THE MANUFACTURE AND MECHANICAL PROPERTIES OF ALIGNED LONG HARAKEKE FIBRE REINFORCED EPOXY COMPOSITES

Tan Le [1] and K.L. Pickering [2]

[1, 2] School of Engineering, The University of Waikato, Hamilton, New Zealand.
Email: tml14@waikato.ac.nz; klp@waikato.ac.nz

ASTRACT: Aligned long harakeke fibre reinforced epoxy composites were prepared using hand lay-up followed by compression moulding. Densities of harakeke fibre and epoxy resin were determined for the purpose of composite design. The evenness of composites fabricated by two different size moulds was compared. It was found that more even composites were produced when using a small mould than a big mould. In this work, the dependence of tensile and flexural properties of harakeke/epoxy composites on fibre content was also investigated. The results showed that the addition of fibre enhanced tensile properties of epoxy. The tensile strength and Young's modulus increased with the volume fraction of harakeke fibre. The flexural strength and flexural modulus increased as the fibre volume fraction increased up to 0.4. Further addition of fibre did not result in an improvement of composite flexural properties.

KEYWORDS: *harakeke fibre, tensile properties, flexural properties, mould size, fibre volume fraction, epoxy resin, compression moulding.*

INTRODUCTION

Harakeke is the Maori name for the New Zealand native plant commonly known as New Zealand flax. The name "flax" is actually a misnomer here because harakeke is not biologically related to European flax [1]. Long fibre extracted from the harakeke leaves has a long history of use for production of clothes, sacking and rope. Harakeke products used to account for around 20% of the total export income of New Zealand in the early 1920s [1]. Sales decreased during the 20th century due to the presence of synthetic fibres and the expansion of the sisal industry, and the current use of harakeke is confined to crafts [2]. Harakeke fibre has similar properties to sisal – another leaf fibre [1, 2]. While the application of sisal fibre in composites has been reported by a variety of papers [3], harakeke fibre has only been recently studied for composites [1, 2, 4-8]. The specific tensile strength of composites reinforced with aligned long harakeke fibre has been found to comparable to that of composites reinforced with other plant fibres, while it is poor relative to glass fibre reinforced composites [5]. Other mechanical properties of aligned long harakeke fibre reinforced composites have not been reported. Therefore, further studies should be conducted to show the potential of harakeke fibre for use in composite.

In this work, the uniformity of harakeke/epoxy composites made using two different size moulds was assessed by comparing the coefficient of variation (CVs %) of tensile strength and Young's modulus to find out the optimal mould using for further research. The tensile and flexural properties of aligned long harakeke reinforced epoxy composites manufactured using the chosen mould with various fibre volume fractions were also evaluated.

EXPERIMENTAL

Materials

Harakeke fibre was obtained from Templeton Flax Mill, Riverton, New Zealand. The fibre bundles were combed manually in a single direction before being cut into the same length to fit the size of compression mould, and then dried at 80^{o}C overnight before composite fabrication.

The matrix was a low viscosity epoxy system comprised of Nuplex resin R180 and Nuplex standard hardener H180 (mixing ratio 5:1 by weight).

Density measurement

Natural fibre density can be measured by one of five methods: (1) diameter and linear density, (2) Archimedes, (3) helium pycnometry, (4) gradient column and (5) liquid pycnometry. Among them, Archimedes using canola oil as an immersion fluid was recommended because it is simple, quick to give the test results and bears lowest cost [9]. Testing was based on ASTM D3800-99 (Standard Test Method for Density of High-Modulus Fibers). Three specimens of harakeke fibre bundles weighing about 1 g were oven dried at 60^{o} C for 72 hours and then placed in a vacuum oven at room temperature for 5 minutes to remove trapped air between fibre cells before testing. The average density was calculated and reported.

The density measurement of cured epoxy resin was based on ASTM 792-00 (Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement). Distilled water was used as an immersion fluid. Densities of five cured epoxy specimens were measured. The average density was calculated and reported.

