EFFECT OF RIVETING ON THE JOINT STRENGTH OF ADHESIVELY BONDED DOUBLE LAP JOINTS

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ABSTRACT

The scope of this study is to determine the effectiveness of using rivets in the adhesive joints in order to combine plastic-based composite materials which are often used in today's engineering structures, to the joint strength. For this purpose, double lap joints are prepared in 3 different types of configuration included adhesive, pinned and both adhesive and pinned and also prepared in 3 different overlap lengths as 30, 45 and 60 mm. Stress-strain diagrams were derived by exposing the joints obtained, to the axial tensile test and then the most appropriate joint type was determined by comparing each of the results obtained. The evaluation of the results pointed out that the hybrid joints where adhesive and rivet are used together can carry much more load than the joints where the only adhesive was used or the joints which are combined with a rivet in terms of joint strength.

Keywords: Double lap joint, Adhesive, Rivet, Overlap length

1. INTRODUCTION

Adhesive bonding technology has been studied for many years and it has played an essential role in the development and growth of the rehabilitation and repairing techniques of timber structures involving adhesive joints instead of mechanical joints [1]. Accordingly, it is also possible to endurance these type of connections by considering riveting connections together with adhesives. Generally, the joining methods of the composite structures are classified into the mechanical and adhesive types. The adhesive joints do not require holes, and they distribute the load over a larger area than the mechanical joints; however, they are very sensitive to the surface treatment, service temperature, humidity, and other environmental conditions [2, 3].

Amongst the advantages of adhesives, we can highlight their high resistance, (even under unfavourable atmospheric conditions), their lower weight, water tightness and elimination of galvanic corrosion [4, 5]. Besides, the stress distribution over the area of adhesively bonded connections is assumed to be quite complex, which is leading to do very difficult strength and failure predictions numerically. There are various studies concerning stress distribution and behaviour of different adhesive types for double lap joint connections in structural composites and other basic assemblies where not much endurance of joint is required. One of the investigations for this subject was presented by Reis et al. [6] studied the effect of adhesive overlap length on the ultimate joint strength in a numerical–experimental work. They found that the overlap length should be 15–30 mm and by increasing this length, the values of peel and shear stresses increase. This length would result in the best stress distribution, confirmed by the variation of equivalent stress [7]. A study was performed related to the one-dimensional elastic solution of double lap joints at different overlap lengths by L. Goglio and M.Rossetto. They have claimed that the solution is accurate if elastic properties are taken into account [8]. Yong-Bin Park et al. studied composite lap joint under different environmental conditions and they concluded that high strength can be obtained at low temperatures [9].

The strength of adhesively bonded joints can be predicted using one of the two methods: (i) stress analysis or (ii) fracture mechanics. According to the stress analysis approach, failure of the adhesive is expressed in terms of a strength failure criteria, such as the maximum stress and maximum strain criteria [10] or strain energy density criteria [11]. In the fracture mechanics approach, failure of the adhesive is expressed in terms of the critical values of strain energy release rate [12, 13] or other fracture parameters. Suo and Huchinson [14] analysed the strain energy release rate between two elastic layers, and their cracked-beam model (CBM) has been adopted for the analysis of fracture in single-lap joints [15] and cracked lap-shear joints [16,17]. Besides, an experimental study was performed by Min-Gyu Song et al. to determine strength and fracture of adhesively bonded joints with their effects of manufacturing types on the joint strength. And they found that secondary bonded joints had higher strength and failure load, the stacking sequence of the composites was slightly effective in joint strength as well [18, 19].

Due to the complex structure of adhesively bonded composite structures reinforced with riveted joints, an experimental method was considered and models were subjected to tension tests for the failure prediction of manufactured specimens. Therefore, the study is aimed to find out the effects of riveting and different overlap lengths on the strength of adhesively bonded joints for polymer-based composite connections. For this purpose, different configurations of double lap joints were created and subjected to tensile tests. As a result of the experiments, the strength of the hybrid connections at different overlap lengths was determined for only adhesively bonded, riveted and a mix of them.

2. MATERIAL AND METHOD

In this study, glass fibre reinforced epoxy plates as adherent material and a polyester resin as adhesive were chosen to study the behaviour of the adhesively bonded double lap joints under the static unidirectional loadings. The double lap joints comprising a rivet, adhesive and rivets and adhesives together were created by using glass fibre reinforced epoxy plates (G11 EPGC 203 Hgw 2372.4) having 8 layers and their mechanical properties are given in Table 1.

