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Performance of Plain Concrete Beam Retrofitted with Textile Waste Composite

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ABSTRACT

The increasing numbers of textile waste in Malaysia are alarming when in 2018 approximately 195300 tonnes of textile waste were dumped and occupied about 6.3% and this was double in 2012 (2.8%). Textiles made of synthetic fibers such as nylon, lycra, polyvinyl chloride, polyurethane, and spandex could be detrimental to the environment and take up to 200 years to decompose in landfills. The tensile strength of the textile could achieve up to 800 MPa and potentially be used as retrofitting materials. This study aims to utilize textile waste as one of the structural retrofitting materials with specific objectives (i) to determine the tensile strength of textile waste layered with epoxy namely textile waste composite (TWC) and, (ii) to determine the optimal configuration of TWC retrofitting on plain concrete beams. The tensile strength of TWC with different layers (1 layer, 2 layers, and 3 layers) was determined by conducting a tensile test. For the TWC retrofitting works, several methods were implemented for the plain concrete beamlets samples i.e., full wrapping, diagonal wrapping, and mesh wrapping. Four -point bending test was conducted to determine the flexural strength of the retrofitted concrete beamlets. The TWC showed promising results on the flexural strength performance of the plain concrete beamlets.

1. Introduction

Textile is made of organic or synthetic fibres. The term *"textile"* was derived from the French word *"texere"* and Latin word *"textilis"* which come to the meaning of "to weave" and originally it was only to woven fabrics. However, the term textile now includes all types of fabric that were produced by other methods such as threads, cords, ropes, braids, lace, embroidery, nets, and fabrics made by weaving, knitting, bonding, felting, and tufting.

The textile manufacturing process consists of several steps i.e. (i) procuring, (ii) spinning process, and (iii) warping. During the procuring process, the raw materials of the fibers are selected i.e., natural fibers (cotton, hemp, silk) or synthetic fibers (nylon, polypropylene, polyester). The selected fibers are twisted to produce long continuous thread through the spinning process. The threads are then used to the warping process which is the process of separation of thread on a long cylindrical beam. The warping of threads is important as the weaving process is the interlacing of threads at an angle. The weaving takes two steps which are warping which is the long continuous whereas weft is the threads that interlace in between the warp threads and produces woven textile. The basic patterns of weaving are plain, which is the most common pattern, the satin weave, which can result in the smooth surface of fabric, and the twill pattern weave, that can be distinguished by the diagonal pattern weave.

Nowadays, fast fashion addiction results in large numbers of textile production when about 60% of total global fabric used represents clothing [1]. This situation causes global environmental issues due to waste generation and contributes immensely to landfills [2-4]. Textile waste in Malaysia was reported as the second most polluting industry and the textile waste numbers significantly increased from 2012 (2.8%) to 2018 (6.3%). It becomes more detrimental to the environment when 60% of the textile is made of synthetic fiber that takes up to 200 years to decompose. Synthetic fibre such as nylon, polypropylene, and polyester are commonly produced as similar to plastic using petroleum as raw materials [5]. The hydrophobic characteristic of synthetic fibre offers a good potential to be integrated into building construction materials with the ultimate tensile strength of the synthetic fibre between 80 MPa to 830 MPa (see Table 1) [6].

Table 1
Ultimate tensile strength and Young's modulus of various fibres [6]

Fiber type	Ultimate tensile strength, UTS (MPa)	Young modulus (MPa)
Cotton	287 – 597	5500 – 12600
Silk	35 – 83	Not detected
Hemp	591 – 857	38000 – 58000
Polypropylene	320 – 500	3500 – 3900
Polyester	80 – 600	1450 – 2500
Nylon	156 – 830	530 – 4100

Innovation and research have been reported in utilizing textile waste in the engineering field as a textile composite [5,6,7-12]. [11] reported that incorporation recycled textile waste as reinforcement in cement-based composite with silica fume increased the flexural and tensile resistance up to 45% and 55%. Finding by [12] also revealed that the textile waste nonwoven fabric enhanced the ductility and cracking control when mixed as internal reinforcement for cement-based matrices. The incorporation of woven polypropylene fibres and textiles in gypsum-based composite false ceiling tile exhibited and satisfied the acceptable limit for the non-structural application [13]. The sound insulation materials were developed using cotton/polyester mixed waste and natural with outcome of the sound insulation properties were in par with the commercial sound insulation panels [14].

