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Effect of Polypropylene Fibres on Torsional Strength of Ferrocement

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Abstract

Objectives: This paper presents a study on effect of adding Polypropylene (PP) fibres on torsional strength of ferrocement. **Method:** The main investigation was based on experimental works on torsional strength of ferrocement. In this study, the different percentage of PP fibres was added into the ferrocement mortar. The amount of PP fibre was added from 0%, 0.3%, 0.6% and 0.9%. A torsion test rig was developed specifically for this study to ensure torsional force applied equally at both end of the test specimens. **Finding:** It is determined that 67.2% of the torsional strength variation of the ferrocement was influenced by PP fibres. In comparison to the normal ferrocement without additional PP fibres, there was torsional strength improvement about 38% contributed by PP fibres to the ferrocement specimens. The effects given by interaction of PP fibre and volume faction of the mesh on torsion were only 2.3%. The predictive applied torque equations were derived from this study. There is a good agreement between the predicted values of maximum applied torque to the observed value from the experiment where less of 5% different was observed. **Application:** From this study, it is concluded that by adding PP fibre to the ferrocement mortar the crack can be reduced and the PP fibres contribute to the torsional strength.

Keywords: Ferrocement, Polypropylene Fibre, Predicted Applied Torque, Torsional Strength, Volume Fraction

1. Introduction

Ferrocement was defined in general as a thin cement-based matrix which reinforced by steel wire meshes. It had become the promising composite material for prefabrication and industrialization of the building industry[1]. However, its acceptance is mired mainly due to labour intensive method of production[2]. As a cement-based matrix, ferrocement is a non-uniform mixture in composition, which can lead to undesirable effects such as developing of internal micro-cracks. These micro-cracks tend to propagate due to external imposed structural load and environmental effects, which later causing the joining of micro-cracks and yield larger cracks. Application of fibres in concrete starts getting attention in construction sector since its potential has been discovered in improving the concrete integrity. In the mid-1980, the application of high-performance fibre reinforced polymeric reinforcement has started getting attention in structural engineering[3]. Those fibres were not added to improve the strength of concrete but mainly to control cracking due to plastic shrinkage and drying shrinkage[4,5]. Fibres also able to change the behaviour of material by bridging the cracksit was demonstrated that adding a few short fibres can increase the capability of concrete to sew the crack sides and preventing crack opening[6]. Apart from durability against shrinkage cracks, fibres in thin concrete are also can provide energy absorption capability in term of their impact and delamination resistance[7]. Had observed that additional amount of 0.1% of PP fibres in the plain concrete had increased 44% of flexural toughness of the concrete[8]. A study by Fathoni and Syazwan also found that adding amaximum of 0.6% of PP fibres had increased the flexural strength average by 40% and

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the steel wire meshes reinforcement had sustained bending on ferrocement beam more than PP fibres. There are 66.6% of the variation in the flexural strength of ferrocement was influenced by the volume fraction of steel mesh reinforcement V_r. Thus, for the continuation of understanding the effect of PP fibre in ferrocement, the objective of this paper is to determine the torsion capacity of ferrocement plate with the different volume fraction of steel fibre and percentage of PP fibre.

2. Experimental works

There are 12 samples of ferrocement beam with a dimension of 250 mm × 80 mm × 25 mm had been prepared and tested for torsion. Each sample was reinforced with different percentage of PP fibres (i.e. 0%, 0.3%, 0.6% and 0.9%). For each percentage value of PP, the ferrocement beam was reinforced with adifferent number of layers of steel wire meshes (i.e. 2 layers, 4 layers and 6 layers) that contribute to volume fraction. The volume fraction, V_r is ratio of the volume of reinforcement to the volume of the composite. The percentage of PP fibre and V_r are listed in Table 1. In this study, three different number of mesh layers, N had been used which are 2, 4 and 6 layers that would give difference value of V_r. Since square steel wire meshes were used, the distance centre to centre between longitudinal wires, D_L is equal to distance centre to centre between transverse wires, D_T which is 10 mm ($D_L = D_T = 10$ mm). The diameter of mesh wire, $d_w = 1$ mm was measured. The volume fraction of steel wire mesh, V_r can be calculated by using following Equation as in (1).

