NUMERICAL MODELLING ON FIBRE REINFORCED POLYMER STRENGTHENED REINFORCED CONCRETE BEAM AT ELEVATED TEMPERATURE

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DEDICATION

This project report is dedicated to my beloved mother, father and family for showering me with endless loves and support throughout my journey of lifelong learning.

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ABSTRACT

This research presents the study of on insulated Fibre Reinforced Polymer (FRP) strengthened Reinforced Concrete (RC) beam at elevated temperature using finite element program, ABAQUS. The study aims to investigate effects of different concrete cover thickness of insulated FRP strengthened RC beam when exposed to elevated temperature. The modelling consists of insulated and non-insulated FRP strengthened simply supported RC beam with a rectangular size of 200mm x 300mm. The beam modelled with different concrete cover thickness of 15 mm, 25 mm, 30 mm and 35 mm, and strengthened using Carbon Fibre Reinforced Polymer (CFRP) with U-shaped insulation. The beams were exposed to standard fire exposure of ISO 834 for the duration of two hour. The verification was carried out based on the previous experimental test results. It has been found that rebar temperature decreases with the increment of concrete cover and was significant for the non-insulated FRP strengthened beam compared to the insulated FRP strengthen RC beam where the max rebar temperature of 285^{0}C and 622^{0}C for model I_C15 and NI_C15 respectively. The thermal-mechanical response resulted in a maximum deflection of 21 mm and 83 mm for I_C15 and NI_C15 respectively at the temperature of 945^{0}C.The results from this study shows that concrete cover contributes to the fire resistance of structure for FRP strengthened beam at elevated temperature and affects on the overall performance of structure especially for non-insulated beam.

ABSTRAK

Kajian ini membentangkan kajian mengenai rasuk konkrit bertetulang (RC) yang diperkukuhkan dengan Polymer Bertetulang Gentian (FRP) bersama penebat dan didedahkan kepada suhu tinggi dengan menggunakan program perisian ABAQUS. Kajian ini bertujuan untuk mengkaji kesan ketebalan penutup konkrit berlainan saiz bagi rasuk RC yang diperkukuhkan dengan FRP bersama penebat apabila terdedah kepada suhu tinggi. Model rasuk yang digunakan adalah terdiri rasuk yang disokong mudah dengan dua keadaan iaitu ditebat dan tanpa tebatan dengan keratan rentas segi empat tepat bersaiz 200mm x 300mm. Rasuk ini dimodelkan dengan penutup konkrit yang berlainan saiz iaitu 15 mm, 25 mm, 30 mm dan 35 mm. FRP yang digunakan adalah Polymer Bertetulang Gentian Karbon (CFRP) dan ditebatkan dengan menggunakan penebat berbentuk U. Rasuk didedahkan kepada pendedahan kebakaran piawai ISO 834 selama tempoh dua jam. Pengesahan data adalah berdasarkan hasil eksperimen makmal terdahulu. adalah didapati bahawa suhu rebar berkurangan dengan kenaikan saiz penutupan konkrit dan keputusan adalah ketara bagi rasuk yang tidak ditebat berbanding dengan rasuk yang ditebat di mana suhu rebar maksimum masing-masing adalah 285^{0}C dan 622^{0}C bagi model I_C15 dan NI_C15. Analisis tindakbalas haba-mekanikal menunjukkan pesongan maksimum masing-masing adalah 21 mm dan 83 mm untuk I_C15 dan NI_C15 pada suhu 945^{0}C. Hasil daripada kajian ini menunjukkan bahawa penutup konkrit menyumbang kepada ketahanan api struktur untuk rasuk yang diperkukuhkan dengan FRP pada suhu tinggi dan ia juga memberi kesan ke atas prestasi keseluruhan struktur terutamanya bagi rasuk yang tidak bertebat.

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LIST OF ABBREVIATIONS

AFRP	-	Aramid Fibre Reinforced Polymer
ASTM	-	American Society for Testing and Materials
CFRP	-	Carbon Fibre Reinforced Polymer
CB	-	Control Beam
EC	-	Eurocode
FEA	-	Finite Element Analysis
FRP	-	Fibre Reinforced Polymer
ISO	-	International Standard Organization
RC	-	Reinforced Concrete
VP	-	Vermiculite/Perlite

LIST OF SYMBOLS

δ	-	Deflection
B	-	Breadth
H	-	Height
L	-	Length
ρ	-	Density
X_{500}	-	Isotherm 500
T_g	-	Glass Transition Temperature
ε	-	Strain
λ	-	Thermal Conductivity
a	-	Thermal diffusivity
c	-	Specific Heat
α	-	Coefficient of Thermal Expansion
θ	-	Temperature

CHAPTER 1

INTRODUCTION

1.1 Problem Background

There are various methods available for repair and strengthening of damage RC structure. Retrofitting is one of the common method widely used for such purpose. This can extend the service life of the structure and also increase its performance compare to current deteriorate or damage state. One of retrofitting method is by using bonded steel plate to increase the strength of damaged RC structure. However, there are disadvantages in using steel plate as they are susceptible to corrosion and its self-weight becomes additional load to the existing structure. Not only that, special tools and equipment are also required for the installation and such high cost is incurred for such method. Currently, there are high interest in the usage of Fibre Reinforced Polymer (FRP) as an alternative to steel plate as it provides more advantages.

