PERFORMANCE OF HYBRID FIBER REINFORCED CONCRETE CONTAINING POLYPROPYLENE AND RING-SHAPED POLYETHYLENE TEREPHTHALATE FIBERS

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ABSTRACT

Polypropylene (PP) and recycled polyethylene terephthalate (PET) fiber as structurally sound materials have been adopted by many researchers to improve the properties of concrete especially tensile strength and crack resistance. However, the irregular shape and straight fibers of PP and PET exhibited weak interfacial bond strength during fiber bridging. Therefore, ring-shaped polyethylene terephthalate (RPET) fibers were developed with straight PP fiber as a combination fiber to improve the fiber bridging mechanism of the fiber reinforced concrete. This study aims to determine the slump and passing flow of fresh concrete, the density, compressive and tensile strength, and water absorption of hardened concrete containing PP and RPET fiber. A total number of 144 cube and 48 cylinder specimens of hybrid fiber reinforced concrete (HFRC) with 0 %, 0.5 %, 1.0 %, and 1.5 % of each PP and RPET fiber content, respectively, were prepared and tested to evaluate the properties of the hardened fiber reinforced concrete. Then statistical optimization using Design-Expert software was performed to determine the optimum percentage of PP and RPET fiber content for the hybrid fiber reinforced concrete. For the hybrid fiber reinforced concrete, the maximum slump flow was achieved with 1.5% of RPET fiber and 0 % of PP fiber content, and the minimum slump flow was recorded with 1.50 % of each RPET and PP fiber content. Furthermore, the highest passing flow index was obtained with 0.5 % of each PP and RPET fiber content, and the minimum passing flow index was achieved with 1.50 % of each RPET and PP fiber content. On the other hand, the density of the hybrid fiber reinforced concrete was increased with increasing RPET fiber content and decreasing PP fiber content. Meanwhile, the maximum compressive and tensile strengths were recorded at 1.0 % of each PP and RPET fiber content, respectively compared to other specimens. Finally, it was noticed that increasing PP and RPET fiber content increases the water absorption percentages gradually. In conclusion, the properties of fresh concrete containing hybrid fibers were decreased, while the mechanical properties of hardened were improved compared to the control specimen.

ABSTRAK

Fiber polypropylene (PP) dan recycled polyethylene terephthalate (PET) digunakan sebagai bahan berstruktur yang telah digunakan ramai ahli penyelidik untuk meningkatkan kekuatan konkrit terutamanya kekuatan mampatan dan rintangan ketegangan. Walau bagaimanapun, bentuk lurus fiber PET dan PP menunjukkan kekuatan ikatan antara permukaan yang lemah dan terlucut semasa tegangan fiber dalam konkrit. Oleh itu, fiber berbentuk bulatan polyethylene terephthalate (RPET) dibangunkan bersama dengan fiber PP yang lurus sebagai kombinasi untuk meningkatkan mekanisma tautan tegangan fiber konkrit bertetulang. Kajian ini bertujuan untuk mengetahui aliran konkrit basah, ketumpatan, kekuatan mampatan dan tegangan serta penyerapan air kombinasi fiber PP dan RPET di dalam konkrit. Sebanyak 144 kiub dan 48 spesimen silinder konkrit mengandungi fiber PP dan RPET sebanyak 0%, 0.5%, 1.0%, dan 1.5% pada setiap jenis fiber telah disediakan dan diuji untuk menilai sifat-sifat konkrit fiber. Kemudian, pengoptimuman statistik digunakan menerusi perisian Design-Expert siri 11 untuk menghasilkan peratusan kandungan fiber PP dan REPT yang optimum bagi hibrid fiber konkrit. Bagi hibrid fiber konkrit, aliran runtuhan maksimum dicapai dengan hibrid fiber konkrit mengandungi 1.5% fiber RPET dan 0% kandungan fiber PP. Manakala, aliran runtuhan minimum direkodkan dengan 1.50% setiap kandungan fiber RPET dan PP konkrit. Selain itu, indeks aliran melepasi tertinggi diperoleh dengan konkrit mengandungi 0.5% fiber hibrid konkrit dan indeks aliran melepasi minimum dicapai dengan 1.50% fiber hibrid konkrit. Sebaliknya, ketumpatan konkrit fiber hibrid meningkat dengan peningkatan kandungan fiber RPET dan penurunan kandungan fiber PP. Walau bagaimanapun, kekuatan mampatan dan tegangan maksimum pada 28 hari pengawetan direkodkan dengan 1.0 % fiber hibrid konkrit. Akhirnya, peningkatan kandungan fiber PP dan RPET meningkatkan peratusan penyerapan air secara beransur-ansur. Kesimpulannya, sifat-sifat konkrit baru berkurangan apabila menggabungkan fiber PP dan RPET manakala sifat-sifat mekanikal konkrit menunjukkan peningkatan berbanding sampel kawalan

