MECHANICAL PROPERTIES OF HYBRID FIBRES REINFORCED POLYMER MODIFIED MORTAR IN PROMOTING SUSTAINABLE MATERIALS IN CONSTRUCTION

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ABSTRACT

Fibre reinforced polymer modified mortar (PMM) was widely accepted for multipurpose application in construction industry. However the use of natural fibre in cementitious material in terms of durability performance was not encouraging. This paper aims to investigate the mechanical properties of the hybrid fibre namely kenaf, polypropylene and bar chip in polymer modified mortar with a low water-cement ratio. The results concluded that the hybridisation of 0.4% kenaf, 0.6% polypropylene and 0.6% bar chip (G sample) exhibited the significant increment of compressive and flexural strength for both curing regimes.

Keywords*: Polymer modified mortar, Hybrid fibre, Mechanical properties.*

INTRODUCTION

The current construction industry scenario is solemnly moving towards a green building approach by adopting various aspects of recycling, reuse, and energy conservation materials (Ragheb et al., 2016). Consequently, using natural fibre from oil palm, coir, pineapple leaf, kenaf, and wood which comes from the local resources is one of the potential ways to innovate local green building materials in the construction.

Natural Fibre in Cement-Based Composite

Most of the abundant sources of natural fibre were not fully utilised and causing pollution to the environment as it was left untreated and rot (Aji et al.,2011). Many studies reported that natural fibre reinforcement showed a significant improvement of strength performance over plain cement-based composite (Ismail, 2007; Kolop et al., 2008; Aji et al., 2011; Dawood, 2011; Elsaid, et al., 2011 and Priyadharshini & Ramakrishna, 2016). However, natural fibre possesses high permeability to water and lack of crack resistance (Savastano et al., 2009 & Stevulova et al., 2014). It also requires protection from moisture since it is hydrophilic and also deteriorates over prolonged exposure. Therefore, to enhance the performance of natural fibre as a reinforcement in composite, polymer modification to the matrix was introduced. Furthermore, previous researchers have concluded that natural fibres should be adopted as part of the replacement in securing successful results as they possess low density with an excellent low strength to weight ratio, cheaper than manufactured fibres, and, importantly, are recyclable (Khalil et al., 2007). However, according to Jawaid & Abdul Khalil, (2011), there is limited information regarding the adoption of natural fibre as reinforcement in polymer-modified cement-based materials.

Many studies were conducted to incorporate synthetic fibre into a polymer-based composite to mitigate crack of the structure such as glass fibre, polyethylene fibre and carbon fibre (John, 2004; Mohammad, 2007; Jawaid & Abdul Khalil, 2011). However, most of the manufactured fibres cost viable for the industry. Therefore, there has been a definite interest in natural fibres for the last decade due to their advantages and potential as a green material.

Khalil et al. (2007) revealed that the hybridisation of natural fibre and synthetic fibre could obtain the best properties of both constituents. However, the investigation has been limited to polymer composites only, not in polymer modified cement-based composite. The literature also revealed that there is a limited study conducted worldwide regarding the hybridisation of natural fibres and synthetic fibres. Therefore, this study intended to investigate the mechanical properties of hybrid fibre reinforced polymer modified mortar by using kenaf (Kf) as a natural fibre and polypropylene (PP) and bar chip (BC) as micro and macro synthetic fibre.

Polymer Modified Mortar

According to Ohama (1995), polymer modified mortar (PMM) is a polymer composite made by partially replacing the cement hydrate binders of conventional cement with polymer additives, such as latexes, powdered emulsions, water-soluble polymers, liquid resins, and monomers. PMM provides several benefits, such as increase the tensile and adhesive bond strength, improved water retention, and reduced permeability. However, according to Colville et al. (1999), the addition of polymer to cement matrix could reduce the compressive strength, depending on the polymer type and addition rate. The suitable addition rates of the polymer usually are less than 20% by weight of cement and are commonly between 10 and 15%.

The objective of this study is to examine the mechanical properties of various types of hybrid fibre reinforced polymer modified mortar in different curing conditions. Styrene-butadiene rubber (SBR) is used as a polymer in this study due to its ability to provide consistency by the ball bearing effect of the polymer particles (Rixom & Mailvaganam, 1999) and can be successfully bonded to many materials (Huang et al., 2010).

LITERATURE REVIEW

A study conducted by Dawood (2011) on the development of fibres reinforced flowable high strength mortar and concrete as repair materials reported that the compressive strength increased with the inclusion of steel fibre in the polymer mortar. It was due to the enhancement in the mechanical bond between the mortar and the steel fibre. The study also revealed that the

incorporation of a low volume fraction of palm and bar chip fibre improved the compressive strength.

Kim & Park (2013) conducted a study on the strength, permeability, and durability of hybrid fibre-reinforced concrete containing SBR latex. Two types of synthetic fibres namely polyvinyl alcohol (PVA) and polypropylene (PP) were used in this study with different percentage of SBR latex. The result revealed that the compressive strength decreased with an increase in the latex content. However, the tensile and flexural strengths of concrete were increased with the addition of latex.

