IMPACT AND FLEXURAL PROPERTIES OF FLAX FABRICS AND LYOCELL FIBER REINFORCED BIO-BASED THERMOSET FOR AUTOMOTIVE AND STRUCTURAL APPLICATIONS

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Abstract
A bio-based thermoset resin was reinforced with flax fabrics and Lyocell fiber. The effect of different weave architecture was studied with four flax fabrics with different architecture: plain, twill (two different types) and dobby. The effect of the outer ply thickness was studied and characterized with flexural and impact testing. Composites manufactured with plain weave reinforcement had the best mechanical properties. The tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength was 280 MPa, 32 GPa, 250 MPa, 25 GPa and 75 kJ/m^2 respectively.

1 Introduction
Natural fiber reinforced composites have been studied by many authors, and natural fibers such as flax, jute, bamboo, sisal, hemp, ramie, abaca, kapok etc are of particular interest as reinforcement in structural composites. However the shortcomings of these natural fibers cannot be overlooked if they are to replace the man-made glass fibers. Moisture uptake [1], inadequate fiber/matrix adhesion [2] as a result of poor compatibility with the hydrophobic matrix, low thermal stability and lack of uniformity of properties due to climatic conditions when cultivated, decortications etc, make natural fibers less attractive in composite manufacturing [3].

These shortcomings have been overcome by pretreatment of the fibers which will modify the fiber surface and reduce the moisture absorption and increase the surface roughness for better fiber-matrix adhesion, consequently leading to composites with good mechanical properties [4-6]. Mwaikambo et al [6] did comprehensive studies on fiber alkalization and found that alkalization modifies plant fibers and it promotes the development of fiber-resin adhesion, which will result in increased interfacial energy and, hence improvement in the mechanical and thermal stability of the composites. Stuart and co-workers [7] explored the use of enzymes, chelators and enzyme/chelators systems as an environmentally friendly means of improving the quality of flax fiber for composite applications.

Natural fibers have been found to have extensive applications in building and civil engineering fields [4]. Flax fibers possess moderately high specific strength and stiffness compared to other natural fibers and the properties of flax fiber are controlled by the molecular fine structure of the fiber which is affected by growing conditions and the fiber processing techniques used [4, 8]. Variation in natural fiber properties depending on cultivation, location or on climate has been major problem to composite manufacturers as compared to glass and carbon fiber which have well defined manufacturing processes and techniques. Despite all research efforts, the challenge is still to replace conventional glass reinforced composites with completely bio-based composites that exhibit acceptable mechanical and thermal properties, good structural and functional stability during storage use and yet susceptible to environmental degradation upon disposal [9].

In this study, flax fabrics and carded Lyocell fiber were used to reinforce unmodified acrylated epoxidized soybean oil. The reinforcement with plain weave architecture had the highest mechanical properties. The aim was to manufacture a flax/Lyocell hybrid composite with better mechanical properties and at the same time has low water absorption characteristics than composites reinforced with only flax fibers.

2 Experimental

2.1 Materials

Acrylated epoxidized soybean oil (AESO) was used as matrix in the composite preparation. The chemical structure of the AESO is shown in Figure 1. The AESO resin is referred to as TRIBEST, and it was supplied by Cognis GmbH, Monheim, Germany. Khot et al [10], have also characterized the AESO resin. Four different types of flax woven fabrics were used as reinforcements in the composite preparation (see Table 1 and Figure 2), the fabrics were supplied by Libeco Lagae, Belgium. A Lyocell staple fiber (Tencel Lenzing Lyocell, 1.7 dtex, 30 mm cut length) was supplied by Lenzing AG, Austria. The Lyocell fiber was carded and needled (see Figure 3) to get a non-woven mat. The free radical initiator, tert-butyl peroxybenzoate was supplied by Aldrich Chemical Company, Wyoming, IL, USA.

