ICMIEE-PI-140138

Selection of Hemp Fabric as Reinforcement in Composite Materials

Mohd Iqbal Misnon [1, 2], Md Mainul Islam [1], Jayantha Ananda Epaarachchi [1], Kin-tak Lau [3]*
[1] Centre of Excellence in Engineered Fibre Composites and School of Mechanical and Electrical Engineering, Faculty of Health, Engineering and Sciences, University of Southern Queensland, Toowoomba, Queensland 4350, AUSTRALIA
[2] Faculty of Applied Sciences, Universiti Teknologi MARA, 40450, Shah Alam, Selangor, MALAYSIA
[3] Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, HONG KONG

ABSTRACT

One of the main problems on utilising the plant fibres in composite materials is control of fibre orientation and distribution. This problem can be solved by converting the plant fibres into yarns or fabrics. Plant fibres in the form of fabric are the most convenient material for a reinforcement considering its good fibre distribution as well as easy to handle during composite fabrication. The selection of fabric criterion on top of fibre type is also essential to ensure its suitability as reinforcement. In this work, three types of fabrics were analysed for their characteristics. Fabrics were analysed in terms of their physical characteristics such as fabric density, weight, thickness, yarn size and yarn crimp. The analysis continued with the fibre density and cloth cover factor determination which are related with the resin penetration. Tensile property characterisation was also done on the fabric which is important to predict their contribution on the composite materials. Fabric characteristics are important to be determined as we need to decide which fabric is more suitable as reinforcement and could give desired composite properties.

Keywords: Hemp fabrics, fabric characterisation, cloth cover factor, tensile properties, composites.

1. Introduction

The growth of global awareness on the environmental issues leads for the developing, creating and innovating eco-friendly materials. One of the remedies for this situation is the utilisation of natural fibres from plant (either fibre crops or agricultural wastes) in composite materials which suit the global direction above [1-4]. As for natural fibres, these kinds of fibres have existed for quite sometimes and their utilisation in composite materials is not new including those in automotive and building industries [5-7]. This is mostly driven by lower price, global availability and complete data of natural fibres which seem promising to be used as raw materials [7, 8].

Natural fibres possess good mechanical properties; however, the main problem in utilising natural fibres is control of the fibre orientation and distribution. This is because the optimum mechanical properties will not efficiently utilised as reinforcement if the problem cannot be resolved [9]. A wide range of techniques have long existed to convert the natural fibres into yarn and then into fabric in the textile industry [10]. However, utilisation of yarn is quite difficult in terms of reinforcement handling in composite fabrication. Utilisation of traditional textile fabric (high performance fibres) is more convenient considering their advantages on high strength, good fibre orientation and fibre distribution and more importantly easy to handle during composite fabrication [11]. Nevertheless, in the case of natural woven fabric, there is less work reported on their utilization especially when considering the type of natural fabrics to be used as reinforcement in composite material [4].

Several fibres such as jute and hemp were established in woven fabric and they possess good properties as reinforcement in composite materials. However, they come in different qualities depend on the manufacturing parameters which could affect the composite properties at the end. Therefore, a study to characterize a different fabric batch is needed to assess how far the difference in their properties is as well as to decide on which fabric is suitable for reinforcement in composite materials. Therefore, in this work, two hemp fabrics in a similar quality but two different batches have been characterized with respect to; i) fabric physical properties, ii) fibre density, iii) fabric appearance structure, and iv) mechanical properties. Another fabric in different quality was also characterized, which follows the similar procedure in order to seek and decide the suitability of these fabrics as composite reinforcement.

2. Materials and Method

Commercial hemp woven fabrics in two (2) batches were bought with time interval of about three (3) months were investigated and supplied by Hemp Wholesale Australia. According to the supplier, the two fabrics were having equal nominal properties. The weight of fabrics is 271 g/m^2 and due to this, it can be categorized as ‘heavy fabric’ in textile term. These two fabrics will be denoted as Fabric A and Fabric B for this work. Another thicker and heavier woven hemp fabric (Fabric C) with the weight of 407 g/m2 supplied by similar supplier was also investigated in this work. The

* Corresponding author. Tel.: +61-746311338
E-mail address: mainul.islam@usq.edu.au

fabrics were produced by 100 % yarn hemp in both warp and weft. These yarns were then converted into fabric via weaving processes and the fabrics were woven by employing plain weave (taffeta) structure.

2.1 Fabric Characterisation

All fabric characterisations have been done employing several textile materials standard methods. These standard methods (Table 1) are commonly used in textile industry for characterization as well as product quality determination purposes.

Table 1 List of standard methods for fabric properties determination.

