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Paper No. 06-168

Flax Fibre Based Composite Profiles For Construction Industries

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Written for presentation at the

CSBE/SCGAB 2006 Annual Conference

Edmonton, Alberta

July 16 - 19, 2006

ABSTRACT

The potential use of agricultural fibre in reinforced plastics composite materials is latest to construction industry. The advantages of bast fibre based composite materials are lightweight and low stiffness compares to conventional material such as lumber, aluminium and synthetic fibre composite construction profiles. It is also environmental friendly and economically practicable. Engineering fibres such as flax and hemp are available in North America and sustainable, biodegradable and renewable in nature. In this research, we investigate the probable replacement of synthetic fibre with Saskatchewan oilseed flax to make a cost effective alternative and compliments to existing profiles such as aluminium profiles, lumber and synthetic fibre based profiles used in housing industries. These bast fibre based profiles are made out of thermoset plastics (i.e. Epoxy and Polyester) as matrix and Saskatchewan grown flax fibre as reinforced material through Resin Transfer Moulding (RTM) process. In ambient temperature, flax fibre contains about 10% moisture and it causes dimensional instability in the profiles due to moisture release in dry condition. To avoid this problem we use economically viable microwave drying system by incorporating halogen lamp microwave combination oven in our experimental design to reduce the moisture of bast fibre before incorporating in polymer matrix. We investigated the mechanical properties, water absorption, and weather resistance properties of these profiles and found it can be used as a construction material for housing industries in North America.

Keywords: Natural and glass fibre composite, flax fibre, Resin Transfer Moulding, RTM, Thermoset plastics, construction profile

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INTRODUCTION

Considerable attention has been given to glass fibre reinforced plastic (FRP) over steel and aluminium as structural materials in construction, automotive, and aerospace industries due to a variety of reasons: a high strength-to-weight ratio, a high stiffness to weight ratio, corrosion and fatigue resistance, ease of handling, and ease of fabrication (Murphy 1998 and Mallick 1993). ISIS 2003, Bakis et al. 2002 and Uomoto et al. 2002 have extensively reviewed the state-of-the-art of FRP.

Natural fibres are in general suitable as reinforcement materials both in thermosets and thermoplastics due to their relative high strength, stiffness, and low density (Bledzki and Gassan 1999). Flax (Linum usitatissimum) fibre, which is a renewable resource, shows relative high mechanical properties (Voorn et al. 2001 and Baley 2002). Over 50% of Canadian flax is cropped in Saskatchewan (Warick 2001). On the one hand, flax-fibres are well known for their versatile production and wide use in industries such as fabrics and currency. On other hand, disposing of flax straw by burning creates environmental problems and damage to resources. Additionally, the high material cost and aggressive environmental factors moderate the benefits of FRP as engineering materials (Helblign et al. 2005). Natural fibres have recently attracted the attention of researchers as reinforcing materials because natural fibre reinforced composites offer specific properties comparable to those of conventional fibre composites (Shaheb and Jog 1999).

Natural fibres are in general suitable to reinforce plastics (thermosets as well as thermoplastics) due to their relative high strength and stiffness and low density. The characteristic values for flax and soft-wood-kraft-fibres reach levels close to the values for glass-fibres (Bledzki and Gassan, 1999). Nevertheless, the drawbacks for all natural products are remarkably higher than those of glass-fibres. The glass fibre possesses, for instance, higher tensile strength over flax (Bledzki and Gassan, 1999). Appropriate modifications of fillers with physical or chemical methods before their incorporation into the polymer matrices are performed, in order to enhance the final properties of composites (Georgopoulos, et al, 2005).

The general objective of this study is to identify the mechanical properties of construction profiles composed of natural fibres and epoxy resin in the resin transfer moulding (RTM). The study is therefore sub-divided into the following tasks: (i) perform the tensile-impact, tensile and flexural tests for natural and glass fibre composite sheets, (ii) evaluate the feasibility of the hand lay-up process of the flax in the RTM process and (iii) observe and assess the workability of RTM process in the production of construction profiles.

