Study on Mechanical Properties of Flax Fibre Textile Reinforced Composites Fabricated Using Bio-Based Epoxy Resin Matrix

Arunjunai Raj Mahendran*, Gunter Wuzella, Stefan Pichler and Herfried Lammer

Kompetenzzentrum Holz GmbH, Wood Carinthian Competence Center, Klagenfurter Strasse 87-89, A-9300 Sankt Veit an der Glan, Austria

Abstract: Flax fibre reinforced composites were made from non-crimp and woven flax fabric reinforcements using bio-based epoxy resin matrix. The fabrics impregnated with epoxy resin containing 55% biomass carbon were fabricated using vacuum bag technique. The fibre weight content of around 40 wt% was achieved through the vacuum bag technique. The fibre assembly and the morphology of the composites were studied using optical microscope. The influences of different weave type and fibre layup direction on the mechanical properties of composites were studied. It was found that, the woven fabric had lower impact strength values than the unidirectional and biaxial oriented fibres. But the woven fabric had achieved relatively equal impact energies on both directions. The maximum flexural strength (196 MPa) and modulus (13.5 GPa) was observed for the unidirectional non-crimp fabric on 0° fibre layup direction.

Keywords: Natural fibre, non-crimp and woven fabric, bio-based epoxy resin, mechanical properties.

1. INTRODUCTION

In the last two decades the utilization of natural fibre reinforced composites for the engineering applications is getting popular due to high specific strength and modulus, as well as their potential environmental benefits. The matrix binder resins used for fabricating natural fibre reinforced composites were mainly from petroleum derived raw materials and they are either thermoset or thermoplastic material. The unsaturated polyester, epoxy and phenolic binders are generally used as thermoset resin matrix and polypropylene, polyethylene and elastomers are used as thermoplastic resin matrix. If the composites are made using any one of the processing methods like pultrusion, filament winding, resin injection or transfer moulding technique then thermoset resins were preferred. In composite industries, epoxies were used as one of the structural matrix material along with different reinforcements and these epoxies are generally obtained from fossil fuel derived raw materials. Currently the composite industries are attempting to introduce a renewable carbon in the matrix resin and also natural fibre reinforcement which is due to increased environmental consciousness and depletion of non-renewable resources [1-3]. The flax, hemp, kenaf and jute are the most common bast fibres used to prepare natural fibre reinforced composite. The bio-based thermoset resin matrix along with natural fibre reinforcement was studied in detail by Williams *et al.*, [4]. Mechanical properties of composite made using hemp fibre and polyester resin matrix using RTM process were investigated by Sebe *et al.*, [5]. Natural fibre mats with thermoplastic resin matrix was studied by Oksman [6] and Garkhail *et al.*, [7]. In the current investigation, an epoxy system derived from plant resource was used as resin matrix and it contains 55% of “green” carbon.

The fibres in the form of woven and non-woven mats were used as reinforcement. The woven fibre textiles as reinforcement in the composite are advantageous since it allow for the precise placement, which could improve the mechanical properties of the reinforcement. Due to above reason the woven fabric reinforced composites are most commonly used in structural applications like aircrafts, boats and automobiles. The weaving pattern and the fibre layup pattern can also determine the mechanical properties of the composite.

Adekunle *et al.*, [8] investigated the impact and flexural properties of flax fabrics and lyocell fibre oriented composite made using bio-based thermoset. It was found that, plain and dobby weave architecture gave better reinforcing effects and the flexural properties were increased with an increase in outer ply thickness. George *et al*., [9] studied the mechanical properties of the flax fibre reinforced composites made using autoclave moulding technique and the results show that fibre modification improved the fibre-matrix interaction and also the tensile and impact strength of the composites. Similarly Khot *et al*., [10] investigated the mechanical properties of the flax fibre reinforcement with the bio-based thermoset resin. It was found that, the flax composites had tensile and flexural strengths in the ranges of 20-30 and 45-65 MPa, respectively. In this study, the flax fabric having

*Address correspondence to this author at the Kompetenzzentrum Holz GmbH, Wood Carinthian Competence Center, Klagenfurter Strasse 87-89, A-9300 Sankt Veit an der Glan, Austria; Tel: +43 4212 494 8016; Fax: +43 4212 494 8099; E-mail: a.mahendran@kplus-wood.at

E-ISSN: 2311-8717/14

different fibre orientation and weave type were impregnated with epoxy from renewable resource. The flexural and impact strengths were investigated for the flax fabric reinforced composites.

