Shear Behaviour of Permanent Precast Formwork Beams

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Abstract. An experimental research was conducted to evaluate the shear capacity of permanent precast formwork beams and compared to normal cast in-situ concrete beams. The traditional approach of normal construction uses conventional timber and plywood, which requires laborious and time consumption of installation. This paper studies the shear behaviour of permanent precast concrete beams using different glass fibre volume (ranging from 0% and up to 1%) in mortar mixes to act as permanent formwork. The mechanical properties tests involved in the mortar were compressive and flexural strength tests. The optimum content of glass fibre then was determined based on several trial mixes made beforehand. Two permanent precast formwork beams, one used 0.52% of glass fibre and the other one used wire mesh were tested under $a_v/d = 1.5$ and compared with normal control beam. All beam specimens were tested to obtain the ultimate shear load. The results showed that permanent precast formwork beam with wire mesh gave better performance in terms of ultimate load. Measured shear capacities of the tested beams were then compared with the theoretical values calculated according to BSEN1992:2004.

Introduction

Traditionally timber formwork is built in construction for production of beam, column and other structures. The formwork which is made of plywood or timber may have to be replaced after few times of usage. Moreover, timber formwork would subject to the shrinkage factors and water which cause the defect to the concrete, thus requires high skills labor to construct wood formwork in the construction site. The cost of formwork exceeds the cost of concrete or steel products. Economy in construction involves many factors including the cost of labor in making, erecting and removing the formwork. Thus, glass fibre reinforced concrete permanent formwork provides one of the most cost effective methods for constructing bridges and viaduct decks when used in conjunction with precast beams [1].

In the new era of construction, a more efficient and advantageous type of formwork which widely being is the permanent precast formwork. Permanent precast formwork is of the highest possible quality, both in terms of strength and durability [2]. The innovative approach was proposed the combination of permanent precast formwork with wire mesh and glass fibre. Aashwaq and Hafiz (2012) reported that ferrocement permanent forms to be used for construction of reinforced concrete beam showed that high ultimate and serviceability loads, crack resistance control, high ductility, and good energy absorption [3]. The beams rehabilitated with mesh show better performance in terms of ultimate strength, first crack load, crack width, ductility and rigidity of the section [4].

Utilization of glass fibers in concrete was first attempted in Russia in the late 1950s. Significant development work at the building research establishment in England led to the production of alkali-resistance glass fibers containing zirconia in the late 1960s. The use of alkali resistant glass fibers significantly improves the flexural strength irrespective of affecting the workability of concrete mixes [5]. It has been proved that fibers in the mortar will improve the mechanical properties by restraining the cracks propagation. The ultimate flexural strength increased with increasing volume fraction of the fiber by the arresting growth of cracks [6].

Materials

The concrete mortar used for casting permanent formwork beam was designed to achieve the compressive strength of 30 Mpa at 28 days. The materials for the mortar are cement, water and sand. The type of glass fibre used in mortar is E-glass with density of 2550 kg/m^3. The proportions of cement to sand in the mortar are 1:2 and 2:3. The design method determines a set of mix proportions for producing a mortar that has approximately the required properties of strength and workability. The mortar has been designed in three different of fibre volume fractions which are 0.5%, 0.75% and 1.0%. After several trial mixes, the proportion 2:3 of cement and sand and 0.52 % content of optimum glass fibre was used as mortar mix design for casting the permanent formwork beam. Water-cement ratio is constant 0.5 for all mixtures. The mix proportions for mortar shown in Table 1.

Table 1: Mortar mix design

	Mortar with ratio 1.5 : 3	Mortar with ratio 2 : 3
Cement (kg)	6.83	8.19
Sand (kg)	13.66	12.29
Water (kg)	3.42	4.10

Beam Specimens

Three beam specimens were casted. Two beams were made of permanent precast formwork beams, one using 0.52% of glass fibre in the mortar (GF) and another one used 10mm x 10mm steel wire mesh (WM). The third beam acts as control specimen (NC) are shown in Figure 1. The dimension of all beam specimens is 150 x 300 x 3000mm. The reinforcement was designed according to BSEN1992:2004. All beams contain 16mm and 10mm diameter of the bottom and top reinforcement, respectively. The shear link with 6mm diameter was spaced at 150mm c/c.