Composite manufacture

The fabrication of harakeke/epoxy composites was similar to that which has been used to make flax/epoxy composites [10]. Combed and dried fibre was hand laid into simple rectangular moulds which had been covered by a Teflon sheet to form a fibre mat. Six different fibre volume fractions were used (0.1, 0.2, 0.3, 0.4, 0.5 and 0.6) to make composites in two different size moulds (28 x 22 x 0.3 cm^3 and 22 x 15 x 0.3 cm^3). The essential mass of fibre appropriate to each fibre volume fraction is indicated in Table 2. The epoxy resin and hardener were thoroughly mixed in a plastic cup and then degassed in a vacuum oven at room temperature for 10 minutes (longer degassing time may accelerate the curing reaction). The epoxy mixture was poured over the fibre and then was left to soak into the mat for 20 minutes. A wide flat ended metal scraper was used to squeeze out trapped air of the fibre mat. The mould with fibre and resin was degassed in a vacuum environment for 5 minutes to remove trapped air from the resin impregnated fibre mat. A steel plate was then laid on the top of the mould. Finally the mould was place into a compression moulder and then the epoxy soaked fibre mat was pressed until the mould closed and was left for curing for 24 hours. The composite sheet was removed from the mould and post cured for 4 hours in an oven at 80 ^{o}C.

Tensile testing

Composite tensile testing was based on ASTM D 3039 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials) using abrasive paper tabs. Six composite specimens with nominal dimensions of 200 x 15 x 3 mm^3 were cut from cured composite sheets using a circular saw. The tensile properties of neat epoxy were measured according to ASTM D 638 - 03 (Standard Test Method for Tensile Properties of Plastics). Six dumbbell-shaped epoxy specimens were cast and cured in a silicone mould for 24 hours and then post cured at 80^{o}C in an oven for 4 hours. All tensile specimens were conditioned at 23^{o} ± 3^{o} C and 50% ± 5% relative humidity for 40 hours and then tested on an Instron-4204 universal testing machine fitted with a 50 kN load cell at a crosshead speed of 5 mm/min. Strain was measured by Instron 2630-112 extensometer with a 50 mm gauge length. The mean value of densities of composites and neat epoxy were calculated and reported.

Flexural testing

Cured composites were cut into six flexural test specimens with nominal dimension of 85 x 12 x 3 mm^3 using a circular saw. The flexural test (three-point bending) was carried out in accordance with ASTM D 790-03 (Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials) on an Instron-4204 fitted with a 5 kN load cell. A support span-to-depth ratio of 16:1 and a crosshead speed of 2 mm/min were used. The average density was calculated and reported.

RESULTS AND DISCUSSION

Harakeke fibre and epoxy densities

The densities of harekeke fibre and cured epoxy matrix are presented in Table.1. Fibre weight fraction, fibre mass and composite densities were calculated and are indicated in the Table 2.

Table 1: Densities of cured epoxy and harakeke fibre

	Cured epoxy	Harakeke fibre
Density (g/cm^3)	1.1575	1.2741

Comparison of composites manufactured by two different size moulds

Coefficients of variation (CVs) of tensile strengths and Young’s modulus were calculated for the composites fabricated by two different mould sizes and are presented in Figs 1 and 2, respectively. It was found that composites made using the big mould possessed higher CVs for both tensile strength and Young’s modulus than those of composites made using the small mould.

This suggests that composites with better uniformity were produced using the smaller mould. The composite unifrormity can be affected by variation of fibre mat thickness crossing the mould. The fibre mat was prepared using hand layup, so the fibre mat thickness was mainly controlled by the worker. Therefore, the variation of fibre mat thickness can be considered as human error which can be less in the case of smaller mould.

Table 2: Composite design for two different size moulds

				Mould size 28 x 22 x 0.3 = 184.8 cm^3		Mould size 22 x 15 x 0.3 = 99 cm^3	
No.	v_f	p_c (g/cm^3)	w_f	m_c (g)	m_f (g)	m_c (g)	m_f (g)
1	0.1	1.17	0.11	216	24	116	13
2	0.2	1.18	0.22	218	47	117	25
3	0.3	1.19	0.32	220	71	118	38
4	0.4	1.20	0.42	223	94	119	50
5	0.5	1.22	0.52	225	118	120	63
6	0.6	1.23	0.62	227	141	122	76

Where, v_f = fibre volume faction; v_m = matrix volume fraction; p_c = composite density; m_c = composite mass; m_f = fibre mass.

