# THE MECHANICAL PROPERTIES AND STRUCTURAL PERFORMANCE OF HYBRID FIBRE REINFORCED CONCRETE COMPOSITE

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*…Dedicated to…*

*My beloved Father and Mother*

*Othman Bin Che Mat and Che Wan Asma' Binti Khalid*

*My Brothers and Sisters*

*Thank You from the Bottom of My Heart for Being My Inspirations..*

*My Supervisor*

*Dr. Izni Syahrizal Ibrahim*

*For Being Patient and Give Me A Lot of Knowledge*

*And Lastly To All My Dear Friends*

*Thank You for Supporting Me.*

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All praise is to Allah the all Mighty and peace is upon the holy Prophet Muhammad S.A.W.

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# ABSTRACT

Fibres in concrete provide a mean of preventing crack growth. Short discontinuous fibres have the advantage of being uniformly mixed and dispersed throughout the concrete. In this research, the mechanical properties of hybrid fibre reinforced concrete composite (HyFRCC) were investigated by combining polypropylene fibre (PP) with steel fibre (ST). PP fibre is good in preventing micro cracks while steel fibre is reliable in preventing macro cracks in concrete. Specimens incorporated with ST and PP fibres were in the mix proportion of 100-0%, 75-25%, 50-50%, 25-75%, and 0-100% at volume fraction of 0.5%, 1.0%, and 1.5%. Compression test, flexural test, splitting tensile test, flexural toughness, and Young's Modulus were carried out to determine the mechanical properties of HyFRCC. By combining these two fibres in concrete, the crack growth reduced where PP fibre was found to improve the tensile strain capacity, while ST fibre contributed to the improvement on the ultimate tensile strength. HyFRCC specimens also delayed the failure phenomena due to the different tensile strength of PP and ST fibres compared with the sudden failure experienced by plain concrete. The experimental test results found that HyFRCC with the combined mix proportion of 75% ST fibre + 25% PP fibre at volume fraction of 1.5% can be adjudged as the optimum percentage. This optimum percentage was then applied in reinforced concrete beams to study the structural performance in flexural of shear. In conclusion, HyFRCC beam is tougher and stronger compared with the control beam based on the load-deflection relationship. Crack pattern of HyFRCC beam shows that the crack width and crack spacing reduces compared with the control beam. The effect of combining ST and PP fibres in concrete enhances the tensile strength, the concrete strain hardening and flexural toughness.