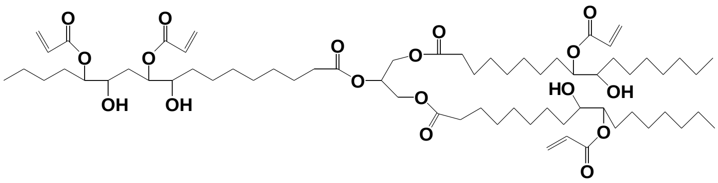

Figure 1. Acrylated epoxidized soybean oil

Fiber Type	Composition	Warp (Threads/cm)	Yarn number (tex)	Weft (Picks/cm)	Yarn number (tex)	Surface weight (g/m^2)	Weave
A	100% Li	3.4	667	3	27,8	250	Plain
B	100% Li	10	104,2	10	104,2	220	Twill 2/2
C	100% Li	8	263	8	263	430	Twill 2/2
D	52% Li/48% Basalt	16.8/1.67	42/380	16.8/1.69	42/380	285	Dobby

Table 1. Flax fabric specifications

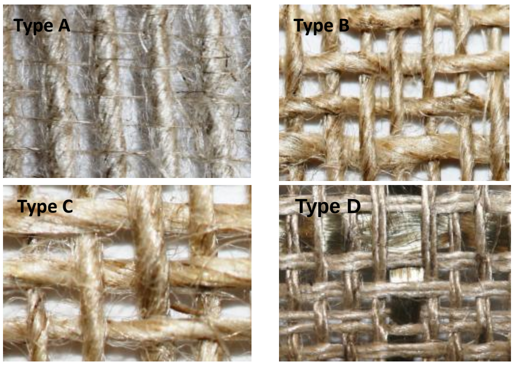

Figure 2. Flax fabric reinforcements (fiber type A, B, C, and D)

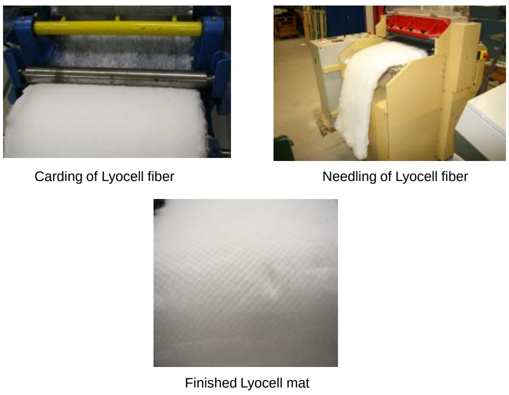

Figure 3. Carding and needling of Lyocell fiber to achieve a non-woven fiber mat

2.2 Composite preparations

Acrylated epoxidized soybean oil (AESO) was used as matrix and blended with 2 weight-% tert-butyl peroxybenzoate as free radical initiator. Composite laminates were made by first stacking sheets of reinforcements and by resin impregnating each sheet by hand spray. The stack was then placed in a metallic mold (20cm x 20cm) and compression moulded at 160ºC for 5 minutes using a pressure of 40 bar, no specific fiber direction in the case of the flax fabrics due to biaxial woven pattern except for flax fabric type A, which is plain weave with very thin fiber in the weft direction. This fabric is similar to a unidirectional fabric, as the thin weft reduces the crimp considerably. The hot press was supplied by Rondol Technology Ltd., Staffordshire, UK. The fibre-resin ratio was about 60:40 weight-% in all cases. The surface weight of flax fabric reinforcements and the weave architecture are shown in Table 1.

3 Mechanical testing

The tensile testing was performed according to ISO 527 standard test method for fiber reinforced plastic composites with a universal H10KT testing machine (maximum capacity 10 kN) supplied by Tinius Olsen Ltd., Salfords, UK. Ten specimens were analyzed for each composite laminate. The flexural testing was performed according to ISO 14125, with the same testing machine. At least 7 specimens were tested for every material. Impact testing was done on the composite laminates to determine the Charpy impact strength of the un-notched specimens which was evaluated in accordance with ISO 179 using a Zwick test instrument. A total of 10 specimens were tested to determine the mean impact resistance. The samples were tested flatwise.