RESIN TRANSFER MOLDING PROCESSES

There are many variants on RTM techniques exist; the following overview gives a good indication of production possibilities.

Hand laminating

The fibres (usually mats) are cut and placed in a mould, and then using hand rollers apply the resin. Use a vacuum bag to seal the mould, while the resin is curing. By applying vacuum, all of the air is sucked out and the atmospheric pressure applies pressure to compact the composite. The advantages are the high flexibility and the simplicity of the process and the cheap tooling. The time-consuming production, the labour-intensive character and limited potential for automation are the disadvantages. (Van Rijswijk, 2003)

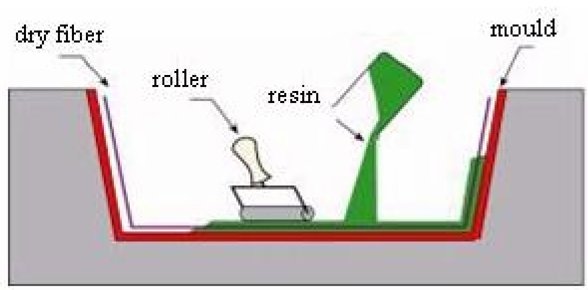


Figure 1. Hand Laminating (Van Rijswijk, 2003)

Resin transfer moulding (RTM)

The fibre reinforcement mats are placed inside a mould. This mould consists of two solid parts, while with vacuum injection a single solid mould and a foil are used. A tube connects the mould with a supply of liquid resin and catalyst, which are premixed and then injected or transferred through the mould under low pressure, impregnating the fibres. After curing the mould is opened and the product is removed. The advantage is the capability of speedy manufacture of large, complex, high-performance structures. (Van Rijswijk, 2003 and Composite World, 2006)

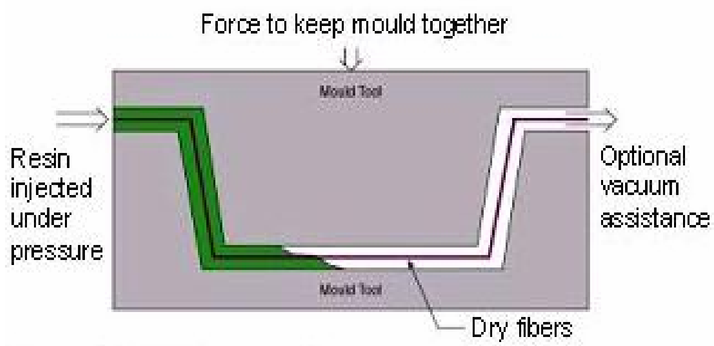


Figure 2. RTM Principle (Van Rijswijk, 2003)

Reaction injection moulding (RIM)

RIM injects the rapid-cure resin and the catalyst into the mould in two separate streams. Then they both are mixed and the chemical reactions take place in the mould. (Composite World, 2006)

Vacuum-assisted resin transfer moulding (VARTM)

VARTM draws resin into a fibre mat through use of a vacuum instead of positive pressure. It does not require high temperature or pressure. So VARTM operates with low cost tooling, and making it possible to economically produce large, complex parts in one injection. (Composite World, 2006)

Resin film infusion (RFI)

RFI is a combined process in which a dry fibre mat is placed inside a mould on top of a layer or layers of high viscosity resin film. Applied heat, vacuum and pressure, the resin is drawn up through the thickness of the fibre mat in one direction, resulting in homogeneous resin distribution, even with high viscosity, toughened resins. (Composite World, 2006)

FIBRE REINFORCED POLYMER

A specific type of two-component thermoset material consisting of high strength fibres embedded in a polymer matrix is called fibre-reinforced polymer (FRP). The limitless combinations of materials complicate the study of FRP; that can be used to create an FRP composite. Basically, FRP is composed of matrix and fibre. There are several textbooks and reference materials available discussed the basic components of FRP. However, the extraordinary of them are ISIS, 2003; Jones, 2001; and Seymour, 1987.