A short period investigation on fibrous latex modified concrete overlays with a combination of macro and micro-synthetic fibres by Alhassan & Ashur (2011) revealed an outstanding achievement of mechanical strength. At four days testing the samples achieved 28 MPa and later at 14 days testing the mixtures achieved 41 MPa of compressive strength.

Fibres types also influenced the mechanical strength of composite (Fordos, 1988; Alhassan & Ashur, 2011; Habib & Begum, 2013; Armagan & Canbaz, 2016 & Lerch et al., 2018).

The investigation of natural fibre reinforcement used a similar approach to that used for other types of fibre. Therefore, crack propagation, tensile strength, flexural strength, workability, and other mechanical and physical properties of the composite were investigated using a similar approach to that used for other non-natural fibres (Yao & Ge, 2012; Yousif et al., 2012; Kim & Park, 2013; Susilorini et al., 2014; Atiqah et al.,2014; Saba et al., 2015; Zia & Paul, 2015; Fallah & Nematzadeh, 2017 & Lee et al., 2017).

Many researchers (Balaguru & Shah, 1992; Yao et al., 2003; Wang et al., 2006; Dawood and Ramli, 2011; Hossain and Awal, 2011; Jawaid & Abdul Khalil, 2011; Dawood, 2011; Ramli & Tabassi, 2012 & Subham & Singh, 2015) agreed that single fibre reinforcement alone does not overcome other performance aspects, such as flexural strength and tensile strength. By adopting the hybridisation system, one type of fibre may overcome the limitations of the other fibre. The larger fibres increase the ability to resist macro-cracks, while the smaller fibre is able to resolve the post-cracking mechanism.

METHODOLOGY

Experimental Programme

The experimental programme was formulated to investigate the mechanical properties of the natural and synthetic fibres hybridisation in a polymer-modified mortar.

Materials and Methods

Materials and method used in this study are described in Table 1. The SBR latex DL470 copolymer adopted for this research was supplied by SUKA CHEMICAL (M) SDN BHD. Kenaf fibre V36 variant was obtained from MARDI Serdang in a long fibre form and cut into 25-30 mm length (Figure 1). Elasto Plastic Concrete Inc. supplied the bar chip fibre type 54 in straight form with a continuously embossed and rough surface (Figure 2). This fibre characteristic produces a non-slip effect in the cement matrix. The fibrillated polypropylene fibres used in this study was supplied by Timuran Engineering Sdn Bhd. (Figure 3). This fibrillated fibre provides an excellent bonding characteristic in the matrix by increasing the surface area in contact with the matrix.

Table 1: Materials and Methods used in the this Study

Constituents of Materials and Method	Description
Cement	Ordinary Portland cement conforming to MS 522:1989 with a specific gravity of 3.15
Fine aggregates	River sand with a maximum fineness modulus of 3.12
Water	Tap water
SBR latex	Styrene-butadiene rubber in emulsion form with specific gravity of 1.01 and containing 46% of solid polymer content
Water/cement ratio	0.20
Percentage of SBR latex content (by weight of cement)	15%
Cement:Sand (C:S) mix proportion	1:2.25

Target flow diameter	150mm – 160mm
Fibre type	Kenaf, , polypropylene, bar chip
Fibre length	Chopped to average length of 25-30mm to reduce entanglement.
Fibre volume (by cement volume)	Fibre volume total of 1.6%.
Hybrid fibre proportion (by cement volume)	Combinations of fibre percentage are as Table 2
Curing	•Water Curing: 7 and 28 days. •Air Curing for 91, 182, and 365 days. •NaCl 4% solution for 91, 180 and 365 days
Target design compressive strength at 28 days	About 30 N/mm2 (MPa)

Figure 1: Kenaf Fibre

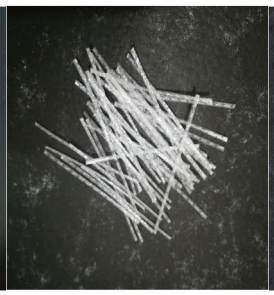


Figure 2: Bar Chip Fibre

Figure 3: Polypropylene Fibre

Design Mix

The mix proportion was designed to achieve the desired mortar density of 2200 kg/m3 with a targeted strength of 30MPa at 28 days. The detail mix design is shown in Table 2.

