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# EXPERIMENTS ON SINGLE LAP JOINTS MADE OF NATURAL FIBRE REINFORCED COMPOSITES

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**Abstract.** *In this paper, similar and dissimilar adhesive joints of synthetic and natural fibre-reinforced polymer composites were investigated experimentally. Several important factors, such as adhesive type and adherend stiffness, influencing the strengths of the adhesive joints were investigated. The composite substrates were manufactured by hand lay-up technique of fibre mats following a 30/70% volume of fibre/matrix. The resin used was a brittle two component epoxy. All studied groups were fabricated with two distinct adhesive systems with different properties. One was the Betamate 2096 structural adhesive and the other was the AR 260 Epoxy Resin system that was also used in the manufacture of the composite substrates themselves. The bondline thickness was 0.2 mm. The following single lap joints were fabricated: Purely natural Sisal and Jute joints; Sisal/Glassfibre, Jute/Glassfibre reinforced joints, both similar and dissimilar joints with GFRP purely synthetic composites; and finally, purely similar synthetic joints of GFRP. The bonded joints were subjected to tensile tests in a universal testing machine at 1mm/min. The results were compared in order to assess the feasibility of the natural fibre reinforced composites (NFRCs) in the transportation industry. It was found that the reinforced Jute composite presents a better performance than the Sisal ones for both adhesives and the Jute/Glassfibre composite joints reached nearly 80% of the pure synthetic (GFRP) composite joints.*

**Keywords:** *Natural Fibres, Adhesives, Synthetic Fibres, Hybrid Composites, Bonded Joints*

## 1. INTRODUCTION

The application of adhesively bonded joints in the automotive industry has increased significantly in recent years mainly because of the potential for lighter weight vehicles, fuel savings, and reduced emissions. The use of composites in making automotive body components to achieve a reduced vehicle mass has also continuously increased. Natural fibre composites have recently attracted a great deal of attention by the automotive industry due to their many attractive benefits (e.g. high strength-to-weight ratio, sustainable characteristics and low cost). Nowadays, all of the main international automotive manufactures use these materials and the use of sustainable composites is expected to increase in this area. For example, natural composites are eligible to side and front panels of vehicles as they are not primary structural components. In this way, cost and weight of vehicles could be partially reduced when natural fibre-reinforced composites replace traditional glass fibre composites and aluminium in these components. However, this subject needs further investigations (Banea and da Silva, 2009).

The demand for energy efficiency through the diminishing of weight and manufacturing costs is ever increasing. This is seen across multiple industries including the transportation industry. The need to lower vehicular mass while maintaining structural integrity has never been more important due to increasing pressure to lower emissions and fuel consumption. Furthermore, the joining of different materials gives great flexibility to all types of engineering design. Adhesive bonding can be used to virtually join all types of materials and combinations of materials and is increasingly used in the automotive industry (Banea and da Silva, 2009; Banea et al., 2014; Joshi et al., 2004).

Natural fibre reinforced plastics (NFRPs) have been used in many areas since the 90s. The automotive industry has been using NFRPs as car interior parts and other non-loadbearing applications such as door panels and frames, roofing sheets, window frames and many others (Mohammed et al., 2015).

The objective of the present study was to investigate experimentally single-lap adhesive joints made of synthetic and natural fibre-reinforced polymer composites by using various combination of adherends plastics. A modern tough structural adhesive used in the automotive industry was used. In addition, the same resin used in composite fabrication was used for bonded joints.

## 2. MATERIALS AND METHODS

## 2.1. Adhesive

A two-component structural epoxy adhesive, Betamate™2096, supplied by Dow (Dow, Brazil) was selected. Composite adherends were fabricated using a two-part epoxy resin, AR260, supplied by Barracuda Advanced Composites (Barracuda Advanced Composites, Brazil). The resin used in the fabrication of the composite substrates was also used as an adhesive in this study. The tensile properties of the Betamate™2096 adhesive and AR260 resin were obtained in a previous work. The tensile data of the adhesive and resin are summarized in Table 1.