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LIST OF ABBREVIATION

PP	-	Polypropylene
RPET	-	Ring shaped polyethylene terephalate
SCC	-	Self-compacting concrete
HFRC	-	hybrid fiber reinforced concrete
RSM	-	Response surface method
A-A	-	The main effect
B-B	-	Liner effect
AB	-	Interaction
A^2	-	An direct effect
B^2	-	An direct effect
R^2	-	The correct result
SV	-	According to the result from the RSM

CHAPTER 1

INTRODUCTION

1.1 Research Background

Concrete has some shortcomings in terms of low tensile strength and crack resistance. Therefore, extensive attention was given to overcome those shortcomings and improving the tensile strength of the concrete and its crack resistance by adding fibers made from recycled polyethylene terephthalate (PET) and polypropylene (PP). For instance, several studies have been developed to assess the material properties of the fiber reinforced concrete by adding small percentage of PP fiber ranging from 0.5 to 2.5 % with different types and shape of plastic fibers (Fraternali et al., 2011; Foti, 2013; Khalid et al., 2018). On the other hand, the utilization of PP fibers in the reinforced concrete structures is consistently expanding as it improves the tensile strength and crack resistance of concrete and reduces the impact of the solid waste to the environment.

PP fibers are made of chemical fibers. They are mass-produced in enormous quantities and rank fourth in terms of volume after polyesters, polyamides, and acrylics. PP fibers are manufactured around the globe at a rate of around 4 million tons per year (Younus, 2018). Reinforced composite concrete is a heterogeneous building material with great mechanical properties in terms of strength, stiffness, and durability. By incorporating PP fibers into concrete, optimal material usage and cost saving can be accomplished (Younus, 2018).

As concrete has brittle behaviour under tensile and flexural loading, reinforcing plain concrete with PP fiber became crucial. The fiber reinforced concrete is the plain concrete reinforced with PP fiber. According to some researchers (Fraternali et al.,

2011; Foti, 2013,; Khalid et al., 2018), reinforcing plain concrete with PP fibers in the reinforced concrete structures led to increasing its ductility which in return improved the brittle response of the concrete under tensile and flexural loading. On the other hand, adding the fibers to the reinforced concrete structures improved post-cracking behavior of concrete and decrease shrinkage and thermal cracks (Sadrmomtazi and Tahmouresi, 2017).

The consumption of plastic used in packaging and beverage containers has generated huge amount of solid waste causing significant impact to the environment all over the world. For instant, the beverage containers made of PET are disposed off after a single usage and managed by landfill site and incineration (Kim et al., 2010). However, disposing plastic trash into landfills is a serious issue due to its mass and slow decomposition rate. Therefore, the adoption of recycled plastic to produce fiber to be utilized in the reinforced concrete structures is innovative solution to dispose the plastic wastage and provide ecological and economic advantages (Saikia & De Brito, 2014).

PET fiber is extensively used in beverage containers that represents one of the most common sources of solid waste. The latter is obtained in large quantities from plastic bottles used as beverage and mineral water containers (Foti, 2013). PET is one of the polymer wastes which does not create a direct hazard to the environment, but its high resistance to the atmospheric and biological agents has made it as a noxious material. Moreover, recycled PET waste as aggregate in masonry mortar concrete was good solution to this environmental hazard (Rahmani et al., 2013). On the other hand, reinforcing plain concrete with PET improves its mechanical properties and can even transform the construction industry towards sustainability.