Matrix

A polymer matrix is an organic compound comprised of long-chain molecules consisting of smaller repeated units called monomers. The matrix works as a binder for FRP and plays many important roles. Some of the more critical functions played by the matrix are: (i) to bind the fibres together; (ii) to protect the fibres from abrasion and environmental degradation; (iii) to separate and diffuse fibres within the composite; (iv) to transfer force between the individual fibres; and (v) to be chemically and thermally compatible with the fibres.

A major selection criterion for matrix materials is that they have a low density, usually considerably less than the fibres, such that the overall weight of the composite is minimized. While the fibres provide the strength and stiffness of an FRP, the matrix is essential to transfer forces between the individual fibres. This force transfer is accomplished through shear stresses that develop in the matrix between the individual fibres. Obviously, the quality of the bond between the fibres and the matrix is thus a key factor in obtaining good mechanical properties. Although an enormous variety of polymer matrix materials exist for the manufacture of FRP materials, the focus herein is on FRPs used in infrastructure applications, and thus only a few specific matrix materials are epoxies, vinylesters, and polyesters.

Epoxies

Epoxies are often used in wet lay-up applications of FRP plates and sheets because of their ability to cure well at room temperature and owing to their outstanding adhesion (bonding) characteristics. Epoxies have high strength, good dimensional stability, relatively high-temperature properties, strong resistance to chemicals (except acids), and superior toughness. Epoxies, however, cost significantly more than polyesters or vinylesters.

Polyesters

Polyesters are the most widely used polymers in the manufacture of FRP components for infrastructure applications due to their relatively low cost and ease of processing. Numerous specific types of polyesters are available for use, with varying degrees of thermal and chemical stability, moisture absorption, and shrinkage during curing.

Fibres

The fibres provide the strength and stiffness of an FRP. Because the fibres used in most structural FRP applications are continuous and are oriented in specified directions, FRPs are orthotropic, and they are much stronger and stiffer in the fibre direction(s). Fibres are generally selected to have (i) high stiffness; (ii) high ultimate strength; (iii) low variation of strength between individual fibres; (iv) stability during handling; and (v) uniform diameter.

Glass fibres

Generally, glass fibres are produced by the direct melt process, but glass fibres with a diameter of 3 to 25 microns are formed by rapid and continuous drawing method. Glass fibres are the most inexpensive, and consequently the most commonly used, fibres in structural engineering applications. There are several different grades available, but the most common are E-glass and the more expensive, but stronger, R-glass. Glass fibres are characterized by their high strength, moderate modulus of elasticity and density, and by their low thermal conductivity. Glass fibres are often chosen for structural applications that are not weight critical (glass FRPs are heavier than carbon or aramid) and that can tolerate the larger deflections resulting from the comparatively low elastic modulus of the glass fibres (ISIS, 2003). Glass fibres are often used in the manufacture of FRP reinforcing bars, pultruded FRP structural sections, FRP wraps for seismic upgrade, and filament wound FRP tubes.

Natural fibres

The organic natural fibres can be classified as plant based and animal based. Plant based fibres included seed (cotton), bast (flax, hemp, jute, kenaf), leaf (sisal, abaca) and fruit (coir). Animal based fibres included wool, hair and silk. Amongst these, the bast fibres are the most interesting candidates for the replacement of glass fibres as the enforcement in the composites. (Olesen, 1999 and Mohanty, 2000) The bast fibres, especially flax and hemp, are common grow in Canada, and will be used in our experiment. The physical properties and chemical composition of flax and hemp are shown in Table 1.