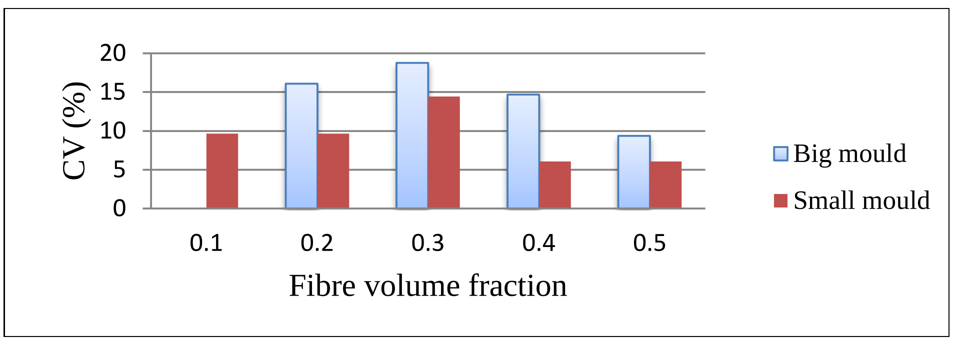

Fig. 1: Tensile strength CV versus fibre volume fraction for uniformity assessment

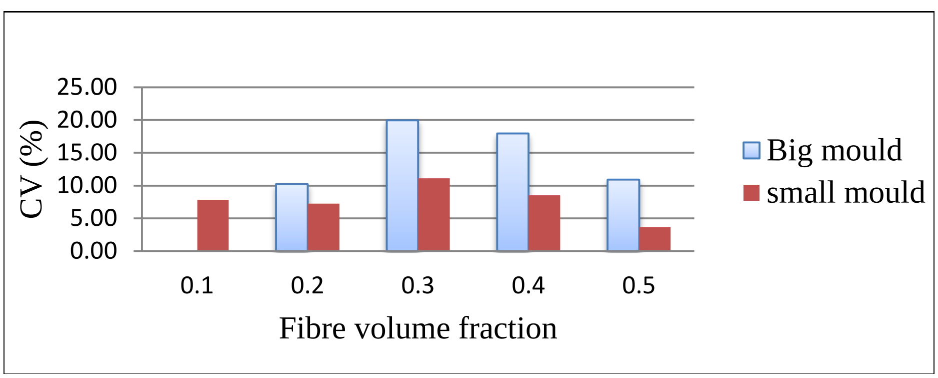

Fig. 2: Young's modulus CV versus fibre volume fraction for uniformity assessment

Tensile properties

Average tensile strength and Young's modulus of composite specimens with different fibre volume fractions (0.1, 0.2, 0.3, 0.4 and 0.5) and cured epoxy specimens were calculated and are presented in Figs 3 and 4, respectively. These figures show that the addition of harakeke fibre makes epoxy matrix stronger and stiffer. Both figures share the same trend such that the increase in fibre volume fraction increases the tensile strength and Young's modulus of composites. A least-squares best fit line was drawn through all data points with presenting a regression equation and high R-square for both the tensile strength and Young's modulus. The high R^2 shows a high correlation between tensile strength and fibre volume fraction.

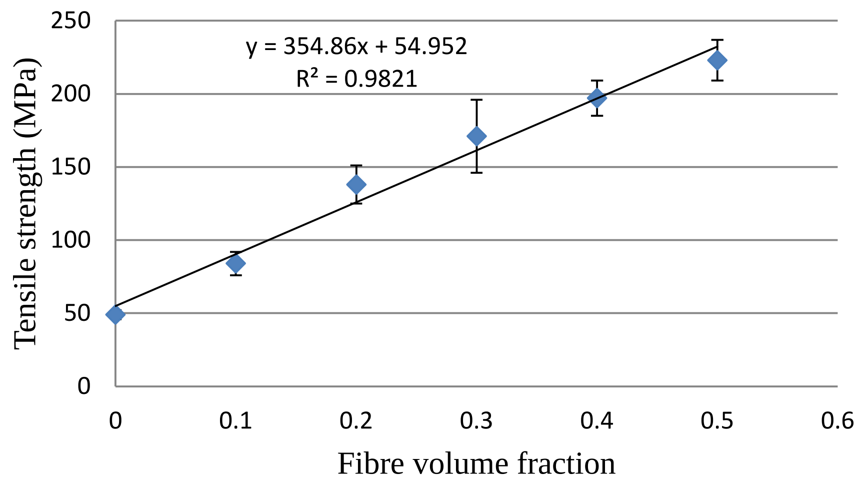

Fig. 3: Tensile strength of harekeke/epoxy composites versus fibre volume fraction showing least-square best fit line and R^2