Reinforced concrete (RC) is a typical building construction material in Malaysia with an average design lifetime of about 50 years. In tropical countries, the RC buildings are usually exposed to extreme weather thus causing concrete deterioration that weakens the capacity of the RC structural elements. Structural retrofitting is one of the solutions to restore and/or improve the performance of the RC structural elements. Conventionally, structural retrofitting is carried out using steel. However, the use of steel as the main material showed a risk of corrosion for long-term durability and aesthetic appearance requires acceptance from clients [15]. A convenience material was discovered to mitigate the problems with the introduction of fibers reinforced polymers (FRP) strengthening materials such as carbon, glass and aramid. Externally bonded reinforced (EBR) wet layup method is the most common method used for the FRP retrofitting due its fast and easy installation [16-18]. However, the material and installation costs are become major concerns when compared to other materials [19].

This research was conducted to investigate the potential of textile waste composite (TWC) to be utilized as structural retrofitting materials. Tensile strength of different layers of TWC were determined prior to installation to the plain concrete beamlets as retrofitting materials. Three different configurations of TWC retrofitting were applied on concrete beamlets to determine its flexural strength.

2. Methodology

2.1 Sample preparation and experimental testing

Prior to retrofitting procedure, 12 TWC samples were prepared and tested subject to tensile test to determine the optimum layers of TWC to be installed on plain concrete beamlets as retrofitting materials. The type of textile used in this study was cotton and were cut and layered with rubber epoxy resin as adhesive with three different layers i.e., one layer (1L), two layers (2L) and three layers (3L) (see Fig. 2) and subsequently, were cut into dog bone shapes with dimension of 200 mm length and 20 mm width [20] for tensile strength test (see Fig. 3).

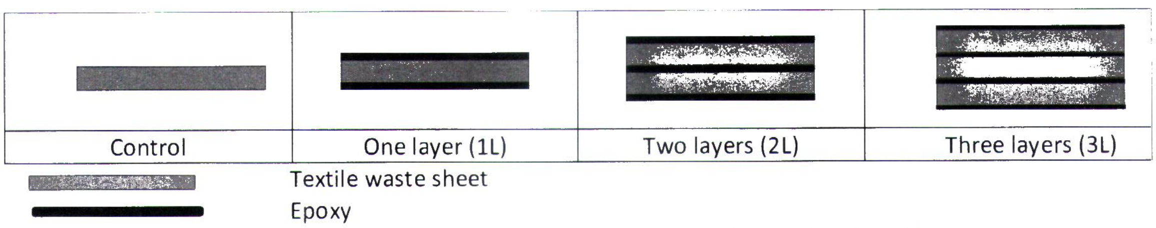


Fig. 2: Configurations of textile waste composite layered with rubber epoxy

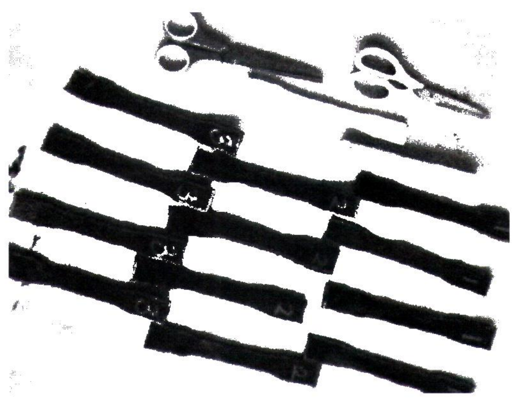


Fig. 3: Dog bone shape of textile waste composite samples for tensile strength test

The TWC were left up to three days for epoxy to set and then were tested subject to tensile strength test according to the ASTM E8 [20] using Universal Testing Machine (UTM) with capacity of 100 kN. The linear variable displacement transducer (LVDT) was placed at the center of the samples to record the sample's displacement during the tensile test. The setup of the testing is shown in Fig. 4.

12 numbers of grade 30 plain concrete beamlets with dimensions of 100 mm (B) x 100 mm (W) x 500 mm (L) were cast and cured by immersing in water for up to 28 days. The concrete beamlets then were installed with three different configurations of TWC retrofitting i.e., full wrapping (FW), diagonal wrapping (DW), and mesh wrapping (MW) with detail parameters as shown in Table 2. The retrofitted concrete beamlets were left dried up to three days prior to the testing.