Table 1. Comparison of flax and hemp fibres (Olesen,1999 and Mohanty, 2000)

Fibre		**Physical Properties**		**Chemical Properties**				
Type	Form	Length, mm Range	Diameter, mm Range	Cellulose,%	Hemi-cellulose, %	Lignin, %	Pectin, %	Moisture, wt %
Flax	Bundle	250 -1200	0.004 - 0.6	68 -85	10 - 17	3 -5	5 -10	10
Flax	Single	9 - 70	0.005 - 0.038					
Hemp	Bundle	1000 - 4000	average 0.025	70 - 75	12 -15	10 -15	1	10.8
Hemp	Single	5 - 55	n/a					

MATERIALS AND METHODS

The use of flax straws (shives and fibres) as reinforcing material was studied using the Vacuum-assisted resin transfer moulding (VARTM) processing technique. The flax straws, coarse and fine size were used (were hand laid within thin layer of glass fibre mats) as a reinforce material and epoxy resin as a matrix in the composite. This forms a hybrid laminates i.e., epoxy-glass-flax-glass-epoxy sandwich. The mechanical properties (tensile, impact tensile and bending tests) of the epoxy-flax-glass fibre composites were compared to conventional RTM manufactured epoxy-glass fibre composites.

Fibres used in this experiment

Glass and natural fibres were used as reinforcing materials in order to compare the improved mechanical and physical properties in composite matrix for construction. Traditionally, glass fibre is widely used in structural engineering applications. Oilseed flax straw is available in prairies province in Canada. In certain application flax fibre can be used as a supplement to glass fibre in construction industries due to its engineering properties. In this research an attempt has been made to use the hybrid of flax and glass fibre through RTM process to make the composite product for construction application. Glass fibre mat (NIKO) was used in this experiment supplied by Buhler Versatile Inc., Saskatoon, Saskatchewan, Canada. The flax was obtained from linseed flax grown in Saskatchewan and decorticated at Bio-Fibre Industries Ltd (only flax fibre processing plant in Saskatchewan) Canora, Canada. Flax fibres used in this experiment contained 40% shives and 60% fibres.

Matrix used in this experiment

Epoxy resin is used as a matrix to form the composite product due to its properties i.e. high strength, good dimensional stability, relatively good high-temperature properties, and strong resistance to chemical (except acids), and superior toughness. The liquid general-purpose epoxy resin was mixed with the catalyst MEKP for hardness and better curing. Both epoxy resin and catalyst and chemicals were supplied by Buhler Versatile Inc., Saskatoon, Saskatchewan, Canada.

Moulding Processes

Four different samples were moulded by using RTM processing system at Buhler Versatile Inc. industries in Saskatoon, Canada The mould was sprayed uniformly with a mould release agent and then flax fibres was uniformly hand-laid in the mould (or flax fibre within glass fibre mats) and then closed the mould. A tube connects the mould with a supply of liquid resin and catalyst, which are premixed and then injected or transferred through the mould through use of a vacuum with low pressure, impregnating the fibres. After curing the mould is opened and the sandwich like material product is removed.

Sample A: Epoxy-Coarse Flax

Sample B: Epoxy-Fine Flax

Sample C: Epoxy-Glass-Flax-Glass-Epoxy

Sample D: Glass-Epoxy

Experimental tests

The performance of any construction material in any specific application depends on its mechanical properties. Unless the test result is available, it is unwise to use any material in constructions. Therefore, several tests including tensile impact, tensile and flexural tests have been carried out.

Tensile test Test specimens were cut and machined from the moulded sheet of epoxy-fibre composite according to the standard of ASTM-D638 Type I tensile bar. Specimens were tested in the Instron (Model 1011) testing machine with a maximum tensional load of 5KN. Specimens were placed in the grips of the Instron at 115mm apart and pulled until failure. For ASTM-D638 the test speed (typically 5 mm/min) was determined by the material specification. An Instron's computer program (Series IX Automated Materials Testing System 1.08) can interface the data digitally. Thus, the maximum tensile stress and the young modulus can be printed out from the computer directly.

Tensile impact test Test specimens were cut and machined from the moulded sheet of epoxy-fibre composite according to the dimensions of the Type L (long) tensile-impact specimen geometries of ASTM-D1822M. Tinius Oslen Tensil Impact Tester was used to do the test. One end of the specimen was clamped to the crosshead clamp and the other end was clamped to the pendulum head. Release the pendulum from the resting position; the pendulum swing to the anvil on the base of the tester. As the anvil arrested the crosshead travelled with the pendulum, the specimen broke into two. The maximum kinetic energy required to break was displayed on the pointer of the centre of the pendulum at that instant of impact. From the energy reading, the calculation was done for the tensile-impact strength of the epoxy-fibre composite.

