Cardanol Based Matrix for Jute Reinforced Pipes

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Summary: The aim of this work is the development of composite pipes using renewable resources. The pipes, manufactured by filament winding technology, were obtained using an epoxy resin crosslinked with a cardanol based novolac as matrix and jute fibres as reinforcement. Cardanol is a natural oil extracted from the shell of the cashew (*Anacardium occidentale* L.) nut. An amount of natural materials higher than 50% by weight was achieved in the final composites. Tensile and parallel plate compression tests were carried out on the composite pipes.

Keywords: cardanol; composites; filament winding; jute fibres; pipes

Introduction

Thermosetting resins deriving from renewable resources are finding increasing commercial applications, particularly in times of global warming and depleting petroleum oil reserves. Therefore, a great interest has recently risen for a wide range of high-performance and low cost materials made from plant oils and natural fibres.

For example, soy and linseed oils were used as base monomers for unsaturated polyester resins,[1,2] as polyols in polyurethane formulations,[3–5] and as additives in coatings, inks, plasticizers, lubricants and agrochemicals.[6–8] In recent years, natural fibres have also gained an increasing interest as reinforcement in composite materials, due to the high cost of synthetic fibres as well as to their inherent features such as biodegradability, low density and comparable properties to glass fibres in high volume applications.[9] Numerous studies about the properties of natural fibre reinforced composites using hemp,[10,11] agave,[10] flax,[11–13] bamboo,[14] banana[10] and jute[15–19] have been published. However, in those applications the bio-based composites are usually characterized by an amount of renewable resources lower than 50% by weight.

This study describes for the first time the development of composite pipes using jute fibres as reinforcement. In particular, after a preliminary design, the pipes were manufactured by filament winding technology and characterized by tensile and parallel plate compression tests. Glass fibre reinforced pipes were also manufactured and tested for comparison purposes. An epoxy resin crosslinked with a cardanol based novolac, containing 35% by weight of unreacted cardanol, was used as matrix for both types of pipe. Cardanol is a natural phenol obtained by distilling Cashew Nut Shell Liquid (CNSL), a renewable resource contained in the spongy mesocarp of the cashew (*Anacardium occidentale* L.) nut. The cardanol based novolac was synthesized in a pilot plant by stirring a blend of cardanol and formaldehyde water solution under acid condition. The synthesis of the cardanol based novolac and the characterization of the thermosetting resin obtained using the novolac as epoxy curing agent were previously reported.[20–21]

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Experimental Part

Materials

Jute fibres in form of twisted yarns (Canapajuta S.A.S., Italy) and Hiper-tex e-glass fibres (Owens Corning) with a linear density of 270 TEX and 1200 TEX (weight per unit length, i.e. 1 g/1000 m= 1 TEX), respectively, were used in the manufacture of the pipes. The matrix, a commercial DGEBA (Diglycidil Ether of Bisphenol-A, DER 331 from DOW) was crosslinked with the cardanol based novolac, synthetized as proviously reported,[20–21] employing 2,4 EMI (2-ethyl-4-methyl-imidazole from Sigma Aldrich) as catalyst.

For the liner manufacturing a C glass veil (Veil 1790 C from Freudemberg) and a glass mat (Owens Corning) were used.

Measurements

Tensile and Parallel Plate Compression tests

Parallel plate compression test and tensile test were carried out using a dynamometer LLOYD LR30K equipped with a 5 kN capacity load cell, according to ASTM D 2412 and ASTM D 3039, respectively.

The parallel plate compression test was carried out using two plates with a diameter of 150 mm and a crosshead speed of 12.5 mm/min. Samples with a length of 150 mm were tested. Tensile test was performed on specimens with an overall length of 250 mm using a Epsilon Technology Corp. extensometer. The specimens were obtained from the pipe walls cutting them along the pipe axis. The crosshead speed was fixed at 2 mm/min.

All mechanical properties were obtained as an average of five trials.

Fibre Content Determination

The fibre content of the glass reinforced pipes was determined by gravimetric measurements of the samples heated at 500 °C for 10 minutes, according to ASTM D 2584. Five specimens were tested for each composite pipe.

