Effect of Adding Polypropylene Fibres to Flexural Strength of Ferrocement

1st Fathoni Usman
Institute of Energy Infrastructure
Universiti Tenaga Nasional
Kajang, Malaysia
0000-0002-3684-3347

2nd Syazwan Shaharuddin
Institute of Energy Infrastructure
Universiti Tenaga Nasional
Kajang, Malaysia
syazwanshaharudin@gmail.com

3rd Noor Mahmudah
Department of Civil Engineering
Universitas Muhammadiyah Yogyakarta
Bantul, Indonesia
noor.mahmudah@umy.ac.id

4th Monita Olivia
Department of Civil Engineering, Faculty of Engineering
Universitas Riau
Pekanbaru, Indonesia
monitaolivia@gmail.com

***Abstract*— Developing a lightweight structure is a increasing trend throughout the globe in the construction industry. For this form of building, Ferrocement, a thin-shell concrete strengthened with continuous wire mesh layers, had been seen as an alternative material. Ferrocement had become the promising composite material for applications of prefabricated components and strengthening. However, the cracking potential attributed to drying shrinkage is high considering the tiny size and big ferrocement surface area. The application of polypropylene fibres (PPF) as secondary reinforcement in ferrocement mortar was used in this study to manage such cracks. This paper introduces the effect of adding PPF to the behaviour of flexural ferrocements. This study revealed that 66.6% of the variation in ferrocement flexural strength was dictated by volume fraction (V_r) under flexural testing; 31.4% by a proportion of PPF (P_f) and 2% by P_f and V_r interaction.**

Keywords—ferrocement, Polypropylene fibre, flexural strength.

I. Introduction

Ferrocement had become the promising composite material for prefabrication and industrialisation of the construction industry [1-3]. The ferrocement mostly used in the strengthening of reinforced concrete beam and column [4-6]. However, in Malaysia, its acceptance is delayed, mainly due to its small thickness and labour-intensive method of production [7]. Limited to Ferrocement is the fact that larger global organisations, such as the ACI (American Concrete Institute), FIB (Structural Concrete Federation) or RILEM (International Union of Laboratories and Construction Materials, Systems and Structure Experts), are yet to adopt and sponsor Ferrocement [8].

The compressive strength of the mortar does not significantly influence the resistance to bending of ferrocement. Only an average improvement of 11% in flexural strength resulted in increased mortar compressive strength up to 80% [9]. The most critical layer of mesh in ferrocement is the closest of the reinforcement to the face of the element that resists the bending moment compared to reinforced concrete. Therefore, it is not possible to add a volume fraction of reinforcement to boost the ferrocement flexural strength; in reality, it may result in delamination. Naaman and Homrich suggested a non-dimensional regression equation as in Eq. (1) to Eq. (3) calculate the ferrocement capacity in flexural [10].

$$y = 0.005 + 0.422x - 0.0772x^2 \tag{1}$$

$$x = \frac{V_r f_y}{f_c} \tag{2}$$

$$y = \frac{M_u}{\eta_0 f_c \cdot bh^2} \tag{3}$$

Where V_r is volume fraction of the wire mesh; f_y is the yield strength of the wire mesh; f_c is cylinder compressive strength of the matrix; η_0 is the global efficiency factor of mesh reinforcement; b is the width of the beam, and h is the overall depth of the section.

In structural engineering applications in the mid-1980, the use of high-performance fibre-reinforced polymeric reinforcement has begun to gain attention [9]. Fibres are added to regulate cracking owing to plastic shrinkage and drying shrinkage, not to enhance concrete strength [11]. One of the essential benefits of ferrocement is the lightweight, elevated tensile to weight ratio, impact resistance, toughness and readily moulded into any shape [12-15]. Ferrocement offers the opportunity to create a relatively light composite and prefabricated structural elements within 50% of traditional reinforced concrete structures [5]. It can also influence the material's behaviour by bridging fibres across cracks.

Application of fibres in concrete is not a new concept in industries. Generally, fibres in cement mortar were distributed in short length and discontinue form. The amount of fibres added to the fresh concrete mixture is expressed as the percentage of fibres, P_f. The fibres can act most effectively if they are aligned in the direction of the largest tensile stresses.

