Applications of Jute in Resin Transfer Molding

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ABSTRACT

Resin Transfer Molding (RTM) is a modem technology which is adopted to produce fiber reinforced composites using unsaturated polyester, vinyl ester, etc.. In most U.S. applications the fiber mainly used is glass fiber. Jute, a very stiff natural fiber, has been used in the present study to replace glass to mold samples following RTM technique. Some samples were made using jute or glass as the reinforcement and polyester as the matrix following identical procedure and parameters. Strength properties of both the jute and the glass composites were evaluated The properties of jute composites were then compared with the glass composites. The results show that jute composites may be used in a large number of applications where higher cost and higher mechanical properties of glass composites are not justified.

Introduction

Natural fibers can be substituted for glass and carbon fiber in polymer composites. Their potential for use in molded articles not needing high strength for acceptable performance has been tried in equipment housings, roofing, for low cost housing and in large diameter piping [1,2,3]. These authors were primarily exploring production feasibility.

As in synthetic fiber composites, the mechanical properties of the final product depend on the individual properties of the matrix, fiber and the nature of the interface between the two. Typically, glass fiber is treated with a silane coupling agent to improve the properties at the interface with the resin. Where the fiber is an agricultural fiber, opportunities exist to tailor the end properties of the composite by selection of fibers with a given chemical or morphological composition. Several studies of fiber composition and morphology found that cellulose content and microfibril angle tend to control the mechanical properties of cellulosic fibers [4,5,6]. Pavithran et al. found that higher cellulose content and lower microfibril angle resulted in higher work of fracture in impact testing [7]. For example, a sisal polyester composite had higher work of fracture (98.7 kj/m^2) than a coir polyester composite (43.5 kj/m^2), where sisal had a cellulose content of 63-67% and coir had cellulose content of 43%.

Other authors have studied the mechanical properties of lignocellulosic/polyester composites with well defined fiber orientation (unidirectional or bidirectional) [8,9,10,11,12]. The samples were produced either by wet lay-up or by press molding of MgO thickened prepregs (similar to sheet molding compound).

Liquid composite molding - LCM

LCM is an umbrella term covering a variety of molding technologies using liquid thermoset resins. Early studies of this technology were centered on phenolformaldehyde and melamine resins. The simplest example of LCM is hand lay-up. Within this technology are several specific semi-automated molding systems including resin transfer molding (RTM), resin injection molding (RIM), structural reaction injection molding (SRIM), reinforced reaction injection molding (RRIM), bulk molding compound (BMC) and sheet molding compound (SMC).

Resin injection molding - RIM

In unreinforced RIM technology, no reinforcing fiber is used in the mold. Two or more reactive component streams are rapidly mixed and then injected into a closed mold where polymerization and cross-linking occur (time scale 3-5 minutes). Typically urethane (isocyanate-polyol) foam chemistry is used which lends itself to low cost, high volume applications, with the advantage of rapid curing seconds or minutes after mixing. Time to de-mold is short. The disadvantage of this system is the need for special impingement mix heads to rapidly combine and inject the reacting mixture before it cures. A wide variety of starting materials allows tailoring of

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properties, from rigid to flexible. Characteristics are low finished product density which is good for light weight parts. Reinforcement fibers can also be used which improves strength and stiffness properties. Applications of RIM are mainly in automotive parts and insulation with some use in aerospace.

Structural reaction injection Molding - SRIM

This is a variation of RIM where a reinforcing fiber, usually a continuous strand mat, is placed in the mold prior to filling. In many cases, the fiber mat is premolded using a small amount of thermoplastic in the fiber (called a preform). Viscosity of the resin used must be low enough to allow the resin to penetrate the fiber mat before the resin begins to gel. The high speed of the injected resin. into the mold, under pressure, can result in what is termed 'wash out' or a non-uniform distribution of reinforcement fiber in the finished product. Chopped fiber mats can also be used, but this adds to the probability that there will be washout under high pressure. SRIM is currently used in the automotive industry.

Reinforced reaction injection molding - RRIM

This variation of RIM uses chopped fiber which is premised with the two or more reactive components before very rapid injection into the mold. Along with reinforcing fibers, inorganic fillers are often used. Higher viscosity's mean higher injection pressures must be used, as compared to unreinforced RIM.