The fibre content of the jute reinforced pipes could not be obtained using this method because at 500 °C both the matrix and the jute fibres undergo to decomposition. Consequently, the jute fibre content was obtained by weighting the jute spools before and after the pipe winding.

Composite Fabrication

The technology employed to manufacture the composite pipes was the discontinuous wet filament winding. The equipment used was characterised by two degrees of freedom: the longitudinal motion of the feeding head and the rotation of the cylindrical mandrel.

The manufacturing parameters were the comb width and the minimum number of runs that were necessary to cover completely the whole surface of the mandrel (indicated as one wrapping). One run has to be intended as a two ways travel of the feeding head going back and forth between the two ends of the mandrel. The number of runs necessary to obtain one wrapping depends on the mandrel diameter and on the winding angle of the fibres.

Two types of composite pipe were manufactured using an epoxy matrix, crosslinked with 30% by weight of the cardanol based novolac, and either glass or jute fibres as reinforcement.

The following manufacturing parameters were chosen to lay down the structural layers for both types of pipe: a double wrapping, winding the reinforcement on a 150 mm mandrel, was obtained from 40 runs. The liner was made winding a glass mat on a layer of C glass veil and a medium wall thickness of 5 mm for both types of pipe was obtained.

For the jute and glass reinforced pipes, 12 and 4 filaments, respectively, were placed on the comb, giving a 30 mm bundle width. The winding angle of the fibre reinforcement for both types of pipe was of 55 °, since it is the standard value usually used for the manufacture of helical filament wound pressure pipes, having joints that transmit axial loads.

Pipes with diameters higher than 400 mm and installed underground need also hoop layers (winding angle 90 °C) to prevent ovalization contributions. A thermostated roller driven impregnation vat was used for the impregnation of the fibres and the resin was heated at 50 °C in order to reduce its viscosity. The pipes were cured at a temperature range between 115 and 125 °C for 4 h using infrared radiation, according to the calorimetric characterization previously reported.[20–21]

Table 2.
Circumferential and axial modulus calculated by STARCOMPOSITE software for jute and glass pipes.

	Glass reinforced pipe	Jute reinforced pipe
Circumferential Modulus (GPa)	14.72	7.15
Axial Modulus (GPa)	5.98	3.18

Results and Discussion

A preliminary design of the glass and jute reinforced pipes was made using STARCOMPOSITE, a composite design software based on the classical micromechanics equations and macromechanic lamination theory.[22] The pipe design was performed for low pressure water transport applications, setting the working pressure at 6 bar. The pipe modulus along axial and hoop directions were calculated using the following input data: the fibre and matrix properties, the winding angle, the pipe thickness and the loads corresponding to the working pressure. The jute fibre properties were determined in a previous study.[23] The input and output data are summarized in Tables 1 and 2.

The fibre content of the jute and glass reinforced composites are reported in Table 3. As can be seen, the jute reinforced pipes had a fibre content lower than the glass reinforced ones, indicating that the wetting of the jute fibres was critical during the pipe winding. This can be explained considering the use of twisted jute yarns that are much less permeable towards the resin compared to continuous untwisted glass rovings. A second reason of the lower fibre content in the jute reinforced pipes could be the polar nature of natural fibres, that does not favour the jute wettability.

The hoop mechanical properties of the composite pipes were measured by a parallel plate compression test loading the pipe sections in a direction perpendicular to the pipe axis, between parallel plates up to 30% of their initial diameter. The equipment used for this test is shown in Figure 1.

According to ASTM D 2412, the pipe stiffness (PS) is the ratio between the force per unit length (F) and the deflection (Δy):

$$PS = \frac{F}{\Delta y} \quad (1)$$

The shape of the cross section does not keep constant during the test, varying from a circle to an ellipse. Therefore, it is necessary to apply a proper correction

Table 1.
Main input data used in STARCOMPOSITE software.

