PERFORMANCE OF HYBRID STEEL FIBRE REINFORCED CONCRETE SUBJECTED TO AIR BLAST LOADING

MOHAMMED ALIAS YUSOF

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ABSTRACT

In Malaysia, most of the buildings are constructed using reinforced concrete. The main problem with the reinforced concrete is that it has a low tensile strength and it's a brittle material. When subjected to blast loading or attack by the terrorist it will be damaged badly and also cause fragmentation. The fragmentation can lead to substantial injuries to personnel, causing loss of life and also damage to the surrounding area. Therefore, there is need to enhance the capability of the concrete to resist blast loading from any kind of attack and also explosion. Previous research on the behavior of single fibres reinforced concrete under blast loading found that steel fibre has the potential to be used in the blast resistance concrete material. However studies show that the use of a single fibre in the mix improved the mechanical properties of the concrete to a limited level. Many researchers have started using concrete mix by having a combination of two or more fibres which are also known as hybrid fibres that are proportionally mixed. Concrete mixtures of hybrid fibres have the better energy absorption capability than the single fibre. Until now there has been no study carried out by researchers to investigate the potential of using hybrid steel fibre in the concrete mix for the application in blast protective structure and also explosive storage buildings. Therefore this research examines the properties of the hybrid steel fibre concrete focusing on the blast resistance capability of the concrete materials. The methodology is divided into two parts. In the first part the experimental work was conducted to investigate the performance of hybrid steel fibre concrete subjected to air blast loading.

A total of twenty one mixes, including one control mix without fibre, with different aspect ratios and steel fibre volume were prepared and tested to obtain the mechanical properties of hybrid steel fibre concrete. In addition to this, ten concrete panels with different aspect ratios were tested under one kilogram of plastic explosive to investigate the performance of the concrete materials under air blast loading. In the second part of the research, simulation work was carried out using AUTODYN simulation program to simulate the blast loading effect on hybrid concrete panel and validate the simulation using experimental data. The results of mechanical properties for hybrid steel fibre with the combination of 70 % long and 30 % short hooked end steel fibre at 1.5 % volume shows that the flexural strength of the concrete was increased up to 114 % and the split tensile strength test was increased up to 67 % . On the other hand the compressive strength of the hybrid concrete was increased up to 24 % as compared with all other mixes. The air blast test result shows that hybrid steel fibre with the combination of 70 % long and 30 % short steel fibre at volume fraction of 1.5 % have the optimum performance to blast loading as compared with the control mix. In the simulation works, hybrid concrete panel with the combination of 70 % long and 30 % short hooked end steel fibre at 1.5 % volume were simulated and the results were compared with experimental results. The simulation results using AUTODYN simulation program are found to be tally with experimental results. Based on the experimental and simulation results a blast resistance concrete material using hybrid fibres was developed. It is recommended that this material to be tested further under internal blast loading.

ABSTRAK

Di Malaysia, sebahagian besar bangunan dibina menggunakan konkrit tetulang. Salah satu kelemahan utama konkrit tetulang ini ialah ia mempunyai kekuatan tegangan yang rendah dan merupakan bahan binaan yang rapuh. Sehubungan dengan itu, konkrit mudah pecah dan membentuk serpihan bila ianya terdedah kepada impak letupan. Oleh yang demikian, adalah amat penting untuk mempertingkatkan kekuatan struktur bangunan agar dapat menahan kesan daripada impak letupan pada masa akan datang. Kajian sebelum ini mendapati kekuatan tegangan konkrit dapat ditambah dengan mencampurkan serat keluli di dalam konkrit. Selain itu, telah terbukti bahawa penggunaan serat keluli dapat meningkatkan potensi menahan impak letupan. Namun begitu, kajian mendapati bahawa manfaat penggunaan hanya sejenis serat keluli di dalam konkrit adalah terbatas. Kebanyakan penyelidik telahpun mengkaji penggunaan lebih daripada satu jenis serat di dalam campuran konkrit yang juga dikenali sebagai serat *hybrid* yang didapati lebih banyak memberi manfaat kepada sifat kekuatan konkrit berbanding dengan serat yang terdiri daripada satu jenis sahaja. Walau bagaimanapun, masih belum ada kajian yang dijalankan berkaitan dengan pengunaan serat keluli jenis *hybrid* di dalam campuran konkrit bagi tujuan menahan kesan impak letupan sehinggalah kajian ini dijalankan. Jelasnya, kajian ini tertumpu kepada mengkaji keupayaan pengunaan serat keluli *hybrid* di dalam campuran konkrit tetulang bagi tujuan untuk menahan kesan impak letupan. Kaedah kajian ini terbahagi kepada dua bahagian utama. Di bahagian pertama, kajian makmal dan juga ujian letupan dijalankan untuk mengenalpasti kesan campuran keluli hybrid disebabkan oleh impak letupan.