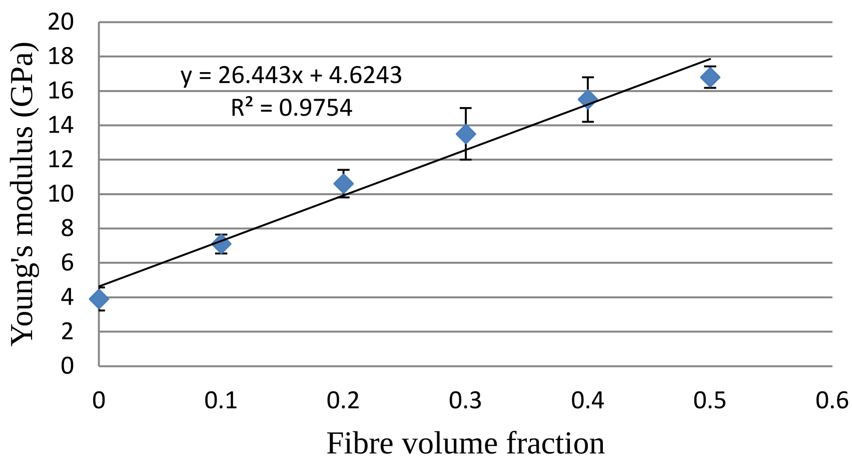

Fig. 4: Young's modulus of harekeke/epoxy composites versus fibre volume fractions showing least-square best fit line and R^2.

Flexural properties

Average flexural strength and flexural modulus of composite specimens with different volume fractions of harakeke fibre (0.1, 0.2, 0.3, 0.4, 0.5 and 0.6) were calculated and are presented in Figs 5 and 6, respectively. It can be seen that the flexural strength and flexural modulus of harakeke/epoxy composites increases as the volume fraction of harakeke fibre increases up to 0.4; at this volume fraction, the flexural strength and flexural modulus of composites are 223MPa and 13.7 GPa. Further addition of harakeke fibre did not bring about improvement of these flexural properties.

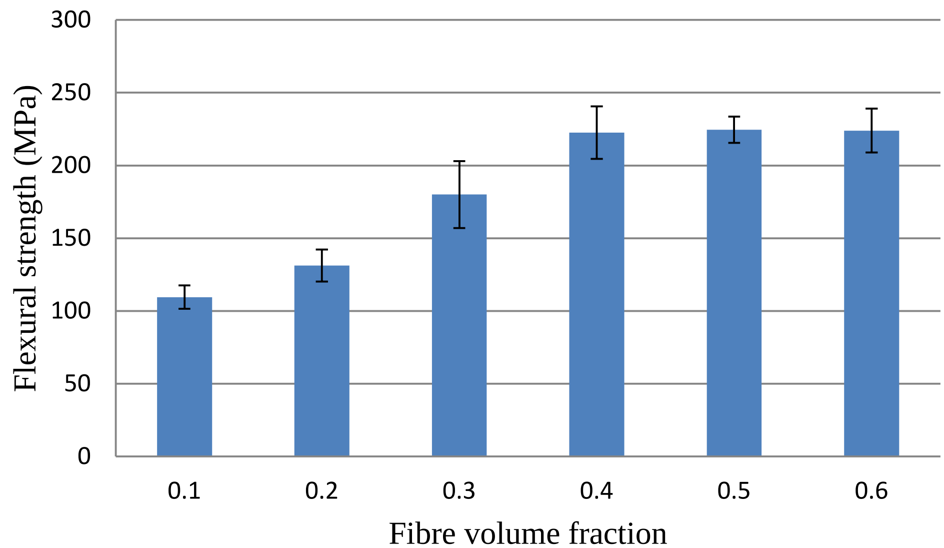

Fig. 5: Flexural strength of harakeke/epoxy composites versus fibre volume fraction.

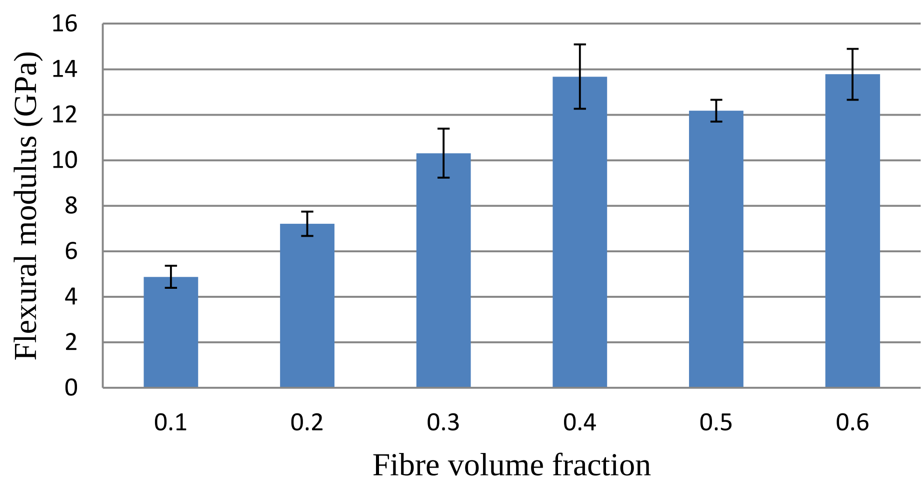

Fig. 6: Flexural modulus of harakeke/epoxy composites versus fibre volume fractions.

CONCLUSION

The uniformity of aligned long harakeke fibre reinforced epoxy composites fabricated using two moulds with different size was compared. The results suggest that the smaller mould creates more uniform composites. It can be due to less human error occurring for smaller mould when the fibre mat is prepared using hand layup.

The addition of aligned long harakeke fibre enhances the tensile strength and Young's modulus of epoxy significantly. These tensile properties increase with volume fraction of harakeke fibre. For flexural properties, it was found that the fibre volume fraction of 0.4 is optimal for aligned long harakeke fibre reinforced epoxy composites with flexural strength of 223MPa and flexural modulus of 13.7 GPa.

REFERENCES

1. Duchemin, B. and M. Staiger, *Treatment of Harakeke fiber for biocomposites.* Journal of Applied Polymer Science, 2009. **112**(5): p. 2710-2715.

2. Newman, R., et al., *Epoxy composites reinforced with deacetylated Phormium tenax leaf fibres.* Composites Part A, 2007. **38**(10): p. 2164-2170.

3. Li, Y., Y. Mai, and L. Ye, *Sisal fibre and its composites: a review of recent developments.* Composites Science and Technology, 2000. **60**(11): p. 2037-2055.

4. Dalu, L., et al., *Acoustic emission monitoring of cyclic flexural tests on phormium/epoxy composites.* E-Journal of Non Distructive Testing, 2009. **14**(2).

5. Newman, R., et al., *Failure mechanisms in composites reinforced with unidirectional Phormium leaf fibre.* Composites Part A, 2009.

6. Duchemin, B., K. Van Luijk, and M. Staiger, *New Zealand flax (Phormium tenax) reinforced eco-composites.* Proc of EcoComp, 2003: p. 1–2.

7. Le Guen MJ and Newman RH, *Pulped Phormium tenax leaf fibres as reinforcement for epoxy composites.* Composites Part A, 2007. **38**(10): p. 2109-2115.

8. De Rosa IM, Santulli C, and Sarasini F, *Mechanical and thermal characterization of epoxy composites reinforced with random and quasi-unidirectional untreated Phormium tenax leaf fibers.* Materials and Design, 2009.

9. Truong, M., et al., *A comparative study on natural fibre density measurement.* The Journal of The Textile Institute, 2009. **100**(6): p. 525-529.

10. Hepworth, D., et al., *The manufacture and mechanical testing of thermosetting natural fibre composites.* Journal of materials science, 2000. **35**(2): p. 293-298.