Table 1. Tensile data of adhesives used.

Adhesive Systems	Young's modulus [GPa]	Tensile strength [MPa]	Tensile strain [%]
Betamate™2096	1.7	29	9
AR260 Epoxy Resin	3.9	28	8.8

## 2.2 Composite substrate

The fibre reinforcements used were both natural and synthetic. The natural fibres used were Sisal and Jute bidirectional mats supplied by Sisalsul (Sisalsul, Brazil). The glass fibre synthetic reinforcement used was supplied by Barracuda Advanced Composites (Barracuda Advanced Composites, Brazil). The synthetic reinforcement was weaved manually through the natural bidirectional base of both Jute and Sisal in a modified twill weave pattern, Fig. 1. Then, the resin and hardener were mixed based on the weight of the base fibres to fabricate a 30%/70% volume of fibre/matrix.

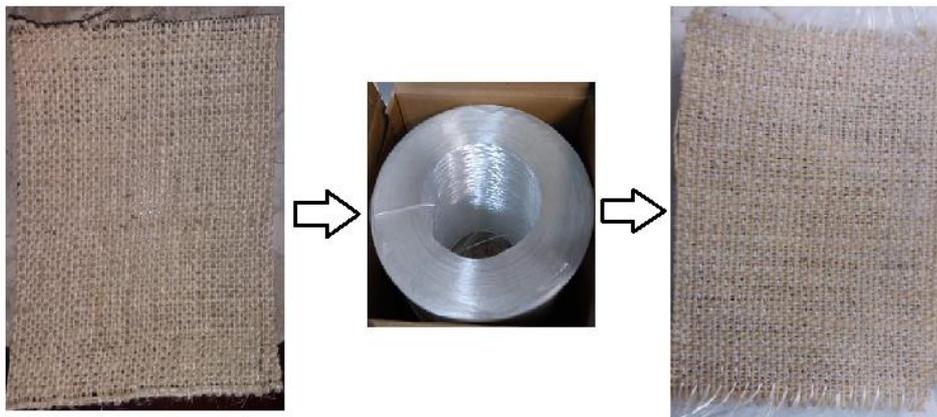


Figure 1. Resulting glassfibre reinforced sisal mat.

The lay-up process was done in a metal tool and a hydraulic press with heated plates was used to cure the composites at a temperature of 80 degrees Celsius for a period of 6 hours as per manufacturer guidelines, Fig. 2. The press used was a Solab SL-20, Fig. 3. After curing, the composite substrates were manually cut from the plates in order to fabricate the adhesive joints.



Figure 2. Finished GFRSP composite plate.



Figure 3. Heated hydraulic press used.

They received specific nomenclature according to reinforcement type. It is as follows:

- GFRSP: Glass Fibre Reinforced Sisal Polymer;
- GFRJP: Glass Fibre Reinforced Jute Polymer;
- GFRP: Glass Fibre Reinforced Polymer;
- JFRP: Jute Fibre Reinforced Polymer;
- SFRP: Sisal Fibre Reinforced Polymer.

### 2.3 Specimen fabrication

The geometry of the SLJ specimens is shown in Fig. 6 based on the ASTM D5868 standard (ASTM, 2008). A mould with spacers for correct alignment of the substrates was used (Banea et al., 2012), Fig. 5. The bondline thickness used was 0.2 mm and the length of the overlap was 12.5 mm. The adhesive layer thickness was controlled using metal spacers, Fig. 5. Tabs were glued at the specimen edges for a correct alignment of the specimens in the testing machine.

The surface was sanded manually using a 50 grit sanding paper in criss-crossing 45-degree angles to improve the mechanical interaction between adhesive and substrate (dos Reis et al., 2017), Fig. 4. The bonding surface area was then cleaned with acetone before the application of the adhesive in order to avoid adhesive failures (Campilho et al., 2009). The joints were cured using the heated plates hydraulic press for 2 hours at 60 degrees Celsius as per manufacturer guidelines. Examples of finished joints can be seen in Fig. 7.