Properties	Testing	Standard Method
Fabric Density	Warp (end) and filling (pick) count of woven fabrics	ASTM D3775
Fabric Weight	Mass per unit area (weight) of fabric	ASTM D3776
Fabric Thickness	Thickness of Textile Materials	ASTM D1777
Yarn Size	Yarn number (linear density)	ASTM D1907
Yarn Crimp	Yarn crimp and yarn take-up in woven fabrics	ASTM D3883

2.2 Fibre Density

The density of the hemp fibres was determined by Multipycnometer MVP D160E using Helium gas as a displacement medium. The data reported are the average and standard deviation of 3 measurements.

2.3 Moisture Content

Moisture content of the fabric was determined by using Sartorius Moisture Analyser MA100/MA50. This instrument will heat up the sample up to 105 °C.

2.4 Tensile Properties

Tensile properties (ASTM D 5034) of hemp fabrics were characterized using universal testing machine MTS Alliance RT/10. Tensile tests were performed using a gauge length of 75 mm and a cross-head speed 2 mm/min. The cross-sectional area used to convert load into stress was calculated from the test specimen width and the thickness of fabric obtained from the fabric characterization [12, 13]. The initial response of the curve was nonlinear but then the slope increased slowly until finally becoming linear. Tensile moduli of the fabric were determined from the linear part of the curves.

3. Results and Discussion

3.1 Physical Properties of Hemp Fabric

Table 2 presents the determined physical properties of hemp fabrics. When observing all the fabrics, no defect was found along the fabric length for at least 5 meters. Therefore, it can be concluded all fabrics were manufactured in good loom (most probably shuttleless loom) and they are good-quality fabrics.

Table 2 Physical properties results of woven hemp fabric.

Fabric Types		Fabric A	Fabric B	Fabric C
Weave Structure		Plain	Plain	Plain
Fabric Density (per 2cm)	Warp	25	25	34
	Weft	23	23	26
Fabric Weight (Reading) (g/m^2)		231.410	228.520	410.720
Thickness (mm)		0.41	0.41	0.71
Yarn Size (Tex)	Warp	89.661	90.459	106.717
	Weft	92.896	92.970	123.600
Yarn Crimp (%)	Warp	5.4	6.0	27.4
	Weft	9.3	9.3	3.6

According to Table 2, fabric density for Fabric A and B was determined similar but lower in comparison with Fabric C indicates that Fabric C is more compact than Fabric A and B. In terms of fabric weight, Fabric A was found a slightly heavier than Fabric B and yet their weight was at least 17 % lesser than the specification given by the supplier (271 g/m^2). In comparison with Fabric C, they are recorded at least 77 % lower than Fabric A and B. All the weights reflected their measured thicknesses which were 0.41 mm for Fabric A and B and 0.71 mm for Fabric C. In terms of yarn size, the weft yarn for Fabric A and B were recorded similar which was 93 tex, yet their warps' sizes were recorded a little different which were 89.661 and 90.459 tex respectively. The sizes of warp and weft for Fabric C were determined even higher by at least 24 % than other two fabrics and this is the reason why it is heavier.

It is well known that yarn crimp in a woven fabric is an important parameter that affects most of its physical properties and that include the thickness and the weight of fabric [14]. Based on the results in Table 2, both fabrics have relatively similar warp and weft crimp percentage which is 5.4 and 9.3 % respectively. The slight different warp between fabric A and B was normally due to the different ‘picking stroke’ action in loom machine during fabric manufacturing. More importantly is the yarn crimp for Fabric C, which was measured to have very significant difference with other two fabrics for at least 78 % in warp and 158 % for weft yarns. This will relatively give a significant different between Fabric C and other two fabric in their mechanical properties responses.

3.2 Density of Fibre

The density of fibre for Fabric A and B determined by pycnometry are presented in Table 3. The results show that for each series of measurements, the fibre density is higher for Fabric A than Fabric B with overall means of 1.512 and 1.473 g/cm^3 respectively. The determined density of the hemp fabric fibres is comparable and within the typically reported densities of hemp fibres varying between 1.4 and 1.5 g/cm^3 [4, 15]. Fibre density of Fabric C was determined a little higher than other two fabrics which is 1.526 g/cm^3.

Normally, the bulkiness of natural fibre makes it quite difficult to compress. Even with a good spinner and loom, the pressure given is unable to compact the fibre to make the density lower than 1.4 g/cm^3, due to fibre irregularities along the fibre length. The irregularities create higher cavities on the yarn as compared to the synthetic fibres [16]. In the case of hemp fabrics, Fabric C was determined to have higher fabric density in its both warp and weft direction as compared to Fabrics A and B (refer Table 2). The higher warp and weft that accommodate in fabric make the fabric more compact thus affects the fibre density of the fabric [17]. This is main the reason of the slight higher fibre density of Fabric C in comparison with other two fabrics.