Table 1. Mechanical properties of G11 EPGC 203 Hgw 2372.4, adhesive and rivet

Properties	G11 EPGC 203 Hgw 2372.4	Adhesive (Polyester Resin)	Rivet (St 37)
Tensile Strength	320 MPa	3.28 MPa	370 MPa
Flexural Strength	450 MPa	-	-
Compressive Strength	550 MPa	-	-
E-Modules	20 GPa	39 MPa	210 GPa

The three adhesive systems used for joining were 1-double layer polyester bonding, the 2-riveted connection of epoxy composite plates, 3-double layer hybrid bonding. The joining types and overlap lengths of composite specimens were changed to study these effects on the joint strength, failure mechanism as well as on the ultimate joint stress. The adhesive resin was used as a bonding material and its mechanical properties and material behaviour were determined by subjecting bulk specimens, which were manufactured from that adhesive resin to tensile tests according to ISO 527 standards. Stress-strain diagram of the bulk specimens of adhesive material obtained as a result of tensile tests performed is presented in Figure 1. The boundary conditions and dimensions of the manufactured double lap joints in the experimental tests are also illustrated in Figure 2.
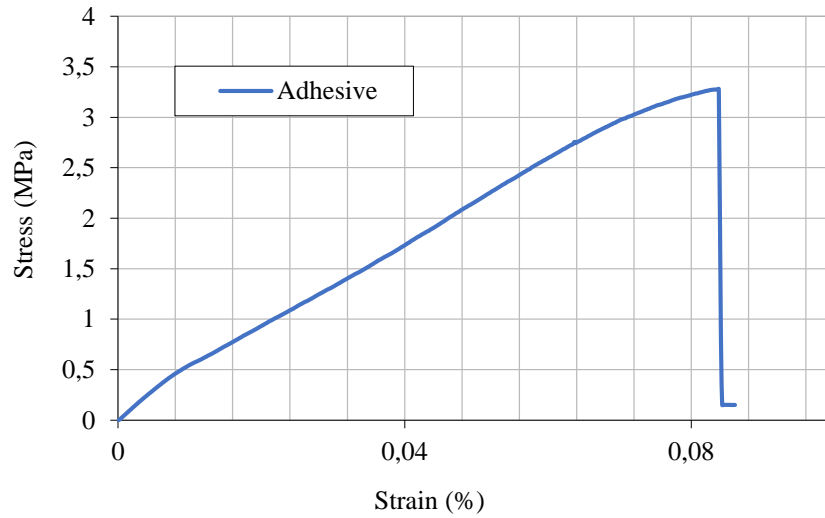
Figure 1. Stress-strain curve for the polyester adhesive.
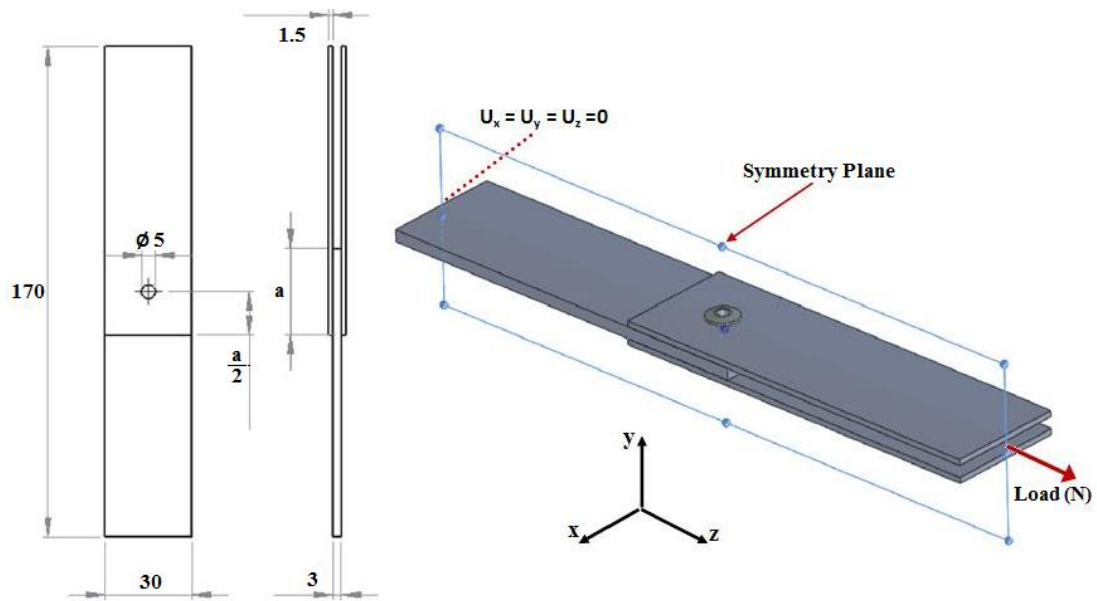
Figure 2. Dimensions of the double lap joints and their experimental boundary conditions.

