COIR FIBRE COMPOSITES: FROM FIBRE PROPERTIES TO INTERFACIAL ADHESION AND MECHANICAL PROPERTIES OF COMPOSITES

L. Q. N. Tran[1*], C. Fuentes[1], C. Dupont-Gillain[2], A. Van Vuure[1], I. Verpoest[1]

[1]*Department of Metallurgy and Materials Engineering (MTM), Katholieke Universiteit Leuven, Leuven, Belgium.*
[2]*Institute of Condensed Matter and Nanosciences, Université Catholique de Louvain, Louvain-la-Neuve, Belgium.*
** Corresponding Author: Ngoc.Tran@mtm.kuleuven.be*

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Abstract

Vietnamese coir fibres are studied and modified for use in composite materials. Tensile properties of the fibres are characterized using single fibre tensile tests, in which optical strain mapping is used to determine fibre strain, to produce more reliable values of E-modulus and strain at failure. In this study, the interface of unidirectional (UD) composites of untreated and 5% alkali treated coir fibres in thermoplastic matrices (polypropylene, maleic anhydride grafted polypropylene and polyvinylidene fluoride) is investigated using wetting analysis and interfacial mechanical tests. The results show that the interfacial adhesion of both untreated and treated fibres with maleic anhydride grafted polypropylene and polyvinylidene fluoride are higher than in case of polypropylene. When comparing untreated and treated fibres, the interfacial strength of the alkali treated fibre composites is increased. Mechanical properties of the UD composites are assessed by flexural tests in fibre direction and unnotched Izod impact tests. In agreement with the interface evaluation, higher flexural strength and stiffness are found in treated fibre composites, probably thanks to the better interfacial adhesion. The impact strength of coir thermoplastic composite is not significantly different from that of neat polymer, while coir fibres can improve the toughness of the epoxy by minimum a factor of three, when the impact strength is considered as toughness indicator.

1 Introduction

Natural fibres such as flax, jute, sisal, coir, hemp and bamboo have been used as reinforcement in polymer composites during the last decades. They are available in large amounts, at low cost, have low energy utilisation and are renewable and biodegradable. In most cases the specific properties of the natural fibre composites were found to compare favourably with those of glass fibre composite [1]. Among natural fibres, coir fibres have low density in the range from 1.0 to 1.3 g/cm3 and high strain to failure up to approximately 40%. This property may ameliorate the toughness when they are used in composite [2]. Besides, coir fibres are moderately cheap and available in large quantities (over one million ton a year). These properties of coir fibres show that there is a potential for application in polymer composites.

In this work, Vietnamese coir fibres are studied and modified for use in composite materials. To find out their potential in composites, performing fibre tensile tests is a straightforward way to determine the mechanical properties of fibres. For single fibre tensile tests, it is a challenge to measure the fibre strain since the fibres are typically too small to use an extensometer. Hence, an optical strain mapping system was used to determine fibre strain, to produce more reliable values of E-modulus and strain at failure. In composite materials, the interfacial adhesion between fibre and matrix plays an important role in the final mechanical properties. In this study, the interfacial adhesion of untreated and alkali treated coir fibre composites with various thermoplastics is investigated based on wetting analysis of the fibres and the matrix, and micro-mechanical tests of fibre-matrix interface. Finally, mechanical properties of the UD composites are assessed by flexural tests in fibre direction and by un-notched Izod impact tests.

2 Materials and testing methods

2.1 Materials

Fibres

Technical coir fibres were extracted from husk shells of coconuts with a purely mechanical extraction process. The fibres were then soaked in hot water at 70^0C for 2h, washed with ethanol, rinsed with de-ionized water and dried in a vacuum oven at 90°C. These fibres are referred to as untreated coir fibre in this work. The treated coir fibres were obtained using 5% NaOH solution for 2h at room temperature, then washed thoroughly with de-ionized water and dried in a vacuum oven as described above. The alkali treatment was expected to remove wax and fatty substances present on the untreated fibres.