Table 3 Density of fibre (g/cm^3) of the Fabrics A and B determined by 3 series of measurements.

Fabric Types	Series of measurement				
	I	II	III	Average	Stdv.
Fabric A	1.528	1.499	1.510	1.512	0.015
Fabric B	1.481	1.472	1.466	1.473	0.007
Fabric C	1.518	1.531	1.530	1.526	0.007

3.3 Fabric Appearance Structure

Fig. 1 shows the appearance structure of woven hemp fabrics. It was observed that all the fabrics were woven with the plain/taffeta weave structure. This is the most basic woven structure other than twill and satin and is usually utilised for technical purposes [18].

Yarns for all fabrics were observed to vary in cross-sectional dimensions, especially for Fabrics A and B. It can be shown in Fig. 1 that lots of thick and thin yarns found to be running in the warp and weft directions. The yarns' size determined for both fabrics are just the average values (refer Table 2). Since the fabrics used are made of natural fibres, this kind of irregularities and inconsistencies with the yarn were expected to happen [4]. The yarns for both fabrics were observed to have twists with a right-handed angle to the yarn axis (Z-twist). Yarns in Fabric C are also varied in cross-sectional; however, since it is more compact than other two fabrics, the variation was less appeared and a bit difficult to be seen. The weft yarn for this fabric was spun in Z-twist whilst the warp yarn was two plied-yarns in S-twist, and each ply yarn was spun in Z-twist. This twist value is received as specified by the supplier.

More importantly, the properties related to the fabric appearance should be emphasized.

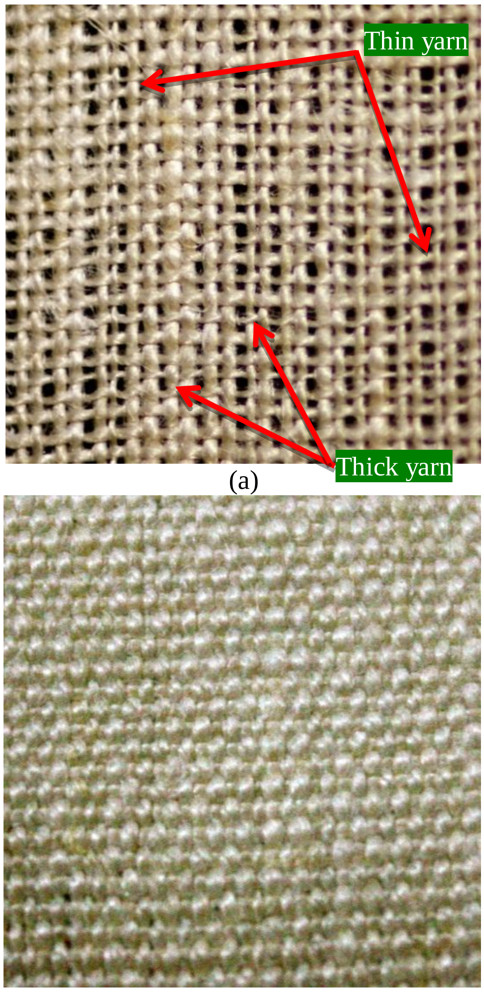


Fig. 1 The structure of woven hemp fabrics, (a) Fabric A and B, (b) Fabric C.

Fabric cover factor indicated the extent to which the area is covered by one set of yarns. For composite fabrication, this characteristic can tell how well the resin could penetrate into the fabric system. In order to determine the total fabric cover factor, a modified equation introduced by Chen and Leaf [19] was used and the K-value is the ratio on how big the area is covered by the yarns.

Table 4 Result of cover factor for both fabric used in this work.

Fabric Types	Fractional yarn cover		Total Fabric Cover
	Warp C1	Weft C2	K
Fabric A	0.435	0.406	0.664
Fabric B	0.433	0.405	0.663
Fabric C	0.642	0.529	0.832

The results tabulated in Table 4 clearly show that 66 % (0.66) of the fabric sheets are therefore covered by yarn for Fabrics A and B. From the textile point of view, these fabrics share identical cover factor quality and can be used in a similar batch of textile product for certain application. The total cover factor for Fabric C was determined higher than other two fabrics with 83 % of the yarn cover the fabric sheet and this is consistent with the fabric density it possesses (refer Table 2). From the K-values, it can be inferred that Fabrics A and B would have better resin penetration than Fabric C thus better adhesion is expected from these fabrics.