Fibre mechanical properties	Young Modulus (GPa)		Tensile Strength (MPa)	
	Jute	Glass	Jute	Glass
	38	75	380	2800
Matrix mechanical properties	Young Modulus (GPa)		Tensile Strength (MPa)	
	1.7		35	
Fibres (%v)	Glass reinforced pipes		Jute reinforced pipes	
	33		56	
Pipe thickness (mm)	5			
Winding angle (°)	55			
Axial load per unit length (N/m)	22500			
Circumferential load per unit length (N/m)	50000			

Table 3.
Results of parallel plate compression test for the jute and glass reinforced pipes.

Pipe	Pipe Stiffness (KPa)		E_{flex} (GPa)	Fibre content (% volume)
	5%	10%		
Jute/epoxy resin	325 ± 28	296 ± 36	2.0 ± 0.25	33
Glass/epoxy resin	1135 ± 42	1129 ± 22	6.8 ± 0.34	56

Figure 1.
Equipment used for the parallel plate compression test.

factor in Eq. 1 as follows:

$$PS = \frac{F}{\Delta Y}\left(1 + \frac{\Delta y}{2d}\right)^3 \qquad (2)$$

where d is the inside pipe diameter.

Figure 2 shows pipe stiffness and corrected pipe stiffness curves obtained in a typical parallel plate compression test.

As shown in Figure 2, after an initial decrease, the corrected stiffness reaches a plateau. The pipe stiffness was calculated at

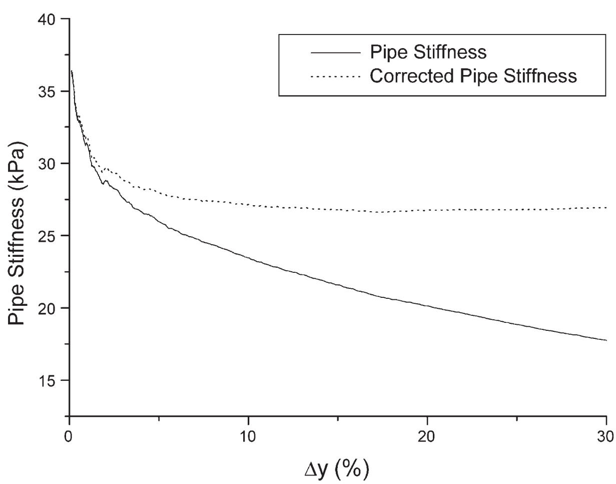

Figure 2.
Pipe stiffness and corrected pipe stiffness curves.

5% and 10% of the diameter deformation according to ASTM D 2412.

The corrected pipe stiffness was used for the calculation of flexural modulus (E_{flex}) according to ASTM D 2412:

$$Eflex = 0,149^{*} \frac{PS^{*} r^{3}}{\left(\frac{t^{3}}{12}\right)} \quad (3)$$

Where t is the pipe thickness and r the inside pipe radius. The results obtained are reported in Table 3.

As shown in Table 3, the properties obtained for the glass reinforced pipes are much higher than those obtained using the jute reinforcement. The observed behaviour could be explained considering the lower modulus of jute fibres and the lower fibre content in jute reinforced pipes.

The pipe stiffness values for both types of pipe are in accordance with AWWA (American Water Works Association), since the minimum stiffness required for a pipe with an internal diameter of 150 mm is 248 KPa.

The tensile modulus values obtained for jute and glass samples were 3.5 ± 0.3 and 7.1 ± 1.4 GPa, respectively. These are in a good agreement with the theoretical Young Modulus values reported in Table 2.

Conclusion

In this study two bio-based composites, glass and jute reinforced, were fabricated and tested. An epoxy resin matrix cross-linked with a cardanol based novolac was used. Filament winding technology was employed to fabricate thin wall pipes to be applied to sewage water. The amount of natural components in the jute reinforced pipes reached 53% by weight. The theoretical analysis satisfactory predicted the Young modulus of the composites developed and the pipe stiffness recorded was in accordance with AWWA standards. Future work will be devoted to increase the fibre content and to improve the fibre/matrix adhesion.

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