Adhesive Joints for Vegetal Natural Fibres Reinforced Composites

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Abstract. The increased interested for the utilisation of natural fibres, to produce new ecological composites materials, need the analysed and development of joining processes to assemble of different parts made with these materials.
In this work we present the mechanical characterisation of adhesive single lap joints for the joining of sisal fibres reinforced composite materials with an epoxy matrix.
We made experiences with different surface treatments of the fibres, with the objective of increasing the adhesion between the fibres and the matrix, and consequently to improve mechanical behaviour of the composite material and the adhesive joint.
A brief description of the production and test setups of the composite materials and the adhesive joints is made.
An analytical and numerical calculation of the behaviour of the adhesive joints is presented and compared with the experimental results.

Introduction

Today the search for new, recyclable and renewable materials is leading the researchers in new ways. Natural products applications are emerging and some research is starting in this matter.
The work presented here analyse the utilization of adhesives single lap joints at joining processes to assemble of different parts made with natural vegetal sisal fibres reinforced composite materials.
Some different sisal/epoxy composite plates are made utilising sisal fibres with different surface treatments, with the purpose of increasing the adhesion between the fibres and the matrix, and consequently to improve mechanical behaviour of the composite material [1,2 and 3] and the adhesives joints. The treatment used is called mercerization, and is described below. Before the treatment application the natural fibres were cleaned in order to remove contaminating agents.

Manufacturing a Sisal/Epoxi Composite Material

To manufacture a 4mm thickness sisal/epoxy composite plates, with 25% volume content of aleatory fibre reinforcement, was used the compression moulding technique [2]. For the matrix was used the epoxy resin Reapox WOOD RX8 from REA Industries (σ_r = 49,98 MPa, E = 2,91 GPa)
A fibre surface treatment has been done to increase the fibre/matrix adhesion. This treatment (mercerization) is made in some steps. First, the fibres were immersed in a bath of Sodium Hydroxide solution (NaOH), prepared with distilled water. During this process the bath was stirred continuously using a mechanical agitator. Finished the immersion stage the solution presented a yellow colour, because of the substances removed from the fibres. Next, the fibres were washed

several times with distilled water, until the water pH came to neutral. To dry the fibres we left them 5 days at ambient temperature, and then exposed six hours at 60º C in an oven.
The main objective of the treatment is the fibre superficial cleaning by the remove of some agents (grass, silica, etc.) that difficult the chemical reactions between the fibres and the matrix. Additionally, can remove the lignin and the hemicelluloses, responsible for some degradation mechanisms.
This treatment improves the interface fibre/matrix adhesion by increasing the chemical compatibility (exposing the hydroxyl groups of the fibres) and the mechanical anchorage.
Four different treatments of mercerization were made, with different volume percentage of Sodium Hydroxide (NaOH) of 4% and 8%, bath time immersion of 1hour and 2 hours, with a bath temperature of 20ºC.
To manufacture the composite plates, with the compression moulding technique, the steel mould used, have a cavity of 150x100x4 mm^3 and was prepared with the application of the mould release agent QZ13 from Ciba-Geigy. After the preparation of the resin, we introduce it in the mould (Fig. 1). The sisal mat is then placed in the mould (Fig. 2) and the mould closed. At last, the mould is placed in the hot plate press, and submitted to a cure stage of 1 hour at 60 ºC.


Fig. 1.- Introducing the resin


Fig. 2.- Placing the mat


Fig. 3.- Final Plate

Single Lap Joint Manufacturing

To stud an adhesive joint solution to the assemble of different parts made with sisal/epoxy composites, several single lap joints are made with the different sisal/epoxy laminates manufactured, according to the ASTM 1002 standard, with a overlap length of 14mm and 0.1mm of adhesive thickness. The adhesive utilised was a two components epoxy Araldite AW106/HV953U from Ciba-Geigy with the following mechanical properties show in the Table 1.

Table 1. Araldite AW106/HV953U

Compression Stress [MPa]	Tensile Stress [MPa]	Shear Stress [MPa]	Young Modulus [GPa]	Poisson Coef.
45,3	22,3	14 - 17	1,2	0,33

Mechanical Characterization of Sisal/Epoxi Composite Materials

For the mechanical characterisation of the sisal/epoxy composite plates it was used an INSTRON 4208 universal testing machine. The tests were made according to the ISO 527-4 standard, using a 100 kN load cell and a 2 mm/min traction speed.
The Tables 2 and Fig. 4 and 5 shows the results of the mechanical characterisation for the REAPOX WOOD RX8 resin and for the composite plates made with 25% volume fraction of sisal fibre with and without surface treatment.