Table 2: Summary of the Mix Proportion used in the Study

Specimen	Cement kg/m3	Water cement ratio	Sand kg/m3	SBR (%)	Vol. fraction of fibre (%)			Total vol. fraction of fibre (%)
					Kf	BC	PP	
Control	677	0.2	1523	15				-

A	677	0.2	1523	15	0.4	1.2		1.6
B	677	0.2	1523	15	1	0.6		1.6
C	677	0.2	1523	15	1.6			1.6
D	677	0.2	1523	15	0.4		1.2	1.6
E	677	0.2	1523	15	1		0.6	1.6
F	677	0.2	1523	15			1.6	1.6
G	677	0.2	1523	15	0.4	0.6	0.6	1.6
H	677	0.2	1523	15	1	0.3	0.3	1.6
I	677	0.2	1523	15		1.6		1.6

The control specimen was prepared with non-fibrous polymer modified mortar. The hybridisation of fibres was between Kf and BC (specimen A & B), Kf and PP (specimen D & E), and Kf, PP and BC (specimen G & H) with different fibre proportions. The mechanical properties of a single fibre configuration (Specimen C, F & I) was also investigated to examine any significant enhancements of the natural and synthetic fibres. The distribution of fibres was set to total 1.6% of fibres content to cement volume. A low volume fraction of 0.3% – 0.6% was used as the lowest percentage in the combination of the composite system to reduce the particle-matrix debonding between the macro and micro fibre as adopted in Dawood (2011).

Details of Test

This paper highlighted only three mechanical properties testing namely density, compressive strength and flexural strength test under two curing regimes. Air curing was adopted due to the favourable dry curing condition of polymer modified mortar which is required to enhance the polymerization film stage. While SBR latex was proven to enhance the durability of cementitious materials in marine environments, saltwater was prepared to observe if agricultural fibres in PMM encourage the chloride ion penetration, thus reduce the durability of the composite.

DENSITY TEST

The density of the hardened mortar prism was determined using the BS 1881: Part 114: 1983 water displacement method. Two batches of specimens were cured into different curing regime of air curing and 4% of NaCl solution after 28 days of water curing. The density of specimens were recorded at 1, 7, 28, 91, 182 and 365 days.

Compressive Test

All specimens underwent standard testing according to BS EN 12390-3:2009. The cube was prepared according to BS EN 12390-2:2009 with fibre inclusion at 30mm length in 100 x 100mm mould. Two different batches were prepared and cured into normal water curing for 28 days and subsequently removed from water curing and placed under normal ambient temperature for curing. Meanwhile, the following batches were immersed in sodium chloride with 4% concentration after 28 days. The testing period was programmed at 7, 28, 91, 182 and 365 days.

Flexural Test

Flexural strength of the specimens was conducted by using the method of determination of flexural strength according to BS EN 12390-5:2009. The test was performed on 100mm x 100mm x 500mm prisms at the ages of 7, 28, 91, 180, and 365 days.

RESULTS AND DISCUSSIONS

Density

The density of the fibrous samples of Polymer Modified Mortar (PMM) was compared with the control samples to observe any significant enhancement due to the fibres incorporation. Table 3 and 4 shows the density result obtained for the fibre reinforced PMM in water curing followed by air curing and water curing followed by sodium solution curing.

Table 3: Density of Fibre Reinforced Polymer Modified Mortar in Water Curing Followed by Air Curing

Specimen	Fibre Percentage	Curing Age (days)					
		1d	7d	28d	91d	182d	365d
Control	0	1930.2	1935.5	1958.3	2105.6	2106.5	2117.7
A	0.4Kf + 1.2BC	2119.2	2124.6	2145.0	2063.8	2093.7	2002.3
B	1.0Kf + 0.6BC	2080.2	2088.1	2100.0	2031.9	2032.2	2114.2
C	1.6Kf	2210.3	2213.3	1974.4	2165.4	2164.8	2178.3
D	0.4Kf + 1.2PP	1967.2	1970.2	2225.6	1942.0	2195.9	1951.1
E	1.0Kf + 0.6PP	2200.1	2201.0	2204.9	2096.1	2112.4	2116.8
F	1.6PP	2185.2	2198.0	2203.3	2076.9	2058.7	2090.9
G	0.4Kf + 0.6BC + 0.6PP	2200.0	2202.0	2210.0	2147.6	2129.4	2149.8
H	1.0Kf + 0.3BC + 0.3 PP	1987.0	1581.2	2115.6	2164.1	2166.3	2111.9
I	1.6BC	2100.9	2105.9	2104.2	2103.2	2104.5	2105.5

Table 4: Density of Fibre Reinforced Polymer Modified Mortar in Water Curing (1 until 28 days) followed by Sodium Curing (kg/m3)

Specimen	Fibre Percentage	Curing Age (days)					
		1d	7d	28d	91d	182d	365d
Control	0	1930.2	1935.5	1958.3	2099.4	2094.2	2135.3
A	0.4Kf + 1.2BC	2120.3	2124.6	2144.9	2115.8	2151.2	2053.9
B	1.0Kf + 0.6BC	2085.2	2088.2	2099.9	2042.2	2064.6	2089.7
C	1.6Kf	2210.0	2213.3	1974.4	2198.7	2197.0	2123.3
D	0.4Kf + 1.2PP	1999.6	1970.2	2225.6	2228.4	2221.3	2058.2
E	1.0Kf + 0.6PP	2200.2	2200.9	2204.9	2139.9	2130.7	2144.2
F	1.6PP	2187.3	2197.9	2203.3	2113.7	2115.9	2096.3
G	0.4Kf + 0.6BC + 0.6PP	2195.6	2201.9	2209.9	2149.4	2177.6	2157.2
H	1.0Kf + 0.3BC + 0.3 PP	1867.0	1581.2	2115.6	2183.4	2192.3	2123.8
I	1.6BC	2101.4	2105.9	2104.2	2106.8	2111.2	2109.2

From the result, it shows that PMM as in control specimen and fibrous specimen show an increment of density during water curing until 28 days. At air curing regime, the control specimen showed a steady increase throughout the final curing while the fibrous sample indicated a slight decrease of the density at the final curing age. A similar trend was also observed in the sodium solution where control specimen and specimen B, H and I showed an increase in density while other specimens exhibited fluctuation of density value but with a lower density value at final curing age.