(a) (b)

Figure 1: Permanent Precast Formwork Beam Specimen (a) and Tested Specimens (b)

Experimental Testing

Compressive Strength Test

Compressive strength test was performed on the cubic specimen and the test was accordance to BS EN 12390-3:2009. The size of cube test specimens is 70mm × 70mm × 70mm and size of the concrete test specimen is 100mm × 100mm × 100mm. All specimens were tested at the age of 7, 14 and 28 days respectively.

Flexural Tensile Strength Test

Flexural Strength test was conducted on prism specimens with dimension 50mm×50mm×250mm of mortar. The flexure strength was determined according to ASTM C293 – Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading). This test was conducted to see the ability of glass fibre in enhancing the mortar performance with presence of glass fibre.

Shear Strength Test

Figure 1 shows the test setup for beam specimen. Hydraulic jack with load cell was placed at the location on the beam. Linear variable differential transformer (LVDT) was connected to the data logger that transferred measured deflection respective to the applied load to the computer. Load, strain and deflection were monitored automatically until the end of the test. The beams were subjected to loading with values of span-to-depth ratio (a_v/d) is 1.5.The failure mechanism of the beams which are varies according to the span-to-depth ratio (a_v/d). The failure mechanism of permanent precast formwork beams and normal beam changed from a diagonal tension failure to a shear compression failure as a_v/d decreases.

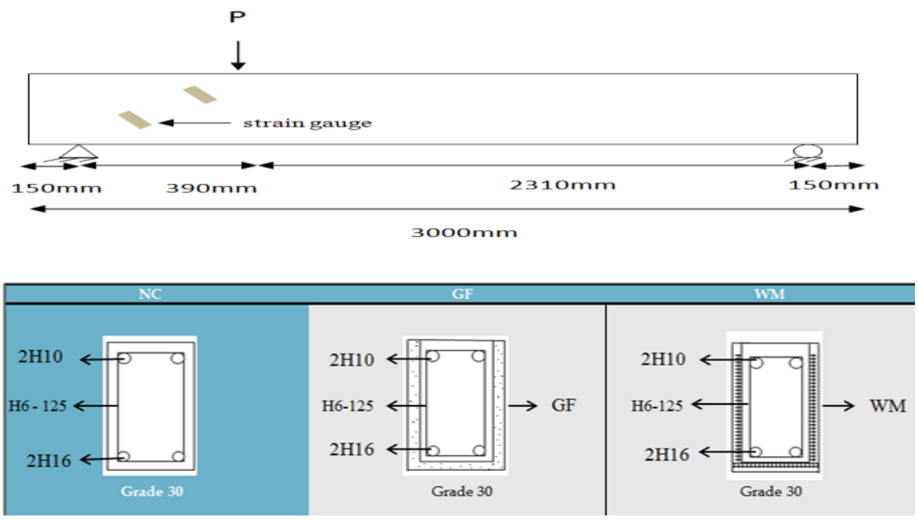

Figure 1: Beam specimens detailing and dimensions.

Result and Discussions

Compressive and Flexural Test

Figure 2 and 3 showed the strength development of mortar with various percentages of glass fibre volume. The average strength achieved for the mortar with no addition fibres was 24 MPa while for mortar ratio 1.5:3, it varied between 21 MPa and 29 MPa. The 28-days compressive strength values of mortar ratio 2:3 are 26, 35, 29 and 26 MPa, respectively. From Figure 3, the optimum content of glass fibre in mortar was found at 0.52% of glass fibre by volume with compressive strength at 28 days is 35.5 MPa. Mortar with glass fibre decreases the workability but improves the mechanical properties of mortar in compressive strength. It was also observed that at 0.75% of volume fraction, the compressive strength of concrete started to decrease.