The mechanical properties of reinforced concrete beams containing PET waste fibers were evaluated (Adnan & Dawood, 2020). The authors declare that the ultimate load capacity of the specimens and secant stiffness had a little decreasing but there was an increasing in the initial stiffness and enhancement in ductility for all specimens. On the other hand, according to some researchers (Foti, 2013; Kim et al., 2010) there was good bond mechanism between the concrete and fibers. Furthermore, PET fibers with ring-shape are fundamentally intended to activate fiber yielding (tensile rupture) instead of pullout fiber (slipped by fiber force), which is an essential benefit over irregularly or straight formed PET fiber.

Therefore, this study aims to discover material such as manufactured PP and PET waste as combination synthetic fiber to increase tensile strength of concrete. The combination of these two materials can potentially serve as substitute for fiber materials as way to produce eco-friendly and toughness performance building materials. Additionally, this study intends to conserve resources and promote sustainability to structural design of building in construction industry.

1.2 Problem Statement

As plain concrete has low tensile strength and crack resistance under flexural loading, enhancing the flexural behaviour of concrete is essential to achieving structurally sound construction material. In this research work, two types of plastic waste were adopted to improve the flexural behaviour of concrete. Researchers like Foti (2013) Khalid et al. (2018) and (Al-Hadithi et al., 2020; Foti, 2013; Khalid et al., 2018)have been added PP fiber content as fiber materials to plain concrete to enhance its tensile resistance. These authors claim that the length of PP fiber can enhance the interlocking mechanism of fiber bridging with concrete as PP fiber can be embedded between aggregate compared to short length of PP fiber. However, straight PP fiber exhibited limited performance in term of concrete strength when the load applied was high. The PP fiber tends to slipped out from concrete matrix and not due to fiber rupture by stress loads (Shahidan et al., 2018).

Meanwhile, the irregular or lamellar shapes PET fiber content on the fiber reinforced concrete was weak on the interfacial bond strength between the surfaces of PET fibers and the surrounding concrete during the fiber bridging mechanism (Al-Hadithi et al Al-Hadithi, A. I., Abdulrahman, M. B., & Al-Rawi, M. I. (2020) . It shows that irregular or lamellar fiber in concrete does not help to increase flexural strength due to limited on surface contact with matrix concrete and tends to slip-out during fiber bridging stress.

Therefore, ring-shaped PET (RPET) fiber was propose to improve the fiber bridging mechanism and the tensile strength by yielding until the fiber rupture. Besides, the combination of straight and long PP fiber with RPET fiber will give an advantage during stress bridging pullout-slippage. As a result, the RPET fiber mode of failure is fiber yielding (tensile rupture) instead of fiber pullout (pullout-slippage)

which is an essential advantage over irregular and short PP fiber. In this regard, the combination of PP fiber and ring-shaped PET fiber was the fundamental factor to achieving fiber bridging mechanism and fiber yielding to improve the mechanical properties of fiber reinforced concrete. Therefore, this research work is developed to investigate the properties of fresh and hardened fiber reinforced concrete with the combination of PP and RPET fiber .

1.3 Objective of study

This study aims to investigate the performance of hybrid fiber reinforced concrete (HFRC) containing PP and RPET fibers. To achieve that, there are three main objectives have been developed for this study which are as follows:

i. To determine the slump flow and passing abilities of concrete containing PP and RPET fiber,
ii. To investigate the density, compressive strength, tensile strength, and water absorption of concrete containing PP and RPET fiber.
iii. To evaluate the optimum of percentage of PP and RPET fiber content using statistical optimization software Design-Expert software.