To prepare the composites there are wide varieties of processing methods available and it depends on process parameter, cost of manufacturing and tooling. Among the processing methods vacuum bagging is a clamping method that uses atmospheric pressure to hold the matrix and reinforcement in a vacuum bag. The vacuum pressure is applied over the mould until the resin cures. The vacuum bagging technique is advantageous, because it gives freedom to control the resin content which can yield higher fibre to resin ratios. Another major advantage is that, variety of moulds can be used simply to manufacture composite. On the other hand the maximum pressure is limited to <1 bar. In this investigation, the vacuum bag technique was used to manufacture the flax fibre textile reinforced composites. The impregnated flax fabrics were cured under vacuum and the mechanical properties of the cured laminates were characterized.

2. MATERIALS AND METHODS

2.1. Materials

The unidirectional (UD) non-crimp flax fabrics were purchased from Sicomin composites, France. The weight of the fabric was 315 g/m^2 and the warp and weft count of the UD fabrics were 21 ends/cm and 3 pick/cm respectively. The hopsack and biaxial fabrics were purchased from Composites Evolution Ltd., Chesterfield, United Kingdom. The woven fabric had a 4x4 plain weave style and weight of 500 g/m^2 and it is called hopsack in the following. The warp and weft count of the fabrics was 7 ends/cm and 11 picks/cm respectively. The biaxial non-crimp fabric was stitched +/- 45 fibre orientation and the weight of the fabric was 600 g/m^2. The stitch type is pillar and the stich thread is polyester for the biaxial fabric. The photos of three different fabric types are shown in Figure **1**. The matrix resin containing 55% “green” carbon (Greenpoxy 55) was purchased from Sicomin composites, France. The resin was cured with GP 505 epoxy hardener which is

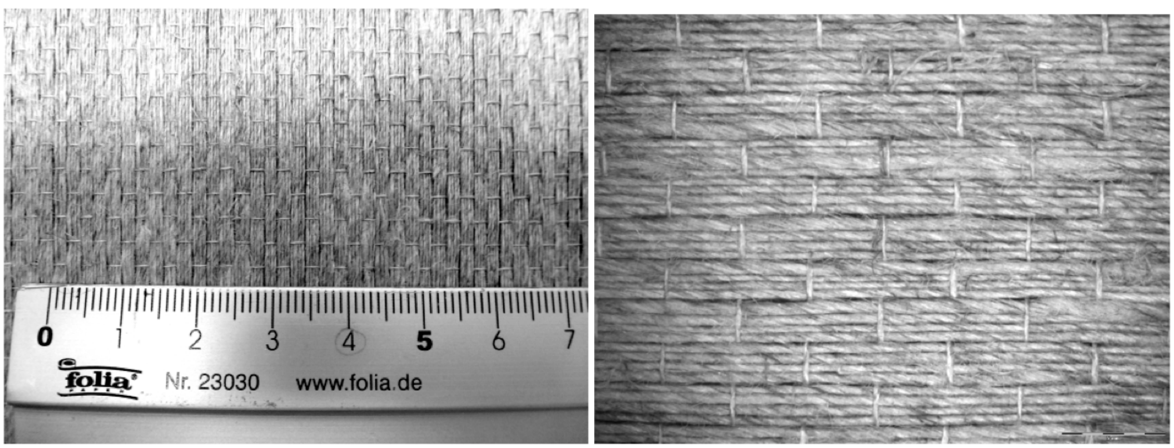

Figure 1: UD non-crimp flax fabric from Sicomin (**a**) and its microscopic view (**b**).