This finding indicated that incorporating polymer latex and fibre resulted in the inconsistency of density although the mixture was prepared according to the mix design. During the water curing, the specimens underwent cement hydration where the particles of aggregates and cement bonded and packed closer to each other. This resulted in a steady increment of density to most of the specimens.

While in air curing regime, the specimen was removed from the water and exposed to the air. From the observation, most of the specimens showed a slight increase in density which explains that the polymerisation process occurred interpenetrating with the aggregate and cement. During this process, the polymer acting as a filler, filling the gaps and voids which leads to fewer voids, thus increasing the density slightly.

In sodium solution curing, the polymerisation of the SBR polymer continues, resulted in the increased porosity of the surface and air entrapment, thus reducing the density (Ali, Jawad, & Majeed 2012; Wang, Lackner, & Wang 2011; and Wang, Wang, & Li 2005).

Findings also showed that at final curing ages, the density of all specimens are lower than the targeted density of 2200kg/m3 for both curing regimes.

Compressive Strength

The compressive strength of all specimens were recorded at 7, 28, 91, 182, and 365 days. The specimens were exposed to water curing at 7 and 28 days followed by air curing and sodium curing.

The compressive strength results obtained from the experiment when the specimens were immersed into water curing followed by air curing are shown in Table 5 and Figure 4.Table 6 and Figure 5 show the result obtained by all specimens when immersed in water curing followed by sodium chloride solution curing.

Table 5: The Result of the Compressive Strength for All Specimens in Water Curing followed by Air Curing

Specimen	Fibre Percentage	Water Curing (MPa)		Air Curing (MPa)		
		7d	28d	91d	182d	365d
Control	0	24.20	27.19	34.23	40.77	40.26
A	0.4Kf + 1.2BC	29.71	30.21	34.70	40.29	40.24
B	1.0Kf + 0.6BC	29.81	30.30	32.69	33.65	45.38
C	1.6Kf	34.79	35.37	38.47	45.62	46.40
D	0.4Kf + 1.2PP	23.30	33.25	34.31	46.17	46.83
E	1.0Kf + 0.6PP	39.21	42.42	39.71	39.67	42.78
F	1.6PP	39.19	41.42	35.37	37.24	47.52
G	0.4Kf + 0.6BC + 0.6PP	40.46	44.56	46.81	47.05	61.99
H	1.0Kf + 0.3BC + 0.3 PP	32.50	33.54	43.24	44.66	49.97
I	1.6BC	26.70	27.39	33.23	35.35	35.45

The G specimen (0.4Kf + 0.6BC + 0.6PP) exhibited the highest final compressive strength (at 365 days) of 61.99MPa in air curing (Table 5 and Figure 4).

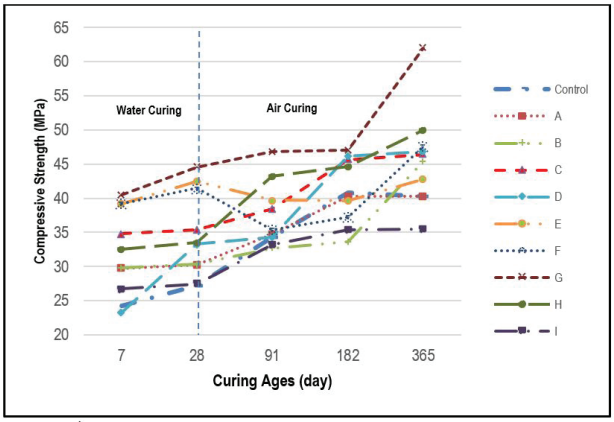


Figure 4: The Compressive Strength of All Specimen in Water Curing followed by Air Curing

Similar results were observed in sodium solution curing in which the G specimen gained the highest compressive strength at 365 days (Table 6). However, the strength value was lower than observed in air curing (Figure 5).