Dalam kajian makmal sebanyak dua puluh satu jenis campuran konkrit yang mengandungi campuran yang berbeza di sediakan dan kekuatan campuran tersebut telah diuji di makmal. Selain daripada itu, sepuluh buah panel konkrit dengan campuran *hybrid* serat yang berbeza disediakan dan diuji dengan mengunakan bahan letupan sebanyak satu kilogram. Manakala bahagian kedua pula melibatkan penggunaan perisian simulasi impak letupan iaitu "AUTODYN" untuk mengenalpasti kesan impak letupan di atas panel konkrit *hybrid* dan mengesahkan hasil simulasi dengan mengunakan keputusan ujian letupan. Hasil daripada keputusan ujian makmal mendapati bahawa campuran serat keluli *hybrid* yang terdiri daripada 70 % serat keluli panjang dan juga 30 % serat keluli pendek pada nisbah isipadu serat keluli sebanyak 1.5 % meningkatkan kekuatan lenturan konkrit sebanyak 114 % dan kekuatan tegangan konkrit sebanyak 67 %. Manakala kekuatan mampatan konkrit didapati bertambah sebanyak 24 % berbanding dengan sampel konkrit kawalan. Keputusan ujian letupan yang dijalankan mendapati bahawa campuran serat keluli *hybrid* yang terdiri daripada 70 % serat keluli panjang dan juga 30 % serat keluli pendek pada isipadu serat keluli sebanyak 1.5 % memberikan kesan yang paling optima daripada impak letupan di atas konkrit tetulang berbanding dengan campuran konkrit tetulang biasa. Hasil dari ujian simulasi menggunakan perisian simulasi "AUTODYN" mendapati bahawa terdapat persamaan yang ketara di antara keputusan ujian simulasi dengan keputusan ujian letupan. Oleh yang demikian, berpandukan kepada keputusan ujian letupan dan juga simulasi suatu konkrit yang mengunakan serat *hybrid* bagi tujuan menahan impak letupan telah dihasilkan. Walaubagaimanapun disyorkan bahawa bahan ini perlu ujian lanjut untuk mengenalpasti kesan terhadap impak letupan .

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Col. Prof. Dr. Ir. Norazman bin Mohammad Nor
Dean of Post Graduate Studies
Universiti Pertahanan Nasional Malaysia
(Chairman)

Assoc. Prof. Dr. Risby Shohaimy
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Member)

Lt. Col. Assoc. Prof. Ariffin Ismail
Faculty of Defence Studies
Universiti Pertahanan Nasional Malaysia
(Member)

Prof. Dr. Fauzi Mohd Zain
Faculty of Engineering and Built Enviroment
Universiti Kebangsaan Malaysia

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Author's full name	:	Mohammed Alias Bin Yusof
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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ALE	Arbitrary Lagrangian Eulerian
ASTM	American Standard for Testing and Materials
BS	British Standard
DOE	Department of Enviroment
FRC	Fibre Reinforced Concrete
GFRP	Glass Fibre Polymer Reinforced Composite
HSC	High Strength Concrete
HSFRC	Hybrid Steel Fibre Reinforced Concrete
HPRC	Hybrid Polypropylene Reinforced Concrete
LF	Long Fibre
LVDT	Linear Variable Displacement Transducer
NFPA	National Fire Protection Association
NI	National Instrument
NSC	Normal Strength Concrete
PE4	Plastic Explosive 4
PP	Polypropylene
PVA	Polyvinyl Alcohol
RHT	Riedel – Hiermair- Thoma
S	Steel Fibre
SF	Short Fibre
SFRC	Steel Fibre Reinforced Concrete
STRIDE	Science and Technology Research Institute for Defence
TM5	Technical Manual No.5
TNT	Trinitrotoluene

UPHC	Ultra Performance Steel Fibre Reinforced Concrete

CHAPTER 1

INTRODUCTION

1.1 Introduction

Since the attack on the World Trade Centre in New York on September 11, 2001 and the Pentagon in Washington, United States of America, the construction industry around the world has been challenged to design and build civil and military structures which are capable to withstand explosions due to terrorist attacks. Attacks directed towards vulnerable structures have caused considerable damage and loss of life. The immediate effects of such attacks are blast overpressures propagating through the atmosphere, fragments generated and scattered by the blast wave and ground shock loads resulting from the energy imparted to the ground.

Concrete is a widely used construction material for building infrastructures and also military facilities. Concrete has a low tensile strength and brittle which leads to spalling and scabbing when it is subjected blast attack by terrorist (Chuan, 2004). As a result there is a requirement to increase the blast resistance capability of the concrete used for building structures especially for government, military and corporate buildings, strategic bridges, dams and also chemical or petroleum plants

that are all at risk from terrorist attacks. Studies show that by introducing steel fibres into the concrete increase the tensile, shear and flexural properties of the concrete (Bayazi, 1989). Benefits of using steel fibres were also reported by (Nagarkar, et *al.,*1989) which include impact resistance, flexural and tensile strengths, ductility, and fracture toughness. Therefore the use of steel fibres within the concrete can be an economical method to improve blast resistance of concrete, with distinct advantages over other fibres such as carbon and PVA fibre, as these materials are cheap and available locally.

By utilizing fibre reinforced concrete, it is expected that the capacity of the concrete elements to resist the blast can be increased, while the effect of fragmentation can be reduced by the bridging action of the steel fibre. The reduction in secondary fragmentation is a critical property of the material since this fragmentation can lead to substantial damage to both personnel and equipment, and it is difficult to prevent with current normal strength concrete materials.

1.2 Problem Statement

In Malaysia, the attack on three churches in the Klang Valley using explosive were reported in the local newspaper (Mazwin, 2010). In the first incident, the three storey Metro Church in Desa Melawati was attacked using homemade petrol bomb, this was followed by another two similar attacks on the Church in Jalan Templer and also Section 17, Petaling Jaya, Selangor. This arson attack is shown in Figure 1.1 and Figure 1.2.

Arson slammed

Govt to come down hard on trouble-makers

Figure 1.1: Newspaper report on arson attack at three churches in Klang Valley (Mazwin, 2010)

Figure 1.2: Damaged due to the attack on the building (Mazwin, 2010).