Figure 4. Sanded GFRP substrates.

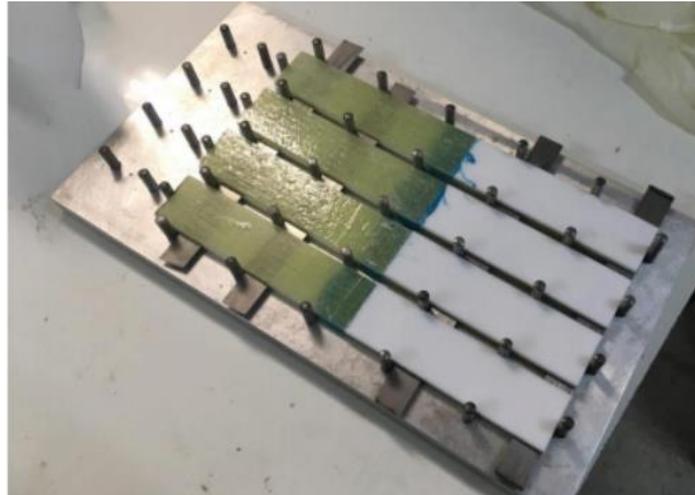


Figure 5. GFRP-GFRP (B) prior to curing process.

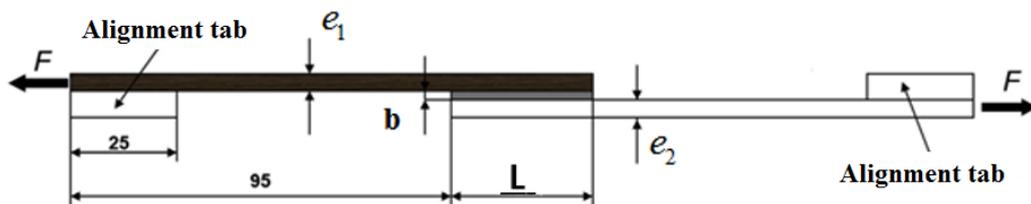


Figure 6. Single lap joint geometry.

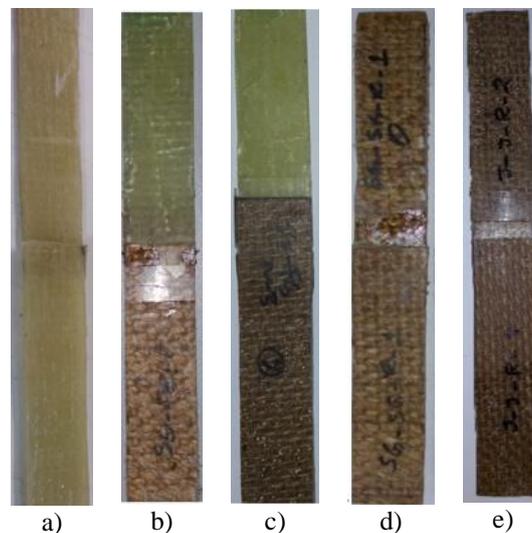


Figure 7. Examples of finished joints. a) GFRP-GFRP (R), b) GFRSP-GFRP (R), c) GFRJP-GFRP (R), d) GFRSP-GFRSP (R), e) JFRP-JFRP (R)

### 3. RESULTS AND DISCUSSION

The specimens were tested using a universal testing machine (INSTRON® model 5966), at a cross-head speed of 1mm/min. All tests were conducted at room temperature. Load-displacement curves were recorded during testing. Figure 9 presents the average failure load of all studied joint groups while Fig. 10 and 11 present representative load-displacement curves. The failure modes were analysed. It was observed a predominance of cohesive failure, thin layer cohesive failure and delamination mixed modes throughout the groups as well as stock break, Fig. 5. The most catastrophic and brittle failures were observed in the Jute base groups. The joints presented a significant variation of rigidity as a function of adherend material as can be seen on Fig. 10 and 11, as expected. However, this was not observed as a function of adhesive material. Average failure loads for all studied groups can be seen in Fig. 6. The