Hundreds of fibres have been invented. However, not all of them are suitable for a concrete application. Because of plastic shrinkage and drying reduction, the fibres are generally used in concrete to regulate crack. They also decrease the permeability of concrete, thereby reducing water bleeding. The concept of fibres with a steel reinforcement consists of satisfying the ultimate resistance limit status by reinforcing the metal mesh and controlling cracking under fibre reinforcement service loads [12-14]. An extra 0.1% of polypropylene fibres in flat concrete improved 44% in the flexural strength of the concrete [16].

This study is aimed to determine the effect of adding Polypropylene fibre (PPF) to the ferrocement mortar to control delamination and cracks subjected by the flexural load on ferrocement rectangular prism.

II. The Experiment

There were three main steps in conducting this study. The first step was the compressive test of cement mortar with different content of the percentage of polypropylene fibres (PPF) in the cement mortar. The percentage of the PPF were 0%, 0.3%, 0.6%, and 0.9%. Three sets of ferrocement specimens of 250 mm length, 80 mm width and 25 mm thick were prepared for 4-points load flexural test. A square welded wire mesh was used as a type of steel wire mesh. The net cover of the reinforcement was set to 3 mm as recommended by ACI Committee 549, which is from 2 mm to 5 mm to ensure proper distribution of the mesh throughout the thickness [17]. Table I lists the mesh reinforcement arrangements. The flexural test on ferrocement specimens was conducted following standard testing ASTM C78. The third steps were physical observation and analysis of the experimental result.

TABLE I. THE MESH ARRANGEMENT

Sample	Mesh arrangement		Layers
A	Net cover	3 mm	2
	Distance between meshes	19 mm	
B	Net cover	3 mm	4
	Distance between meshes	6 mm	
C	Net cover	3 mm	6
	Distance between meshes	19 mm	

Volume fraction, V_r is the ratio of the volume of reinforcement to the composite volume. In this study, three distinct numbers of mesh layers, N, were used, which are 2, 4, and 6 layers that would offer a distinct value of the steel reinforcement in the ferrocement samples. Due to the use of square steel wire meshes, the distance centre to centre between longitudinal cables, DL is equivalent to the distance centre to centre between transverse wires mesh, DT being 10 mm ($DL = DT = 10$ mm). The mesh wire diameter, $d_w = 1$ mm, was measured. For square meshes, the volume fraction can be calculated using (4).

$$V_r = \frac{N\,\pi\,{d_w}^2}{4\,h}\left[\frac{1}{D_L}+\frac{1}{D_T}\right] \quad (4)$$

Where N is the number of mesh layers; dw is the mesh wire diameter; DL is the centre-to-centre distance between longitudinal wires; DT is the centre-to-centre distance between transverse wires, and h is the ferrocement element width.

III. Results and Discussion

A. Compressive Strength of Mortar

Cube test was conducted on the mortar with a different percentage of PPF content, and the result is shown in Fig. 1. The increased amount of PPF decreased the compressive strength of the mortar. About 38% of increment of compressive strength for each 0.3% addition of PPF into the cement mortar.

B. Physical Observation

Based on physical observation, it was observed that by increasing the percentage of PPF, ferrocement taking a longer time to reach failure. This observation shows that PPF can reduce failure of ferrocement structure due to flexural. Fig. 2 shows ferrocement was cracking at the middle of the span due to flexural load.