FRP is a composite material comprise of high strength fibres and matrix (resin) which binds the fibres. It have extended use in civil engineering due to having high strength and ease of handling and installation. Apart from that, FRP is also light weight and non-corrosive as compared to steel. Among other advantages are that it is use to increase the structure load bearing capacity and improve structure durability against environmental impact. Based on intended use, several type of FRP are currently available for such purpose including Carbon Fibre Reinforced Polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP) and Aramid Fibre Reinforced Polymer (AFRP). CFRP widely used in increasing structural strength while GFRP and AFRP used in increasing structure ductility (Len C. Hollaway, J.G. Teng, 2008).

The application of FRP can be found in RC component such as beam, column, slab and wall. The usage of FRP in RC structure strengthening can be used either internally or externally respectively as reinforcement bar and as plate and laminated sheet. FRP can be found used for structure in outdoor and indoor applications where several factors have to be considered in both application. In outdoor usage, environmental impact can be seen more significant, while fire resistance effect can be seen more crucial for indoor FRP application such in building structure.

For the past years, there were several cases of fire incident have been reported worldwide. Case involving fire incident in World Trade Centre (WTC), New York in 11th September 2001 is widely known catastrophic incident which had caused structural collapse resulting in high number of casualties. In addition, recent fire incident involving high rise office building in Dhaka, Bangladesh in 29th March 2019 have occurred which had caused at least six casualties. Several cases have also been reported in Malaysia which include fire incident involving government buildings such as fire incident Sultanah Aminah Hospital, Johor in 25th October 2016 and fire incident which happened at Employment Provident Fund (EPF) building at Jalan Gasing, Selangor in 13th February 2018. With that, the importance of structural resistance at elevated temperature should be emphasized in FRP application.

The fire resistance of FRP strengthening RC beam depends on the behaviour of concrete, steel, FRP and interface between the elements. Information on concrete and steel have been widely studied and specified in Eurocode 1992-1-2 (2004). On the contrary, there is little information regarding FRP behaviour when exposed to fire. FRP have a low glass transition temperature which results in degradation of stiffness and strength when exposed to elevated temperature higher than its transition temperature ductility (Len C. Hollaway, J.G. Teng, 2008). Therefore, usage of insulation is introduce in order to address the fire resistance issue of FRP application.

1.2 Problem Statement

For externally FRP strengthened RC beam, FRP materials are usually bonded to the concrete with adhesive resins such as epoxy. FRP material is susceptible to elevated temperature when it is directly exposed to fire. In order to overcome the situation, common practice provide insulation for the FRP in various form including using sprayed-on applications or boards of insulating materials. 1.5-50mm of fire proof coating and 40mm thickness calcium silicate board are example of insulation used for FRP strengthen RC beam (Dong *et al.* 2016).

Experimental testing have been conducted in the past years to study the behaviour of insulated FRP strengthened beam but some met with limitation mainly on the understanding element structural behaviour at local level (Dai, Gao and Teng, 2014). Numerical techniques have now become a very helpful part of most structural research. This is because this type of technique serves as an alternative to overcome the limitation of experimental testing and it is efficient yet economical tool for analysing structure's behaviour. Past research in numerical modelling of insulated FRP strengthened RC beam focus on type and thickness of the insulation. At elevated temperature, interface bonding of FRP to concrete is essential as may cause the failure of the structure and introduced by Dai, Gao and Teng, (2014) in the FE modelling. Dong *et al.* (2016) founds that the beam specimen continues to withstand the load even though the glass transition temperature, T_g of 73^0C was reached within 60mins. It shows that the insulation play a major role in delaying the failure of adhesive in early stage where which can results in performance of RC beam.

However, previous study in numerical modelling provides limited information the effects of the concrete cover for insulated FRP strengthened RC beam. Concrete cover plays important role in fire resistance as it provide protection to the reinforcement in the structure which influence on the structure capacity. The requirement of concrete cover is stipulated in Eurocode 1992-1-2 (2004) based on the fire duration. Therefore, this study will emphasis on the effects of concrete cover thickness in the behaviour of insulated FRP strengthened RC Beam.

1.3 Objective of the Study

The principal aim of this study to simulate and study the behaviour of insulated FRP strengthened RC beam at elevated temperature and compare the results with theoretical and testing.

1.3.1 Research Objectives

The specific objectives of the project are:

(a) To simulate insulated FRP strengthened RC beam modelling based on testing using finite element analysis (FEA).

(b) To verify insulated FRP strengthened RC beam modelling based analytical solution.

(c) To study the effects of different concrete cover thickness of insulated FRP strengthened RC beam at elevated temperature by using finite element analysis (FEA).

1.4 Scope

The study involves a finite element modelling and analysis of insulated FRP strengthened RC Beam at elevated temperature. The scopes of study for this project are as bellows:

(a) Critical review on behaviour of insulated FRP strengthened RC beam at elevated temperature

(b) Computational study using ABAQUS finite element modelling software on effects of different concrete cover of insulated FRP strengthened RC beam at elevated temperature.

(c) RC beam strengthened using CFRP laminate and insulated with U-shaped type of insulation.

(d) Simply supported rectangular RC beam with two-point concentrated loads.

(e) Analytical study on reinforcement bar temperature and mid span deflection.

(f) RC beam and FRP are fully bonded and in composite action.

1.5 Significant of Study

The finding from the study provide contribution to the understanding of the structural behaviour of insulated FRP strengthened RC beam at elevated temperature. The numerical model provides the effects of thermal and mechanical response of RC beam at elevated temperature in term of different concrete cover thickness. This provide additional information in which can be used for future analysis and design of insulated FRP strengthened RC beam.

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