Overlap regions of the double lap connections were created by three different methods which are adhesive, rivet and both of them. Images of the double lap joints taken before tensile tests for three different connection types (adhesive, rivet, both of them) are presented in Figure 3.
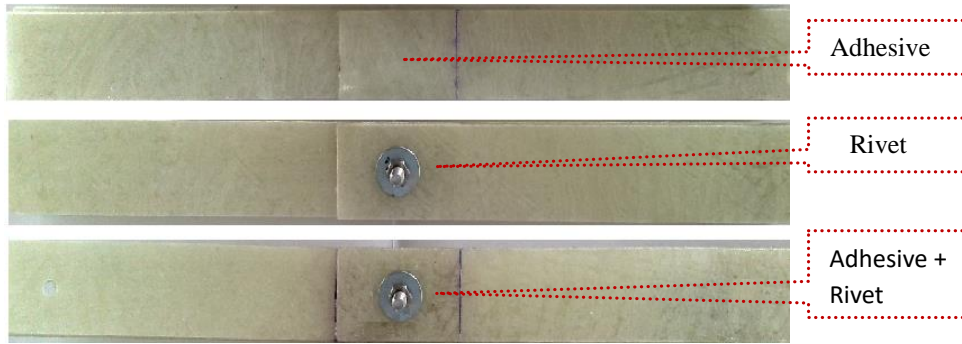
Figure 3. Double lap joint connections created by using adhesive, rivet and together adhesive and rivet at 30mm overlap length.

Totally, nine different double lap connections were comprised of three different overlap lengths (30, 45 and 60mm) at three different configurations (adhesive, rivet and adhesive plus rivet) as it can be seen in Figure 3. The most appropriate connection type and overlap length were specified as a result of tensile tests, subjected to the prepared connections, under a constant axial elongation speed of 2mm per minute.