# ABSTRAK

Gentian di dalam konkrit menyediakan pencegahan pertumbuhan retak. Gentian pendek tidak berterusan mempunyai kelebihan keseragaman bercampur dan tersebar di seluruh konkrit. Dalam kajian ini, sifat mekanikal gentian hibrid komposit konkrit bertetulang (HyFRCC) dikaji dengan menggabungkan gentian polypropylene (PP) dan keluli (ST). Gentian PP bagus dalam mencegah keretakan mikro manakala gentian ST dipercayai dalam mencegah keretakan makro di dalam konkrit. Spesimen digabungkan dengan gentian ST dan PP pada kadar campuran daripada 100-0%, 75-25%, 50-50%, 25-75%, dan 0-100% pada pecahan isipadu sebanyak 0.5%, 1.0%, dan 1.5 %. Ujian mampatan, ujian lenturan, ujian tegangan, kekuatan lenturan, dan Modulus Young dijalankan untuk menentukan sifat-sifat mekanik HyFRCC. Dengan menggabungkan kedua-dua gentian dalam konkrit, pertumbuhan retak berkurangan di mana gentian PP didapati meningkatkan keupayaan terikan tegangan, manakala gentian ST menyumbang kepada peningkatan kekuatan tegangan muktamad. Spesimen HyFRCC juga melambatkan fenomena kegagalan disebabkan kekuatan tegangan yang berbeza gentian PP dan ST berbanding dengan kegagalan secara tiba-tiba yang dialami oleh konkrit biasa. Keputusan ujian eksperimen mendapati HyFRCC dengan nisbah campuran gabungan 75% ST + 25% PP pada pecahan isipadu sebanyak 1.5% boleh diputuskan sebagai peratusan optimum. Peratusan optimum ini kemudiannya diaplikasikan pada rasuk konkrit bertetulang untuk mengkaji prestasi struktur dalam lenturan dan ricih. Kesimpulannya, rasuk HyFRCC adalah lebih tahan lasak dan lebih kuat berbanding dengan rasuk kawalan berdasarkan hubungan beban-lenturan. Corak retak rasuk HyFRCC menunjukkan lebar dan jarak retak berkurangan berbanding rasuk kawalan. Kesan daripada penggabungan gentian ST dan PP di dalam konkrit meningkatkan kekuatan tegangan, pengerasan terikan konkrit dan kekuatan lenturan.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ACI | - | American Concrete Institute |
| ASTM | - | American Society for Testing and Materials |
| BMD | - | Bending Moment Diagram |
| BS | - | British Standard |
| C-S-H gel | - | Calcium Silicate Hydrate |
| CN | - | Cyanoacrylate |
| DoE | - | Department of Environment |
| EN | - | European Standard |
| FBD | - | Free Body Diagram |
| FRC | - | Fibre Reinforced Concrete |
| GFRP | - | Glass Fibre Reinforced Polymer |
| HyFRCC | - | Hybrid Fibre Reinforced Composite Concrete |
| ISO | - | International Organization for Standardization |
| LVDT | - | Linear Variable Displacement Transducer |
| MOE | - | Modulus of Elasticity |
| MOR | - | Modulus of Rupture |
| N.A | - | Neutral Axis |
| OPC | - | Ordinary Portland Cement |
| PE | - | Polyethylene |
| PP | - | Polypropylene |
| prEN | - | Draft for European Standard |
| RC | - | Reinforced Concrete |
| SFD | - | Shear Force Diagram |
| SFRS | - | Steel Fibre Reinforced Shortcrete |

| | | |
|---|---|---|
| SP | - | Superplasticizer |
| ST | - | Steel |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $A$ | - | Weight of the solid in air |
| $A_a$ | - | Area of Tension Reinforcement |
| $a_v$ | - | Distance From Support To Load |
| $B$ | - | Weight of the solid in the distilled water |
| $b$ | - | Width of Section Average/ Width of The Specimen at The Fracture |
| $d$ | - | Effective Depth/ Average Depth of The Specimen at The Fracture |
| $D$, $Ø$ | - | Diameter |
| $E$ | - | Modulus of Elasticity |
| $F_{cc}$ | - | Internal Force From Concrete |
| $F_{st}$ | - | Internal Force From Steel |
| $f_{600}$ | - | Flexural Strength at l/600 |
| $f_{150}$ | - | Flexural Strength at l/150 |
| $f_{ck}$ | - | Characteristic Strength of Concrete |
| $f_{cu}$ | - | Compressive Strength |
| $f_{ct}$ | - | Tensile Strength |
| $f_t$ | - | Flexural Strength |
| $f_{yk}$ | - | Characteristic Strength of Steel |
| $h$ | - | Overall Depth |
| $L$ | - | Span Length |
| $l/d$ | - | Aspect ratio |
| $M$ | - | Moment of Resistance |
| $P,V$ | - | Applied Load |
| $P_{600}$ | - | Load at l/600 |