Sheet molding compound - SMC

Glass fiber (chopped or continuous) is typically used in SMC with unsaturated polyester resin, a free radical initiator, a thickening agent, a particulate filler (often $CaCO_3$ or Al $(OH)_3$) and is extruded between release sheets (plastic). The sheets are rolled up and refrigerated to thicken the resin. The sheets are then compression molded under moderate pressure. Heated presses are used to initiate the curing resulting in short cycle times. A lot of SMC is used in automated equipment in the U.S automotive industry with glass fiber for side panels and trim. It is well suited for large pan volumes using automated equipment, but can also be used anywhere a large flat compression molded part is needed. Jute fiber is well suited for this molding techniques, and fiber dust or short fibers from the textile industry could be used to fill and thicken the SMC.

Resin transfer molding - RTM

Resin Transfer Molding or RTM literally means the transfer of the resin mix from one system (the RTM machine) to another system (the closed mold containing the reinforcement) while molding a product. It bridges the gap between labor intensive hand lay-up process and capital intensive compression molding process. In the RTM process a combination of continuous mat is laid in the mold cavity. A matching mold half is mated to the first half and the two are clamped together tightly. A pressurized resin system mixed with a free radical initiator is then pumped from one or more ports into the closed mold containing the preplaced reinforcement. The resin and fiber remain in the mold until crosslinking occurs, then the composite can be removed. The material can be cured at room temperature or in heated mold by proper choice of initiator. It is important to balance the speed of gelation with the time needed to till the mold and wet out the reinforcement fiber. Usually unsaturated polyester or vinyl ester are used, although epoxides and acrylatcs can also be used in this equipment. Applications are in consumer goods such as helmet, bathroom fixtures, boats. car body panels, instrument panels, truck caps, building panels etc..

The cycle time is the sum of the time taken for each individual step during molding and is given by: Cycle time·= Mold cleaning time + Mold preparation time + Fiber packing time + Mold till up time + Gel time of resin + Resin cure time + Demolding time.

Factors affecting RTM are: resin characteristics, reinforcement characteristics, resin injection pressure, design of the mold, mold temperature, vacuum state of the system, flow rate of resin mix, and mold filling time.

Some of the advantages of RTM process include: relatively low tooling cost, design flexibility, faster productivity, labor savings, energy savings, lower emissions of volatiles, no air entrapment, smooth surface finishing on both sides, both sides can be gel-coated, close dimensional tolerances maintained, a more consistent product, thus reducing bad product thrown away, and more parts for the money.

Flow chart for RTM process

REACTANT A → REACTANT B → MIXING

↓

FIBER MAT → CLOSED MOLD → FILLING → CURING → DEMOLDING → FINISHING

Experimental

Materials

Polyester samples - Unsaturated polyester / styrene resin solution (styrene < 45%), $CaCO_3$ filler, methyl ethyl ketone peroxide (<=45%) in dimethyl phthalate, cobalt napthenate, and a commercial black pigment paste.

Epoxy samples **-** Bisphenol F/Epichlorohydrin Epoxy resin, grade Epon resin 862 and Catalyst 1: Substituted sulfur compound (Epi-cure R 537), Catalyst II: Diethyl toluene diamine (Epi-cure R W).

Polyurethane samples **-** Polyether polyol grade Spectrim MM 310 B and diphenyl methane di-isocyanate grade Spectrim MM 310 A.

All samples **-** Glass fiber mat was a commercial grade with a thermoplastic binder, produced by Owens Corning. Jute felt was non-woven needle punched, 300-350 GSM, obtained from Birla Jute Mills.

Legends used for the composites

JUSP =	Jute mat with unsaturated polyester
TJUSP	Treated jute mat with unsaturated polyester
GUSP	Glass mat with unsaturated polyester.

Sample preparation process

RTM Process using unsaturated polyester resin and jute **-** Jute and glass mat were precut in 10 cm x 15 cm sizes. Some of the raw jute mats were treated with 5% propylene glycol and air dried. The mold surface was polished properly for maximum surface quality. Usually a gel coat, to the desired film thickness, is applied and cured to a tacky state, but for these samples no gel coat was used. Three layers of the prepared jute or glass mat were placed separately in the mold. The mold was closed and clamped. The resin mix ($CaCO_3$ at the rate of 5% by resin wt., NEKP at the rate of 1.5% by resin wt., cobalt napthanate less than 0.1% and pigment paste were added < 5% of a proprietary composition) was then injected into the mold to till it properly through a static mixer. The mold temperature was 55° C at the time of resin injection. Due to design of the mold, pressure probably was a time dependent pressure distribution, from 35 psi at the inlet to atmospheric pressure at' the edge vents. It is assumed that the pressure distribution would tend to equalize after resin stopped flowing. After the resin cured, the material was removed from the mold and subjected to post curing operation. Samples were cut to size and tested for tensile, flexural and impact strengths.