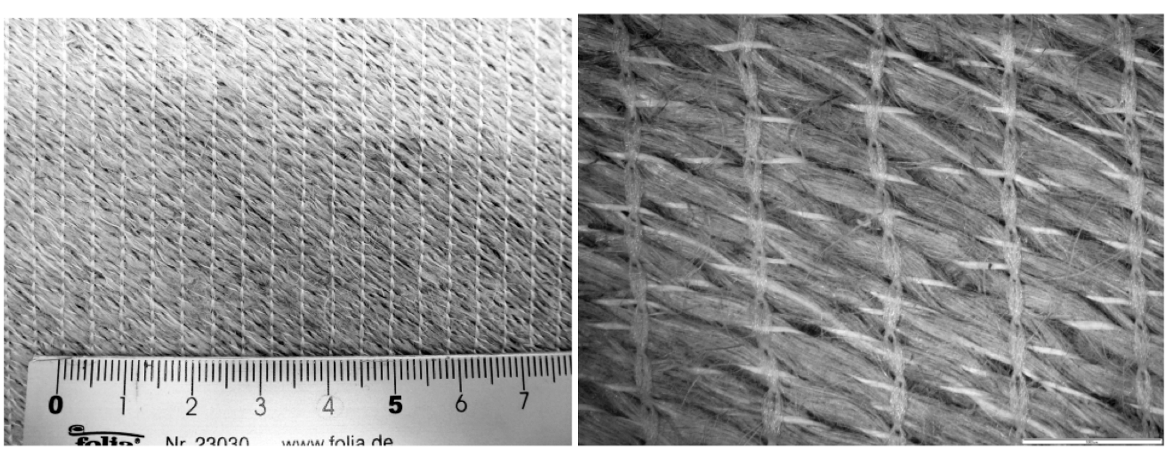

Figure 2: +/- 45 biaxial flax fabric from Composite Evolution (**a**) and its microscopic view (**b**).

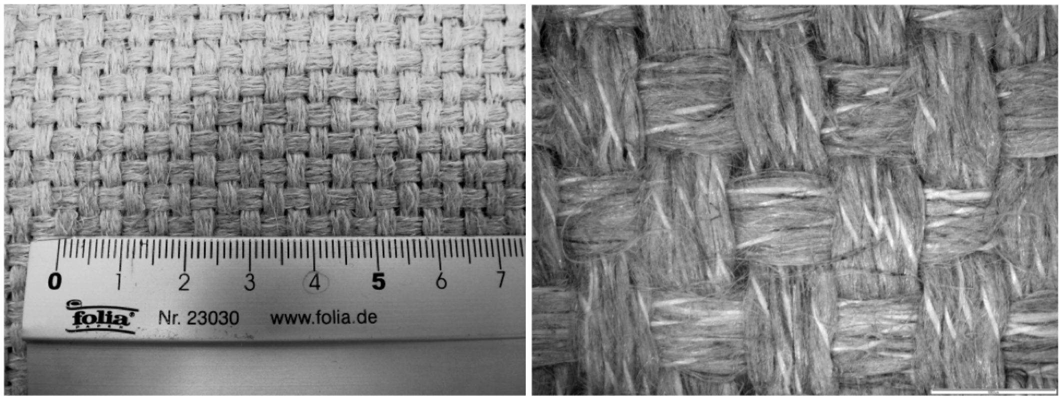

Figure 3: 4x4 Hopsack flax fabrics from Composite Evolution (**a**) and its microscopic view (**b**).

also supplied by Sicomin composites. Densities of resin and hardener were 1.152 and 0.99 g/cm^3, respectively.

The fabrics were cut in the size of 30x30 cm and they were impregnated with a matrix resin by hand layup technique using soft foam rollers. The impregnated fabrics were stacked together depending on the type of construction and they were cured under vacuum at room temperature. The different constructions for fabricating natural fibre reinforced composites are shown in Figure **4**.

2.2. Methods

The vacuum bag technique was used to prepare the reinforced composite and for this the impregnated woven fabrics were compressed inside the vacuum bag along with peel ply, bleeder and breather. The vacuum has been applied with the help of external vacuum pump. The laminate was allowed to cure at room temperature for the duration of 24 h under vacuum. The samples were post cured at 80°C for the duration of 15 h in an oven.