Table 6: The Result of the Compressive Strength for All Specimens in Water Curing followed by Sodium Chloride Solution Curing (4% NaCl solution)

Specimen	Fibre Percentage	Water (MPa)		Sodium 4% (MPa)		
		7d	28d	91d	182d	365d
Control	0	24.20	27.19	28.09	30.7	33.43
A	0.4Kf + 1.2BC	29.71	30.21	32.91	35.33	36.90
B	1.0Kf + 0.6BC	29.81	30.30	23.63	29.9	36.11
C	1.6Kf	34.79	35.37	34.37	31.46	35.84
D	0.4Kf + 1.2PP	23.30	33.25	38.67	38.44	39.45
E	1.0Kf + 0.6PP	39.21	42.42	30.27	31.01	39.33
F	1.6PP	39.19	41.42	31.13	29.57	42.36
G	0.4Kf + 0.6BC + 0.6PP	40.46	44.56	33.92	38.9	45.74
H	1.0Kf + 0.3BC + 0.3 PP	32.50	33.54	31.73	35.95	40.84
I	1.6BC	26.70	27.39	31.21	32.38	33.57

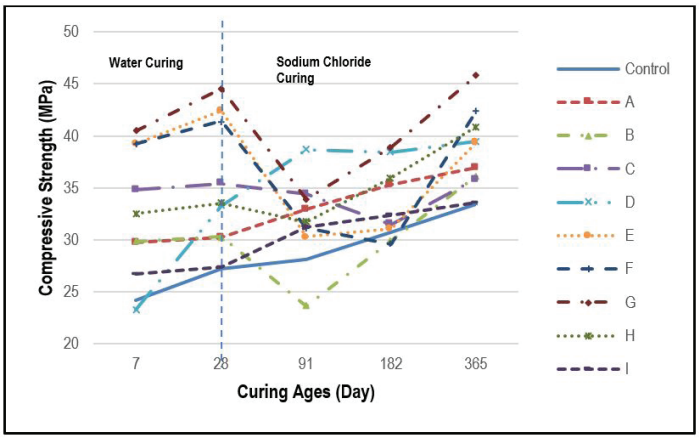


Figure 5: The Compressive Strength of All Specimen in Water Curing followed by Ssodium Chloride Curing

This result showed that the hybridisation of natural and synthetic fibre in polymer modified mortar using SBR latex could enhance the strength of the composite for both air and sodium solution curing. The control specimen obtained the lowest compressive strength at the final curing age in sodium curing, but slightly higher in air curing. This is because the favourable curing condition for the polymer-modified mortar is under dry conditions as stated by Ohama, (1995). Under the wet condition, at the early ages, the polymer modified mortar will obtain the reasonable extent of cement

hydration. After that, the polymer film formation is developed due to the coalescence of polymer particles in latexes under the dry condition, thus achieved the optimum strength (Ohama, 1995).

Flexural Strength

The flexural strength results revealed that G specimen exhibited the highest flexural strength with 8.77 MPa at 28 days whereas the control specimen obtained the lowest flexural strength at the same age. The summary of the result was demonstrated in Table 7.

For the hybrid fibre configuration, the highest flexural strength was observed in D specimen with the value of 9.98 MPa., followed by the G specimen. Other hybrid samples also showed an increment of strength towards the final curing age.

Table 7: Flexural Strength of Fibre Reinforced Polymer Modified Mortar in Water Curing followed by Air Curing and in Sodium Solution Curing (MPa)

Series	Fibre Percentage (%)	Curing Ages (days)							
		7d	28d	91d		182d		365d	
		Water Curing		Air Curing	Sodium 4%	Air Curing	Sodium 4%	Air Curing	Sodium 4%
Control	0	4.91	4.92	4.13	6.47	5.55	6.25	7.71	6.39
A	0.4Kf + 1.2BC	8.34	8.26	6.21	7.24	7.60	6.75	8.86	6.73
B	1.0Kf + 0.6BC	6.58	5.86	4.30	4.1	7.64	5.42	8.59	7.06
C	1.6Kf	7.91	5.67	5.06	6.64	7.70	7.29	8.36	6.78
D	0.4Kf + 1.2PP	6.37	7.46	6.48	7.67	8.15	8.46	9.98	7.56
E	1.0Kf + 0.6PP	7.47	8.14	7.16	7.25	8.69	6.69	9.43	6.59
F	1.6PP	5.64	5.95	6.43	6.60	7.72	6.18	9.48	6.99
G	0.4Kf + 0.6BC + 0.6PP	7.87	8.77	7.11	8.27	8.37	8.22	9.84	8.73
H	1.0Kf + 0.3BC + 0.3 PP	6.61	6.89	6.69	6.80	8.77	8.01	9.58	7.63
I	1.6BC	6.08	5.51	6.41	6.51	7.12	6.75	8.01	7.02

In air curing, the control specimen showed an increment of flexural strength from 4.13 MPa to 7.71 MPa. However, this specimen still exhibited the lowest strength value compared to the fibrous specimen. The strength dropped slightly after the water curing (Figure 6).