RTM Process using Epoxy resin and jute **-** At first two layers of jute felt were laid in the mold and the mold was then placed in a press. The mold was pre-heated to 120° C and 3.0 ton pressure was applied on the mold. The moisture in the mold was removed by a vacuum pump for approximately 15 minutes. The liquid reactants, resin: accelerator. catalyst = 100: 1: 26.1 were heated at 65° C to maintain the viscosity and mixed at low pressure using a static mixer. The computer controlled process modulates the speed of the resin being injected into the mold initially fast, then slower to complete the filling of the mold. As the resin enters the mold cavity it wets, but does not displace the mat preform. After gelation of resin the Injection was stopped and the panel was cured in the mold at 120° **C** for 1.5 h. The panel was removed from the mold and subjected to post cure at 120° C for 1.5 - 2.0 h to complete the reaction..

SRIM process using polyurethane resin and jute **-** Polyol mixed with 0.3% catalyst and diisocyanate were used in this system. Both the liquid reactants were heated first at 35°C to reduce the viscosity during injection. After applying a mold release agent, jute mat was placed in the mold. The mold was closed and the resin mix was introduced rapidly into the mold. The resin reacts quickly to cure fully within a few seconds. Both the reactants require very fast high pressure impingement mixing to achieve thorough mixing. Mix ratio of typical system is nearly 1:1, which is desirable for rapid mixing. This reaction is in progress as the resin flows through the reinforcement, therefore wetting of reinforcement and displacement of the air in the mold must occur rapidly. Curing is completed shortly after the resin reaches the extremities of the components, and the viscosity of the resin is generally too high to escape through vents. The component was removed from the mold after completion of the curing. Time to demold was short.

The disadvantage of this system is the need for special impingement mix heads to rapidly combine and inject the reacting mixture before it cures. The high speed of the injected resin into the mold, under pressure, can result a non-uniform distribution of reinforcement fiber in the finished product.

Results and discussion

Process observations

Jute Fiber Mats used in the RIM system wetted well with resin. Due to the design of the test mold. some mats tore at the point where the width narrowed. Short fibers due to cutting the mat could not hold the mat completely together. It is expected that larger specimens or a different injection design would eliminate this tearing. Compared to glass mat, the jute fiber diameters are smaller, but more numerous, thus though the fiber volume fraction may have been similar. the additional surface area increased back pressure in the mold and mat, also contributing to the mat tearing. Using larger diameter fibers from the lower portion of the stem might improve the flow of resin in the mold. Also, a slower curing resin system would have a lower viscosity and reduce this in-mold pressure, making better composites. Further study is warranted for jute in this resin system.

Jute fiber mats used in the RTM system wetted well with resin. Pressures in the system were within those expected for the glass fiber usually used. No evidence of fiber washing was noted, though several of the test panels were thicker near the center injection port than at the edges. Incomplete mold filling is probably responsible, and was due to researcher’s desire to minimize resin use. This would occur no more frequently with jute than in glass filled parts. In fact, several samples were made near the end of the trial with up to five mats, with little evidence of back pressure in the equipment. Further study of maximum fiber loading is warranted, as is the effect of coupling agents. lower viscosity resins, different combinations of filler loading levels, and cure conditions.

Product visual observations

Surface finish of glass and jute parts were nearly identical. Fibers were visible on the surface of both, and wetout, bubbles and voids appeared to be nearly identical. This is promising, since a hydrophilic fiber in a hydrophobic resin might be expected to retain air, but did not. The fibers visible on our samples would in production typically be covered by a surface veil of a lightweight glass mat, and a gel-coat, and the visual appearance of both should be identical. Samples exposed to accelerated weathering in a Weatherometer for 600 hours showed surface whitening and nearly identical fiber exposure.

Figures 1 and 2 show scanning electron micrographs of fracture surfaces of JUSP. Resin has infiltrated the cell lumens of the jute fiber, but adhesion is poor, as evidenced by the gap between the resin and fiber surfaces both inside and outside the fiber bundles.