The results of flexural strength test as depicted in Figure 4 and 5 showed that addition of glass fibers up to 1% increased the flexural strength of mortar. From the results, the flexural strength of fibrous mortar is higher about 19% to 42% than control mortar. The first crack flexural strength is also increased with the addition of glass fibers up to 3 times the strength of the plain mortar [7].

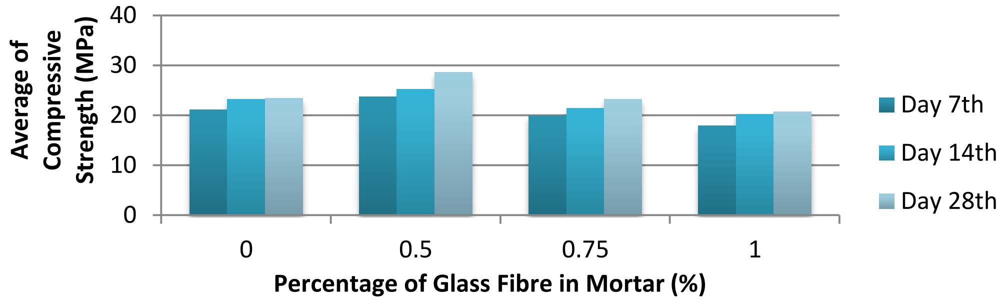

Figure 2: Average Compressive Strength (MPa) versus Percentage of Glass Fibre in Mortar (%) with ratio 1.5:3.

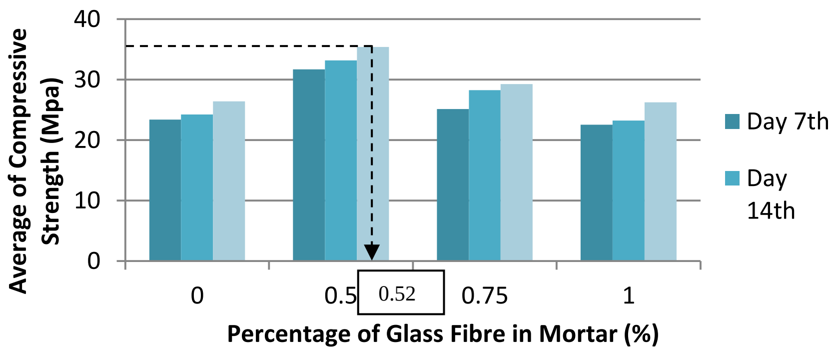

Figure 3: Average Compressive Strength (MPa) versus Percentage of Glass Fibre in Mortar (%) with ratio 2:3