The edges of the fabricated composites were trimmed and the test specimens for the impact and flexural tests were cut on both longitudinal and transverse directions of the panel. The thickness of the specimens was varied from 1.8 to 2.3 mm based on type of construction. The cross section of the composites was inspected using optical microscope in order to identify the fibre alignment in the resin matrix.

The flexural testing was carried out in a Beta A20-10 universal testing machine from Messphysik Materials Testing GmbH, Austria. The flexural testing was done at a cross head speed of 2mm/min and test specimens were prepared as per the EN ISO 178 standard. For the Charpy impact testing, the specimens were cut as per the ISO 179 standard and the tests were carried out at room temperature in Instron CEAST 9050 instrument from Instron GmbH, Germany.

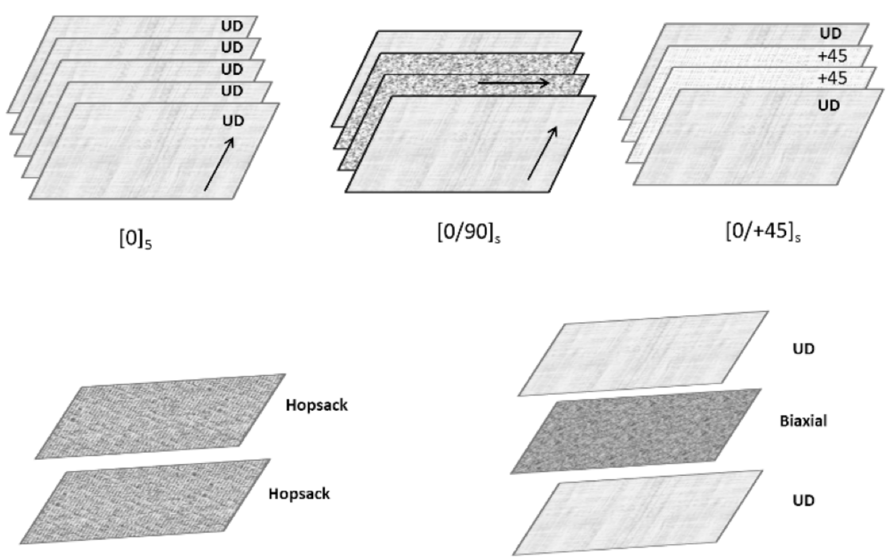

Figure 4: The construction pattern for the different woven flax fabric reinforced composite.

Table 1: Fibre Weight, Volume and Void Volume Fraction for each Laminate

Laminate	Fibre weight fraction (%)	Fibre Volume fraction (%)	Void volume fraction
$[0]_5$	53.4	46.1	5.4
$[0/90]_s$	55.4	48.1	14.1
$[0/+45]_s$	53.5	45.6	6.6
[0/±45/0]	53.0	46.2	6.5
Hopsack	49.4	42.1	11.4

The laminate fibre weight fraction was determined from the weight of the laminates and the weight per unit area of the reinforcement using the formula.

$$W_f = \frac{n \times w_f}{w_c} \times 100 \quad (1)$$

Where n is the number of laminate, w_f is the weight per unit area of each layer of natural fibre used, and w_c is the weight per unit area of the composite laminate.

The laminate fibre volume fractions (V_f) were calculated from the fibre weight fraction (W_f) values using the following formula.

$$V_f = \frac{1}{\left[1 + \frac{\rho_f}{\rho_r}\left(\frac{1}{W_f} - 1\right)\right]} \times 100 \quad (2)$$

Where, ρ_f and ρ_r are the densities of the fibre and matrix resin.

The void volume fraction (V_v) was calculated using equation (3) in terms of the mass fraction ($\%_m$) and density (ρ) of the matrix and fibre respectively.

$$V_v = 100 - \rho_{comp}\left(\frac{\%_m matrix}{\rho_r} + \frac{\%_m fibre}{\rho_f}\right) \quad (3)$$

Where, ρ_{comp} is the density of the composite.

