


PROPERTIES AND PERFORMANCE OF HIGH STRENGTH FIBRE  
REINFORCED CONCRETE BY USING STEEL AND POLYPROPYLENE  
FIBRES

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## DEDICATION

Alhamdulillah, praise to Allah for giving me the strength and opportunity to complete this study.

I dedicate this Ph.D thesis to my beloved husband, Syed Mohd Fareed Bin Syed Zin and my gorgeous sons and daughter, Syed Hafiz Arsyad, Syed Danish Ammar and Sharifah Alya Maisarah. Thank you for the love, sacrifice and always being there for me through happiness and sadness.

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## ABSTRACT

Many reinforced concrete structures suffer severe degradation due to the effect from freezing and thawing, shrinkage and expansion, aggressive environment, earthquake and drastic increase of live loads. The most common sign of deterioration in concrete is cracking. Plain or unreinforced concrete is characterised by its low tensile strength, low strain capacities and brittle in nature. The tensile strength of plain concrete is considered lost once cracking occurred. Discrete short fibre reinforcement is being considered to be used for structural applications since it can reduce cracking phenomena, improve ductility and failure mode, and to some extent improve the durability of reinforced concrete. Fibre added in concrete has also been found to be effective in controlling cracks due to plastic and drying shrinkage. Shrinkage in concrete is greatly influenced by the surrounding environment and types of fibre included. Therefore, the aim of this research is to investigate the engineering and shrinkage properties of reinforced concrete containing a combination of steel and polypropylene fibres under different exposure conditions. In this study, the physical and engineering properties of fibre reinforced concrete (FRC) are investigated by using steel fibre (SF) type hooked end and polypropylene fibre (PPF) type virgin fibrillated. The objectives of the study are to assess the effect of hybrid fibres on its engineering properties, shrinkage properties under the influence of tropical climate and finally the structural performance of the FRC beams. Laboratory testing program is first conducted to determine the physical properties of the fibres. Then, the fibre reinforced concrete were tested to determine the engineering properties include compressive strength, tensile splitting strength, flexural strength, toughness, Modulus of Elasticity and shrinkage. The desired optimum mix is evaluated by the volume fractions ( $V_f$ ) of 0.5%, 1.0% and 1.5%., and the combination of SF 100% + PPF 0%, SF 75% + PPF 25%, SF 50% + PPF 50%, SF 25% + PPF 75%, SF 0% + PPF 100%. The engineering properties and structural performance are then determined based on the optimum percentage using high strength concrete grade C60 to simulate concrete strength of sample manufactured at the factory. Test on the efficiency of fibres in limiting the shrinkage deformation for indoor and outdoor exposure are performed. The results indicated that the best combination of fibres is for concrete containing SF 75% + PPF 25%. The combination of SF and PPF fibres in concrete is able to enhance the engineering properties and controlling the growth of cracks in concrete. The results also indicated that concrete with both SF and PPF produced higher tensile and flexural strengths as compared with the control by 77% and 170%, respectively. The variation in relative humidity and temperature was found to have small effect on the drying shrinkage of the FRC. Results for the FRC beam test show that the percentage proportion of SF 75% + PPF 25% give the best flexural performance compared to other beams. Thus, the use of hybrid fibres, SF 75% + PPF 25%, was found to enhance the performance of either plain concrete or reinforced concrete.

