STUDY OF THE COMPACTION BEHAVIOR OF NATURAL FIBER REINFORCEMENTS IN LIQUID COMPOSITE MOLDING PROCESSES

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ABSTRACT: The study of the compaction response of the reinforcements used in LCM processes is of major importance, because it affects the processing variables such as clamping forces and fabric permeability, the part quality and thickness, fiber volume content, and composite final mechanical properties. In this work, the compaction behavior of natural fiber reinforcements is analyzed. It was found that natural fibers structure affected the compaction response of the preform by increasing the permanent deformation. The effect of fluid absorption on the compaction behavior of jute woven fabrics and sisal fiber mats was analyzed by changing the immersion time of the fabrics in the test fluid. It was found that fluid absorption reduced the compaction pressure in natural fiber performs due to fiber softening. This phenomenon was not observed in glass fiber mats.

KEYWORDS: Natural Fibers, Compaction, Fabric, Resin Transfer Molding

INTRODUCTION

The growing interest in reducing the environmental impact of materials is leading to the development of newer materials or composites, based on natural resources. Glass, carbon and aramidic fibers have better mechanical properties than natural fibers, but they are much more expensive. There are many applications that do not require high performance composite materials, where synthetic fibers should be replaced for natural fibers. However, natural fibers have some limitations, such as water absorption [1,2] and low thermal stability, because they suffer lignocellulosic degradation at low temperatures (about 200°C) which restricts their use in some applications and also the processing temperatures. This is a very important issue in most thermoplastics processing techniques, but in LCM the processing temperatures are lower. Also, fibers do not suffer thermo-mechanical degradation as in the extrusion process. Therefore liquid composite molding (LCM) techniques seem to be a good choice for processing these materials.

It is crucial for being able to process natural fiber composites by LCM techniques, to have knowledge on the differences in structure and chemical composition between commercial synthetic fibers and natural fibers, and to know how these differences affect the processing variables. Due to the polar character of this kind of reinforcements, they absorb fluid and, as a consequence, swell during the infiltration process, leading to a decrease in both saturated and unsaturated permeabilities [2]. The absorption of polar water-based fluids is significative, but also some fluid absorption was observed in tests performed with phenolic and vinil ester resins [2]. Some authors studied the compaction behavior of wood fiber mats [3], and they found that the impregnation with polar liquids reduced the compaction forces due to the fluid absorption and softening of the wood fibers, while non polar liquids had no effect on the compaction stress.
The aim of this work is to study the deformation response of natural fiber performs to transverse compressive forces. The effect of fluid absorption and fiber structure on the compaction behavior of jute fabrics and sisal fiber mats was analyzed.

EXPERIMENTAL PROCEDURE

Two different natural fiber fabrics were used in this study, bidirectional woven jute fabric (Castanhal Textil, Brasil; surface density = 0.0300 g/cm2) and sisal random mat (surface density = 0.085 g/cm2). The fabrics were washed with a 2% V/V distilled water and detergent solution, to remove contaminants and normalize the fabrics conditions for all the tests. In addition, glass fiber random mat (surface density = 0.047 gr/cm^2) was used for comparison purposes. Circular preform samples of 130 mm diameter were used in the compaction tests. Glass and jute preforms consisted in 6 layers of fabric while sisal preforms consisted in two layers of fabric. Pictures of the reinforcements used in this study are shown in Fig. 1. Natural fibers structure was analyzed by Scanning Electron Microscopy (SEM, model JEOL JSM 6460 LV).

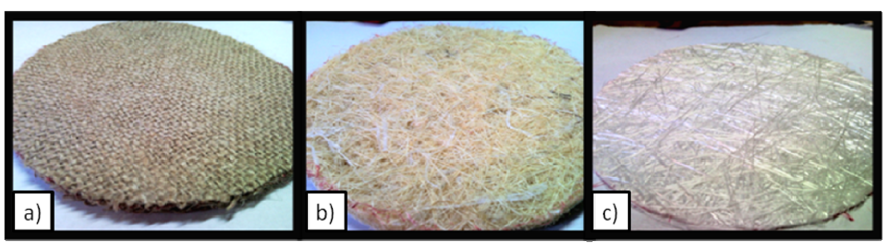

Fig. 1 Reinforcements used in the compaction tests. a) Jute woven Fabric, b) Sisal fiber Mat, c) Glass fiber mat.

