EVALUATION OF EPOXY ADHESIVE THICKNESS IN SIMPLE OVERLAP JOINTS SUBJECTED TO LAP SHEAR

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Abstract: Epoxy adhesives are widely used in the automotive and aerospace markets and have gained notoriety for their versatility and ease of modification to achieve different properties. The purpose of this article was to study simple overlap joints in different thicknesses, 0.1, 0.25 and 0.5 mm, of a two-part epoxy-based structural adhesive under lap shear. In addition, the failure profile of the adhesive on the adherent and the fracture surface of he joints were analyzed by scanning electron microscopy (SEM). The results showed greater resistance to lap shear of simple overlap joints with 0.1 mm of adhesive thickness, failure with stress bleaching and, in the SEM's images, the presence of glass spheres.

Keywords: Structural epoxy adhesive; Lap shear; Simple joints; Thickness.

AVALIAÇÃO DA ESPESSURA DE ADESIVO EPÓXI EM JUNTAS SIMPLES SOBREPOSTAS SUBMETIDAS A CISALHAMENTO

Resumo: Os adesivos epóxis apresentam vasta aplicação no mercado automobilístico e aeroespacial e ganharam notoriedade por sua versatilidade e por serem facilmente modificados para conquista de diferentes propriedades. A proposta de objetivo deste artigo foi estudar juntas simples sobrepostas em diferentes espessuras, 0,1, 0,25 e 0,5 mm, de um adesivo estrutural bicomponente de base química epóxi sob cisalhamento. Além disso, foi analisado o perfil de falha do adesivo no aderente e a superfície de fratura das juntas por microscopia eletrônica de varredura (MEV). Os resultados mostraram maior resistência ao cisalhamento das juntas simples sobrepostas com 0,1 mm de espessura do adesivo, falha com clareamento por estresse e, nas imagens de MEV, a presença de esferas de vidro.

Palavras-chave: Adesivo epóxi estrutural; Cisalhamento; Juntas simples; Espessura.

1. INTRODUCTION

Adhesives are substances capable of joining two materials for extended periods of time, even when subjected to high levels of stress. Adhesive bonds offer numerous advantages over traditional joining methods such as screws, welding, brazing, riveting, and other mechanical joints [1] and, when properly applied, have the ability to provide a more uniform distribution of stresses, with reduced stress concentrations, since the bond obtained is virtually continuous, giving the adhesive joints an excellent resistance to fatigue [2].

Among the advantages of adhesive bonds are the more uniform distribution of stresses, as mentioned above; damping of vibrations, as they allow partial absorption of stresses; structures with regular contours and joining of different materials. However, adhesive bonds have limited resistance to extreme conditions such as heat and moisture, due to the polymeric nature of the adhesive, and the use of geometries that avoid localized stresses and promote uniform stress distribution [1].

Adhesives can be classified as structural or non-structural. Structural adhesives are high strength, high performance materials whose primary function is to hold structures together and withstand high loads [3]. Non-structural adhesives are those that do not support significant loads, they simply hold materials together [3].

Major structural adhesives include epoxies, phenolics, polyurethanes, cyanoacrylates, modified acrylics, and polyesters. In the development of this study, two-part structural adhesives based on epoxy chemical base were used. These adhesives are thermosetting when cured and have excellent tensile and shear strength, but poor tear strength [1].

Epoxy resins are thermosetting and are generally obtained by the reaction of two components, the first being an epoxy resin and the second being a hardener (a curing agent) [4].

In general, epoxy resins contain polyphenols or, less commonly, polyglycols, and epichlorohydrin or oligomers with pendant epoxy groups [5]. Such resins are also cured by hardeners such as amines, amides and polyamides, and anhydride hardeners in addition to certain acids and Lewis bases [5]. Cured resins are insoluble and infusible, have significant adhesion to virtually all types of materials, are chemically resistant, and have excellent dielectric properties [5].

Epoxy adhesives are generally limited to applications below 121 °C, with some adhesives having a short-term service tolerance of 260°C and a long-term service tolerance of 149 – 260°C [3].