| | | |
|---|---|---|
| $P_{150}$ | - | Load at l/150 |
| $P_1$ | - | First-peak Load |
| $P_p$ | - | Peak Load |
| $S$ | - | Ultimate Stress |
| $s$ | - | Depth of Stress Block/ Spacing |
| $T_{600}$ | - | Toughness at l/600 |
| $T_{150}$ | - | Toughness at l/150 |
| $V_{Ed}$ | - | Design Shear Force |
| $V_{Ed, Max}$ | - | Concrete Strut Capacity |
| $V_f$ | - | Volume Fraction |
| $V_{min}$ | - | Shear Resistance of Minimum Links |
| $x$ | - | Depth of Stress Block |
| $z$ | - | Lever Arm |
| $\rho$ | - | Density of solid |
| $\rho_o$ | - | Density of the distilled water at the given temperature |
| $\theta$ | - | Angle |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Fibres in concrete provide a medium of arresting crack growth. Short discontinous fibre have the advantage of being uniformly mixed and dispersed in concrete. According to Parameswaran (1991), composites reinforced with steel, polypropylene and natural fibres have a wider social development to country with low-cost and low-energy construction. Nowadays, the application of fibre in structure components has spread widely throughout the world especially for single fibre. Furthermore, when mixing fibres in plain concrete, it needs to be done properly to avoid failure in the structure components. In order to produce better concrete and to overcome some weaknesses of single fibre in concrete, hybrid fibre is introduced in this study.

This research will explore the potential for achieving balanced improvements in the performance characteristics of composite concrete materials by combining different types of fibre. This combination is known as hybrid fibre. Such efforts can potentially lead to the development of fibrous composite concrete that will provide superior performance under severe loading and environmental effects at a reasonable cost. In this research, polypropylene (PP) fibre (Figure 1.1) is combined with steel (ST) fibre (Figure 1.2) and mix in concrete with various volume fractions. The study is to observe the macro and micro cracking growth development. Application to structural elements such as beam and slab should be able to reduce crack growth and provide additional resistance to the tensile and flexural strengths.

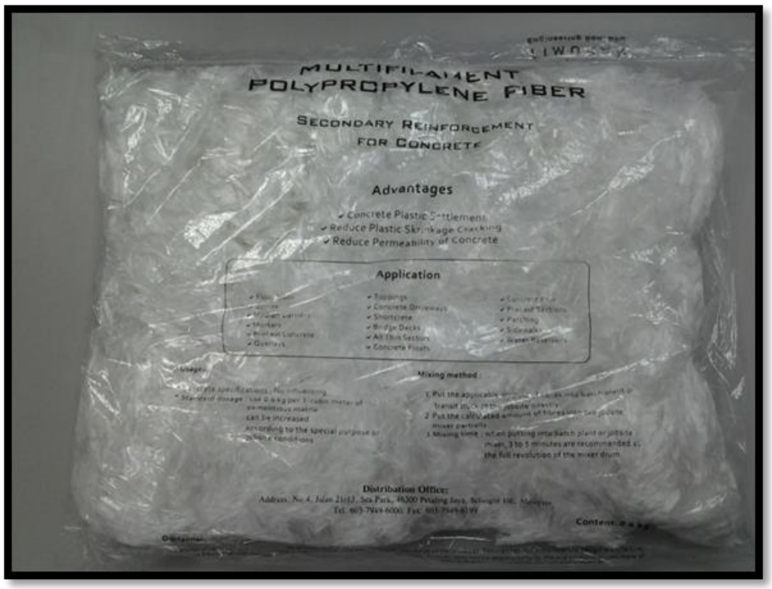


**Figure 1.1**: Polypropylene fibre


**Figure 1.2**: Industrialised steel fibre

The use of PP fibre as a reinforcing medium can only be made in cement matrices. Their natural abundance, wide range and type of fibres, immeasurable source and relative cheapness point to the direction of their development for housing and many related construction. However, their inherent weaknesses such as low Elastic Modulus, high water absorption and low fire resistance contributed to their relatively poor performance for workability and durability (Sharma, 2013). Therefore, it is necessary to carry out development work by mixing together with ST fibre with regards to the choice of fibres and fabrication process. While for ST fibre, it is known to increase the flexural and tensile strengths of the concrete. The wide used of ST fibre concrete in construction has proved its ability in improving the brittle failure of the concrete. ST fibre has higher tensile strength compared to PP fibre. Therefore, the combination of high and low tensile strength of the fibre is used in this study.