Matrices

Both thermoplastic and thermoset polymers were used as matrices for untreated and treated fibres, namely polypropylene (PP), Polyvinylidene fluoride (PVDF), 0.3% maleic anhydride grafted polypropylene (MAPP) and epoxy. The thermoplastics were obtained as extruded films. (The PP was supplied by Propex, PVDF by Solvay and MAPP by Dupont), while the epoxy Epikote 828 and hardener Diaminocyclohexane were used.

2.2 Testing

Single fibre tensile test

Single untreated technical fibres (which consist of a bundle of structurally bonded elementary fibres) were tested in tension on an Instron mini universal test machine integrated with a camera system for the optical strain measurement. Speckles were created on the fibre surface so that the camera system could map the fibre strain during tensile loading. The recorded strain mapping data was analysed using Limess software, which was then linked with the tensile load data to plot the stress-strain behavior of the fibres.

Wetting analysis and fibre-matrix interface tests

In this study, the interfacial properties of untreated and alkali treated coir fibres and the thermoplastic matrices are investigated. Wetting measurements are carried out using the Wilhelmy technique, which allows determining the contact angles of fibres and matrices in various test liquids [3]. The contact angles are used to estimate the solid surface energies and surface energy components (polar and dispersive fractions), and then to calculate the fibre-matrix work of adhesion and the interfacial energy of the various fibre-matrix pairs, following the Owens-Wendt approach [4]. Flexural transverse three-point bending tests on unidirectional composites and single fibre pull-out tests are performed for determining interfacial strength and interfacial shear strength (IFSS) respectively.

Mechanical tests of UD composites

Mechanical properties of UD untreated coir PP and epoxy composites were evaluated with flexural tests in fibre direction and unnotched Izod impact tests. The flexural tests were done following ASTM D790M, while impact tests were performed according to ISO 179.

3 Results and discussions

3.1 Coir fibre tensile properties

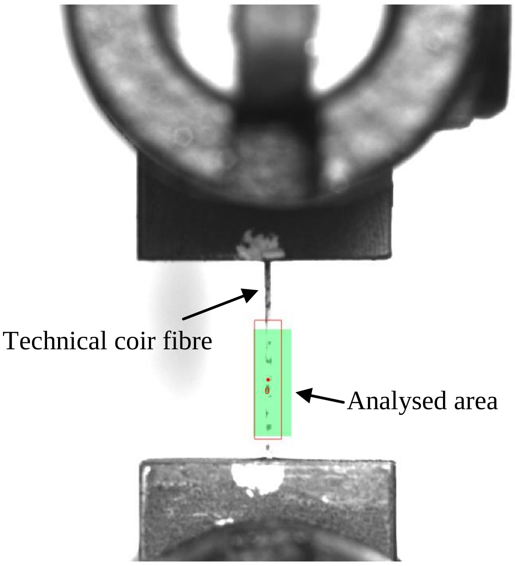

Figure 1. Tensile test of single coir fibre with optical strain mapping

Figure 1 shows the tensile test of single coir fibre with an optical strain mapping system. The movement of speckles on the fibre surface was followed by a camera; then data analysis was done with the software Limess. Subsequently, E-modulus and strain-to-failure of the fibre were calculated and are shown in Table 1. The properties of the fibres are comparable with previously reported results [2, 5], which show high elongation at failure, but the fibres are not so strong and stiff. Concerning the test method, optical strain mapping provides a fast and precise way to determine the fibre elongation during tensile loading, in comparison with the previously used procedure using a correction for slippage and machine compliance, by using different test span lengths [2].

Table 1. Tensile properties of coir fibres

Fibre	E-Modulus (GPa)	Strength (MPa)	Strain-to-failure (%)
Untreated coir	3.8 ± 1.0	167.7 ± 39.3	18.0 – 36.7

3.2 Interfacial characterisation of coir fibre composites

Surface energies and work of adhesion

Surface energies of the fibres and matrices were determined and are shown in Table 2. It can be seen that the untreated fibres seem to be relatively hydrophobic with a low polar fraction of the surface energy. Moreover, 5% alkali treated fibres have higher surface energy with an increased polar fraction. For the matrices, the surface energies of PP and MAPP are quite similar to reported values in literature [20,21]. It is seen that the surface energy of MAPP is not far different from that of PP since grafting a small amount of maleic anhydride on PP does not affect much the wetting behaviour and surface energy. As expected, the surface energy of PVDF is higher than that of PP with a high polar fraction.