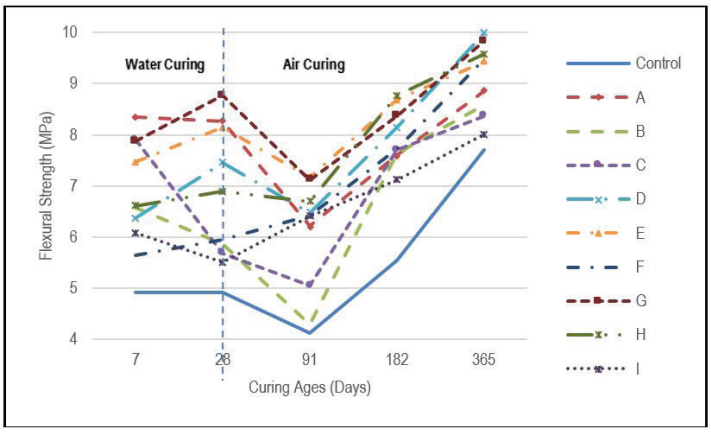
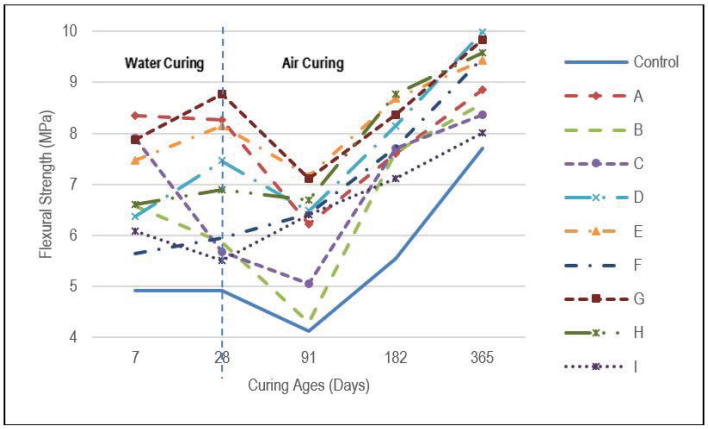


Figure 6: The Flexural Strength of all Specimen in Water Curing followed by Air Curing

Meanwhile, in sodium chloride solution curing, the control specimen was noted to gain strength at the final curing age (Figure 7).



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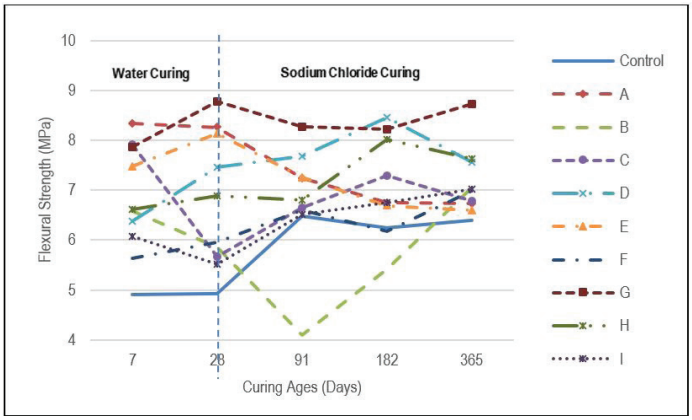

Figure 7: The Flexural Strength of all Specimens in Water Curing followed by Sodium Chloride Curing

In sodium curing, the control specimen had slightly increased in strength with the value of 6.39 MPa at the final curing age. The G specimen recorded the highest flexural strength of 8.73 MPa. This result confirmed that the adoption of hybrid fibres could enhance the flexural strength in both curing regimes. From the result, it can be concluded that kenaf and polypropylene fibre demonstrated an excellent hybrid fibre combination. The higher surface area of the fibrillated polypropylene fibres developed higher contact surface of the fibres and produced an adequate bond with the polymer modified mortar, thus enhancing the flexural strength of the specimen.

CONCLUSION

After reviewing all the results obtained through this research it can be concluded that using hybrid fibre in polymer-modified mortar Mix G which consists of 0.4% kenaf + 0.6%PP + 0.6%BC had shown the highest enhancement of compressive (both air and sodium curing) and flexural strength (in sodium curing).

The highest density was observed in G specimen where the density value at the final curing age recorded at 2149.8 kg/m3 and 2157.2 kg/m3

in the air and sodium curing, respectively. However, the values are below the targeted density at 2200 kg/m3.

This study also concluded that the inclusion of fibre in polymer modified mortar could enhance the mechanical properties of the composite compared to the control specimen. Kenaf also plays a significant role in improving the mechanical strength when combined with the synthetic fibre compared to single fibre configuration for this experimental research. This show that natural fibre had a promising value as reinforcement when the correct amount and fibre combination were applied.

Under aggressive exposure, the result showed a slight declining of strength value when compared to air curing exposure. However, in general, all specimens gained strength throughout the curing period. This indicated that cement hydration and polymerisation with the incorporation of fibres has successfully integrated and interpenetrated to each other.

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REFERENCES

Aji, I. S. Zainudin, E. S. Khalina, A. & Sapuan, S.M. (2011). *Studying the Effect of Fiber Size and Fiber Loading on the Mechanical Properties of Hybridized Kenaf* / PALF-reinforced HDPE composite. http://doi.org/10.1177/0731684411399141

Alhassan, M. A. & Ashur, S.M. (2011). Performance-Based Aspects and Constructability of Bridge Deck Latex-Modified Concrete Overlays with and without Fibrous Additives. IPFW *Journals: Engineering*

Faculty Publications, (Lmc), 1–22.