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

Compression test was conducted on the cube mortar with different percentage of polypropylene fibres content, P_f and the result is shown in Figure 1. The compression test was conducted based on ASTM C109/C109M - 16a[9]. Based on the graph in Figure 1, the compression of mortar cubes was observed decreasing by further increasing of PP fibres content. A possible reason for this observation could be the PP fibres were not dispersed well into cement mortar, which causing the poor integrity of mortar particles. A similar observation was mentioned where they conclude that PP fibres had increased pore volume which creates more macro defects in cement matrix[10]. Type of mesh used throughout this study was square welded wire mesh and anet cover of the reinforcement was set to 3 mm as range recommended by ACI committee 549 which is 2 mm to 5 mm[11,12]. The mesh reinforcement arrangements are shown in Table 2 the same arrangement for flexural test in. To apply torsion on ferrocement beam, both ends of thebeam must be able to rotate around the axis that parallel to the longitudinal axis of the beam. Figure 2 shows the torsional test arrangement where it consists of rotating platform to allow both ends of ferrocement beam to rotate when force, P is applied on the moment arm that attached on top of ferrocement beam. The distance of moment arm, r to the centre of the beam was set to 100 mm. The maximum torque, T applied was calculated as $P \times r$ where P is the maximum point load applied before the beam reaches failure.

Table 1. Test sample specifications

Sample No.	% of PP fibres	V_r
S1	0%	0.0126
S2	0%	0.0251
S3	0%	0.0377
S4	0.3%	0.0126
S5	0.3%	0.0251
S6	0.3%	0.0377
S7	0.6%	0.0126
S8	0.6%	0.0251
S9	0.6%	0.0377
S10	0.9%	0.0126
S11	0.9%	0.0251
S12	0.9%	0.0377

Table 2. Test sample specifications

Meshes arrangement		
Net cover	Distance between mesh	Number of mesh layer
3 mm	19 mm	2
3 mm	6 mm	4
3 mm	3 mm	6

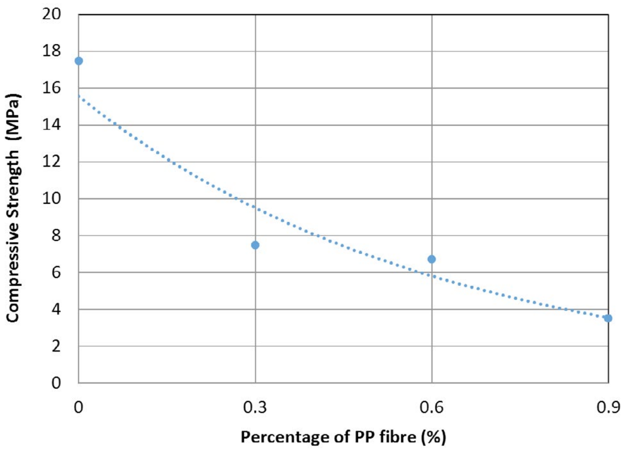

Figure 1. Compressive strength of mortar.

Figure 2. Torsion test arrangement.

3. Result and Discussion

3.1 Physical Observation

All specimens in observation have failed with 45° fracture lines as shown in Figure 3. It was observed that by increasing the percentage of PP fibres, ferrocement takes a longer time to reach failure. It took approximately 10 to 20-second delay to reach failure compared to the control specimen (i.e. ferrocement with $P_f = 0\%$). The same phenomenon also was observed during compression test, where mortar cube with higher P_f took a longer period of compression before it failed. This observation showing that adding PP fibres into the mortar matrix capable to reduce catastrophic failure of ferrocement when torsion is applied.

Figure 3. Line fractures of 45° due to torsion.

3.2 Predictive Maximum Applied Torque

In this study, analysis of 3-dimensional surface plots was performed by plotting three variables of T, V_r and P_f. A surface plot that fit the 3-dimensional scatterplot is produced as shown in Figure 4. The surface function that fit into the surface plot is derived to estimate the maximum applied torque on ferrocement reinforced with PP fibres expressed as in (2).

$$\mathrm{T} = 39.04 + 6199.33P_f + 320.63V_r - 669910\,P_f^2 + 25833.49P_fV_r + 1621.13V_r^2 \qquad (2)$$

The non-linear regression Equation is also derived based on aquadratic function of those variables for comparison purpose. The Equation is expressed as follows:

$$T = 36.12 + 6848.61P_f + 436.88V_r - 669907.41P_f^2 + 1621.13V_r^2 \qquad (3)$$

Table 3 presents the comparison of maximum applied torque observed from the experiment and predicted using Equations as in (2) and in (3). There are different in anaverage of 4.04% for Equation (2) and 4. 17% for Equation (3) on the predicted value compared to the observed value of maximum applied torque. The coefficient of multiple correlations, R^2 for Equation (2) is 0. 893 and 0.883 for Equation (3) show a good agreement on the result of thepredicted value of maximum applied torque.