Table 2. Surface energies of fibres and matrices estimated following the Owens-Wendt approach

Fibre/Matrix	**Surface energy (mJ/m²)** disperse-polar (Owens-Wendt)		
	γ_S	γ_S^d	γ_S^p
Untreated coir	40.4 ± 3.9	35.1 ± 3.6	5.3 ± 1.5
Alkali treated coir	42.2 ± 4.2	33.5 ± 3.7	8.7 ± 2.0
PP	30.7 ± 4.0	27.1 ± 3.7	3.6 ± 1.4
PVDF	37.2 ± 1.1	30.8 ± 1.0	6.4 ± 0.5
MAPP	28.6 ± 6.4	23.6 ± 5.8	5.0 ± 2.8

Work of adhesion and interfacial energy for each composite system were calculated and are shown in Table 3. The work of adhesion shows a higher value for coir fibre in PVDF in comparison with that in PP and MAPP, which is mainly thanks to the higher surface energy and polar component of PVDF. It also can be seen that alkali treatment somewhat improves the work of adhesion of all fibre-matrix systems, which can be partially attributed to the higher surface energy and polar component of the fibres. In coir fibre – PVDF, the surface energy components of both untreated and treated fibres are quite well matched leading to high work of adhesion and a low value of interfacial energy. For PP and MAPP systems, the improvement in work of adhesion for treated fibres is not expected to be significant, since the compatibility is relatively low, caused by mismatching surface energies and relatively high interfacial energy. The adhesion for MAPP is good though, which will be discussed in the next section.

Table 3. Work of adhesion, interfacial energies, apparent IFSS in the single fibre pull-out test; and transverse strength in 3PB of UD composites

Composite	W_a (mJ/m²)	γ_{SL} (mJ/m²)	Trans. strength (MPa)	Eff. Factor of Long. strength	IFSS (MPa) at 0.5mm embedded length
Untreated coir /PP	70.4 ± 4.0	0.7	3.1 ± 0.6	0.63	3.2 ± 0.3
Treated coir /PP	71.5 ± 4.1	1.4	4.4 ± 0.7	0.65	4.1 ± 0.4
Untreated coir /PVDF	77.4 ± 2.8	0.2	16.6 ± 2.7	0.69	6.7 ± 0.9
Treated coir /PVDF	79.2 ± 2.9	0.2	21.5 ± 2.8	0.89	8.2 ± 0.2
Untreated coir /MAPP	67.9 ± 5.9	1.1	21.0 ± 1.3	0.72	8.8 ± 0.4
Treated coir /MAPP	69.4 ± 6.1	1.4	19.1 ± 1.2	0.71	8.3 ± 1.0

Fibre-matrix interfacial strength

The interfacial strength of UD composites measured by 3 point bending in transverse direction and the IFSS from the pull-out test, which are theoretically expected to correspond to the work of adhesion, are shown in Table 3. As can be seen, higher transverse strength and IFSS indicate better interfacial adhesion in case of coir fibres with PVDF and MAPP matrices as compared to PP. Considering the results for the theoretical work of physical adhesion, it is proposed that the effect in case of PVDF is largely due to improved physical adhesion, whereas the improvement in case of MAPP must be attributed to a chemical bonding mechanism.

There is an improvement in interfacial strength for treated fibre with PP and PVDF in comparison with that of untreated coir, while the interfacial strength is similar for both untreated and treated fibre with MAPP. It seems that the change of fibre surface properties by the treatment positively affects the physical adhesion in case of PP and PVDF, but has less influence on the chemical bonding in case of MAPP. The increase in physical adhesion may likely also be attributed to an increase in mechanical interlocking, due to roughening of the fibre surface by the alkali treatment.