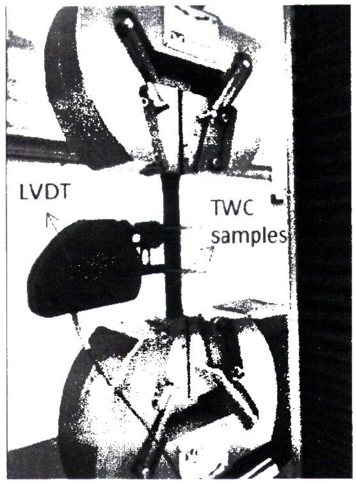
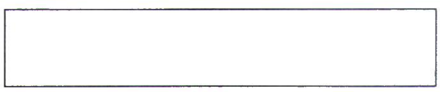
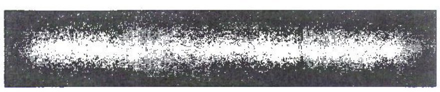
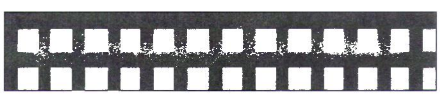
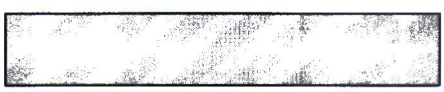


Fig. 4: Tensile strength test of TWC samples

Table 2
Configuration of TWC retrofitted plain concrete beam samples with parameters

Type of retrofitting	Side View	Parameters		
		Percentage of reinforcement, (%)	Spacing between TWC, (mm)	Angle of TWC, (°)
Control sample (CS)		-	-	-
Full wrapping (FW)		100	-	-
Mesh wrapping (MW)		75	25	-
Diagonal wrapping (DW)		25	50	45

*Note
TWC
Plain concrete beam

The concrete beamlets samples were tested under four-point bending test (see Fig. 6) in accordance with BS EN 12390 with constant rate of 0.06 MPa/s [21] to determine the flexural strength. The flexural strength of the concrete beamlets was calculated by using the Eq. (1) as follow:

$$f_{st} = \frac{F_{max} \times l}{10E^5} \tag{1}$$

where f_{st} is the flexural strength (MPa), F_{max} is the maximum loading (N), and l is the distance between the supporting rollers (mm).

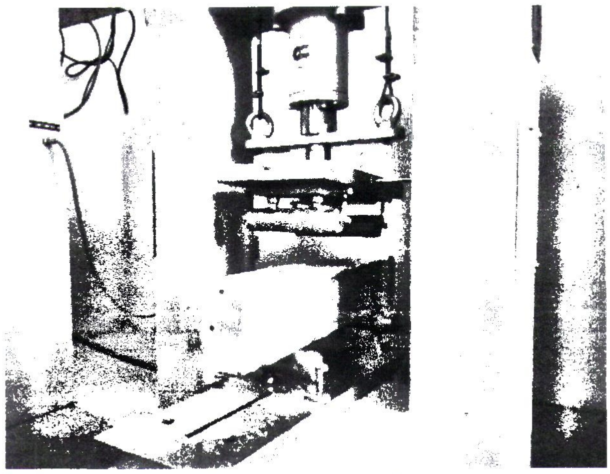


Fig. 6: Four-point bending test setup of concrete beamlet samples

3. Results

3.1 Mode of failure of TWC samples

The failure of the textile samples can be identified with (i) textile failure (TF), (ii) epoxy failure (EF), or (iii) textile + epoxy failure (TEF). The TF was observed when the layer of the textile tear (break into two parts) due to gradual loss of load-carrying capacity. The control sample and the 2L sample showed the TF (see Fig. 7(a) & Fig. 7(c)). The EF was observed on 1L sample when the layer of epoxy failed first and the textile was still presence as a sheet after the test (see Fig. 7(b)). The 3L sample (Fig. 7(d)) showed TEF failure when the combination of failure occurred.