Table 2. Mechanical characterisation of the different sisal/epoxy composite materials

Sisal//Epoxy Composite 25% sisal fibre	Tensile Strength σ_r [MPa]	ST Desv	Young Modulus E [GPa]	ST Desv	Deformation ε_r [%]	ST Desv
Without treatment	45,05	6,90	4,87	0,59	1,07	0,15
4%(NaOH), 1 hour	49,85	2,40	6,51	0,29	0,97	0,08
4%(NaOH), 2 hour	62,81	4,88	6,64	0,79	1,19	0,15
8%(NaOH), 1 hour	59,47	6,88	6,09	0,61	1,25	0,14
8%(NaOH), 2 hour	49,51	3,42	6,17	0,43	1,09	0,13
Resin REAPOX WOOD RX8	49,98		2,91		6,50	

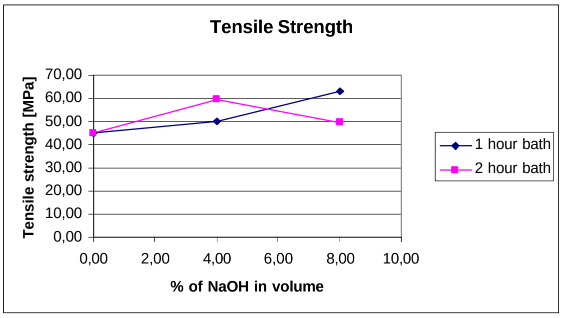

Fig. 4. - Tensile strength graphic

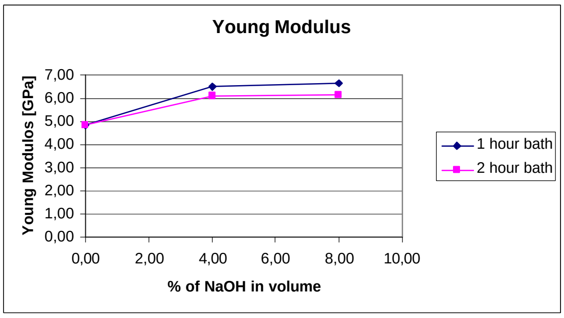

Fig. 5. - Young modulus graphic

Mechanical Characterization of Sisal/Epoxi Single Lap Joints

For the mechanical characterisation of the sisal/epoxy single lap joint it was used an TIRAtest 2705 universal testing machine. The tests were made according to the ASTM 1002 standard, using a 5 kN load cell and a 1mm/min traction speed (Fig. 6). The Table 3 show the results of the mechanical characterisation.

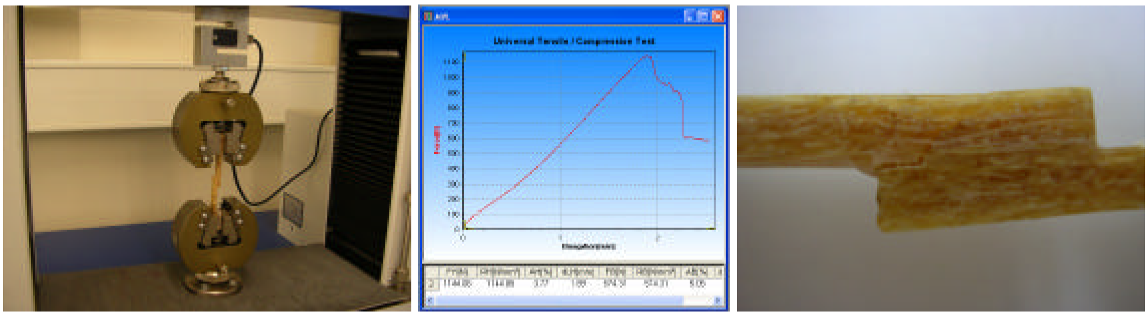

Fig. 6 – Single lap join tested in traction

Table 3. Mechanical characterisation of the different sisal/epoxy single lap joints

Sisal//Epoxy Composite Single Lap Joints 25% sisal fibre	Sisal//Epoxy Composite: Tensile Strength σ_r [MPa]	Sisal//Epoxy Composite: Young Modulus E [GPa]	Single Lap Joint: Over Lap apparent average Shear Stress τ_{xy} [MPa]
Without treatment	45,05	4,87	6,46
4%(NaOH), 1 hour	49,85	6,51	8,26
4%(NaOH), 2 hour	62,81	6,64	9,75
8%(NaOH), 1 hour	59,47	6,09	9,38
8%(NaOH), 2 hour	49,51	6,17	8,21

The ASTM D1002 standard test gives the apparent average shear strength and is not intended for obtaining true shear strength of adhesive. However, it is a sufficient comparative test and is especially useful due to this simple geometry of joints.

Analytical and Numerical Calculations

An analytical and numerical calculation of shear and peel stresses in the interface adhesive/composite for the single lap joints analyses was made, utilizing the Golan and Reissner analytical model [4,5], and an specific software developed for the analysis and design of joints "Joint Design" [6], utilizing 2D mixed interface finite elements.
The Fig. 7 and 8 shows the shear and peel stresses graphics at the adhesive layer and adhesive interface respectively for a tensile load of 1000N.