3. RESULTS AND DISCUSSION

Stress-strain diagrams which were obtained as a result of tensile tests are given in Figure 4 depending on joint configurations and overlap lengths. The joint strengths were determined to be 0.524MPa for only adhesively bonded and 1.975MPa for a hybrid joint having the highest joint strength if the overlap length of 30mm is taken into account. The joint strength of the hybrid configuration was observed to reach an increase of 377 percent comparing to only adhesively bonded joint at 30mm overlap length.
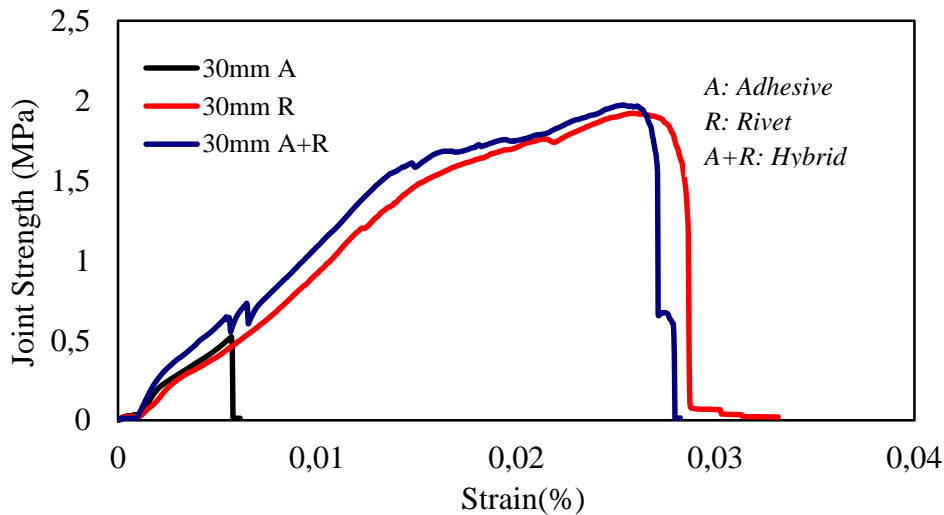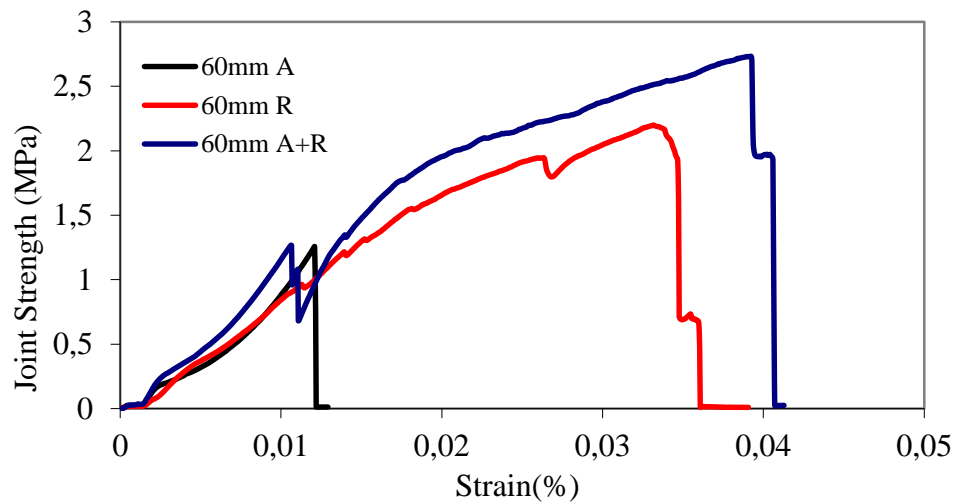

Figure 4. Stress-strain diagram of double lap joints at 30mm overlap length.

In the same way, stress-strain diagrams for 45mm overlap length are presented in Figure 5 according to joint types. The joint strength of the connections for only adhesively bonded, riveted and hybrid configuration were determined to be 0.974, 2.116 and 2.512 MPa respectively, at 45mm overlap length. Similar to results obtained for 30mm overlap length, hybrid joints were found out to have a joint strength which is 258% and 119% greater than only adhesively bonded and riveted joint, respectively.
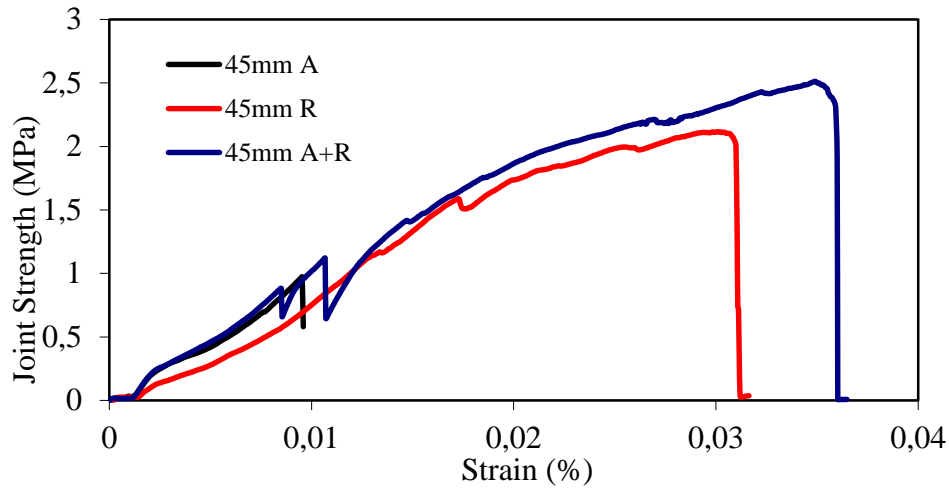
Figure 5. Stress-strain diagram of double lap joints at 30mm overlap length.

For 60mm overlap length, stress and strain values at which the double lap joints rupture are shown in Figure 6. Adhesively bonded lap joint was observed to exhibit the weakest strength of 1.258MPa at 60mm overlap length similar to the previous overlap lengths. The joint strength of riveted and the hybrid connection was specified to be 2.119MPa and 2.773MPa respectively. If the strength of the hybrid joint is compared to the others, it was achieved to be 217% and 124% greater than just adhesively bonded and riveted connection, respectively.