Table 3. Maximum applied torque

P_f	V_r	$T_{exp.}$	T (Eq .2)	Diff.	T (Eq. 3)	Diff.
		Nm	**Nm**		**Nm**	
0.00%	0.0126	46.00	43.34	5.78%	41.88	8.95%
0.00%	0.0251	49.00	48.11	1.81%	48.11	1.82%
0.00%	0.0377	53.20	53.43	0.44%	54.90	3.19%
0.30%	0.0126	52.50	56.89	8.35%	56.40	7.43%
0.30%	0.0251	60.00	62.63	4.38%	62.62	4.37%
0.30%	0.0377	66.00	68.93	4.43%	69.41	5.17%
0.60%	0.0126	59.00	58.37	1.06%	58.86	0.24%
0.60%	0.0251	68.00	65.08	4.29%	65.08	4.29%
0.60%	0.0377	78.75	72.36	8.12%	71.87	8.74%
0.90%	0.0126	48.90	47.80	2.25%	49.26	0.73%
0.90%	0.0251	54.30	55.48	2.17%	55.48	2.18%
0.90%	0.0377	60.50	63.73	5.34%	62.27	2.93%
			Mean	**4.04%**		**4.17%**

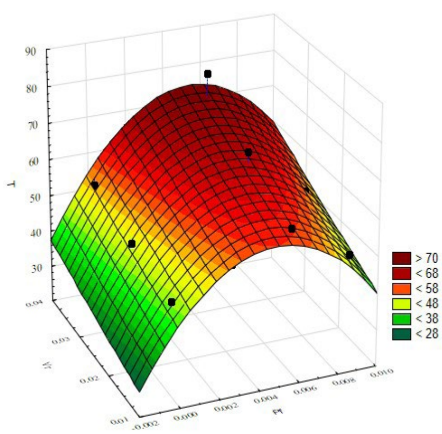

Figure 4. Surface plot of maximum applied torque, T.

3.3 Torsional Strength

For a narrow rectangular beam under torsion, the maximum shear can be calculated as follows[13]:

$$\tau_{max} = \frac{3T}{bh^2} \tag{4}$$

By substitute T into Equation (4), maximum shear to determine the torsional strength of ferrocement reinforced with Polypropylene fibre could be predicted. Under the torsion, P_f was found as the main factor that influences result variation of torsional stress by 67.2% compared to V_r which is influenced by only 30.5% of result variation. The effects given by interaction of P_f and V_r on torsion were only 2.3%. The torsional strength of ferrocement reinforced with PP fibres are calculated both Equations as in (2). A graph of the torsional strength of ferrocement versus volume fraction of reinforcement was plotted as shown in Figure 5. It was observed that by increasing the volume fraction of reinforcement (or equivalently the number of reinforcing mesh layers) lead to the linearly increasing in thetorsional strength of ferrocement due to resistance is given by the mesh reinforcement.

Based on the result, for 0% to 0.6% of PP fibres, the torsional strength was increased by an average of 38.4%. However, the torsional strength of ferrocement was observed decreased on the percentage of PP fibres more than 0.6% and even almost lower than ferrocement without the PP fibres. However, the increment in volume fraction of steel reinforcement does not lead to a proportional increase in twisting resistance. This is because the positioning of meshes also plays role in resisting twisting of ferrocement. As an example, intermediate meshes placed near the centroid of the section do not contribute on resisting twisting as much as meshes placed near the outer surfaces[14].

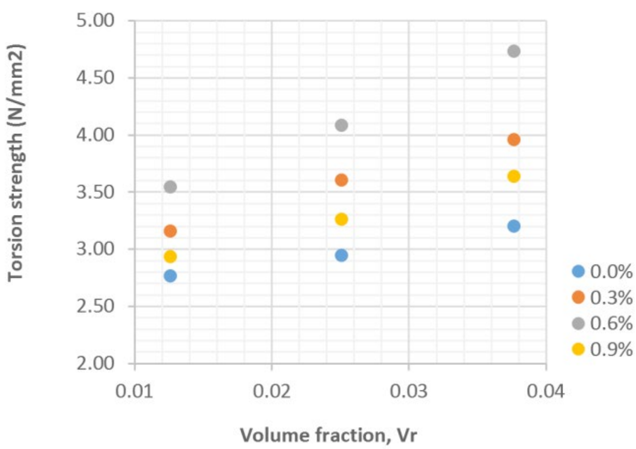

Figure 5. Torsional strength of ferrocement with different V_r.

4. Conclusion

An investigation has been made on the effects of polypropylene fibres on the ferrocement with different layers of steel wire fibres. This is done using experimental works and statistical analysis to derive the non-linear regression equation to predict the torsional strength of ferrocement based on the value of V_r and P_f. A good agreement between the predicted values of maximum applied torque to observed value from the experiment. It is also observed that the existence of polypropylene fibres in ferrocement improve the possibility of failure resistance by providing ahigher value of torsional strength.

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