(a) Control - TF (b) 1L - EF (c) 2L - TF (d) 3L - TEF

Fig. 7: Failure of TWC samples subject to tensile test

3.2 Load-displacement curve and tensile strength of TWC samples

The load-displacement curve of the TWC samples is as shown in Fig. 8. The patterns of the load-displacement curves were seen gradual for the control and 1L samples while 2L and 3L samples showed most likely steep linear curve when the testing was started and rising gradually until the sample break. However, the load of 2L sample started to rise again until it showed sudden drop after the second peak. It suggested that the failure of the 2L sample occurred layer by layer of the textile while the 3L samples indicated good bond between the textile and epoxy resin.

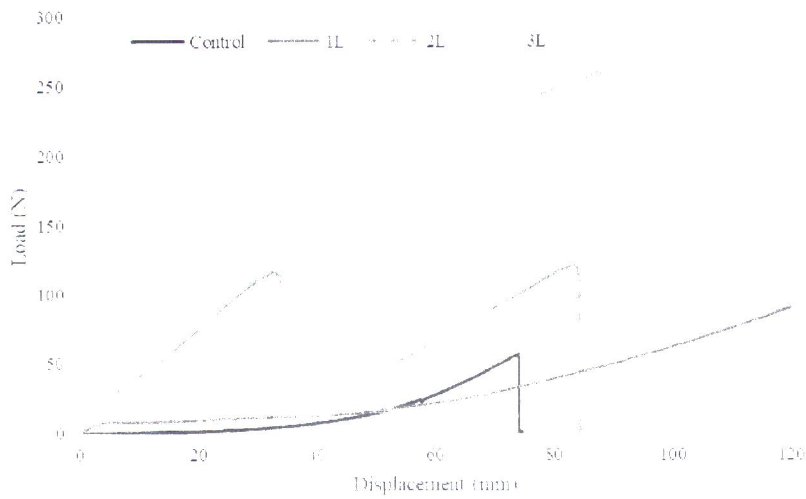


Fig. 8: Load-displacement curve of TWC sample with different layers

The average maximum loading and maximum stress of TWC samples is tabulated in Table 3. As projected, the 3L TWC samples showed the highest maximum loading and maximum stress with increment up to 400% and 30%, respectively relative to the control samples. Inadequate intact between textile and epoxy in 2L TWC samples might be resulting in stress reduction up to 30% when compared to the control sample. The 3L TWC was used as retrofitting material for the concrete beamlets.

Table 3
The tensile strength value for the TWC samples

Sample	Average maximum load, F_{ave} (N)	Average maximum stress, σ_{ave} (MPa)
Control	55.9	5.7
1L	148.8	6.4
2L	147.5	3.8
3L	291.5	7.4

3.3 Failure pattern of retrofitted concrete beamlets

The failure pattern of the concrete beamlets is as shown in Fig. 9. The CS beamlets broke into two pieces when reached the maximum load suggesting the brittle behaviour of the beamlets since there was no reinforcement installed on the beamlets. The beamlets sample with FW retrofitting showed no damage at the outer part, but when the TWC was unwrapped, the beamlets were observed to have a similar failure pattern with CS (see Fig. 9 (b)). A poor bond between the TWC and beamlets substrate was noticed since the TWC sheet was easily peeled from the beamlets. For the DW and MW beamlets, small crack lines appeared on the beamlets' surface with the absence of the TWC materials (see Fig. 9 (c) & Fig. 9 (d)). The installed TWC materials successfully held the beamlet from broke into two parts and also resisted the growth of crack lines on the concrete beamlets. No failure of TWC retrofitting material was observed.