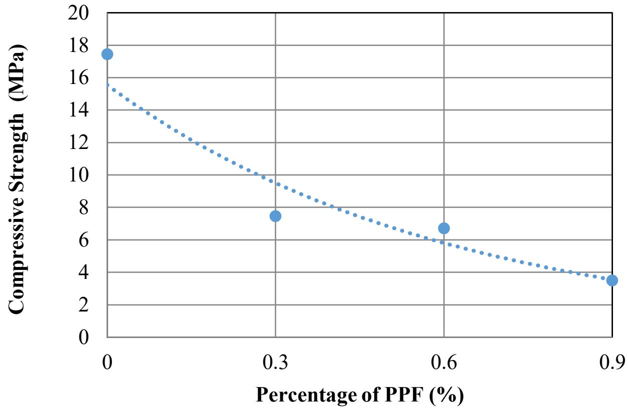

Fig. 1. The compressive strength of the mortar cube

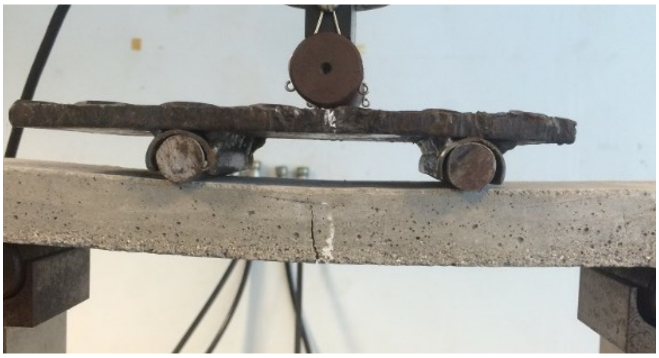

Fig. 2. Failure in the middle of the span due to flexural

C. Flexural Strength

The maximum flexural strength achieved by ferrocement reinforced with polypropylene fibres is shown in Table II. Based on that result, for 0% to 0.6% of fibres, the flexural strength was observed increase. However, by increasing the percentage of polypropylene fibres more than 0.6%, the flexural strength of ferrocement was observed decreased and even lower than ferrocement without the fibres. Fig. 3 shows the graph of flexural stress over the strain for ferrocement with PPF 0.3% and V_r of 0.0377 (i.e. sample with 6 layers of wire mesh)

TABLE II. FLEXURAL STRENGTH OF FERROCEMENT REINFORCED WITH POLYPROPYLENE FIBRE

Layer	0% PPF	0.3% PPF	0.6% PPF	0.9% PPF
2	4.16	6.76	7.61	1.67
4	7.75	8.61	10.23	5.87
6	11.82	12.08	12.75	8.03

The unit is MPa

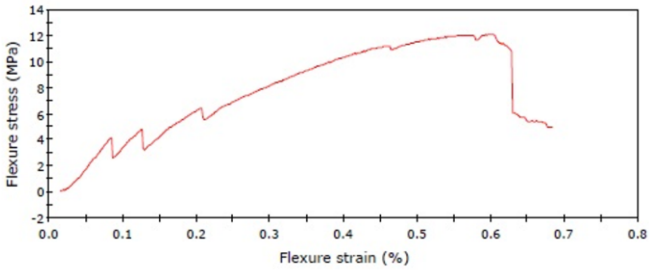

Fig. 3. Graph of the stress and strain from the flexural test.

Fig. 4 plots the flexural strength of ferrocement graph versus the reinforcement volume fraction It was observed that, corresponding to the resistance of the mesh layer, increasing the volume fraction of the structure or the number of reinforcing mesh layers leads to a minor increase in the flexural strength of the ferrocements. However, the increase in the volume fraction of steel reinforcement does not result in a proportional increase in the strength of the bending moment. Positioning meshes also plays a purpose in resisting ferrocement bending and twisting. The intermediate meshes positioned near the centre of the section do not add to the resistance of bending as much as the meshes positioned near the exterior surfaces, as stated in [8].

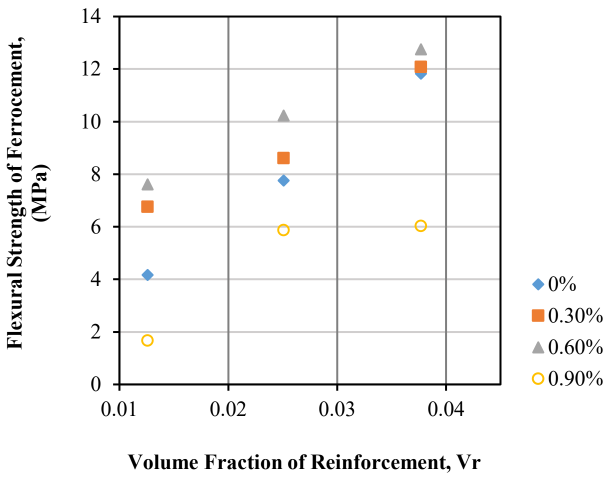

Fig. 4. Flexural Strength of ferrocement versus volume fraction of reinforcement

D. 3-Dimensional Surface Plot

Analysis of 3-dimensional surface plots had been performed. A surface plot that fit the 3-dimensional scatterplot was produced as shown in Fig. 5 which shows the relationship between flexural strength, the percentage of PPF and the volume fraction of steel mesh reinforcement, V_r. A surface function that fit the surface plot was derived to estimate the flexural strength of ferrocement reinforced with polypropylene fibres as in (5).