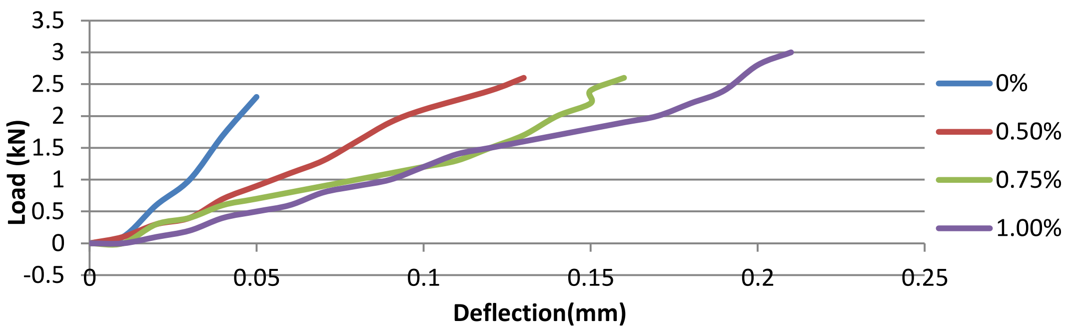

Figure 4: Load (kN) versus Deflection (mm) - Mortar 1.5:3

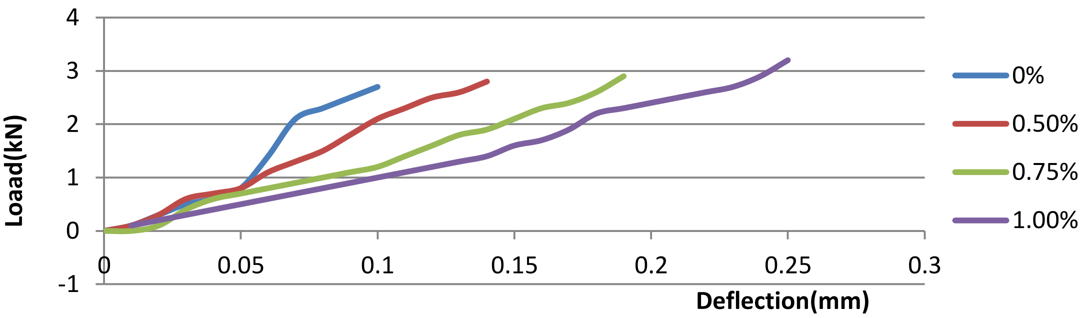

Figure 5: Load (kN) versus Deflection (mm) - Mortar 2:3

Figure 6 shows the compressive strength development of control mortar and mortar with 0.52% of glass fibre at 7, 14 and 28 days. Compressive strengths ranging from 21 to 38 MPa for all mixtures. The reason for increasing compressive strength is that the glass fibers carried the load until the loss of the interfacial bond between the fibers and the matrix.

Figure 7 shows the result of tensile strength test for control mortar and mortar with glass fibre 0.52% by volume. It was observed that the flexural strength increased with increasing 0.52% of glass fibre. The glass fibres effectively enhances the post-crack performance in the mortar. Glass fibres prevent the brittle failure of matrix and delayed the growth of crack. Compared to the compressive strength, the performance of glass fibres mortar was more significant in flexural strength.

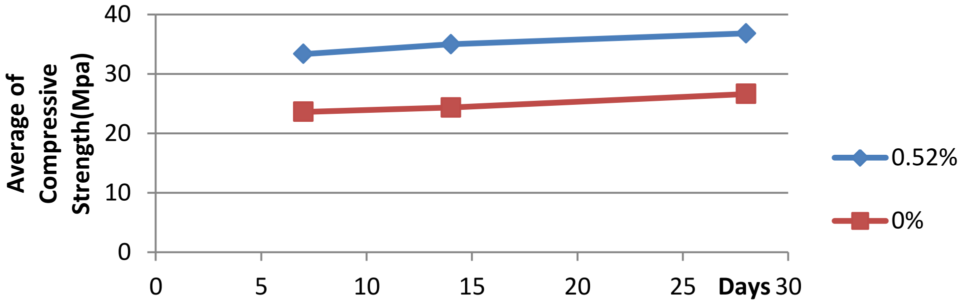

Figure 6: Average Compressive Strength (MPa) versus Days

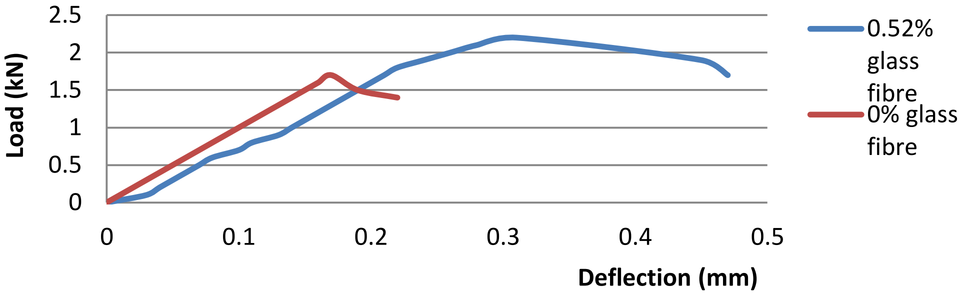

Figure 7: Load (kN) versus Deflection (mm)

