TEMPERATURE EFFECT ON THE STRENGTH OF ADHESIVELY BONDED SINGLE LAP JOINTS

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ABSTRACT

The purpose of this paper is to study some of the factors that affect the shear strength of Single Lap Joints (SLJ). Based in work conditions for different applications, tests were made in order to define the influence of geometry and temperature on the strength of SLJ under shear load. The adhesive used to make the joints was the epoxy adhesive ARC858 and it was tested under temperatures ranging between 21°C and 70°C and overlap length of 12.5mm and 18.75mm. Results of those tests showed that shear strength increased due to geometry with an overlap of 18.75mm and a great shear strength loss ranging from 30°C to 50°C. The failure mechanism was adhesive failure.

Keywords: joints, adhesive, shear, temperature, overlap

NOMENCLATURE

H	array height, mm
W	array width, mm
Mpa	mega Pascal.

INTRODUCTION

Almost every designed structure requires component members to be connected. The most structurally efficient method of connecting the structures is with shear joints, which are either adhesively bonded or mechanically fastened Mathews (1999). In the design of the adhesive joints for engineering structures, strength, stiffness and life are considered to be the most important mechanical properties. Nowadays, bonded joints processes are widely used in many areas of industry. Advantages such as resistance, versatility, reduced weight, high corrosion resistance, besides, neither machining processes nor metallurgical changes are required, are making this technique a great importance in design and repair systems.

Adhesive bonding offers many advantages over the classical fastening techniques such as welding, riveting and mechanical fastening. It has a high resistance to fatigue and as a consequence the life-cycle maintenance costs are significantly reduced (Wahab et al., 2002). The substantial reduction in weight that can be achieved by the use of adhesive bonding is an important advantage, especially for lightweight structures. In joining lightweight composites, adhesive bonding is the most appropriate joining technique. Almost any material or combination of materials can be joined in a wide variety of sizes, shapes, and thicknesses (Garmo et al., 1997). For most adhesives, the curing temperatures are quite low, seldom exceeding 180ºC. A substantial number cure at room temperature, or slightly above and can provide adequate strength for many applications. As a result, very thin or delicate materials such as foils can be joined to each other or to heavier sections. Heat-sensitive materials can be joined without damage and heat-affected zones are not present in the product. When joining dissimilar materials, the adhesive provides a bond that can tolerate the stresses of differential expansion and contraction (Garmo et al., 1997).

Therefore, the advantages of using adhesively bonded joining methods over conventional mechanically fastened joints can be summarized as Wahab et al. (2002), Heslehurst (1999), Loh et al. (2002) and Garmo et al. (1997): (a) few parts in the joint. Adhesive bonding assembly can simplify the assembly process, increase production and quality and reduce production cost.(b) full load transfer can readily be achieved, (c) the joint is fatigue resilient, (d) the method of construction also seals the joint, (e) a stiffer connection is produced, (f) the connection is light weight, (g) a smooth contour results, (h) the action of the adhesive provides corrosion resistance between the adherends, and (i) no open hole stress concentrations are created

The major disadvantages of adhesive bonding according to Wahab et al. (2002), Ansarifar et al. (2001), Blackman et al. (1995), Heslehurst (1999), Loh et al. (2002), Knox (2000) and Garmo et al. (1997) are: (a) There is no universal adhesive. Selection of the proper adhesive is often complicated by the wide variety of available options; (b) Most industrial adhesives are not stable above 180ºC. Oxidation reactions are accelerated, thermoplastics can soften and melt, and thermosets decompose. While some adhesives can be used up to 260ºC, elevated temperatures are usually a cause for concern; (c) High-strength adhesives are often brittle (poor impact properties). The toughness of an adhesive joint may decrease consider- ably under impact loading conditions. Resilient ones often creep. Some become brittle when exposed to low temperatures; (d) Long-term durability and life expectancy are difficult to predict; (e) Surface preparation and cleanliness, adhesive preparation, and curing can be critical if good and consistent results are to be obtained. Some adhesives are quite sensitive to the presence of grease, oil, or moisture on the adherend surfaces to be joined. Surface roughness and wetting characteristics must be controlled; (f) The joint cannot be disassembled readily. Assembly times may be greater than for alternative methods, depending on the curing mechanism. Elevated temperatures may be required, as well as specialized fixtures; (g) The joint design is thickness-limited; (h) Only shear loading is acceptable; (i) It is difficult to determine the quality of an adhesive- bonded joint by traditional nondestructive techniques, although some inspection methods have been developed that give good results for certain types of joints; (j) Many structural adhesives deteriorate under certain operating conditions. The adhesive can be subjected to environmental effects. Environments that may be particularly hostile include ultraviolet light, ozone, acid rain (low pH), moisture, and salt. Thus durability and reliability of a joint over an extended service lifetime may be questioned. The determination of adhesion strength and durability remains largely empirical in nature; (k) Some adhesives contain objectionable chemicals or solvents, or produce them upon curing; and (l) The thermal residual stresses can be induced.

The effects of temperature in SLJs and T joints with single-part paste epoxy with 30% aluminium powder (ESP110 from Permabond) have been studied (Grant et al., 2009). They concluded that the strength of a SLJ decreases the same way for low temperatures (-40°C) and high temperatures (90°C). Da Silva et al. (2009) concluded in another paper that the effects of surface chemical pre-treatment and test speed are negligible for some types of adhesives studied, including epoxy adhesive. They also concluded that the lower the thickness of the adhesive, the stronger is the SLJ and the high influence of overlap length in SLJs shear strength. Other researchers, like Zhang et al. (2010), Kahramana et al. (2008) and Kahramana et al. (2009) reinforced the influence of geometry in SLJs strength using Finite Element Analysis (FEM) and analytical models. Da Silva (2010) studied the influence of SLJ`s width strentgh, showing that increases in SLJ`s width increases the shear strentgh more than increases in the overlap.

The purpose of this work is to present a study about the influence of several factors of the bonded joints process in its shear resistance, focusing on temperature effect in mechanical resistance. Specimens were tested in different temperatures, simulating various working situations, in different adhesive dimensions. The tensile tests were performed in a thermostatic chamber attached to an universal test machine. The results of this paper may help defining applications and behavior of the adhesive studied.

MATERIAL AND METHODS

Specimen geometry and material properties

The SLJs were manufactured with an epoxy resin combined with ceramic particles adhesive (ARC 858). The geometry of the specimens were defined according to ASTM 1002D Standard Test Method for Apparent Shear Strength of SLJ Adhesively Bonded Metal Specimens by Tension Loading and its recommendations of procedures for manufacturing specimens. Also, increases of 50% of the overlap length were applied in order to verify the influence of SLJ`s geometry in a large range of temperatures. The specimens are shown in Fig. 1. The metal used to manufacture the specimens was the 1020 carbon steel.

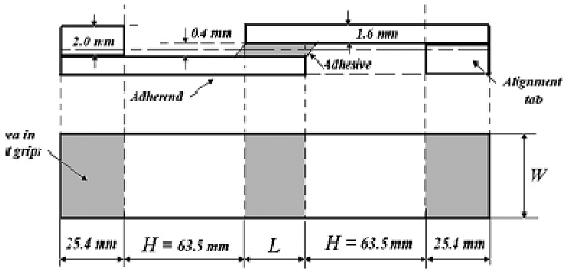

Figure 1. Specimen dimension.

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To ensure a correct alignment of the specimens, a steel table was manufactured with specimens measurements (Figure 2). Packings of 2 mm were used to ensure a 0.4 mm adhesive thickness.

Specimens were made using the ARC 858 adhesive (Figure 3). The cure of the adhesive was performed at room temperature for at least 36 hours, according to the recommendations of the manufacturer. The adhesive in this condition has a lap shear adhesion of 150 kg/mm^2.

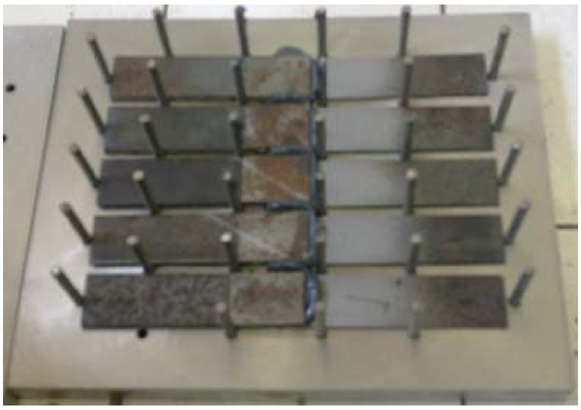

Figure 2. Specimens alignment.