For the water absorption test, the specimens were immersed in deionized water and the change in weight was monitored until the equilibrium level is attained. The percentage of water absorption was determined using the following equations.

$$W_{WA} = \frac{W_t - W_0}{W_0} \times 100 \quad (4)$$

Where W_0 is the weight of specimen before immersion and W_t is the weight of the specimen after certain duration of time.

4. RESULTS AND DISCUSSION

The laminate fibre weight fractions and volume fractions were varied for each laminates and they have a great influence on the mechanical properties and water absorption values. Hence for each laminates weight and volume fractions were calculated and they are tabulated in Table **1**.

The cross section of the laminates made using natural fibre reinforcement and bio-based resin matrix were analysed using optical microscope and this technique were used to gain the morphology of the composite, fibre alignment, fibre packing density and matrix-fibre interaction in the composite. The microscopic view of each laminate is shown in Figures **5-10**.

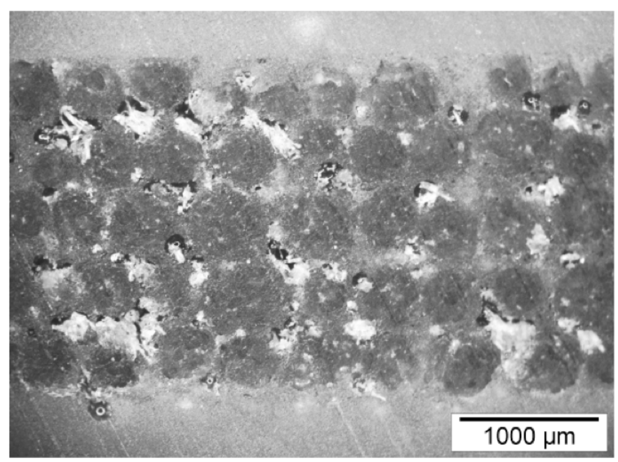

Figure 5: Cross sectional view of the $[0]_5$ laminate viewed under optical microscope.

In Figure **5**, one can observe the close packing density of the unidirectional fibres and also the circular fibre cross section of uniform radius. The pressure applied during vacuum bagging process caused considerable close alignment of the fibres with negligible change in fibre dimension.

In Figure **6**, the dark area in the top and bottom layer shows the assembly of 0 ° oriented UD fabric. The middle layer shows 90 ° orientation of the same

UD fabric. In the interface between the 0° and 90° plies few micro cracks and voids were observed.

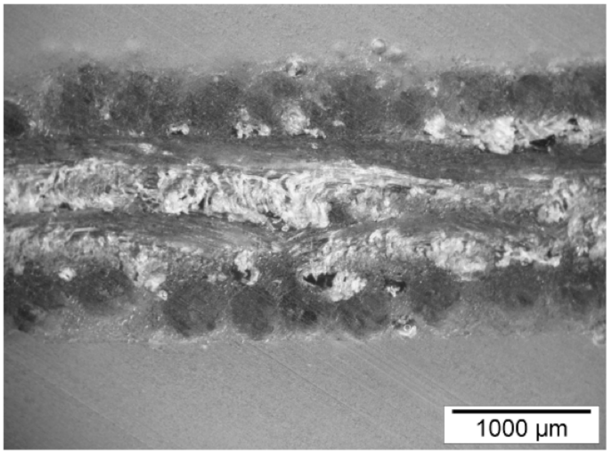

Figure 6: Cross sectional view of the $[0/90]_s$ laminate viewed under optical microscope.

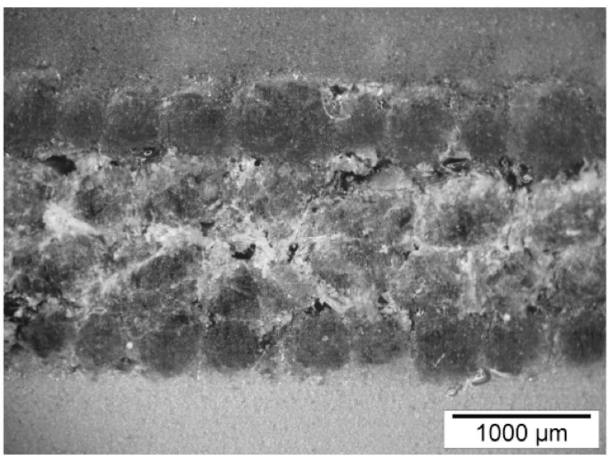

Figure 7: Cross sectional view of the $[0/+45]_s$ laminate viewed under optical microscope.