An Instron Universal Testing Machine with a 30 KN load cell was used to carry out the compression tests. Preform samples were compressed at constant compaction rate, until the desired thickness or fiber volume fraction was achieved. Jute and glass preforms were compacted to a fiber volume fraction of 0.55 while sisal preforms were compressed to a volume fraction of 0.35, due to the excessive clamping forces required achieving higher fiber content. The machine was programmed to hold the final thickness for ten minutes while the load was recorded in order to analyze the preform stress relaxation. After the relaxation step the test was repeated, thus, two loading cycles were obtained. In order to calculate the permanent deformation suffered by the preform, the unstressed preform thickness was defined as the thickness measured by the testing machine when the compaction pressure reached 7 KPa, which is a very low compaction pressure. Therefore the permanent deformation suffered by the preform was calculated using Eqn. 1,

$$\text{Permanent Deformation (\%)} = 100 \cdot (t_0 - t_f)/t_0 \qquad (1)$$

where t_0 (cm) is the unstressed preform thickness in the initial loading cycle, and t_i (cm) is the unstressed preform thickness in the subsequent loading cycles. In order to evaluate the effect of immersion time in the test fluid on the compaction response of the preforms, compaction tests were performed on preforms that were immersed for different periods of time in the test fluid. A 20 % V/V water/glycerin solution was chosen as the test fluid because its viscosity is similar to commercial infusion resin viscosities.

RESULTS AND DISCUSSION

Jute and sisal fibers are composed of several elementary fibers of about 10 μm (called macro fibrils) made of several layers of cellulose microfibrils embedded in a matrix of lignin and hemicellulose. The elementary fibers, which are also glued together with lignin and hemicellulose, have an open channel on the centre called Lumen [4]. Scanning electron micrographs of sisal and jute fibers are shown in Fig. 2a) and 2b). It can be seen that sisal fibers diameter is much higher than jute ones, and they are composed of a larger number of macro fibrils. In addition, the lumen size and the wall thickness of the macro fibrils are similar in both types of fibers.

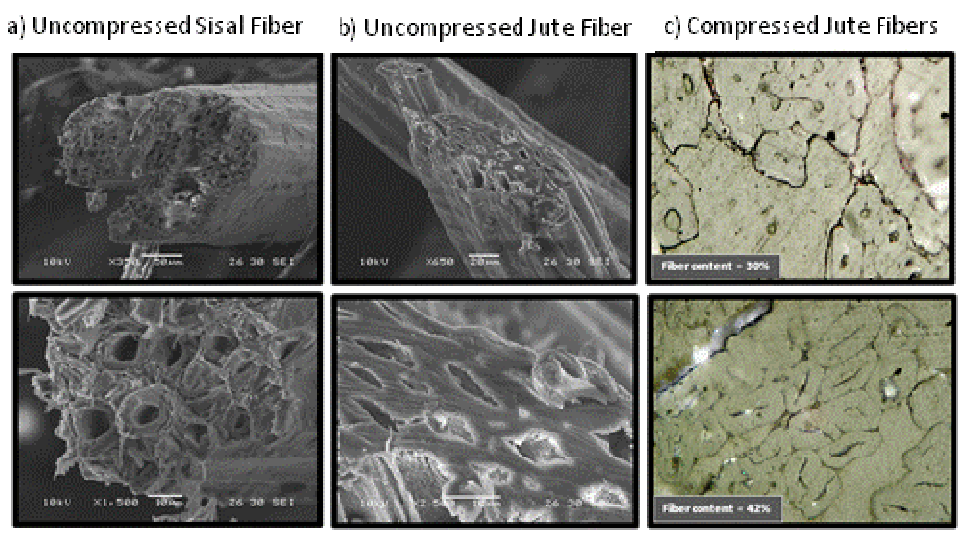

Fig. 2. a) SEM images of Sisal fibers. b) SEM images of Jute Fibers. c) Optical micrographs of compressed jute fibers.

Natural fiber cell walls collapsed and the lumen was closed when transversal compressive forces were applied to the preform, and this phenomenon increased as the fiber content (and transverse deformation) increased. This effect can be seen in Fig. 2c), which shows micrographs obtained by optical microscopy at 300X of the transversal section of jute/unsaturated polyester resin composite specimens manufactured by the compression molding technique.

The compaction response of dry sisal and glass fiber mats as well as dry jute woven fabrics is shown with solid lines in Fig. 3a). The compaction pressure needed to achieve

any fiber volume fraction within the range studied was significantly lower in the case of glass fiber mats, followed by the jute fabrics, and then sisal fiber mats. The difference between successive cycles was larger in the case of natural fiber than in glass fiber preforms, suggesting that natural fiber fabrics experiment larger permanent deformation than glass fiber mats. However, due to the similarity in the architecture it is more appropriate to compare sisal with glass random mats in terms of permanent deformation. Using Eqn. 1, it was found that the permanent deformation was 42 % for sisal and 18% for glass random mats. Sisal fibers could suffer lumen collapse just as jute fibers did (Fig. 2) in addition to the same mechanisms present in glass mats.
The compaction response of the reinforcements impregnated with the test fluid is shown with dashed lines in Fig. 3a). It seems that the pressure caused by the fluid flow through the preform is more significant than the lubrication effect in glass fiber mats, while jute woven fabrics and sisal mats behaved in the opposite manner. In addition, glass mat permeability was found to be almost equal to jute fabrics permeability among the fiber volume fractions studied (not shown in this work), thus the pressure build up in glass and jute fabrics was expected to be very similar. Therefore fluid absorption and fiber softening occurred during the compaction tests of natural fiber preforms decrease the compaction pressure, in accordance to R. Umer et. al.