Figure 6. Stress-strain diagram of double lap joints at 60mm overlap length.

Fracture mechanism of all specimens subjected to tensile tests was observed and failure types were tried to be determined. The pictures of connection regions of each joint configuration for 30, 45 and 60mm overlap lengths taken after tensile tests are presented in Figure 7. Cohesion type of failure was detected in the overlap region of just adhesively bonded joints and the amount of adhesive on the overlap surface of each composite plate was equally scattered while no failure on the contact zones of the composite plates occurred.

The failure type of riveted joints at 30mm overlap length was determined to be shear-out and failure finished as a result of tearing of adhesive in the loading direction (Figure 7a). Accordingly, failure type for the hybrid joints was found out to be net-tension at the same overlap length (Figure 7a).

Net-tension was observed to occur in riveted and hybrid joints at the overlap lengths of 45 and 60mm and type of bearing failure was also observed in all the rivet holes taken place on the surface of composite plates [20] (Figure 7b and 7c).

(a)

(b)

(c)
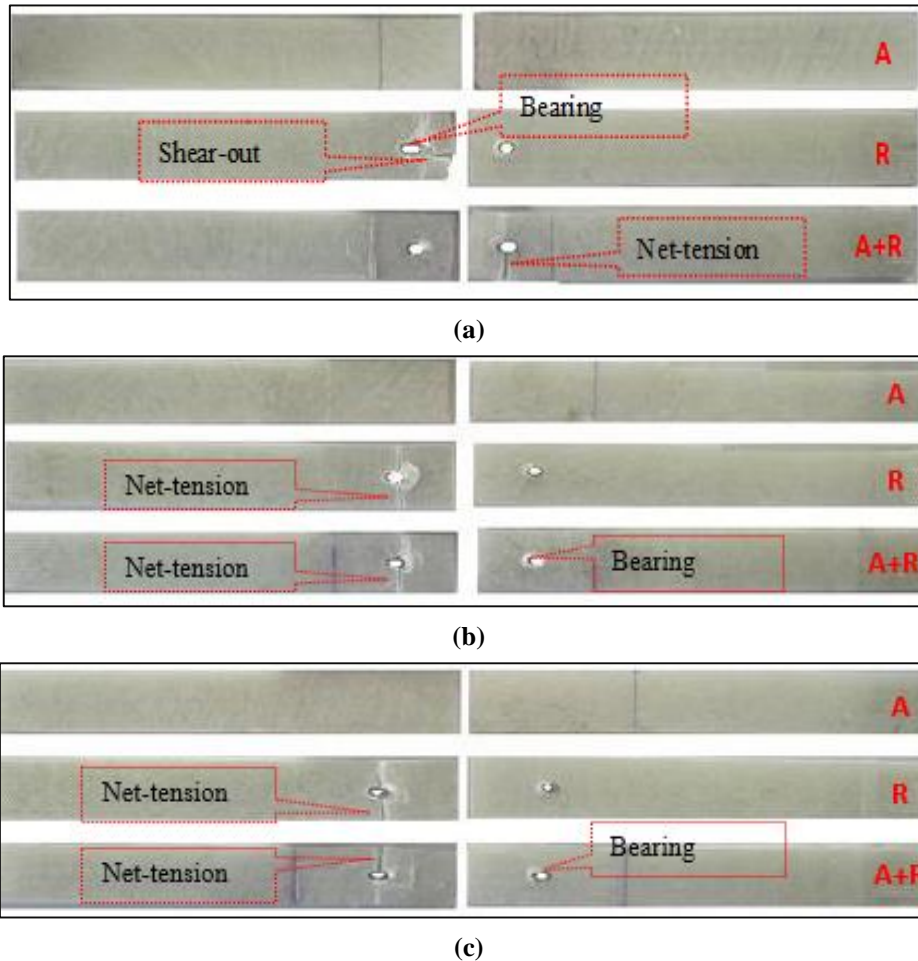
Figure 7. Overlap lengths for each joint configuration and failure mechanism **a)** 30mm overlap length, **b)** 45mm overlap length and **c)** 60 mm overlap length

The highest values of joint strengths obtained according to different joint configurations and overlap lengths are illustrated in Figure 7. As it was seen from the figure, the lowest joint strength was exhibited by adhesively bonded specimens and the highest ones were in hybrid joints. When the experimental results are concerned, the strength values of riveted connections always take place in between the adhesive and hybrid joints.

