PROCESSING AND MECHANICAL PROPERTIES OF UNIDIRECTIONAL HEMP-PAPER/EPOXY COMPOSITES.

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ABSTRACT: Natural continuous bast fibers (hemp, flax…) are gaining popularity in composite materials because they can advantageously replace glass fibers. In unidirectional (UD) composites, it is found that their intrinsic properties are equivalent to those of unidirectional glass fibre composites but it is difficult to get repeatable results because of the variability in the properties of bast fibers compared to glass. Their quality is largely affected by the weather conditions, the extraction location along the plant and the techniques used to extract them (retting, bleaching…). In this work, unidirectional hemp/paper/epoxy composites are manufactured by adding sheets of paper at the surface of a unidirectional layer of hemp fibers before molding. The composites are tested under tensile and shear loads and the results compared with those obtained for UD hemp composites made without paper. The results show a significant increase of the reproducibility in strength and modulus of the composites when the paper is present. A significant increase in strength and modulus was also obtained compared to the base epoxy properties. Difficulties were encountered in the shear tests using the Arcan test setup. These are finally presented to open the discussion about the possible causes of such difficulties.

KEYWORDS: unidirectional composites, hemp, kraft paper, epoxy, tension, shear.

INTRODUCTION

Natural fiber reinforced composites are actually under attention considering their potential to reduce or eliminate some of the problems associated with the non-degradable glass and carbon fibers in actual composites [1]. Natural fibers are fully biodegradable, consume globally less energy for their production and they maintain acceptable specific stiffness, strength and toughness compared to glass fibers [1, 2]. Considering the importance of the fiber-matrix interface on the composite strength, up to now several works have been aimed at improving the strength by compatibilizing the interface and improving the wettability of the fibers by the matrix [3]. The renew in popularity of continuous natural bast fibers has led to the development and manufacture of natural fiber mats or fabrics to be used as base materials for automotive interior parts [1]. These materials allow sufficient stiffness and strength for non structural interior panels but for applications requiring higher strengths and stiffnesses, laminates made of unidirectional plies (such as UD prepregs) are usually more appropriate. Several works have been devoted to the characterization of unidirectional composites made of bast fibers embedded in a synthetic or natural (degradable) matrix. Most of them deal with natural fibers embedded in a synthetic matrix [4, 5] but some other aim at developing fully biodegradable composites by synthesizing the matrix directly from the fibers [6].

To the knowledge of the authors, almost no works have been devoted at combining unidirectional bast fibers with layers of papers to produce unidirectional reinforcements. Being the same nature as bast fibers, thin layers of paper could be advantageously used as binder to keep cohesion and straightness of the fibers in the reinforcement while maintaining the biodegradability of the material. The presence of paper in-between unidirectional plies could also increase the interlaminar properties and serve as protective layers for the inner UD fibers. In what follows, a reinforcement made of sheets of kraft paper deposited on UD hemp fibers is fabricated and used for the fabrication of UD hemp-epoxy plaques. The plaques are tested under tension and shear and the results compared with the same UD composite made without the paper layers.

EXPERIMENTAL

Composites fabrication

Sheets of paper were fabricated using a laboratory dynamic sheet former (from Allimand Inc., France). With this equipment, a thin and wet layer of kraft paste is obtained. This layer is next pressed with a sheet press under different pressures to compact the paste (the short cellulose fibers forming the paper). The sheet press consists in a pressurizing roll and an absorbing felt in between which the paper layer is squeezed in several steps by gradually increasing the pressure. The pressed layers of paper are finally placed over the UD layer of hemp fibers, one each side, and dried at 100°C with a sheet dryer for about 15 minutes. A typical sample of the obtained reinforcement is shown in Figure 1. The hemp layer is fabricated apart by deposing side by side several yarns of unidirectional hemp fibers (commercialized by YugoHemp Inc., Canada) over a flat plate. To ensure that the fibers are kept in place in a well aligned position, they were humidified before deposition. They were finally dried in an oven at 75°C for 16 hours before the final fabrication of the reinforcement described above. No other specific treatment was performed on the hemp fibers. The objective here was more to look at the development of a fabrication procedure for the reinforcement and at evaluating the influence of the layers of paper on the mechanical behaviour of the composites obtained. Before molding, the paper/hemp reinforcement was dried overnight at 75°C for 16 hours