4 Results and discussion

4.1 Mechanical Properties

Figures 4-7 show the tensile and flexural properties of the flax reinforced composites. Compared to the neat AESO resin with a tensile strength of approximately 6 MPa, and a modulus of approximately 440 MPa, much better tensile properties were achieved, as expected. The difference between the composites was the weave architecture of the flax fabrics whereas all other components are the same: equal fiber weight, the same amount of resin and manufacturing techniques.

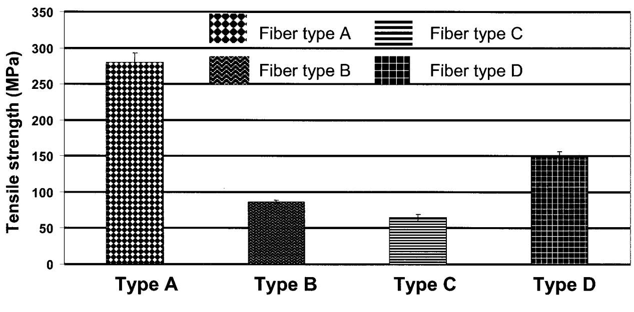

Figure 4. Comparison of tensile strength of the flax fiber reinforced composites

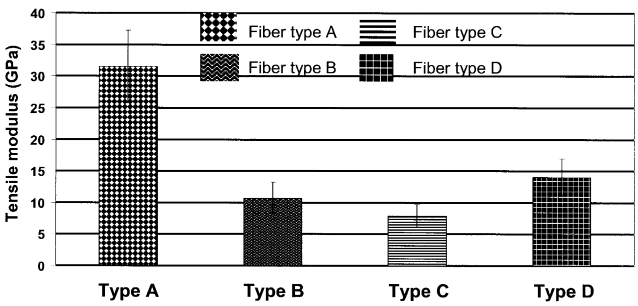

Figure 5. Comparison of tensile modulus of the flax fiber reinforced composites

Composite type A manufactured with plain weave flax fabrics has superior tensile strength and tensile modulus when compared with composites type B, C and D manufactured with twill and dobby reinforcements (Figures 4 and 5). The tensile strength of approximately 280 MPa and modulus of about 32 GPa indicated that the composites manufactured with such plain weave architecture can be used for demanding technical applications. The reinforcement with dobby (basket woven style) also showed better tensile properties (strength of 149 MPa and modulus 14 GPa) compared with composites reinforced with twill weave architecture which had tensile strength of 87 MPa and modulus of 11 GPa. The difference between the composites type B and C is the density, but the fiber type B has a lower surface weight and it had better properties compared to the composites prepared with fiber type C.

Figures 6-7 show the flexural properties of the flax reinforced composites. The trend was exactly the same with the tensile properties. Composite type A had superior flexural properties compared to other composites. The flexural strength of composite A and D was 250 MPa and 146 MPa respectively and the flexural modulus for composite A and D was 25 GPa and 14 GPa respectively, whereas the flexural properties of composites B and C were lower compared to composites A and D.

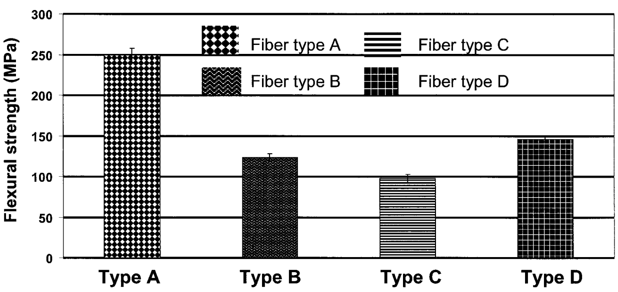

Figure 6. Flexural strength of composite types A, B, C and D.