Increasing the overlap length considerably increased the tensile stress and led to a peak in joint strength as indicated in Figure 8 for all connection configurations. Therefore, the rupture stress of adhesive joint at 30mm increase by 240% corresponding to the increase of overlap length 30 to 60mm only led to a substantial recovery in joint strength from 0.524 to 1.258MPa. In the same way, the joint strength of riveted joints also increased by nearly 124 and 126% corresponding to 2.116 and 2.199MPa at 45 and 60mm overlap length, respectively as it was 1.74MPa at the beginning (Figure 8).
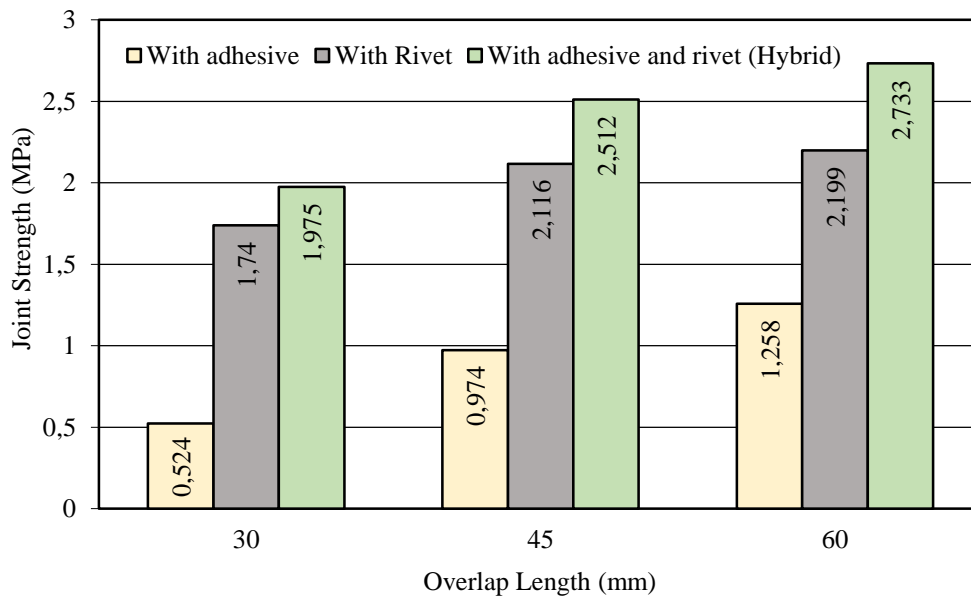
Figure 8. The variation of joint strength depending on the joint system and overlap length

As the effects of overlap length on the strength of hybrid joint was examined, an important improvement has been obtained. In that case, an increase of 127 and 140% corresponding to 2.512 and 2.773MPa was achieved at the overlap lengths of 45 and 60mm, respectively (Figure 8). When the joint strengths were compared, the highest difference observed by 521% between adhesively bonded and hybrid joints corresponding to 30mm overlap length.

5. CONCLUDING REMARKS

In the present paper, the response of composite double lap joints with polyester adherents subjected to unidirectional tension loads as well as tensile tests was experimentally investigated by means of different joint configurations, including only adhesive, rivet and hybrid joints and results were summarized as follows. The results were verified and compared to the well-known theoretical and experimental results in the literature in the case of the polyester adhesive layer for accuracy as well.

- The joint strength of hybrid system was increased by 377% corresponding to 30mm overlap length comparing to the adhesively bonded joint system.
- Accordingly, for the change of overlap lengths from 45 to 60mm, the increase in hybrid joint strength was observed to be nearly 258 and 119% higher than adhesive and riveted joint as indicated in detail (see Figure 8).
- Adhesive double lap joints show improved properties when the riveted connection was used with adhesives.
- Overlap length of composite double lap joints has a significant effect on the strength and strain to failure values and therefore the toughness of the joint. But the effect on stiffness is not significant.
- The adhesively bonded joints showed brittle failure and cohesion type of failure mechanism occurred. In riveted joints, the failure was specified as bearing and shear-out type of fracture matching 30mm overlap length, the others were bearing and net-tension. At hybrid joints, only bearing and net-tension were generated at all overlap lengths [20].

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