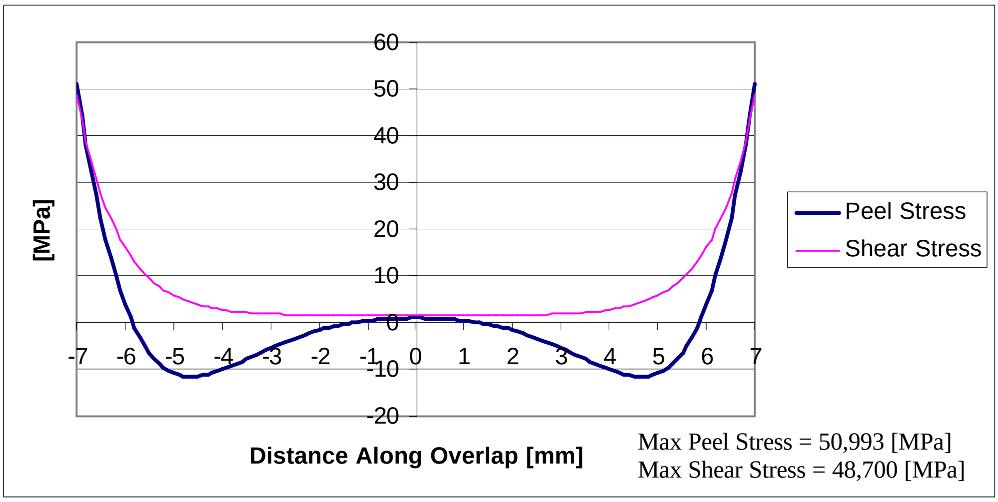

Fig. 7. Shear and Peel stresses graphics (Golan and Reissner model)

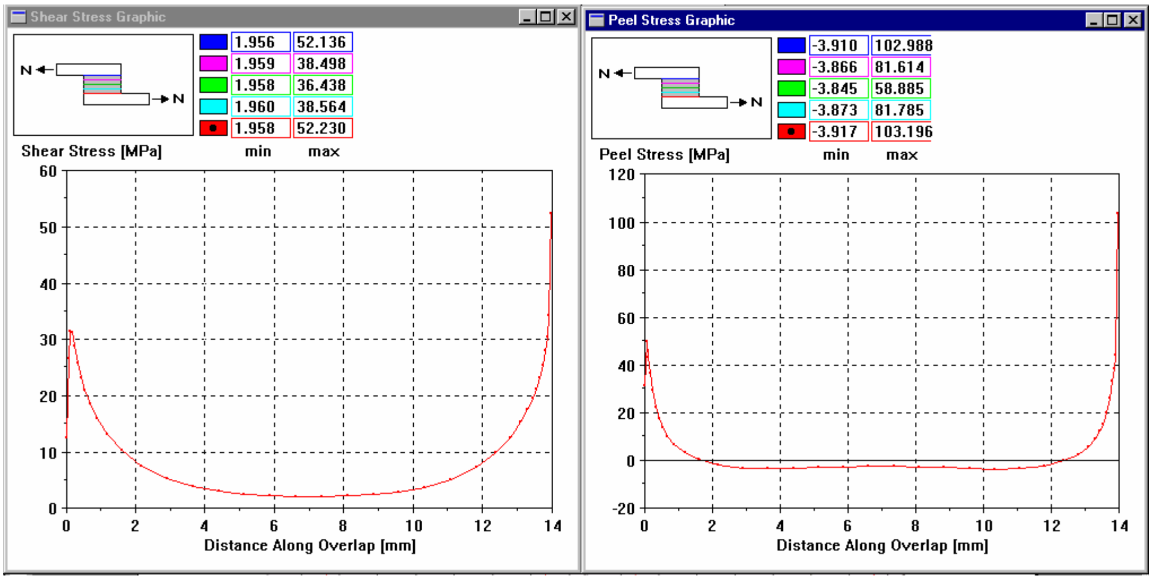

Fig. 8 Shear and Peel stresses graphics (Joint Design software)

Conclusions and Results Analyse

If we look to the tensile strength obtained by the different natural sisal fibres composites, and compare to the apparent average shear strength of the single lap joints respectively, we observe a

similar change of strength, function of the fibre surface treatment. The joint failure mechanism observed was a cohesion rupture of the composite adherent, with an initiation near of the extremity of the lap joint, on a concentration stresses zone of the adhesive and adherents, confirmed by the analytical and numerical calculations.
A bad fibre/matrix adhesion could be responsible for these results even the surface treatments made to the fibres improve the adhesion between fibre and matrix, observed by the results obtained in comparison with the untreated fibres.
It is necessary to point the research in the surface treatment of the fibres. Only with good surface treatment we can obtain a good adhesion fibre/matrix, and that is one key-point to improve the mechanical composite properties and adhesive joint strength, for natural sisal fibres reinforced composites.

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