Armagan, K. & Canbaz, M. (2016). Effect of Fiber Type on Freeze Thaw Durability of Sifcon. *International Journal of Advances in Mechanical and Civil Engineering, 3*(5), 56–59.

Atiqah A, Maleque MA, Jawaid M, Iqbal M. *Development of Kenaf–glass Reinforced Uunsaturated Polyester Hybrid Composite for Structural Applications*. Compos Part B Eng 2014;56:68–73.

Balaguru, P.N., & Shah, S.P. (1992). *Fibre-reinforced Cement Composites.* New York: McGraw-Hill, Inc.

Colville, J., Amde, M.A., and Miltenberger, M. (1999). Tensile Bond Strength of Polymer Modified Mortar. *Journals of Materials in Civil Engineering, 11*(1): 1-5.

Dawood, E.T. (2011). *The Development of Fibres Reinforced Flowable High Strength Mortar and Concrete as Repair Materials* (PhD Thesis). Retrieved from http://eprints.usm.my/view/divisions/sch=5Fhbp/2011.html

Dawood, E.T. & Ramli, M. (2012). *Properties of High-Strength Flowable Mortar Reinforced with Palm Fibers*, 2012, 1–6. http://doi.org/10.5402/2012/718549

Elsaid, A., Dawood, M., Seracino, R. & Bobko, C. (2011). Mechanical Properties of Kenaf Fiber Reinforced Concrete. *Construction and Building Materials.* Vol. 25. http://doi.org/10.1016/j.conbuildmat.2010.11.052

Fallah, S. & Nematzadeh, M. (2017). Mechanical Properties and Durability of High-Strength Concrete Containing Macro-Polymeric and Polypropylene Fibers with Nano-Silica and Silica Fume. *Construction and Building Materials, 13*2, 170–187. http://doi.org/https://doi.org/10.1016/j.conbuildmat.2016.11.100

Fordos, Z. (1988). Natural or Modified Cellulose Fibres as Reinforcement.

In R. N. Swamy (Ed.), Natural Fibre Reinforced Cement and Concrete (first ed., Vol. 5, pp. 173-206). Glasgow and London: Blackie.

Habib, M. M. A. A & Begum,R. (2013). Mechanical Properties of Synthetic Fibers Reinforced Mortars. *International Journal of Scientific & Engineering Research, 4*(4), 923–27.

Hossain, M.Z., & Awal, a. S.M.A. (2011). Flexural Response of Hybrid Carbon Fiber thin Cement Ccomposites. *Construction and Building Materials, 25*(2), 670–677. http://doi.org/10.1016/j.conbuildmat.2010.07.022

Huang, B., Wu, H., Shu, X. & Burdette, E. G. (2010). Laboratory Evaluation of Permeability and Strength of Polymer-Modified Pervious Concrete. *Construction and Building Materials, 2*4(5), 818–823. http://doi.org/10.1016/j.conbuildmat.2009.10.025

Ismail, M.A.(2007). Compressive and Tensile Strength of Natural Fibre-reinforced Cement base Composites. *Al Rafidain Engineering, 15*(July 2005), 42–51.

Jawaid, M. & Abdul Khalil, H.P.S. (2011). Cellulosic/Synthetic Fibre Reinforced Polymer Hybrid Composites: A Review. *Carbohydrate Polymers, 86*(1), 1–18. http://doi.org/10.1016/j.carbpol.2011.04.043

John, K. (2004). Effect of Fiber Content and Fiber Treatment on Flexural Properties of Sisal Fiber/Glass Fiber Hybrid Composites. *Journal of Reinforced Plastics and Composites, 23*, 1601–1605. http://doi.org/10.1177/0731684404039799

Khalil, H.P.S. a., Hanida, S., Kang, C. W. & Fuaad, N. a. N. (2007). Agro-Hybrid Composite: The Effects on Mechanical and Physical Properties of Oil Palm Fiber (EFB)/Glass Hybrid Reinforced Polyester Composites.*ournal of Reinforced Plastics and Composites, 26*, 203–218. http://doi.org/10.1177/0731684407070027

Kim, D. H., & Park, C. G. (2013). Strength, Permeability, and Durability

of Hybrid Fiber-Reinforced Concrete Containing Syrene Butadiene Latex. J*ournal of Applied Polymer Science, 129*(3), 1499–1505. http://doi.org/10.1002/app.38861

Kolop, R., Wim, H. & Eng, J.W. (2008). *Properties of Cement Blocks Containing High Content of Oil Palm Empty Fruit Bunches (EFB) Fibres*. Paper presented at the International Conference on Civil Engineering Practice (ICCE08). Retrieved from http://eprints.uthm.edu.my/270/

Lee, S.-K., Jeon, M.-J., Cha, S.-S. & Park, C.-G. (2017). Mechanical and Permeability Characteristics of Latex-Modified Fiber-Reinforced Roller-Compacted Rapid-Hardening-Cement Concrete for Pavement Repair. *Applied Sciences, 7*(7), 694. http://doi.org/10.3390/app7070694