Betamate<sup>TM</sup>2096 adhesive system had the highest failure loads of all studied joints, as expected, due to its higher ductility and resistance. The percentage differences ranged from -5% to 24% in gain of average failure load. It was found that the mode of failure, substrate thickness and adhesive characteristics were important parameters in failure load. The Jute bidirectional base composites had higher failure loads compared to the Sisal ones in both similar and dissimilar comparisons. For the reinforced similar case these were 32% and 35% for the Betamate<sup>TM</sup>2096 and the

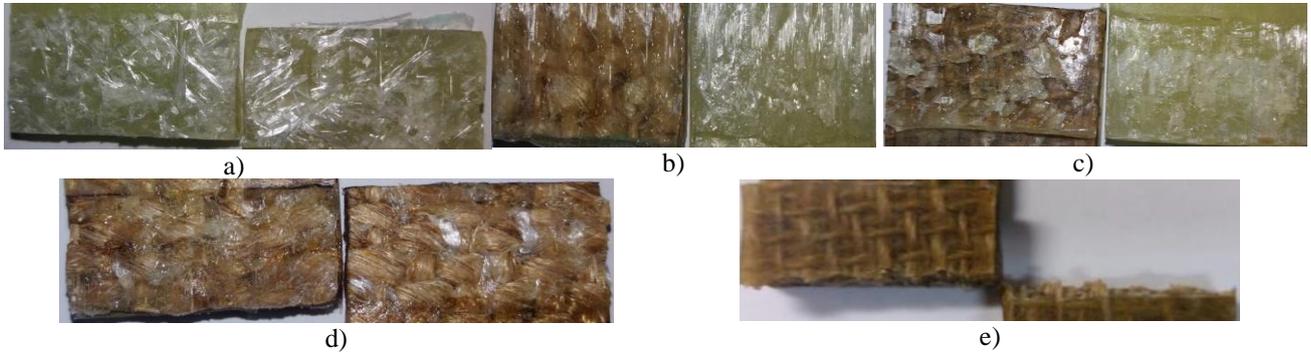


Figure 8. Representative failure modes. a) GFRP-GFRP (R), b) GFRSP-GFRP (R), c) GFRJP-GFRP (R), d) GFRSP-GFRSP (R), e) JFRP-JFRP (R)

AR260 Epoxy Resin respectively. The most efficient joint involving natural fibres was the GFRJP-GFRP, where the purely synthetic similar joint, GFRP-GFRP, had an increase in failure load of 26% and 8% for both adhesive systems respectively. The same comparison of the GFRP-GFRP to all other groups ranged from 23% to 64% and 14% to 56% increased gain from both adhesive systems respectively. Regarding the unreinforced composites, the Jute base once again had higher efficiency compared to the Sisal, with gains of 31% and 7% for both adhesives systems respectively.