1.4 Scope of Study

This study was conducted at the laboratory of the Faculty of Civil Engineering and Built Environment (FKAAB), Universiti Tun Hussein Onn, Malaysia (UTHM). Several investigations and laboratory tests were conducted to determine the workability and performance of concrete. In this study, both PP and RPET fibers were used as fiber with contents of 0 %, 0.5 %, 1.0% and 1.5% of the concrete volume for each PP and RPET fibers. The PP fiber was virgin plastic manufactured with a length of 45mm. RPET fiber was made directly and cut manually from waste plastic bottles. The width of ring-shaped fibers is 5 mm wide. The diameter of the fibers used in the study was 60 mm diameter. In this study, the mix design of concrete was designed according to self-compacting concrete (SCC) requirements as proposed by Khalid et al. (2018) and Al-Hadithi et al. (2020). The purpose of using SCC method is to reduce

the possibilities of fiber balling during mixing and concreting (Khalid et al., 2018). One hundred ninety-two samples were prepared to evaluate the performance of concrete. The experimental work was carried out to assess the concrete characteristics such as workability, density, compressive, tensile strength, and water absorption.

1.5 Significant of Study

This research is mainly focused on investigating the performance strength of hybrid fiber reinforced concrete containing manufactured PP and RPET, which offers the appropriate opportunity to achieve a better understanding and information about behavior and characteristics of concrete containing a combination of PP and RPET fibers. Furthermore, this study could be used as a reference for researchers in the same field of study that focus on the performance of strength of hybrid fiber reinforced concrete.

Moreover, concrete has some poor properties that should be considered due to its full potential roles and numerous applications in the construction industry as the most important construction material. It generally has strong compressive strength, but weak and brittle when it is subjected to various tensile loads. Therefore, utilization of several additives of fibers that considered as a suitable material that improve the performance of the concrete and avoid any structural failures should be investigated. Additionally, this study offers the opportunity to utilize fiber wastes as a reinforcing material to improve the mechanical properties of concrete, such as manufactured PP and RPET fibers that are characterized as low cost, easy availability, and good performance.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

An overview of the properties of fresh and hardened hybrid fiber reinforced concrete with PP, PET and RPET fiber contents are presented in this chapter to understand the literatures, and all the relevant topics related to these materials. Firstly, a brief introduction to the self-compacting concrete is given. Secondly, the theoretical background on the PP fiber and its properties, compressive, and tensile strength of fiber reinforced concrete with PP fiber content is briefly discussed. Thirdly, an introduction to the PET fiber and its properties as well as the flexural, compressive, and tensile strength of fiber reinforced concrete with PET fiber content is briefly explain. Then, the properties of RPET fiber and the compressive and tensile strength fiber reinforced concrete with RPET fiber content are highlighted. Finally, a summary of previous published research works is carried out and tabulated to provide further understanding on the difference between the fiber reinforced concrete with PP and RPET fiber content.

2.2 Polypropylene

Polypropylene (PP) also known as propene or propylene is a strong, rigid, and crystalline thermoplastic material made from a propene (or propylene) monomer. It's a hydrocarbon resin with a linear structure. It has a wide range of applications in daily items including packing trays, home products, battery cases, bottles, and medical

equipment. The properties of fresh and hardened fiber reinforced concrete with different thresholds of PP fiber content in terms of workability, flexural, compressive, and tensile strength will be discussed in this section according to previous published research work. The PP fiber content used for fiber reinforced concrete is shown in Figure 2.1.

Figure 2.1:The polypropylene fiber (Ding et al., 2020)

Ahmed et al. (2016) conducted an experimental study to assess the mechanical property of fresh and hardened fiber reinforced concrete with PP fiber content ranging from 0.1 % to 0.5 %. The slump test was carried out to assess the workability of fresh concrete and compressive strength and flexural strength tests were conducted to evaluate the mechanical properties of hardened concrete at different ages. The authors revealed that the workability of fresh concrete containing PP fiber was decreased. On the other hand, the modulus of elasticity of the fiber reinforced concreter with PP fiber content was reduced after 28 days compared to the control specimen. However, the flexural strength of the fiber concrete with PP fiber content of 0.5 % was increased compared to the control specimen. Furthermore, 25% to 42% increase in the tensile strength of the fiber reinforced concrete with PP fiber content was observed at 28 days.