In Figure **7**, the fibre orientations are much similar to the unidirectional fibres as seen in Figure **5**.

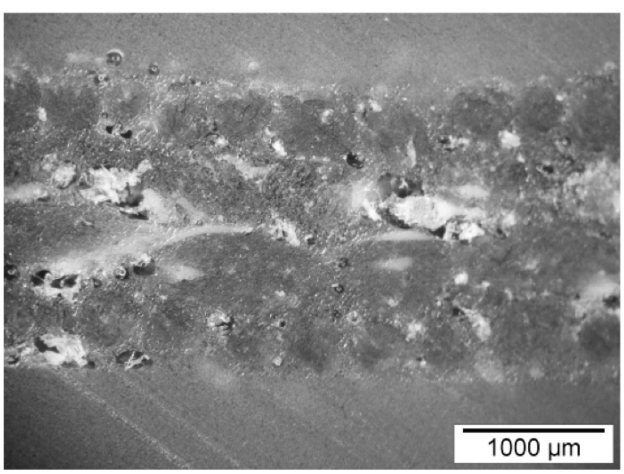

Figure 8: Cross sectional view of the [0/±45/0] laminate viewed under optical microscope.

In Figure **8**, the top and bottom layers were similar as described in Figure **6**. The middle layer shows the stitched biaxial non-crimp fabric which is filled densely filled with resin matrix.

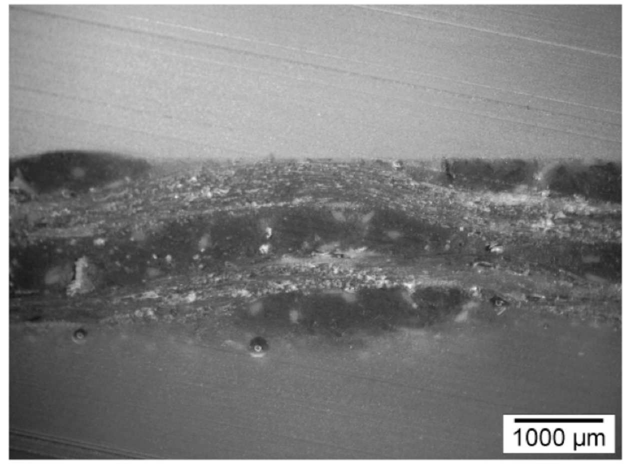

Figure 9: Cross sectional view of the hopsack laminate viewed under optical microscope.

In Figure **9**, the two plies of hopsack fabrics were stacked with symmetrical alignment of warp and weft yarn.

During resin impregnation, the hopsack weave type was more difficult to impregnate with the high viscous bio-based resin than the non-crimp fabrics.

The water absorption results reflect the water absorption capacity of lignocellulosic fibres and the resin matrix. The hydrophilic nature of natural fibres is mainly responsible for relatively high water absorption in the composites. The three laminates $[0]_5$, [0/±45/0], $[0/+45]_s$ showed comparatively less water absorption than other two laminates and those three laminates had a fibre weight fraction of 53 % . The $[0/90]_s$ laminates had a higher water absorption value compared to other laminates which is due to high fibre content and also it showed high void content compared to other composites.

An increase in amount of water absorption could be caused by numerous effects and some of them might be quality of the fibre matrix interfaces, binding of the water molecules to the molecular structure of the resin and also the void content in the resin [11]. The laminates fabricated by vacuum bagging suffer from an inherently high void content compared to other processing methods like autoclaved prepreg system, resin transfer or infusion technique. Due to above reason the void volume content was relatively high for all laminates. The $[0/90]_s$ laminate had the highest void volume content (Table **1**) and may be due to this the laminate had higher water uptake. The following three laminates $[0]_5$, [0/±45/0], $[0/+45]_s$ had lowest water absorption because they had only 6% void volume content. It confirms that the void content has considerable influence on the water uptake property of the laminates.