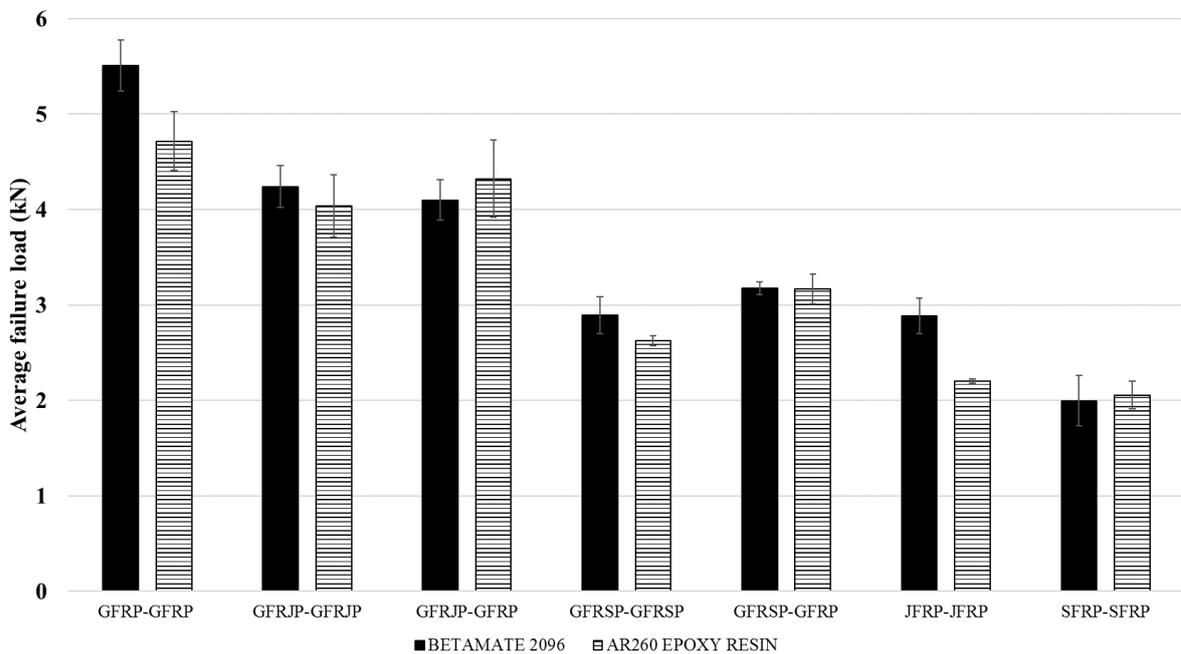


Figure 9. Average failure loads for all studied groups.

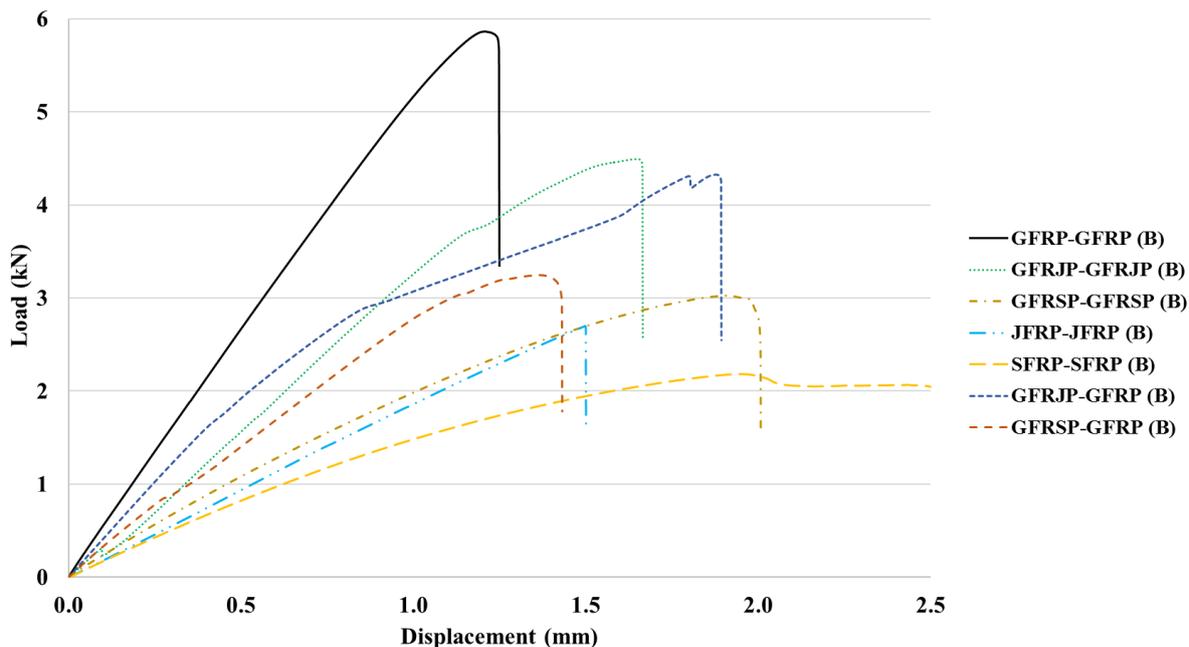


Figure 10. Representative load-displacement curves for the (B) groups.