Epoxies exhibit good to excellent adhesion to steel, aluminum, brass, copper, and most other metals [3]. In addition to these substrates, these adhesives show similar results on thermoset and thermoplastic plastics, glass, wood, concrete, paper, fabric, and ceramics [3].

An adhesive must first wet the surfaces, spreading and forming a near zero contact angle, and then cure to form a cohesive solid [6]. This process of wetting the adhesive to the substrate involves intimate contact between the adhesive molecules and the substrate molecules, creating van der Waals forces in addition to other intermolecular forces such as chemical bonding [6]. This factor is highly dependent on the chemistry of the adhesive and the substrate [6].

Silva et al., 2007 [1] describe that the bonding of an adhesive to a surface is the sum of a number of mechanical, physical, and chemical forces that overlap and influence each other. Adhesive bonding is based on two important properties: adhesion and cohesion. Adhesion occurs between the different materials that make up the surface of the substrate and the adhesive [6,7]. Cohesion is defined as the forces between atoms or molecules within the adhesive [6,7].

One of the characteristics that affects the strength of the adhesive joint is the thickness of the adhesive. Silva et al., 2007 [1] report that the optimum adhesive thickness is between 0.1 and 0.5 mm. Gleich et al., 2001 apud Silva et al., 2007 [1] reported that most manufacturers recommend a thickness of 0.1 to 0.2 mm to achieve maximum strength. In addition, another important factor is the absence of discontinuities such as bubbles and voids within the adhesive joint [8]. Müller et al., 2018 [9] reported that the inclusion of air can significantly reduce the adhesion between the adhesive and the substrate or reduce the cohesion within the adhesive.

Therefore, the aim of this article was to study overlapping joints bonded with a two-component structural adhesive based on epoxy chemistry in two thicknesses subjected to lap shear. For this purpose, a 1.2 mm thick cold-rolled steel substrate was used.

2. METHODOLOGY

2.1. Materials

In this study, the Fusor® 380NS / 383NS epoxy chemical-based bicomponent structural adhesive was used in a 1:1 ratio (adhesive and accelerator, respectively). The thicknesses of the adhesive on the substrate were 0.1 mm, 0.25 mm, and 0.5 mm. The substrate used was a 1.2 mm thick cold-rolled steel 1006.

2.2. Characterization

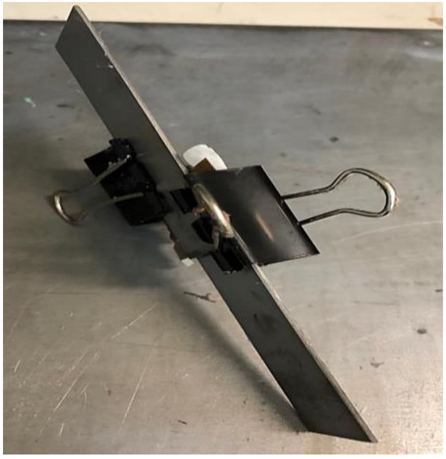
2.2.1 Lap shear

To determine the shear strength of the bonded joints, an EMIC universal testing machine, model DL 2000, with Tesc 2000 data processing software was used. A 20 kN load cell was used at a speed of 1.3 mm/min, according to ASTM D1002-99 [10]. Five replicates were performed for each adhesive on a 1006 cold-rolled steel substrate measuring 100x25 mm, according to the standard [10]. The curing time was 24 hours, as specified in the adhesive data sheet.

The substrates were prepared by immersion in an HCl solution and then sanded with 360 and 600 grit sandpaper to remove oxidation. The samples were cleaned with acetone, heptane, and isopropyl alcohol to remove dirt prior to adhesive application. At the end of this step, PTFE strips were applied to the specimens to delineate the useful area for adhesive application and to ensure thickness (Figure 1 (a)). The adhesive was applied using a mixing nozzle and an applicator gun. The specimens were allowed to cure at room temperature. To ensure thickness, a fastener was used to join the substrates (Figure 1 (b)). The overlap of the five samples for each formulation studied was 0.1 mm thick with a value of 15.83 ± 2.85; 0.25 mm thick with 14.70 ± 1.4 mm; 0.5 mm thick with a value of 12.03 ± 1.61 mm. This variation occurred because the application of the PTFE template in all specimens was performed manually.