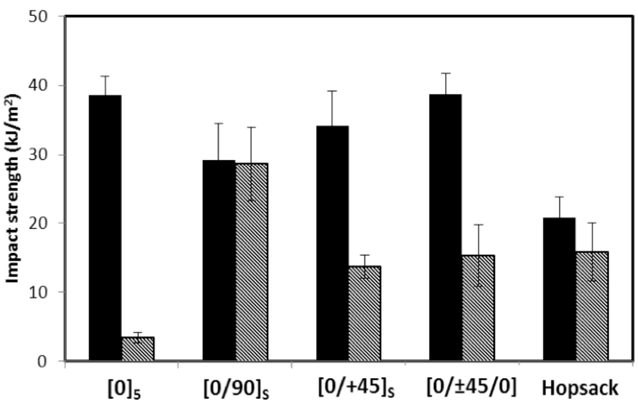

Figure 10: Impact strength of the laminates on the longitudinal (filled) and transverse (crossed) direction of the panel.

The impact strength of the composites based on different fibre layup direction and weave type is shown in Figure **10**. The impact strengths of the laminates was much higher in the directions longitudinal to the fibre layup than in transverse direction $[0]_5$, [0/±45/0], $[0/+45]_s$. The other two composites having $[0/90]_s$ and hopsack fibre layup had smaller difference in impact strength between both directions. The reason is due to the homogeneous distribution of the fibres on both directions. The highest impact strength of 39 kJ/m^2 was observed for the $[0]_5$ and [0/±45/0] laminates. The impact strength was considerably higher for the [0/±45/0] laminate than $[0/+45]_s$ composite which might be due to the presence of stitched ±45 non-crimp fabric.

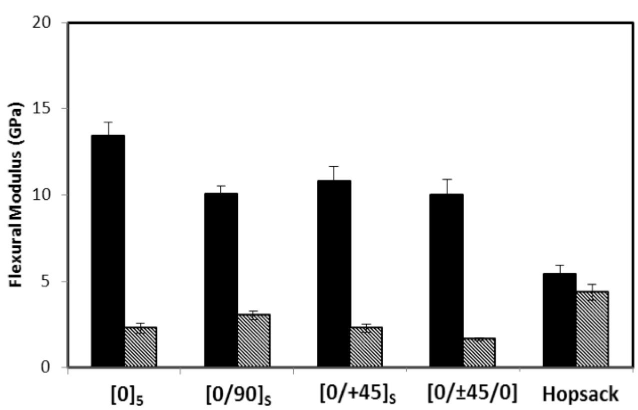

Figure 11: Flexural modulus of the laminates on the longitudinal (filled) and transverse (crossed) direction of the panel.

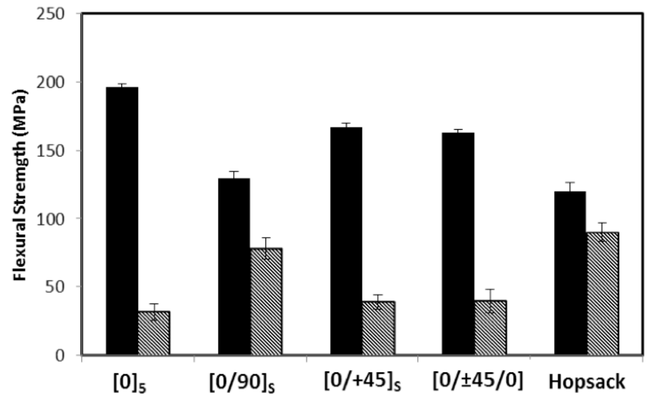

Figure 12: Flexural strength of the laminates on the longitudinal (filled) and transverse (crossed) direction of the panel.