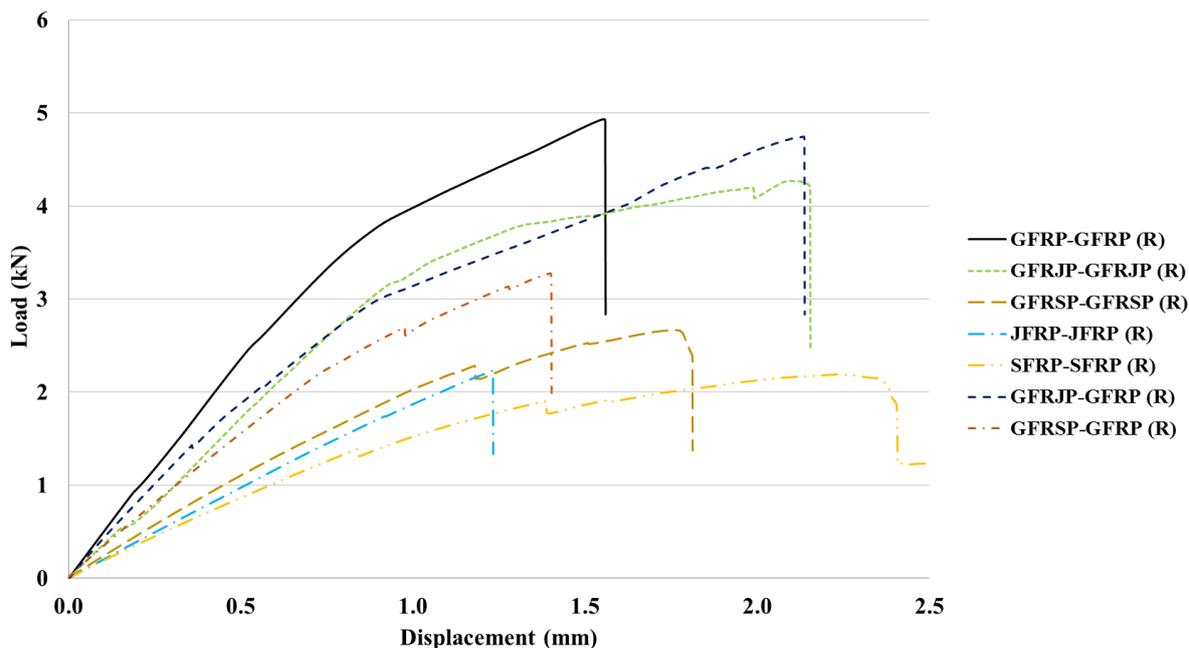


Figure 11. Representative load-displacement curves for the (R) groups.

#### 4. CONCLUSION

The present work studied adhesively bonded joints with composite substrates reinforced by natural and synthetic fibres as well as using two different adhesive systems. Composite substrates were fabricated by the hand lay-up method using purely natural and reinforced Jute and Sisal bidirectional mats. Similar and dissimilar joints were fabricated. Tensile tests were carried out. The failure modes were analyzed. It was observed that the weaved synthetic reinforcement greatly improved the overall joint performance of the NFRCs. The influence of dissimilar joints was investigated. It was found that even though these most likely are imbalanced in stiffness, they reached the highest failure loads with both adhesives. The best result involving natural fibres was that of the Jute hybrid dissimilar joint (GFRJP-GFRP) in relation to the purely synthetic GFRP, having a lower failure load on average of 26% and 8% for the Betamate™2096 and the AR260 Epoxy Resin respectively. In other words, nearly 80% of the pure synthetic efficiency.

The Jute based joints all had higher efficiencies than the Sisal ones and had different failure modes. It was observed that the failure mode coupled with adhesive characteristics are very significant parameters for failure load

## 5. ACKNOWLEDGEMENTS

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