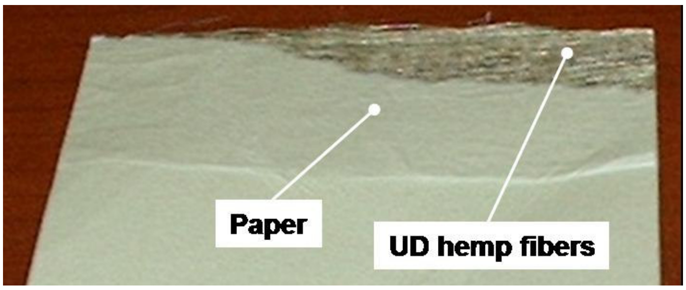

Figure 1. Sample of the reinforcement made of UD hemp fibers in-between two layers of kraft paper.

to remove any residual traces of humidity. Composite plaques were finally molded by impregnating one layer of reinforcement with an Adtech™ 820 epoxy laminating resin. The impregnation was performed by hand (with a roller) and the plaques were cured under vacuum (20 in-Hg) using the vacuum bag technique. A post cure at 75°C for 16 hours was finally performed before testing. Two plaques were moulded, one with layers of paper on each side of the UD fibers and one with the UD fibers only for comparison of the results.

Experimental testing

Table 1 shows the fiber weight (FW) and volume (FV) contents of the materials tested. For comparison purposes, the percent weight content of the short fibers in the paper phase is given based on the weight of the paper phase only and the percent weight content of the UD hemp fibers is based on the weight of the hemp phase only in the plaque. A plaque made of paper only was molded and weighted to isolate the paper contribution (first column of Table 1) in the fiber contents of the hemp/paper plaque. The two plaques show similar weight contents of UD hemp (33.9% versus 35%).

Table 1. Description of the tensile test specimens.

	FW content (%) – paper phase	FW content (%) – fiber phase	FV content (%) – fiber phase	FW content (%) – global
Hemp/paper	34.3	33.9	30.5	34.0
Hemp only	-----	35.0	31.6	35.0

The tension tests have been performed following ASTM D3039. The resin properties were obtained by molding and machining specimen following ASTM D638. Shear tests were finally performed using the Arcan test setup and preliminary results are shown for discussion.

Results

The results of strength (STR) and modulus of elasticity (E) for the UD hemp/paper composite, the UD hemp composite and the unreinforced resin are shown in Table 2. The properties ratios composite/unreinforced resin are shown in the last row. Strength ratio of respectively 2.5 and 2 for the composites with and without the presence of paper are respectively obtained. For the modulus of elasticity, ratios of 3.3 and 3.8 were obtained for the composites without and with the paper layers respectively. Globally, these results are interesting if we consider that no treatments were performed on the hemp fibers to increase the cohesion at the fiber-matrix interface. By comparing the hemp/paper and hemp only composites, the results show that the paper has a beneficial effect on the strength of the composite but it slightly reduces the modulus of elasticity. This is not surprising considering that the paper portion of the composite has a lower modulus than the UD composite, thus contributing to reduce the overall modulus of the composite made with paper, but the reduction is quite limited. The results of strength are however interesting. It seems that even if the fibers within the paper layers are very short, they do contribute to slightly increase the global strength of the hemp/paper composite with a mean strength value of 134.5 MPa compared to 106.3 MPa for the hemp composite. Another (and more important) aspect of these results is the much

Table 2. Average strength (STR) and modulus of elasticity (E) of hemp/paper composite, of hemp composite and of unreinforced resin.