Zhang et al. (2013) have carried out a parametric experimental study to investigate the impact of PP fiber content of 0.04 %, 0.06%, 0.08 %, 0.1%, and 0.12 % respectively on the concrete fracture properties under three-point bending test. It was found that the PP fiber content enhance the fracture properties in terms of fracture toughness, fracture energy, effective crack length, mid-span deflection and critical crack opening displacement. Increasing the PP fiber content from 0 to 0.12 % have

improved the facture characteristic of the concrete and its resistance of crack propagation as well.

Alavi et al. (2012) performed numerical simulation for plain concrete and fiber reinforce concrete under impact loading to compare its findings with the experimental results. PP content of 0.2%, 0.3% and 0.5% were used. The authors revealed that based on the numerical simulation and experimental findings, increasing the PP fiber contents has improved the impact resistance of concrete specimen with respect to crack initiation and fractures. Furthermore, the compressive and tensile strength of fiber reinforced concrete with PP fiber content were increased by 14.4% and 62.1% respectively compared to plain concrete. On the other hand, long PP fiber acts as fiber bridges and provide good bond mechanism with the concrete as it has larger contact area to resist the tension due to pullout.

(Bagherzadeh et al., 2012) studied the mechanical properties of lightweight fiber reinforced concrete with PP content of 0.15 % and 0.35 %. The authors adopted PP fiber content with 6 mm and 12 mm length. The compressive strength for 7 and 28 days, splitting tensile strength, flexural strength, water absorption were evaluated. The flexural and tensile strength of the fiber reinforced concrete with PP fiber content of 0.35 % and 12 mm length was increased by 30.1 % and 27 % respectively compared to the plain concrete. The author revealed that increasing PP fiber content with longer length are suggested to improve the mechanical properties of the fiber reinforced concrete.

(Alberti et al., 2014) performed an experimental study to evaluate the workability of self-compacted concrete with PP fiber content. PP fiber of 60 mm in length and 0.903 mm in diameter was adopted in their study. The authors concluded that as fiber content was increased, slump flow was decreased. The slump flow trends of fiber reinforced concrete with PP fiber content of 1 %, 1.5 %, and 2% was decreased marginally on averages of 1.2 %, 8.4 %, and 10% respectively. Moreover, the authors claimed that an increase in PP fiber content decreases the flow capability of self-compacted concrete.

(Kapse, 2020) studied the mechanical properties and workability of fiber reinforced concrete with PP fiber content of 0%, 0.05%, 0.10%, and 0.15% respectively. According to the obtained test results, it was found that the polypropylene fibers will in general decrease the passing capacity besides expanding segregation. Moreover, adding PP fiber to the concrete diminished deformability of self-

compacting concrete in the fresh condition. On the other hand, at age of 28 days, the fiber reinforced concrete with PP fiber content of 0.1% improved the impact resistance, compressive strength, and tensile strength of self-compacted concrete in hardened condition. Therefore, it was recommended that the optimum PP fiber content for self-compacted concrete is 0.1 % of the concrete volume.

2.2.1 Properties of PP

The adoption of fibers to improve the brittle behaviour of concrete is dramatically expanding by many researchers around the globe. Utilizing fiber content in the reinforced concrete was proven to increase post-peak ductility, pre-crack tensile strength, fracture strength, toughness, impact resistance, flexural strength resistance, and fatigue resistance. On the other hand, the capacity of fibers to bridge cracks at high levels of strain determines the ductility of fiber reinforced concrete. According to Madhavi et al. (2015), the use of PP fiber reduces the unit weight of concrete while increasing its strength. Furthermore, PP fibers is used to regulate the characteristics of fresh and hardened concrete and reduce shrinkage (Xiao & Falkner, 2006).