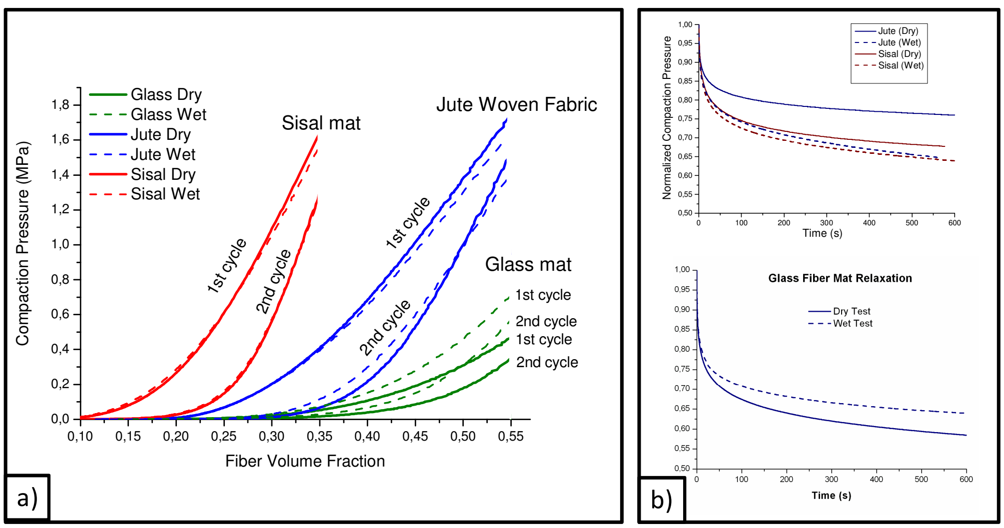

Fig. 3 Compaction behavior of sisal mats, glass mats and jute woven fabrics.

Fig. 3b) shows the stress relaxation of the different reinforcements studied. The results obtained in the wet tests showed an opposite trend for syntetic fiber than for natural fiber preforms. Glass fiber mats experimented larger stress relaxation when compressed dry than when compressed in the presence of the test fluid, while sisal and jute fiber preforms responded in the opposite manner. The lubrication effect was expected to decrease the amount of stress relaxation, because the fiber and tow realignment and reorientation, as well as the interactions between consecutive layers should have been easier during the compaction stage. However, in natural fiber reinforcements the relaxation is enhanced by fiber softening, which is a slow process that takes place, generally, after the maximum load has been reached.
The effect of the immersion time on the maximum compaction pressure is shown in Fig. 4. The compaction behavior of glass preforms did not change with the immersion time, which means that the fibers did not absorb fluid, as expected. Sisal mats and jute woven fabrics showed a similar behavior, despite of the different fabric architecture. The total pressure drop observed in jute fabrics was around 20%, and this value was reached after 15 minutes of immersion. Again, the results can be explained in terms of fiber

softening, consistently with the results obtained in the relaxation tests. Sisal preforms also softened as the immersion time increased, showing a total pressure drop of 10%. Within 15 minutes of immersion, which is the time needed to perform the compaction test and the relaxation step, the pressure decreased 6%. This could explain why the stress relaxation curves for the dry and wet preforms shown in Fig. 3b) did not show a difference as large as jute fiber preforms.

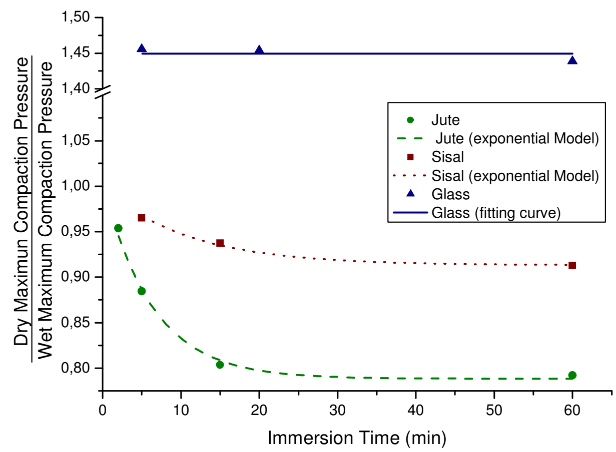

Fig. 4 Maximum compaction pressures reached in preforms immersed in the test fluid different time periods before performing the compaction test.

SUMMARY AND CONCLUSIONS

Natural fiber preforms needed much higher clamping forces than glass fiber preforms to achieve large fiber volume fractions. The compaction response of natural fiber preforms was affected by the natural fiber structure, increasing the permanent deformation due to lumen closure. In addition fluid absorption also affected the compaction behavior of natural fiber preforms, which caused fiber softening, decreasing the compaction pressures. The fluid absorption increased as the immersion time was raised, thus some of the pressure drop that took place at the relaxation stage was caused by fiber softening. As a consequence, the stress relaxation of impregnated performs was higher than dry performs. These phenomena were not observed in the compaction test of glass fiber mats performs.

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