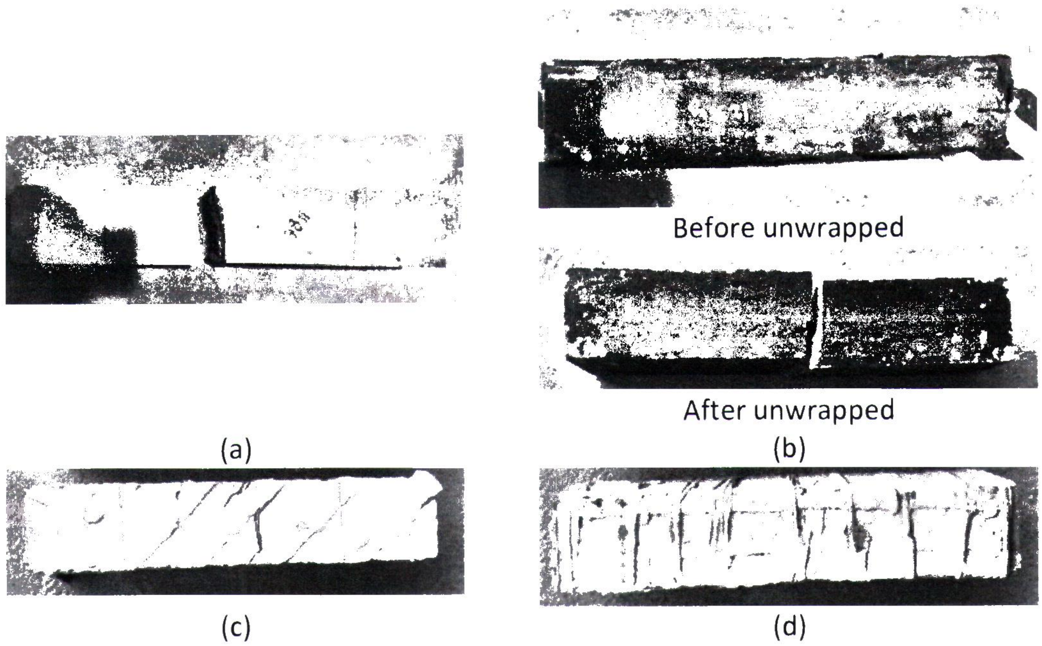


Fig. 9: Failure pattern of concrete beamlets (a) CS (b) FW (c) DW (d) MW

3.4 Flexural strength performance of concrete beamlets

The flexural strength of the beamlets samples is illustrated in Fig. 10. Installation of TWC on concrete beamlets showed a reduction in flexural strength of approximately 12%, 26%, and 5% for the FW, DW, and MW respectively when compared to the CS. Poor bonding between the TWC retrofitting materials and the substrate may lead to strength reduction. The use of rubber epoxy resin that affected the stiffness of the TWC materials might also resulted in strength reduction since the rubber epoxy resin was known for its ductility behaviour. Nevertheless, the MW configuration showed promising result since only slight strength reduction was obtained.

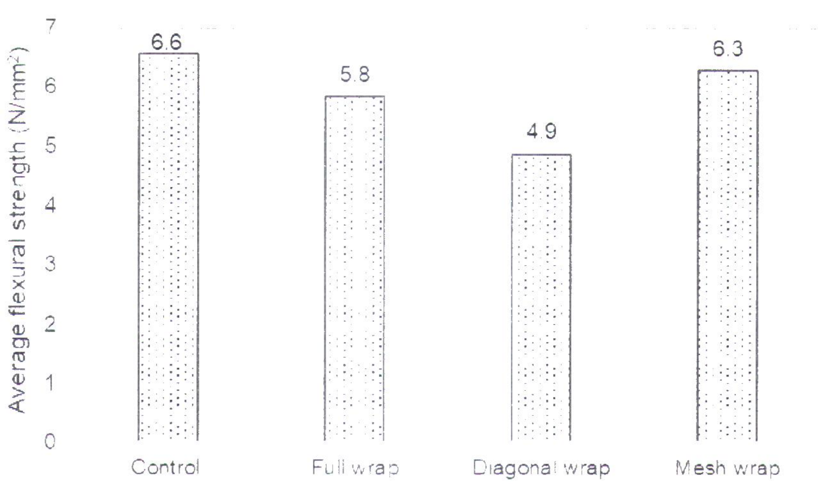


Fig. 10: Average flexural strength of concrete beamlet samples

4. Conclusions

An experimental program was conducted to reveal the potential of textile waste to be utilized as structural retrofitting materials. Cotton textile and rubber epoxy resin were combined to produce TWC retrofitting materials and undergo tensile strength tests. TWC was applied to concrete beamlets with different configurations, i.e., full wrapping, diagonal wrapping, and mesh wrapping. A four-point bending test was conducted on the concrete beamlets to determine their flexural strength performance. It can be inferred that:

(i) The highest tensile strength was 3L TWC samples with load and stress increments up to 400% and 30%, respectively compared to the control sample.
(ii) There was no significant improvement in flexural strength for the concrete beamlets retrofitted with TWC materials, yet mesh wrapping configurations showed promising results.
(iii) A poor bond between the TWC materials and concrete substrates resulted in strength reduction for the retrofitting works.

Further investigation on the development of good bond between the TWC material and concrete substrates are required.

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