Shear Strength Test

The load versus deflection of the beams tested is shown in Figure 8. The ultimate failure of the normal concrete beam reached 189 kN. Permanent precast formwork beams with glass fibre and wire mesh can sustained up to 213 and 243kN, respectively. The results showed that the permanent precast formwork beam with wire mesh achieved higher strength followed by the permanent precast formwork beam with glass fibre and normal beam. The close spacing of wire mesh in permanent precast formwork improves ductility and leads to crack resistance. Glass fibres also helps in restricting the growth of micro-cracks in the permanent precast formwork beam.

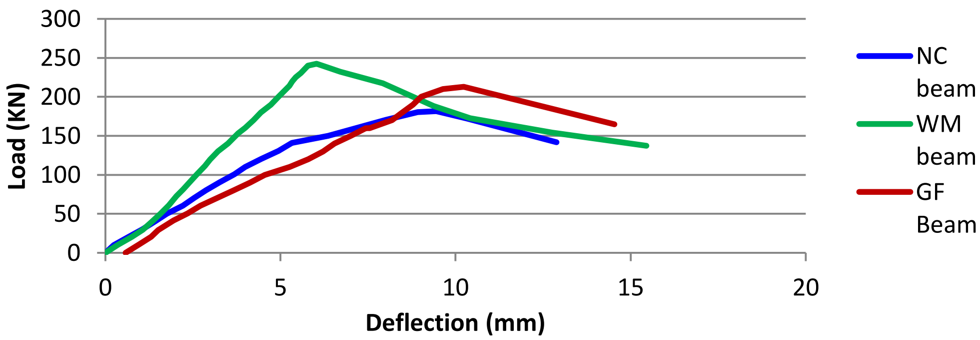

Figure 8: Load (kN) versus Deflection (mm)

Comparing shear experimental with shear theoretical

Table 2 shows the result of shear force values obtained from permanent precast formwork beams and normal beam testing. The ratio *M/V* at the critical subjected to maximum V is expressed by a distance av called shear span between the support and the load.

From Table 3 shown the comparison value of theoretical maximum design shear force, $V_{Rd,max}$ and experimental shear strength. The theoretical values was calculated according to BSEN 1992: 2004, taking into account the measured crack inclination, θ. The comparison showed that normal beam has the lowest shear ratio compared with other two samples with value 0.88. However, two other samples permanent precast formwork beam with glass fibre and permanent precast formwork beam with wire mesh had almost the same value 0.94 and 0.98, respectively.

Table 2: The Experimental Shear Strength

Specimen	Ultimate Load (Experimental) kN	Shear force (V1= 0.856P) kN	Shear force (V2=0.144P) kN
NB	189.5	162.2	27.3
GF	213.0	182.3	30.7
WM	222.5	190.5	32.0

Table 3: Comparison between Experimental Shear and Theoretical Shear

Specimen	θ	b_w(mm)	V_2 (Exp) (kN)	$V_{Rd,max}$ (Theoretical) (kN)	$V_{Exp}/V_{Rd,max}$
NB	37	147	162.2	185	0.88
GF	38	151	182.3	193	0.94
WM	40	150	190.5	195	0.98

Conclusion

The addition of 0.52% glass fibre volume in mortar improved the flexural strength. The application of fibrous mortar as permanent precast concrete formwork beam was found to increase the shear resistance. The inclusion of wire mesh in mortar has increased the shear strength up to 29% compared to normal control beam. In addition, wire mesh and glass fibre in permanent precast formwork beam helped to stop micro cracks and improves durability.

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