Flexural test The rectangular bars of test specimens were cut and machined from the moulded sheet of epoxy-fibre composite according to the standard of ASTM-D790. Procedure A (strain rate of 0.01mm/mm/min) was used in testing, which was designed principally for materials that break at comparatively small deflections. Specimens were tested in the Instron (Model 1011) testing machine with a maximum compression load of 5KN. Specimens (the gel coating surface faced down) were rested on two supports and loaded by means of a loading nose midway between the supports. A support span-to-depth ratio of 16:1 was used. Span distance was 50mm. The specimen was deflected until rupture occurred in the outer surface of the test specimen or a maximum strain of 5% was reached, whichever occurs first. The test speed was determined by the specified equation from ASTM-D790. An Instron's computer program (Series IX Automated Materials Testing System 1.08) had interfaced the data digitally. Thus, the flexural stress at yield and the flexural modulus were printed out from the computer directly.

RESULTS AND DISCUSSIONS

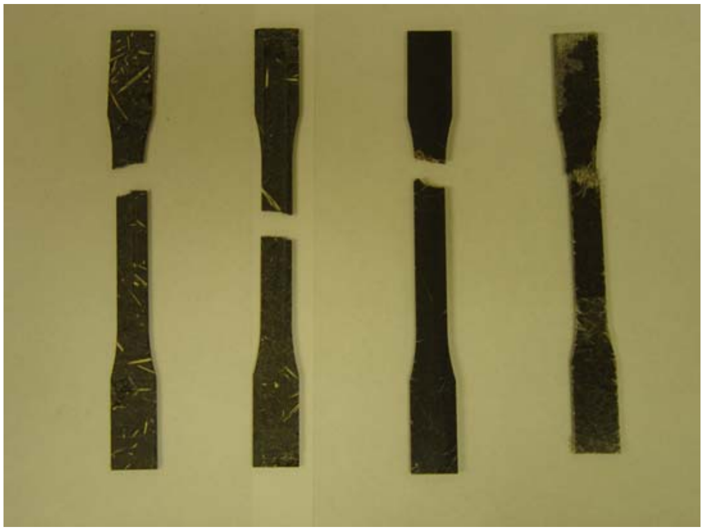
Unless the tensile stress behaviour of the epoxy-fibre composite is clear, their applications in composite will be limited. In general, epoxy-glass fibre composite showed better physical and mechanical properties than those of epoxy-flax and epoxy-flax-glass composites (see Table 2).

Table 2.The experimental results of epoxy/fibre composite in terms of physical and mechanical properties

Sample	Reinforced Epoxy with	Maximum Tensile Stress (MPa)	Young's Modulus (MPa)	Tensile-Impact Energy (joule)	Tensile-Impact Strength (KJ/m^2)	Flexural Strain at Yield (%)	Flexural Stress at Yield (MPa)	Flexural Modulus (MPa)
A	Coarse Flax	11.418	1137.5	N/A	N/A	0.02	42.665	2343.3
B	Fine Flax	13.548	1060.1	N/A	N/A	0.89	56.877	3812.7
C	Glass Fibre / Fine Flax	16.657	872.6	1.144	99.137	1.83	54.884	2920.6
D	Glass Fibre	64.726	1394.7	1.469	116.878	2.54	106.833	4917.7

Tensile strength

The test result shows epoxy-fine flax composite (sample B) is better tensile stress than epoxy-coarse flax composite (sample A), and the sandwich of epoxy-glass-flax fibre composite (Sample C) is even better tensile stress. However, it was only ¼ of the strength of epoxy-glass fibre composite. After the test, the breakage edges of samples A and B were brittle and shown a cross sectional failure. Sample C had a cross sectional breakage with showing some glass fibre on the breakage edges. However, epoxy-glass fibre composite (sample D) failed without broken apart and split longitudinally, the glass fibre still holding the breakage together (see Figure 3). This showed that the matrix impacts insignificantly on the strength properties of the epoxy-fibre composite, and eventually, the fibre (specially glass fibre) in the composite gave itself most of the tensile strength.