Figure 3. Adhesive ARC 858.

Every specimen was manufactured under ambient laboratory conditions. Before attaching the metal parts, surfaces were blasted with steel grit G25 at a 9 bar pressure in a Air Blast machine (Figure 4) model PP-80. Each specimen was blasted at an angle of 45° for 30 seconds and then cleaned with acetone.

Figure 4. Blasting process with steel grit.

EXPERIMENTAL TESTS

The tensile tests were performed in a thermostatic chamber TCLC-382P attached to an universal test machine model Shimadzu AGX-100 at the speed of 1.3 mm/min.

Tests were performed with 5 specimens per group. Each group represents a work situation where the combination geometry, for an overlap of 12.5mm and 18.75mm, and temperature, for 21°C, 30°C, 40°C, 50°C, 60°C and 70°C, with a total of 12 groups and 60 specimens, according to Table 1.

RESULTS AND DISCUSSION

Load vs. Temperature

The effects of temperature increasing in SLJs shear strength loss (Table 1) were stronger between 30°C to 50°C, to joints dimensioned according to ASTM1002D than the strength loss of SLJs with 18.75 mm overlap. At those temperatures, the adhesive got soft and lost its adhesivity. The results are shown in Figure 5.

Table 1. Groups and results comparison.

Group	Overlap [mm]	Tempera-ture [°C]	Average Shear Strength [Mpa]	Strength difference % [compared to Group 1]
1	12.5	21	7.105675	0
2	12.5	30	4.973241	30.01
3	12.5	40	2.601084	63.39
4	12.5	50	1.514723	78.68
5	12.5	30	1.216529	82.87
6	12.5	70	0.865325	87.82
7	18.75	21	7.849636	-10.47
8	18.75	30	6.700385	5.70
9	18.75	40	4.467934	37.12
10	18.75	50	2.453963	65.46
11	18.75	60	1.927781	72.86
12	18.75	70	1.301003	81.69

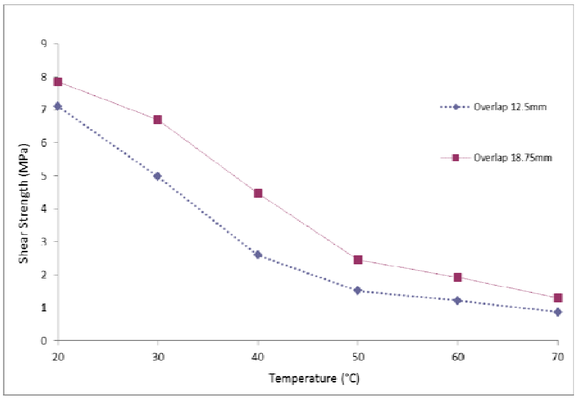

Figure 5. Diagram of shear strength versus temperature.

Failure Mechanism

The failure mechanism was mainly adhesive, showing that the adhesive strength is lower than its adhesivity with the metal. At 21°C, adhesives failures had a transition from one surface to the other. However, for higher temperatures the failure was mostly in one side of the bonded area.

Geometry Influence

A strong influence of the geometry was observed over the SLJs shear resistance. Increases in overlap length increased an average of 30.95% the shear strength.

Discussion

Results show that it`s not advisable the application of this adhesive in situations where temperatures higher than 40°C are required, as the adhesive has shown strength losses of over 60% at this temperature. In the other hand, the increasing the overlap length has shown to be a good way to produce more resistant joints with lower losses of strength. The rates of strength loss decreased after 50°C, even though the shear resistance was already too low.

CONCLUSIONS

This paper presented the results of tests made with SLJ and the adhesive ARC 858, and the conclusions were:

- The range of temperatures that showed higher shear strength loss was from 30 to 50°C.
- Increasing the overlap of the SLJs, the shear strength increases. It also happens for higher temperatures.
-The rates of strength loss decrease for temperatures over 50°C.
- The failure mechanism was mainly adhesive, for all temperatures.

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