3.4 Mechanical Properties

Typical stress-strain curve of all woven hemp fabrics is shown in Fig. 2. In the initial phase, the curve rose with a low slope due to decrimping and crimp interchange. The decrimping and crimp interchange is internal interaction (crossover between warp and weft yarns) of a fabric that results to the initial curve. Second phase is shown in which the stress-strain curve increased sharply. From here, the yarns appear to become less flattened due to the consolidation into more circular cross-section. As the pressure builds up for the yarn in the direction of force, yarn extension now only accounts for a small portion as compared to the extension of yarn in the first phase. This situation continuously happens until it reaches the peak and then breaks.

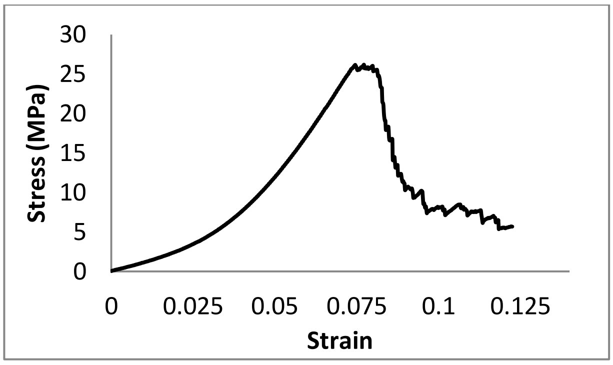
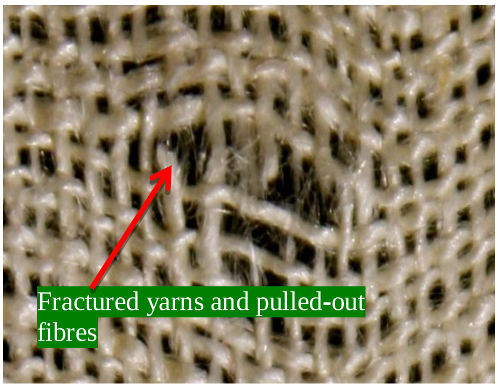


Fig. 2 Typical stress-strain response for all woven hemp fabrics used in this work.



(a)

(b)

Fig. 3 Typical fabric fracture after subjected to tensile force for; (a) Fabric A and B, (b) Fabric C.

Fig. 3 shows magnified yarn fractures area on the fabrics. It was observed that the fractures were happened mainly at the area which has many thin yarns. There were many pulled-out fibres found at the fractured yarns which suggesting that the fibres were resisting the tensile force acting on them.

Table 5 Summary of average tensile properties for woven hemp fabrics.

Fabric Types		Peak Load (N)	Tensile Strength (MPa)	Tensile Strain	Tensile Modulus (GPa)
Fabric A	Warp	442.1 (±29)	23.392 (±1.52)	0.074 (±0.004)	0.540 (±0.023)
	Weft	497.5 (±56)	26.304 (±2.99)	0.121 (±0.008)	0.511 (±0.032)
Fabric B	Warp	415.3(±21)	21.975 (±1.11)	0.093 (±0.026)	0.530 (±0.041)
	Weft	469.3 (±38)	24.833 (±1.99)	0.112 (±0.006)	0.493 (±0.044)
Fabric C	Warp	1289.3 (±17.55)	33.777 (±3.85)	0.353 (±0.036)	0.175 (±0.019
	Weft	1249.3 (±123)	34.58 (±3.41)	0.065 (±0.009)	0.642 (±0.029)

*Figures in parentheses represent standard deviations

The results of tensile properties for both woven hemp fabric are shown in Table 7. The figures in the table are the average ± standard deviation for at least 9 specimens. Overall, it can be said that the tensile strength of Fabric A is higher than Fabric B. In warp direction, tensile strength of Fabric B was recorded 6 % lesser than Fabric A while the weft direction specimen with the tensile strength of Fabric B was determined 6.4 % lower than Fabric A. Tensile strength of Fabric C was determined at least 21 % higher than Fabric A and B due to higher fibre content (fabric weight) in the fabric. The lowest tensile modulus of all the hemp woven fabric was Fabric C in the warp direction which was determined as 0.175 GPa and this most probably due to the higher crimp (refer Table 2) it possesses in warp direction.

4. Conclusions

The results suggest that Fabrics A and B are designed as it should be physically and mechanically balanced in warp and weft direction. The slight difference between these two fabric properties are due to variation on the yarn properties as well as in the process of fabric manufacturing. In terms of Fabric C, the fabric is not balanced in warp and weft direction in all characteristics, especially for their crimps. Even though the properties are different between warp and weft, it has higher fibre content and more compact than other two fabrics. This supposedly gives best mechanical properties for the composite material as compared to Fabrics A and B. However, the total cover factor for Fabric C is far higher than Fabrics A and B. With the 66 % of Fabric A and B are covered by yarns as compared to Fabric B which is 83 %, it is expected that the penetration of resin is far better for Fabric C. This also means a good adhesion between the resin and yarn for those two fabrics than Fabric C if it is used as reinforcement in composite material.

5. Acknowledgement

The authors would like to thank Ministry of Higher Education, Malaysia and Universiti Teknologi MARA, Malaysia for providing scholarship to first author on doing this work.

REFERENCES

[1] Nishino T, Hirao K, Kotera M, Nakamae K, Inagaki H. Kenaf reinforced biodegradable composite. Composites Science and Technology. 2003;63:1281-6.
[2] Mishra S, Tripathy SS, Misra M, Mohanty AK, Nayak SK. Novel Eco-Friendly Biocomposites: Biofiber Reinforced Biodegradable Polyester Amide Composites—Fabrication and Properties Evaluation. Journal of Reinforced Plastics and Composites. 2002;21:55-70.
[3] Misnon MI, Bahari SA, Wan Ahmad WY, Ab Kadir MI, Anuar M. Reinforcement of Textile Fabric in Agricultural Waste Particleboard. in Proceeding 87th Textile Institute World Conference 2010. 2011:408-52.
[4] Misnon MI, Islam MM, Epaarachchi JA, Lau K-t. Potentiality of utilising natural textile materials for engineering composites applications. Materials & Design. 2014;59:359-68.
[5] Chilton J, Velasco R. Applications of textile composites in the construction industry. In: Long AC, editor. Design and manufacture of textile composites. England: CRC Press, Woodhead Publishing Ltd, Cambridge; 2005. p. 424-35.
[6] Netravali AN, Huang X, Mizuta K. Advanced 'green' composites. Advanced Composite Materials. 2007;16:269-82.
[7] Faruk O, Bledzki AK, Fink H-P, Sain M. Biocomposites reinforced with natural fibers: 2000–2010. Progress in Polymer Science. 2012;37:1552-96.
[8] Satyanarayana KG, Arizaga GGC, Wypych F. Biodegradable composites based on lignocellulosic fibers—An overview. Progress in Polymer Science. 2009;34:982-1021.
[9] Madsen B, Hoffmeyer P, Thomsen AB, Lilholt H. Hemp yarn reinforced composites – I. Yarn characteristics. Composites Part A: Applied Science and Manufacturing. 2007;38:2194-203.
[10] Akovali G, Uyanik N. Introduction. In: Akovali G, editor. Handbook of Composite Fabrication. Shropshire, U.K: Rapra Technology Limited; 2001. p. 1-19.
[11] Scardino F. An Introduction to Textile Structures and their Behaviour. Textile Structural Composite. 1989;3:1-26.
[12] Yahya MF, Salleh J, Ahmad WYW. Uniaxial failure resistance of square-isotropic 3D woven fabric modelled with finite element analysis. Business, Engineering and Industrial Applications (ISBEIA), 2011 IEEE Symposium on2011. p. 16-21.
[13] Huang X, Netravali A. Characterization of flax fiber reinforced soy protein resin based green composites modified with nano-clay particles. Composites Science and Technology. 2007;67:2005-14.
[14] Süle G. Investigation of bending and drape properties of woven fabrics and the effects of fabric constructional parameters and warp tension on these properties. Textile Research Journal. 2012;82:810-9.
[15] Dittenber DB, GangaRao HVS. Critical review of recent publications on use of natural composites in infrastructure. Composites Part A: Applied Science and Manufacturing. 2012;43:1419-29.
[16] Kadolph SJ, Langford AL. Textiles. 9th ed. New Jersey:: Prentice Hall; 2001.
[17] Shahabi NE, Saharkhiz S, Varkiyani H, Mohammad S. Effect of Fabric Structure and Weft Density on the Poisson's Ratio of Worsted Fabric. Journal of Engineered Fabrics & Fibers (JEFF). 2013;8.
[18] Sondhelm WS. Technical fabric structures – 1. Woven fabrics. In: Horrocks AR, Anand SC, editors. Handbook of Technical Textiles. North and South America: Woodhead Publishing Limited & The Textile Institute; 2000.
[19] Chen X, Leaf GAV. Engineering Design of Woven Fabrics for Specific Properties. Textile Research Journal. 2000;70:437-42.