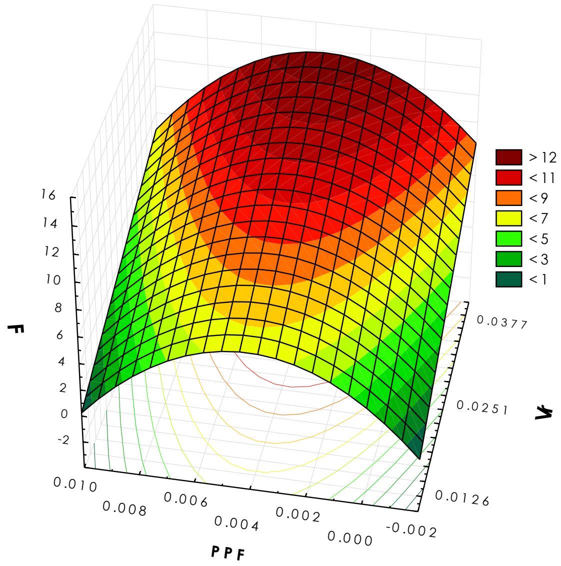

Fig. 5. 3-Dimensional surface plot

$$M_u = 0.82 + 273.78V_r + 1461.15P_f - 109.15{V_r}^2 - 5434.66V_rP_f - 1.74 \times 10^5{P_f}^2 \quad (5)$$

Where M_u is the flexural strength; P_f is the percentage of polypropylene fibres, and V_r is the volume fraction of the steel wire meshes.

In terms of accuracy of (5), most of the empirical values give less than 10% different compared to experiment value, which showing that the equation developed by this analysis can be used in practice. Only three values give percentage different with more than 10% as shown in Fig. 6, which might be due to a technical error while conducting a laboratory experiment.

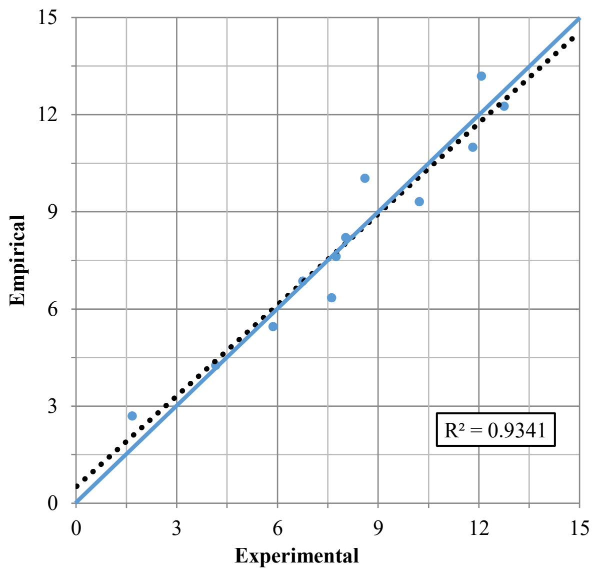

Fig. 6. Correlation of empirical and experimental results

E. Effect of Polypropylene Fibres

Based on the experimental result, the addition of PPF improved the flexural strength of ferrocement however too many fibres in the mortar will reduce the flexural strength due to poor compaction of cement mortar which leads to increases of air voids [18]. During the casting process, the compaction of the matrix mixture is become more challenging to be managed when the percentage of fibres increased from 0.6% to 0.9%. With poor dispersion of PPF in the cement matrix, it could cause increases of entrapped air voids and becomes a weak point of the ferrocement structure.

It was found that under flexural test, 66.6% of the variation in flexural strength of ferrocement was influenced by volume fraction, V_r; 31.4% by the percentage of polypropylene fibres, P_f and 2% by the interaction between P_f and V_r. Based on this analysis, it shows that the flexural strength of ferrocement was more influenced by the percentage of steel wire mesh reinforcement (i.e. volume fraction of the steel wire mesh).

IV. Conclusion

From the experimental result, it can be concluded that adding polypropylene fibres can improve the flexural strength of ferrocement. The optimum percentage of polypropylene fibres to be added is 0.6%; beyond that, the flexural strength will start decreases. The existence of polypropylene fibres in ferrocement also had observed decreasing the possibility of catastrophic failure

Acknowledgment

The authors would like to thank Universiti Tenaga Nasional (UNITEN) for financial support through UNITEN Internal Grant No. J510050439 and for the opportunity to publish this paper.

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