Mechanical properties

Flexural Strength and Modulus - Tables 1 and 2 show the flexural strength and modulus of composites. Here also the flexural strength and modulus in longitudinal direction are greater than transverse direction. In longitudinal direction JUSP and TJUSP have flexural strengths of approximately 44% and 43% of GUSP. In transverse direction these values are 38% and 40% of GUSP. In comparing the flexural modulii JUSP and TJUSP in longitudinal direction have values of 74% and 65% of GUSP. In transverse direction they have modulii 65% and 75% of GUSP.

Tensile Strength and Modulus - Tables 1 and 2 show the tensile strength and modulus of composites. Tensile strength of all composites in longitudinal direction are greater than transverse direction. In the longitudinal direction JUSP and TJUSP have tensile strengths approximately 41% and 38% of GUSP. In the transverse direction these values are 32% and 34% of glass composites respectively. The treated jute composites have a slightly higher tensile strength than untreated jute composites in both the directions Tensile modulii of JUSP and TJUSP have approximately 57% and 47% of GUSP in longitudinal direction where as in transverse direction they have 47% and 58% of GUSP.

Notched and Unnotched lzod Impact Strength - Notched and unnotched lzod Impact values are not available for GUSP as the samples did not break under the tested condition. Tables 1 and 2 show the impact strength of JUSP and TJUSP. The average impact strengths are within the standard deviation for each other, indicating the glycol treatment did not change the impact strength.

Other physical properties

Figures 3 and 4 compare the thickness swelling and water absorption for the glass and jute samples. Though the jute (treated and untreated) samples did not swell much more than the glass samples, after 24 hours soaking, the treated jute samples showed much more swelling and water absorption than either JUSP or GUSP.

Conclusions

Jute is suitable to make products following Resin Transfer Molding technique, which is a viable alternative to hand lay-up, spray-up and compression molding technique. Though the mechanical properties of the jute composites are not as high as those of glass composites, this can be improved by proper chemical modification to increase wettability, adhesion characteristic towards resin and other common limitations of jute. So, jute fiber may well replace glass fiber where high strength and cost of glass are not justified.

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Table 1
Flexural and tensile properties and izod impact strength of jute based composites - Fiber direction longitudinal

Property	JUSP	TJUSP	GUSP
Flexural Strength, MPa	60.1	58.7	138.2
Flexural Modulus, MPa	2971	2625	4015
Tensile Strength, MPa	44.3	48.3	117.4
Tensile Modulus, MPa	2877	3495	6077
Izod Impact Strength, J/M			
Notched	39.8	37.6	---
Un-notched	58.9	49.0	---

Table 2
Flexural and tensile properties and izod impact strength of jute based composites - Fiber direction transverse

Property	JUSP	TJUSP	GUSP
Flexural Strength, MPa	42.5	44.8	112.7
Flexural Modulus, MPa	2197	2539	3364
Tensile Strength, MPa	27.4	29.1	85.9
Tensile Modulus, MPa	3152	2665	5416
Izod Impact Strength, J/M			
Notched	32.5	28.6	---
Un-notched	38.7	32.4	

Figure 1 - Jute fiber in polyester matrix showing resin in cell lumens.

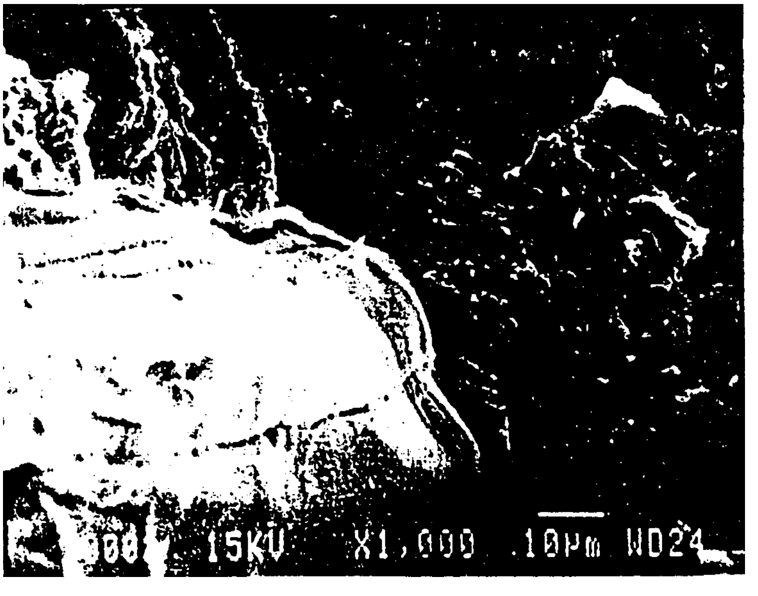

Figure 2 - Jute fiber in polyester matrix showing lack of resin adhesion to the fiber.