Hybrid fibre reinforced composite concrete can be applied in slab, beam, and also column. In this study, application to the structural beam is selected. This is because concrete is good in compression but weak in tension. Therefore, the application in structural beam will study in detailed the fibre effects in both compression and tension zones. This will be done after obtaining the optimum percentage for hybrid fibre reinforced composite concrete, it will be applied in the structural beam.

Mostly, the application of fibre is established on ground slab and road pavement. However, they are also applied on structural beam and column for its function and reaction in concrete to resist tensile stress. Application of fibre in the infrastructure work is widely used in the airport zone because of the heavy loading capacity. Besides that, fibre is also applied in tunnel construction for its segmental lining.

## 1.2 Problem Statement

Concrete due to its brittle behaviour has little ability to resist tensile stress and strain. Therefore, discontinuous fibres are added in concrete to improve energy absorption capacity and cracking resistance (Singh et. al., 2010).

Plain concrete is known to have a brittle behaviour with lower flexural strength and tensile strength. To improve the behaviour, fibre reinforced concrete is introduced which is by adding single type of fibre in concrete. There are many types of fibre available in the market such as steel, glass and even natural. Recycled steel fibres are also an alternative where they can be obtained from used tyres.

Hybrid fibre reinforced composite concrete is introduced in this study. By having two or more types of fibre and mixed in concrete can increase the flexural and tensile strength than the one with single fibre. Furthermore, the presence of fibres in concrete bridged the crack growth thus increase the ultimate loading capacity of the structural elements.

Figure 1.3 shows crack occurred on ground slab at precast yard, Ulu Tiram, Johor Bahru where monofilament polypropylene fibre is applied in the slab. The figure shows cracking occurred because of the single fibre application in the slab which can only prevent micro cracking. In an open wide surface area, concrete experiencing rapid loss of water, thus hydration process cannot take place completely. Expansion and contraction process of the concrete occurred too fast and produce long crack across the slab. Therefore, additional bonding constituent is needed to bond the concrete particles to control the expansion and contraction process and then to overcome crack problem. The tiny cracks need to be prevented at the early stage of concrete setting to avoid additional tiny cracks to further developed into large crack.

**Figure 1.3:** Crack on slab

Therefore, in this study ST fibre is combined with PP fibre and mixed in concrete. Each fibre have their own characteristic in order to improve the strength. Plain concrete experienced sudden failure at ultimate load. For HyFRCC the failure development is in the sequence of exceeding the limit of the PP fibre, followed by pull-out of ST fibre before the concrete fails.

In this study, both hybrid combination methods are considered to produce a better concrete. The used of stronger, stiffer, and long ST fibre with 60 mm length is to prevent macro crack and absorb more energy before the concrete fails, while flexible and short PP fibre with 12 mm length will improve toughness by bridging micro cracking. Positive responses produced by this two combination will increase flexural strength of the concrete.

According to A. Bentur et al. (1990) and G. Xu et al. (1998), there are two methods to combine two types of fibres in concrete. The first method is based on fibre constitutive response. One type of fibre is stronger, stiffer, and provides reasonable first crack strength and ultimate strength, while the second type of fibre is relatively flexible and leads to improve toughness and strain capacity in the post-crack zone. The second method is hybrid combination based on fibre dimension. One type of fibre is smaller, so that it bridge micro cracking and therefore control the growth and delays coalescence. This leads to higher tensile strength of the material. The second fibre is larger and is intended to arrest the propagation of macro cracks and therefore results in a substantial improvement in the fracture toughness of the material.

## 1.3 Objectives of the Research

This study embarks on the following objectives:

1) To investigate the mechanical properties of hybrid fibre reinforced composite concrete at fresh and hardened state.

2) To investigate the toughness and ductility response of hybrid fibre reinforced composite concrete.

3) To determine the optimum percentage of volume fractions of hybrid fibre reinforced composite concrete.

4) To investigate the effect of hybrid fibres on the flexural performance of concrete beams.