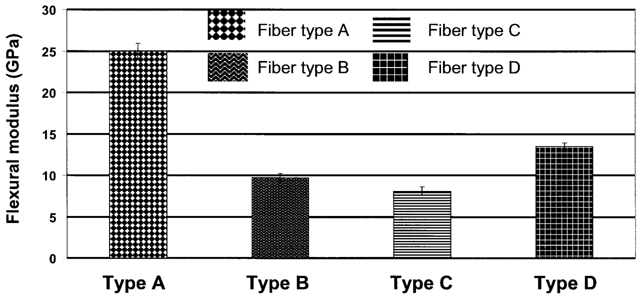

Figure 7. Flexural modulus of composite types A, B, C and D

The impact resistance (see Figure 8) shows the same trend as the tensile and flexural properties. Charpy impact method is used to investigate the behaviour of specimens under the impact conditions defined and for estimating the brittleness or toughness of specimens within the limitations inherent in the test conditions. The impact resistance of the composite type A was 75 kJ/ m^2 whereas the impact resistance for composites B, C and D was 35, 36 and 66 kJ/m^2 respectively.

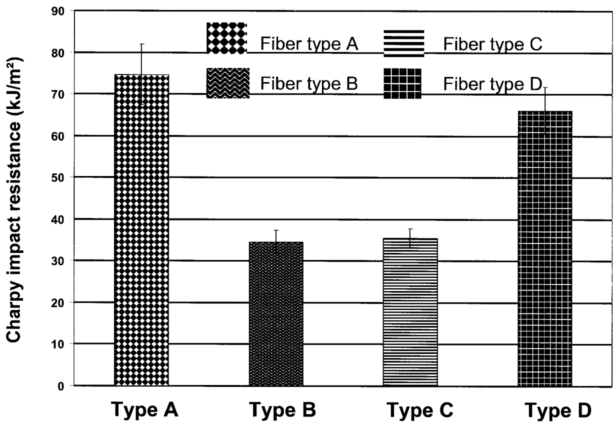

Figure 8. Charpy impact resistance of composites A, B, C and D.

A preliminary conclusion could be drawn here with respect to the three different mechanical analyses, that the type A composites manufactured with plain weave architecture fabric have superior mechanical properties compared to the composites manufactured with dobby (basket woven) and twill weave architecture fabrics. This means that composite type A is the strongest, stiffest and toughest. It should also be noted that the other reinforcements are biaxial woven but irrespective of this the plain woven fiber (type A) showed better properties. The possible explanation for the variation in mechanical properties could be the different weave architectures of the individual fabrics. The composite type A had a plain weave fabric as reinforcement, but this reinforcement is actually more similar to a unidirectional reinforcement, as a very thin weft yarn is used, which reduced the crimp to almost negligible. Therefore the loading of the composites in the direction of the warp fiber might have contributed to the improved tensile strength and tensile modulus. Composite type D had relatively better mechanical properties than composite type B and C, and this was obviously due to the dobby (basket woven) weave type, and the combination of flax and basalt in the fabric type D. Basalt, which is an inorganic fiber, should impart better mechanical properties.

Lyocell fiber was used for comparative study but the results will not be discussed in this report.

5 Conclusions

An important criterion in determining the properties of textile reinforced composites is the weave pattern of the reinforcement. Therefore, weaving natural fibers into different textile forms is an important factor in order to tailor their final properties. Compression moulding is a popular method engaged in making fiber reinforced polymer composites due to its extreme flexibility, capable of making a wide variety of shapes.

Composites manufactured with plain weave architecture had superior mechanical properties compared to dobby (basket woven) and twill weave architecture. Composite type A (plain weave) is the strongest, stiffest and toughest due to higher tensile strength and tensile modulus (280 MPa and 32 GPa) respectively. The flexural strength and flexural modulus of composite type A was (250 MPa and 25 GPa) respectively and the impact resistance was 75 kJ/m^2. The other reinforcements are bi-axially woven. However, general conclusions cannot be drawn because in the composites investigated there are several other parameters which differ from one laminate to the other, not only the weave architecture. For instance the surface weight and, for the fiber type D, there are two different fibers, flax and basalt. All these factors can surely affect the mechanical properties. The obtained results should therefore be seen as indicative regarding the potential to use these fabrics in structural composites.

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