PP fiber is typically hydrophobic material used for cemented composites. In 1965, Polypropylene fabrics were first proposed as a concrete admixture in the construction of blast resistant houses. The low cost, general availability, and broad application of concrete have made the concrete to be the most commonly used building material in the construction industry. However, as concrete is a quasi-brittle material, the principal drawbacks of plain concrete are comparatively low tensile strength and poor resistance to crack opening and propagation. Therefore, PP fibers have been widely used to improve the concrete property and reliability (Wang et al., 2019).

According to (Rathod et al., 2018), fiber reinforced concrete with PP fiber content of 0.1 % to 1.5 % improved the compressive, tensile strength of concrete. Furthermore, Alwesabi et al. (2020) concluded that the inclusion 0.1% and 0.12% of PP fiber with steel fiber improved the compressive strength of concrete by 14% and 10%, respectively and splitting tensile strength by 20% and 27% , respectively. Moreover, Alwesabi et al. (2021) revealed that as PP fiber has low Young's modulus, the toughness, strain capacity in the post crack zone are improved and the crack growth is controlled. It has improved drying shrinkage crack, reduced permeability and

density and provided water tightness. On the other hand, utilizing PP fiber in the reinforced concrete element minimized the usage of steel reinforcement and considered corrosion free material.

2.2.2 Compressive strength of concrete containing PP

An experimental study was carried out by Rathod et al. (2018) to assess the concrete's compressive strength of fiber concrete with PP fiber content ranging from 0.0 % to 1.5 % at 28 days. The control sample of plain concrete without PP content was compared with PP fiber content of 0.5 %,1.0 % and 1.5 % to determine the effect of PP fiber content on the compressive strength of fiber reinforced concrete. The compressive strength test was performed at 28 days using a compression testing machine as shown in Figure 2.2. The obtained results of the compressive strength are tabulated in Table 2.1. According to the experimental findings, after thresholds of 0.5 % of PP fiber content, the compressive strength of the reinforced fiber concrete dropped dramatically with increasing the PP fiber content. However, further study should be performed based on different concrete grades to determine the optimum PP fiber content as the focus of this study was based on concrete grade of 39.91. The drop of the compressive strength as the PP fiber content after thresholds of 0.5 % is due to the fiber balling that weaken the bond mechanism.

Figure 2.2: Compressive strength testing machine (Rathod et al., 2018)

Table 2. 1: Compressive strength of concrete with PP fiber (Rathod et al., 2018)

Fiber Content %	Compressive strength (28 days)
0.0	39.91
0.50	49.56
1.00	43.36
1.50	37.44

Younus (2018) proposed hybrid fiber reinforced concrete by adding thresholds of 0.1,0.2 and 0.3% of PP and coconut fiber to the concrete. The hybrid fiber reinforced concrete with different content of PP fiber and coconut was tested. The control sample of plain concrete without hybrid fiber content was compared with the hybrid fiber reinforced concrete to assess the effect of hybrid fiber on the compressive, splitting tensile, and flexural strengths. The principal findings of this study were that adding hybrid fibers to certain thresholds enhanced the compressive strength of concrete. Therefore, the authors concluded that the maximum compressive, splitting tensile, and flexural strengths of hybrid fiber reinforced concrete were achieved at thresholds of 0.2 % for both PP fiber and coconut fiber content. However, this conclusion was withdraw based on concrete grade 30. On the other hand, this limitation is due to the interaction between fibers' contact area during mixing and pouring of concrete causing fiber balling.

2.2.3 Tensile strength of concrete containing PP

(Khalid et al., 2017) performed pull-out test for fiber reinforced concrete with embedded PP fiber to investigate its behaviour and the interfacial bond between the PP fiber and concrete matrix. The principle finding of their study was that the embedded length of PP fiber in concrete has a considerable impact on the pull-out response of fiber reinforced concrete with PP fiber content. Accordingly, increasing the embedding length of PP fiber from 19 mm to 38 mm improved the yielding of PP fiber from 39 % to 68.2 %. On the hand, the authors also mentioned that the embedded length of PP fiber significantly affected the resistance of pull-out load due to the treated surface of the PP fiber. Increasing the embedding length of PP improves the bond mechanism between the PP fiber and concrete matrix resulting in higher fiber yielding value.

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