## 1.4 Scope of Study

To achieve the objective of the study, experimental work is carried out in three stages. In the first stage, the mechanical properties of both steel (ST) and polypropylene (PP) fibres is justified by carrying out tensile and density test. Mega Mesh II type polypropylene fibre and group 1- cold drawn wire, hooked end steel fibre are used in this research. Both fibres are supplied by Timuran Engineering Sdn. Bhd. The concrete strength is fixed at 30 N/mm$^2$. The second stage of the reseach is to justify the mechanical properties of hybrid fibre reinforced composite concrete (HyFRCC). To achieve the objectives of the study, compression, flexural, tensile splitting, toughness, and Young's Modulus test of HyFRCC are carried out. The volume fraction, $V_f$ are taken as 0.5%, 1.0%, and 1.5%. For every volume fraction, the ST-PP fibre mix proportion by volume in percentage are varied for 100-0, 75-25, 50-50, 25-75, and 0-100. For compression test, cube with dimensions of 150 × 150 × 150 mm is used. Prism with dimensions of 100 × 100 × 500 mm is used for the flexural test where as prism with dimensions of 100 × 100 × 350 mm is used for the toughness test. Cylinder with dimensions of 150 mm diameter × 300 mm high is used for the Young's Modulus and tensile splitting test. The specimens are tested at 3, 7, and 28 days. Therefore, for every concrete batch, 9 cubes, 6 prisms with size of 100 × 100 × 500 mm, 3 prisms with size of 100 × 100 × 350 mm, and 5 cylinders are prepared. All together, 16 batches of HyFRCC are produced including 1 batch of plain concrete as control. The final stage of the research is applying the optimum percentage proportion of ST-PP fibre obtained from the second stage work in 150 mm wide × 200 mm high × 2200 mm long beam. All beams undergoned flexural testing to investigate the structural performance for its deflection, strain pattern and failure mode.

## 1.5 Significance of Study

The significant of the study is to improve the existing fibre reinforced concrete properties by mixing PP together with ST fibre in concrete. In the structural field, PP fibre is used in mortar while ST fibre is widely used in concrete. Also in this study, the optimum percentage of volume fraction of HyFRCC that is suitable for industrial purposes is justified so that it can be widely used in Malaysia. PP fibre in concrete will help to delay micro cracks while steel fibre delays the macro cracks. Theoretically, combining both fibres in concrete will enhance the concrete strength compared with single fibre alone or even the plain ones.

Combination of two types of fibre can enhance the flexural strength of the concrete. Good combination of different type, size, and length of the fibres which is ST and PP fibre, can increase the flexural strength and improve the durability of the concrete. Both fibres must be uniformly mixed throughout the concrete and randomly oriented to make sure that they are well functional as bridging elements in delaying crack growth and automatically enhance the flexural strength of the beam.

## 1.6 Thesis Organisation

This thesis will discuss on mechanical properties of HyFRCC and its structural performance. Background of the study, problem statement, objectives, scope and significance of study are discussed in Chapter 1. Some literature reviews from previous study on PP fibre concrete, ST fibre concrete, and HyFRCC are dicussed in detailed in Chapter 2. Various combination of different fibre type and dimension are used bt previous researchers and this is highlighted in this chapter. Chapter 3 dicussed on methodology of the study by experimental work. Sample calculation on hybrid fibre used, the amount of volume fractions and materials compositions and the laboratory tests conducted to determine the mechanical properties of HyFRCC are also discussed. The beam test method is also discussed in this chapter to study the flexural performance. Chapter 4 revelead the test results together with the dicussions on the mechanical properties of HyFRCC to determine the optimum percentage of volume fraction to be applied in the structural beam. Meanwhile, Chapter 5 revealed the test results and discussions on the fibre reinforced structural beam together with the comparison with the control beam. The structural performance of the beams are then investigated for its deflection, strain pattern and failure mode. Lastly, Chapter 6 discussed the conclusions of the study and recommendations for future works are also given in this chapter.

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