The highest flexural strength and modulus value among the five laminates was obtained for the non-crimp reinforced composite. The hopsack fabric had around 20% difference in the flexural strength and modulus values between warp and weft direction. Whether the composites contains [0/±45] orientation or [0/+45] orientation, both composites had more or less the equal flexural strength and modulus values. The result shows that, the 45° oriented fibres are an effective bending stress transfer constituent in the composite system independent of the layup direction. A 30% decrease in the flexural strength was observed in the longitudinal direction of laminates if the orientation in the middle layer was changed from [0/45] to [0/90]. The stiffness of all three fibre oriented [0/±45/0], $[0/+45]_s$, $[0/90]_s$ composites were relatively same and they had a flexural modulus of 10 GPa.

5. CONCLUSIONS

The effect of stacking sequences on the mechanical properties of the flax fibre reinforced composites was characterized and the bio-based epoxy resin was used as matrix resin for the composite. A fibre volume content of 40% was achieved using vacuum bag technique. Water absorption values of 6 to 9 % were recorded for the laminates. The laminates reinforced with non-crimp fabrics showed higher mechanical strength on the 0° fibre direction but general lower values in the transverse direction. The symmetric and anti-symmetric arrangement of 45° plies had no significant change in flexural modulus of the laminates. The laminates from woven fabrics had a smaller difference in mechanical strength between both warp and weft directions. The reason is due to the homogeneous distribution of the fibres on both directions.

REFERENCES

[1] Kummerer K. Sustainable from the very beginning: rational design of molecules by life cycle engineering as an important approach for green pharmacy and green chemistry. Green Chem 2007; 9: 899-907.
http://dx.doi.org/10.1039/b618298b

[2] Raston C. Renewables and green chemistry. Green Chem 2005; 7: 57-157.
http://dx.doi.org/10.1039/b500769k

[3] Jenck JF, Agterberg F, Droescher MJ. Products and processes for a sustainable chemical industry: a review of achievements and prospects. Green Chem 2004; 6: 544-556.
http://dx.doi.org/10.1039/b406854h

[4] Williams IJ, Wood RP. Composites from natural fibres and soy oil resins. Appl Compos Mater 2000; 7: 421-432.
http://dx.doi.org/10.1023/A:1026583404899

[5] Sebe G, Cetin NS, Hill CAS, Hughes M. RTM hemp fibre-reinforced polyester composites. Appl Compos Mater 2000; 7: 342-349.
http://dx.doi.org/10.1023/A:1026538107200

[6] Oksman K. Mechanical properties of natural fibre mat reinforced thermoplastic. Appl Compos Mater 2000; 7: 403-414.
http://dx.doi.org/10.1023/A:1026546426764

[7] Garkhail SK, Heijenrath RWH, Peijs T. Mechanical properties of natural-fibre-mat- reinforced thermoplastics based on flax fibres and polypropylene. Appl Compos Mater 2000; 7: 351-372.
http://dx.doi.org/10.1023/A:1026590124038

[8] Adekunle K, Cho SW, Patzelt C, Blomfeldt T, Skrifvars M. Impact and flexural properties of flax fabrics and Lyocell fibre-reinforced bio-based thermoset. J Reinf Plast Comp 2011; 30: 685-697.
http://dx.doi.org/10.1177/0731684411405874

[9] George J, Ivens J, Verpoest I. Mechanical properties of flax fibre reinforced epoxy composites. Die Angew Makromol Chem 1999; 272: 41-45.
http://dx.doi.org/10.1002/(SICI)1522-9505(19991201)272:1<41::AID-APMC41>3.0.CO;2-X

[10] Khot SN, Lascala JJ, Can E, Morye SS, Williams SI, Palmese GR, Kusefoglu SH, Wool RP. Development and application of triglyceride-based polymers and composites. J Appl Polym Sci 2001; 82: 703-723.
http://dx.doi.org/10.1002/app.1897

[11] Kumosa L, Benedikt B, Armentrout D, Kumosa M. Moisture absorption properties of unidirectional glass/polymer composites used in composite (non-ceramic) insulators. Comp Part A- Appl S 2004; 35: 1049-1063.

Received on 14-07-2014 Accepted on 28-07-2014 Published on 31-12-2014

DOI: http://dx.doi.org/10.12974/2311-8717.2014.02.02.1