Lerch, J.O., Bester, H.L., Rooyen, A.S. Van, Combrinck, R., Villiers, W. I. De & Bosho, W. P. (2018). *Cement and Concrete Research the Eff ect of Mixing on the Performance of Macro Synthetic Fibre Reinforced Concrete,* 103(August 2017), 130–139. http://doi.org/10.1016/j.cemconres.2017.10.010

Mohammad, N.A.B. (2007). *Synthesis, Characterization and Properties of the new Unsaturated Polyester Resins for Composite Applications* (Masters' Thesis). Retrieved from http://eprints.usm.my/

Ohama, Y. (1995). *Handbook of Polymer-modified Concrete and Mortars: Properties and Process Technology*. Noyes Publications. Retrieved from http://www.sciencedirect.com/science/book/9780815513582

Priyadharshini, & Ramakrishna. (2016). Strength and Durability Evaluation of Latex Modified Sisal Fibre Reinforced Concrete. *In International Journal of Research in Science & Engineering,* 2, 768.

Ragheb, A., El-Shimy, H., & Ragheb, G. (2016). *Green Architecture: A Concept of Sustainability*, 216(October 2015), 778–787. http://doi.org/10.1016/j.sbspro.2015.12.075

Ramli, M. & Tabassi, A.A. (2012b). Mechanical Behaviour of Polymer-Modified Ferrocement Under different Exposure Conditions: An Experimental Study. Composites Part B: *Engineering, 43*(2), 447–456. http://doi.org/10.1016/j.compositesb.2011.11.058

Rixom, R., & Mailvaganam, N. (1999). *Chemical Admixtures for Concrete* (Third). New York: E & FN Spon.

Saba, N., Paridah, M.T., & Jawaid, M. (2015). Mechanical Properties of Kenaf Fibre Reinforced Polymer Composite: A Review. *Construction and Building Materials, 7*6, 87–96. http://doi.org/10.1016/j.conbuildmat.2014.11.043

Savastano, H., Santos, S.F., Radonjic, M. & Soboyejo, W. O. (2009). Fracture and Fatigue of Natural Fiber-Reinforced Cementitious Composites. *Cement and Concrete Composites, 31*(4), 232–243. http://doi.org/10.1016/j.cemconcomp.2009.02.006

Stevulova, N., Cigasova, J., Estokova, A., Terpakova, E., Geffert, A., Kacik, F., Holub, M. (2014). *Properties Characterization of Chemically Modified Hemp Hurds.* Materials, 8131–8150. http://doi.org/10.3390/ma7128131

Subham, & Singh, P. (2015). Enhancement of Properties Polymer Modified Ferrocement. International *Journal of Recent Development in Engineering and Technology, 4*(8), 19–23.

Susilorini, R. M. I. R., Hardjasaputra, H., Tudjono, S., Hapsari, G., Wahyu, S. R., Hadikusumo, G. & Sucipto, J. (2014). The Advantage of Natural Polymer Modified Mortar with Seaweed: Green Construction Material Innovation for Sustainable Concrete. *Procedia Engineering, 9*5(Scescm), 419–425. http://doi.org/10.1016/j.proeng.2014.12.201

Wang, R., Lackner, R. & Wang, P. (2011). Effect of Styrene–Butadiene Rubber Latex on Mechanical Properties of Cementitious Materials Highlighted by Means of Nanoindentation. *An International Journal for Experimental Mechanics*, (47), 117–126. http://doi.org/10.1111/j.1475-1305.2008.00549.x

Wang, R., Li, X.-G. & Wang, P.-M. (2006). Influence of Polymer on Cement Hydration in SBR-Modified Cement Pastes. *Cement and Concrete Research, 36*(9), 1744–1751. http://doi.org/10.1016/j.cemconres.2006.05.020

Wang, R., Wang, P.-M. & Li, X.-G. (2005). Physical and Mechanical Properties of Styrene–Butadiene Rubber Emulsion Modified Cement Mortars. *Cement and Concrete Research, 3*5(5), 900–906. http://doi.org/10.1016/j.cemconres.2004.07.012

Yao, S. Y. & Ge, Y. (2012). *Effect of Styrene Butadiene Rubber Latex on Mortar and Concrete Properties*. Advanced Engineering Forum, 5, 283–288. http://doi.org/10.4028/www.scientific.net/AEF.5.283

Yao, W., Li, J. & Wu, K. (2003). Mechanical Properties of Hybrid Fiber-Reinforced Concrete at Low Fiber Volume Fraction. *Cement and Concrete Research, 33*, 27–30. http://doi.org/10.1016/S0008-8846(02)00913-4.

Yousif BF, Shalwan A, Chin CW, Ming KC. Flexural Properties of Treated and Untreated Kenaf/Epoxy Composites. Mater Des 2012;40:378–85.

Zia, J., & Paul, S. (2015). Study on Effect of Polymer on Fibre Reinforced Repair Concrete. *International Journal of Science Technology & Engineering, 2*(5), 58–62.