Test #	HEMP/PAPER		HEMP		Unreinforced RESIN	
	STR (MPa)	E (MPa)	STR (MPa)	E (MPa)	STR (MPa)	E (MPa)
1	125	6442	75	7910	49	2620
2	127	6471	77	8246	40	1481
3	129	7329	95	6467	41	1517
4	138	6978	108	7924	60	2249
5	139	6971	111	8570	60	2348
6	139	7027	118	9960	59	2305
7	139	7361	123	6871	62	2395
8	140	7360	143	8528		
Mean value	134,5	6992,4	106,3	8059,5	53,0	2130,7
Disparity	±6,3	±370	±23,2	±1077	±9.5	±447
Ratio	2,5	3,3	2,0	3,8	1,0	1,0

lower disparity obtained for the strength and modulus when the layers of paper were present, as observed in Table 2. Not only is the mean strength slightly ameliorated when the paper is added but also the disparity (standard deviation) of results is much lower. This reduction in disparity is also observed for the modulus of elasticity. These results suggest that the paper contributes to reduce the influence of fiber defects and surface defects, maybe by filling the resin rich zones (in between successive fiber tows) and by absorbing voids that could be present at the surface of the fibers. Such attenuation in the disparity of the results is interesting considering that the properties of natural fibers themselves, which rely on many environmental factors, are always more disparate than those of synthetic fibers made in more controlled environments. By using layers of paper for the fabrication of UD reinforcements, this problem could be largely resolved and the presence of paper could eventually contribute to ameliorate the delamination properties of a multilayer laminate made from such reinforcements.

Shear tests were finally performed on the composites using the Arcan test setup shown in Figure 2. Unfailed and failed coupons are also shown on top of the figure. The fracture appears on the side of the V-shaped notch instead of the root. This behaviour was obtained for almost all coupons tested, no matter the radius at the tip of the V notch (from 2 mm as suggested in the procedure down to the size obtained from a razor blade to simulate a crack tip). In all cases (a few exceptions), the coupons fractures were similar to that shown in Figure 3 and we have no explanations for that behaviour.

CONCLUSION

In this work, a new approach to manufacture natural fiber composites is proposed. This is based on the use of two layers of paper, placed on both sides of the continuous unidirectional fiber reinforcement. The results show a sharp decrease in the disparity of strength and elastic modulus measured experimentally. The disparity of strength is reduced from ±23.2 MPa to ±6.3 MPa when the layers of paper are added. With such results, we believe that the presence of paper contributes to absorb and to homogenize the size of the defects and consequently contributes to minimize the disparity in the

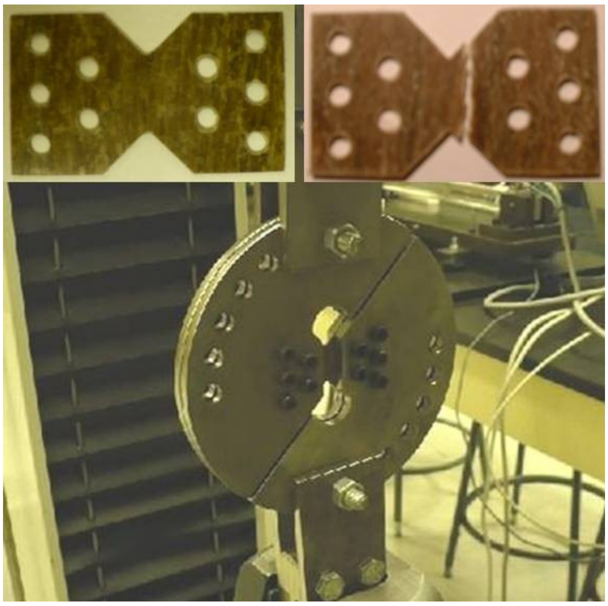

Figure 2. Arcan shear test setup showing a typical specimen in the upper corner.

results. Similar observations are made on the Young's modulus. This work is a first step in the development of new materials for the manufacture of natural fiber composites. Not only the presence of paper mitigates the disparity of properties but it could eventually contribute to ameliorate the delamination properties of laminated composites. These are promising results considering the difficulty to get reproducible mechanical properties for natural fiber composites, phenomenon inherent to the control of growth and to the treatment of natural fibers.

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