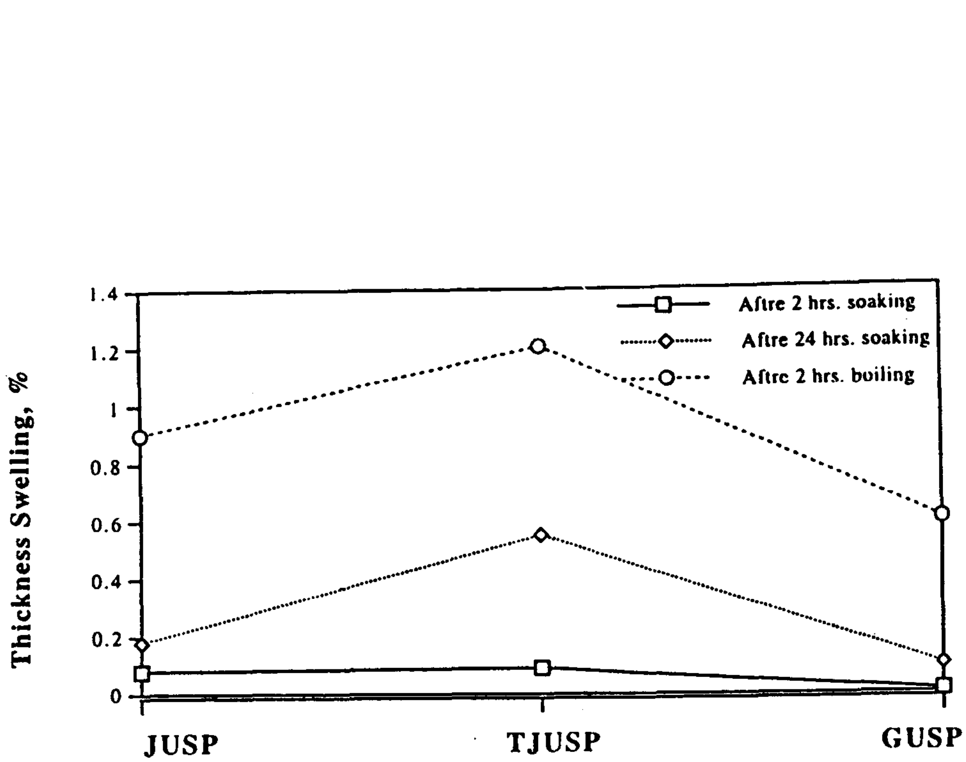

Figure 3 - Comparison of thickness swelling of various RTM samples.

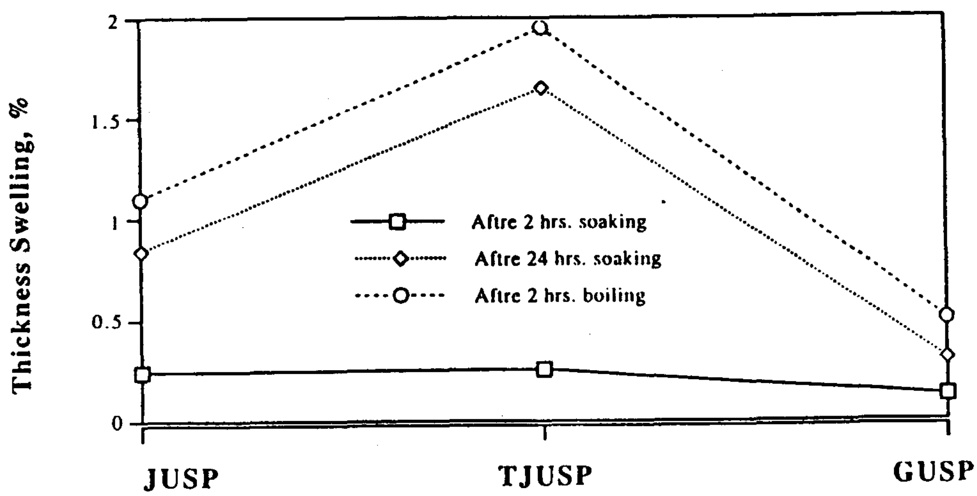

Figure 4 - Comparison of water sorption of various RTM samples.

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