In the next section it will be shown that results for interfacial adhesion are reflected in the composite strength, as determined by the longitudinal strength efficiency factor (ratio of experimental longitudinal strength over the theoretical value following the rule of mixtures).

3.3 Mechanical properties of UD coir fibre composites

The flexural properties of coir fibre PP and epoxy UD composites are presented in Table 4. Higher flexural strength and stiffness are found in treated fibre composites, probably thanks to better interfacial wetting and adhesion which can be seen by higher efficiency factors (experimental properties normalised to theoretical properties).

Table 4. Mechanical properties of UD coir fibre composites

Composite	E-Modulus(GPa)	Stiffness Efficiency factor	Strength(MPa)	Strength Efficiency factor
Untreated coir /PP	2.3 ± 0.3	0.71	66.4 ± 5.8	0.68
Treated coir /PP	2.8 ± 0.4	0.88	71.5 ± 6.2	0.70
Untreated coir/epoxy	3.0 ± 0.2	0.85	99.9 ±3.6	0.94
Treated coir/epoxy	3.3 ± 0.1	0.95	114.8 ±10.3	0.97

In Figure 2, the impact strengths of coir/PP and coir/epoxy composites with the same fibre volume fraction of 40% are presented, and compared to values for the neat polymers. The impact strength of coir polypropylene composite is not significantly different from that of neat polypropylene, while coir fibres can improve the toughness of the epoxy by minimum a factor of three, when the impact strength is considered as toughness indicator. In tough PP matrix, it seems the high strain to failure of coir fibre does not play an important role to decide the final impact resistance of the composite. On the other hand, the fibre provides a high contribution to the improvement of toughness of the brittle epoxy matrix.

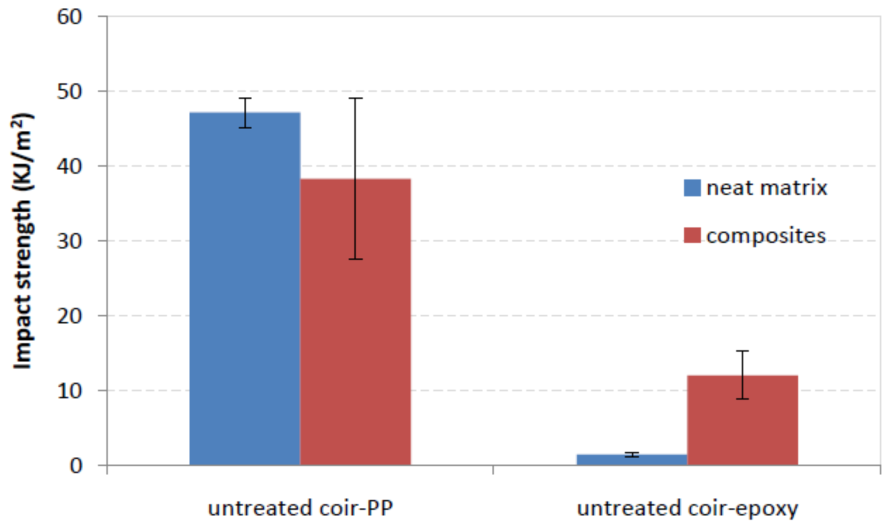

Figure 3. Impact strength of UD coir fibre composites in PP and epoxy matrices, in comparison with impact strength of neat matrices

4 Conclusions

Single fibre tensile testing with optical strain mapping system offers a fast and reliable tool to measure tensile properties of coir fibres. Coir fibres are not very strong and stiff, but have high strain to failure which may increase toughness of some brittle matrices when they are used in composites.

In the interface study, there has been a good agreement between the results of the wetting analysis and those of the composite interface mechanical tests. Combining different characterisations has offered an understanding of the interfacial adhesion and compatibility in coir fibre composites.

The mechanical properties of coir fibre composites reflect well the results from the fibre properties and composite interface characterisations. It shows that coir fibres have potential for use in some composite applications (e.g. in impact loaded composites).

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