Influence of the Adhesive, the Adherend and the Overlap on the Single Lap Shear Strength

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Abstract: The single lap joint is the most studied joint in the literature in terms of both theory and practice. It is easy to manufacture and the lap shear strength is a useful value for strength assessment and quality control. Simple design rules exist such as the one present in standard ASTM 1002 or in a recent paper by Adams and Davies. The main factors that have an influence on the lap shear strength are the type of adhesive, i.e. ductile or brittle, the adherend yield strength and the overlap length. The overlap increases the shear strength almost linearly if the adhesive is sufficiently ductile and the adherend does not yield. For substrates that yield, a plateau is reached for a certain value of overlap corresponding to the yielding of the adherend. For intermediate or brittle adhesives, the analysis is more complex and needs further investigation. In order to quantify the influence of the adhesive, the adherend and the overlap on the lap shear strength, the experimental design technique of Taguchi was used. An experimental matrix of 27 tests was designed and each test was repeated three times. The influence of each variable could be assessed as well as the interactions between them using the statistical software Statview. The results show that the most important variable on the lap shear strength is the overlap length followed by the type of adherend.

Keywords: *lap shear strength, adhesive, overlap, adherend, statistical analysis*

1. Introduction

Adhesive joints can have many configurations, the most common being the single lap, the double lap, the scarf and the stepped lap joints. Because of its ease of manufacture, the single lap joint (SLJ) has been well studied in the literature, both experimentally and theoretically. But this does not mean that it is easy to analyse the stresses present in that joint. In practice, the loading is not collinear, which means that there is bending of the adherends. Thus, the adhesive will experience tensile stresses (peel) at the end of the joint as well as shear. The double lap, the scarf and the stepped joints are designed to decrease peel.

The simplest analysis and the most limited for analysing stresses in SLJs is to suppose that the adherends are rigid and the adhesive deforms only in shear. Volkersen [1] introduced into the analysis what is called differential straining. But there is an important point that was neglected in the Volkersen analysis: the rotation of the joint. The rotation of the joint was included in the analysis of Goland and Reissner [2] and the model gives, in addition to the shear stress, the transverse tearing (peel) stresses in the adhesive. The previous analyses are for elastic behaviour. However, the adhesive and even the adherends may become non-linear or plastic. Hart-Smith [3] developed the theories of Volkersen and Goland and Reissner taking into account the plastic behaviour of the adhesive. A ductile adhesive will yield and sustain further load until eventually its shear strain to failure is attained. A ductile adhesive yields before fracture, redistributing and reducing the peak shear strains.

The SLJ is very common in practice and simple design rules should be available for design purposes.

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Table 1. Adhesive properties (three specimens tested for each adhesive)

	Hysol EA 9361	Araldite 2011	AV138/HV998
Young's modulus E (GPa)	0.67 ± 0.02	1.16 ± 0.03	4.59 ± 0.81
Yield strength σ_{ya} (MPa)	4.23 ± 0.55	24.50 ± 0.20	36.49 ± 2.47
Tensile strength σ_r (MPa)	7.99 ± 1.59	31.68 ± 2.40	41.01 ± 7.28
Failure strain ε_f (%)	44.0 ± 12.3	20 ± 3.30	1.3 ± 0.44
Toughness U_T (MPa)	2.69	5.62	0.34

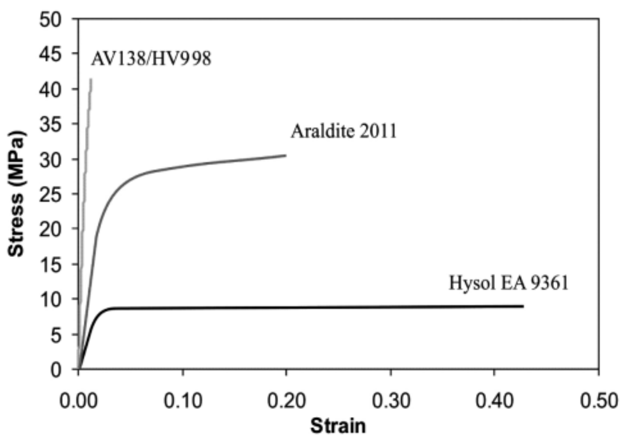

Figure 1. Tensile stress-strain curves of the various adhesives tested.

Hart-Smith [3] proposed a chart where the joint strength is given as a function of adhesive ductility and overlap. The adherends were supposed to remain in the elastic range. This is not realistic since the adherends will yield in many cases (e.g. aluminium or low strength steel). The standard ASTM 1002 proposes a very simple design rule to guarantee that the adherends do not yield. Adams and Davies [4] developed a simple methodology to predict the joint strength. If the adhesive is very ductile (more than 20% shear strain to failure) and the adherends are elastic, the joint strength is given by the load corresponding to the total adhesive plastic deformation. If the adherends yield, the joint strength is governed the adherends yielding, independently of the type of adhesive. For the case of a rather brittle adhesive and elastic adherends, the methodology does not work and the authors propose to use the finite element method.

The objective of the present study was to quantify the influence of the adhesive, the adherend and the overlap on the lap shear strength by means of the Taguchi method [5,6] and to propose a simple predictive equation that contemplates any type of adhesive. Three adhesives (ductile, intermediate and brittle), three adherends (low strength steel, intermediate strength steel, and high strength steel), and three overlaps (12.5, 25, and 50 mm) were selected.

2. Experimental

The adhesives studied were a very ductile adhesive (Hysol EA 9361 from Loctite), a very brittle adhesive (Araldite AV138/HV998 from Huntsman) and an intermediate adhesive (Araldite 2011 from Huntsman). The technique described in the French standard NF T 76-142 [7] for producing plate specimens without porosity was used. Two millimetres plate specimens of the three adhesives were manufactured in a sealed mould and dogbone specimens were machined from those plates afterwards according to BS 2782. Three specimens were tested for each adhesive under a cross head speed of 1 mm/min. The strain was measured using a specially designed non contacting technique for objects suffering high displacement fields, like in tensile tests, developed by Chousal [8,6]. Contacting extensometers tend to interfere with the mechanical behaviour of the adhesive [9] and should be avoided when possible. Typical stress-strain curves of the adhesives are shown in Figure 1. The mechanical properties of the adhesives are shown in Table 1.

The brittle adhesive AV138/HV998 properties present more scatter than the other adhesives because it is more sensitive to defects. However, the failure surface did not contain any noticeable void. The yield strength was calculated for a plastic deformation of 0.2%. The area under the stress-strain curve (U_T) is an approximate value of the toughness [10]: