researcher studied on the mechanical properties of single fibre. There is less information on the combine fibre. The study will be using single and hybrid FRC. The fibres are SF and PPF.

ii. The mechanical properties are not exposed to elevated temperature. Less information on the effect due to the exposure to elevated temperature.

iii. Most previous researches exposed single FRC to concrete. The study will expose FRC which contain single FRC and FRC that contained both SF and PPF.

1.3 Objectives of the Research

The main aim of the research is to determine the effects of elevated temperature on the properties of FRC in terms of strength and behaviour. Therefore, to achieve this aim, several objectives are identified as follows:

i. To investigate the mechanical properties of FRC exposed to elevated temperature.
ii. To investigate the deterioration severity of FRC after exposing them to elevated temperature.
iii. To determine the optimum dosage of fibres proportion which resulted to the minimum strength reduction of FRC after the exposure to elevated temperature.

1.4 Scope of the Research

The scope of research in order to achieve the research objectives are given as follows:

i. Design concrete grade C40 is used throughout the experimental work.
ii. The water cement ratio is fixed at 0.47 for all FRC batches.
iii. The combined fibres percentage is fixed at 1.5% from the total percentage of the concrete.
iv. The 1.5% combined fibre percentage is divided into five concrete batches with different SF and PPF percentage ratios; (a) 0% SF with 100% PPF, (b) 25% SF with 75% PPF, (c) 50% SF with 50% PPF, (d) 75% SF with 25% PPF, and (e) 100% SF with 0% PPF.
v. Every FRC batch is exposed to elevated temperature from 200°C to 800°C with an increment of every 200°C. The FRC batch remained exposed at room temperature (≈ 27°C) is the control.
vi. There are 5 main FRC batches from the fibres percentage, and each 5 batches have another 5 more FRC batches based on the temperature increment. Thus, the total FRC batches in this research are 25 with one normal plain concrete batch for the control.
vii. The samples used are cubes, cylinders and prisms. In each FRC batch, the total numbers of cubes, prisms and cylinders used are 3 cubes (150mm × 150mm × 150mm), 3 prisms (150mm × 150mm × 550mm) and 6 cylinders (150mm diameter × 300mm height).
viii. In order to determine the mechanical properties of FRC, compression test, splitting tensile test, flexural strength test, toughness test, residual flexural tensile strength test, Young's modulus test and Poisson ratio test are done.
ix. Scanning Electron Microscopy (SEM) is carried out to study the spalling on the FRC samples caused by the exposure to the elevated temperature.

1.5 Research Questions

i. What is the effect of FRC when exposed to elevated temperatures? Is different temperature will shows different effects?
ii. Can addition of two fibres into the concrete improve the weaknesses of plain concrete?
iii. Is the mechanical properties of the FRC reduced when exposed to elevated temperature?
iv. Will melting point of the fibres affect the strength of the FRC?
v. What is the highest temperature that the FRC can withstand?
vi. What is the batch that give optimum strength when FRC exposed to elevated temperatures?

1.6 Significance of the Research

This research will show the effect of FRC after the exposure at elevated temperatures especially on its deterioration effect caused by spalling. At the same time, the maximum exposure temperature that the FRC can withstand is determined.

This research will give findings on the effectiveness of steel-polypropylene FRC which resulted to the minimum reduction of concrete strength after the exposure to elevated temperature. At the same time, the weakness of plain concrete can also be improved by adding fibres in the mixture.

To reduce the risk of deterioration and spalling, previous literature claimed that the use of fibre such as PPF or SF have sufficient fire protection on concrete structures (Kalifa et al., 2001). However, minimal or even negative effects of PPF on the residual performance of the heated concrete may also occurred (Chan et al., 2000). The initial moisture state of the concrete and the rate of heating may be the main parameters determining the effect of PPF (Luo et al., 2000). Therefore, there is a necessity to quantify this claim in terms of fibre dosage, strength of concrete and most important is to know the residual mechanical properties of FRC under exceptional actions such as high temperatures from a fire incident.

1.7 Thesis Outline

i. Chapter 1 provides the introduction and background of the research. The research objectives, research scopes, research questions and the research significance are stated in this chapter.
ii. Chapter 2 discussed is the literature reviews which is critically discuss on the previous work carried out by previous researchers. The type of fibres, temperature effects, mechanical properties of FRC and severity of deterioration are explained in this chapter.
iii. Chapter 3 explains the methodology adopted in this research by experimental work. The fibre percentage calculation and the test procedures based on the current Code of Practice are explained in this chapter.
iv. Chapter 4 analyse and reports the result of all the experimental tests. The results are presented in graphs and tables including brief discussion on some of the relationships.
v. Chapter 5 discusses in detail the test results which also includes relationships between the test parameters. The SEM findings and behaviour of deterioration are also explained in this chapter.
vi. Chapter 6 drew the conclusions of the research. Future work recommendations are also stated in this chapter.

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