A **B** **C** **D**

Figure 3. Failure pattern of tensile strength specimens after test

Tensile impact strength

The tensile impact energy of epoxy-glass-flax fibre composite (sample C) is very close to epoxy-glass fibre composite (sample D). The failure patterns of all samples were very similar to tensile test (see Figure 4).. Sample C and D broke apart longitudinally with some glass fibre shown along the breakage edge. Samples A and B showed very insignificantly small tensile impact energy during the test. So we think this tensile impact test may not be suitable to use in the epoxy material.

A **B** **C** **D**

Figure 4. Failure pattern of tensile impact strength specimens after test

Flexural strength

After the flexural test, sample A and B ripped open into a straight crack on the gel coating. However, sample C and D burst unevenly and the glass fibre was exposed. The flexural modulus of samples A, B and C showed not much different, this indicated the epoxy is too brittle to do the flexural test. So in the future experiment, we need to choose other test instead of flexural test.

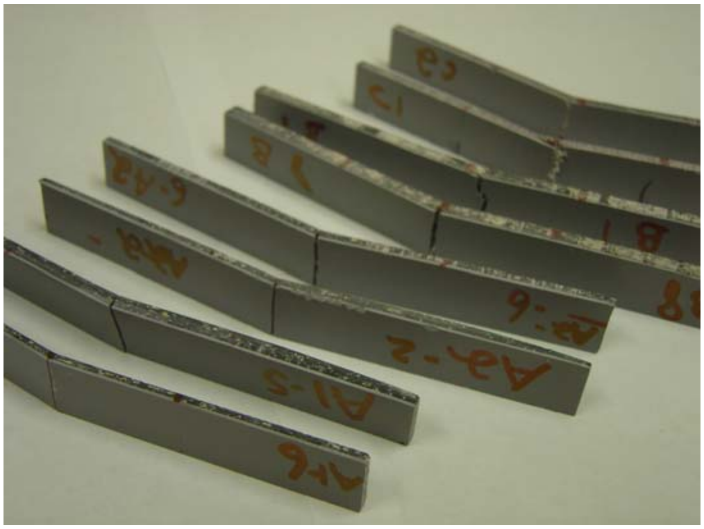


Figure 5. Failure pattern of flexural strength specimens after test

Our experiment was using hands to lay up the flax randomly (without direction) on the mould, so that may reduce the performance of the composites. And there will be a problem that when the resin flow into the mould, the flax will flow along, then the distribution of the flax will be affected. Moreover, the hand laying process is a labour-intensive problem.

CONCLUSIONS

The epoxy-glass fibre composite has shown better performance over epoxy-flax fibre or epoxy-flax-glass fibre composite in terms of tensile strength, tensile impact strength and flexural strength. The hand lay process of flax is not suitable for mass manufacturing epoxy-fibre composite profile for the construction industrial. However, the flax fibre utilized in RTM composite is still a great component to replace glass fibre as reinforcement agent.

FUTURE WORKS

In the future development and experiment, it will be better to use flax mat. It will reduce the problem of distribution and time consuming. In order to produce a better performance of epoxy-flax-glass fibre material, the study of various weight percentage of mixture will be proceed. Also with the aim of investigate the fibre-matrix bonding, the electron-microscopy tests of the composite cross-sections have to be used.

ACKNOWLEDGEMENT

We sincerely thank Dr. Kamal Barghout for his encouragement, guidance in all stages of this project. Special thanks to Mr, H, Berg and his colleagues for machining the test samples. We also thank Buhler Versatile Inc., Saskatoon provides the epoxy, glass fibre mat and RTM process, and thank Bio-Fibre Ltd to supply the flax. Sincerely thanks goes to the Department of Agriculture and Bio-Resource Engineering for allowing us to run the experiments.

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