## ABSTRAK

Banyak struktur konkrit bertetulang mengalami kemerosotan teruk akibat kesan pembekuan dan pencairan, pengecutan dan pengembangan, persekitaran yang agresif, gempa bumi dan peningkatan beban hidup yang drastik. Tanda kemerosotan yang paling biasa dalam konkrit ialah keretakan. Konkrit atau konkrit tidak bertetulang mempunyai sifat kekuatan tegangan yang rendah, kapasiti keterikan yang rendah dan rapuh. Kekuatan tegangan konkrit hilang apabila keretakan berlaku. Penggunaan gentian pendek kini diambilkira untuk aplikasi struktur kerana ia dapat mengurangkan fenomena keretakan, meningkatkan tahap kemuluran dan mod kegagalan, dan meningkatkan ketahanan lasakan konkrit bertetulang. Gentian yang ditambah dalam konkrit juga didapati berkesan dalam mengawal retakan akibat pengecutan plastik dan pengecutan pengeringan. Pengecutan konkrit banyak dipengaruhi oleh persekitaran dan jenis gentian yang digunakan. Oleh itu, kajian ini bertujuan untuk menentukan sifat kejuruteraan dan pengecutan konkrit bertetulang gentian yang mengandungi gabungan gentian keluli dan polipropilena di bawah dedahan yang berbeza. Dalam kajian ini, ciri-ciri fizikal dan kejuruteraan konkrit bertetulang gentian (FRC) telah dikaji dengan menggunakan gentian keluli (SF) hujung bercangkuk dan polipropilena (PPF). Objektif kajian adalah untuk menilai kesan gentian hybrid terhadap ciri-ciri kejuruteraan, pengecutan di bawah pengaruh iklim tropika dan prestasi struktur rasuk konkrit bertetulang gentian. Ujian makmal telah dijalankan terlebih dahulu untuk menentukan sifat fizikal gentian tersebut. Seterusnya ujikaji dijalankan untuk menilai sifat kejuruteraan konkrit bertetulang gentian yang merangkumi kekuatan mampatan konkrit, kekuatan pemisahan tegangan, kekuatan lenturan, kekuatan konkrit, modulus keanjalan dan pengecutan. Campuran optimum yang diinginkan telah dinilai menggunakan pecahan isipadu ( $V_f$ ) 0.5%, 1.0% dan 1.5%, dan kombinasi SF 100% + PPF 0%, SF 75% + PPF 25%, SF 50% + PPF 50%, SF 25% + PPF 75%, SF 0% + PPF 100%. Ciri-ciri kejuruteraan dan prestasi struktur telah ditentukan berdasarkan peratusan optimum menggunakan konkrit berkekuatan tinggi C60 bagi mengambilkira kekuatan sampel konkrit yang dibuat di kilang. Ujian untuk membandingkan kecekapan gentian dalam menghadkan ubah bentuk pengecutan dalaman dan luaran telah dilakukan. Hasil kajian menunjukkan bahawa gabungan terbaik gentian adalah konkrit yang mengandungi SF 75% + gentian PPF 25%. Gabungan gentian SF dan gentian PPF dalam konkrit dapat meningkatkan ciri-ciri kejuruteraan konkrit dan mengawal keretakan dalam konkrit. Hasil kajian juga menunjukkan bahawa konkrit dengan gentian SF dan PPF menghasilkan kekuatan tegangan dan lenturan yang lebih tinggi berbanding kawalan masing-masing sebanyak 77% dan 170%. Perubahan dalam kelembapan relatif dan suhu didapati mempunyai kesan yang kecil terhadap tahap pengecutan konkrit bertetulang gentian. Keputusan untuk rasuk konkrit bertetulang gentian menunjukkan peratusan SF 75% + PPF 25% menghasilkan prestasi lenturan yang terbaik berbanding dengan yang lain. Oleh itu, penggunaan gentian hibrid SF 75% + PPF 25% didapati meningkatkan prestasi konkrit, samada konkrit biasa atau konkrit bertetulang.

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## LIST OF ABBREVIATIONS

ACI	American Concrete Institute
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
$\nu$	Poisson's ratio
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
Avg	Average
BS	British Standard
BSI	British Standard Institution

## LIST OF SYMBOLS

$b$	-	Width of specimen
$C$	-	Celcius
$D_{BZ,j}^f$	-	Toughness value
$E$	-	Young's modulus value
$f_{ct}$	-	Tensile strength
$f_{cu}$	-	Compressive strength of cube
$f_{cy}$	-	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
$V_f$	-	Volume fraction
$l$	-	Length of span
$\nu$	-	Poisson's ratio
$\delta$	-	Deflection
$\sigma$	-	Stress
$\varepsilon$	-	Strain

# CHAPTER 1

## INTRODUCTION

### 1.1 Background of the Problem

One of the main challenges for civil engineers is to deliver sustainable, environmentally friendly and financially feasible structures. Valuable findings from on-going research can help in determining new materials to fulfil this purpose. In relation to that, Fibre Reinforced Concrete (FRC) can be considered as one of the promising materials for structural applications in the current construction industry (Bakis et al., 2002). The utilization of fibres in construction can be traced back to many centuries ago. In ancient Egypt, straws or horsehair were added into mud bricks, whereas straw mats were used as reinforcements in early Chinese and Japanese housing constructions (Victor, 2002). Since 1960's, numerous efforts have been made by scientists and engineers to develop a reliable concrete composite which has progressively led to the development of FRC (Funke et al., 2014). The FRC has undergone through accelerated pace of development during the past four decades. In recent years, FRC has been exploited extensively for both structural and non-structural engineering applications in view of its superior properties such as tensile strength and durability as compared with conventional concrete.

Plain or unreinforced concrete can be characterised as having low tensile strength, low strain capacities and very brittle (low ductility). Plain concrete normally has a random distribution of fine and coarse aggregate particles throughout the cement matrix (Banthia and Nandakumar, 2003; Bazant, 2001; Chanh, 2004; Chen, 1995). It normally goes through a quasi-brittle failure whereby the nearly complete loss of loading capacity once failure was initiated. As a result, these characteristics limit the application of plain concrete in construction industry. These limitations can be overcome by the inclusion of small amount of randomly distributed short fibres. Short



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