Figure 1: Sample preparation. (a) PTFE strips; (b) Substrate bonding mechanism.

(a) (b)



2.2.2 Scanning Electron Microscopy (SEM)

The fracture surface of the specimens was analyzed using a Joel brand scanning electron microscope, model JSM-6510LV, 200× magnification and metallization with carbon wire.

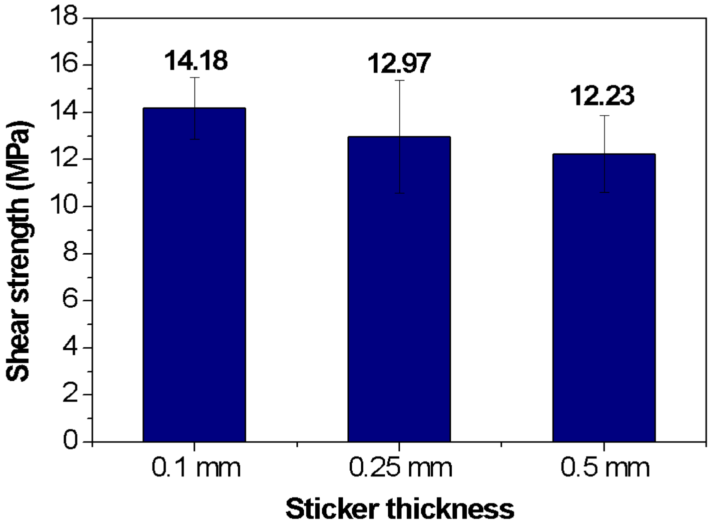
3. RESULTS AND DISCUSSION

Silva et al., 2009 [11] reported that adhesive thickness has an important effect on bond strength. Grant et al. 2008 apud Silva et al., 2009 [11] explained the influence of adhesive thickness on bending moment. The authors reported that for a lap joint under tension, the longitudinal stress from the direct load and the bending moment in the overlap region cause plastic deformation when the steel becomes plastic and cause the adhesive to fail [11]. The lap joint under tension is very sensitive to the thickness of the adhesive [11]. There is a longitudinal stress from the direct load and an additional bending stress due to the displacement of the load which is superimposed on the tensile stress [11]. To achieve the same stress level, as the bending moment increases, the stress due to the direct load must be smaller [11]. As the bond line thickness increases, there is an increase in the bending stress as the bending moment increases [11]. Therefore, the strength of the joint is reduced.

In addition, the authors report that for low strength adherents, an increase in thickness is positive because the adherent becomes stronger and less likely to deform plastically [11]. In contrast, for high strength adherends, increased thickness may decrease bond strength due to increased bending moment [11].

Figure 2 shows the mean stress values at the maximum force in MPa after shear of the single joints with thicknesses of 0.1 mm, 0.25 mm, and 0.5 mm of the two-part epoxy structural adhesive tested.

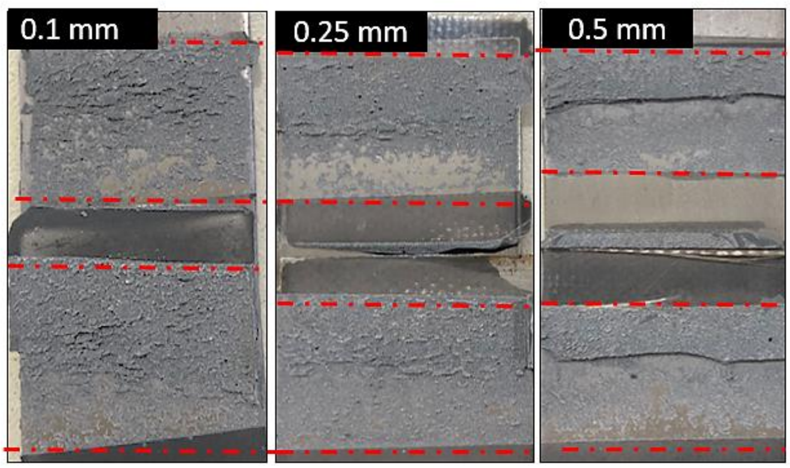
Figure 2: Mean stress result at maximum strength (MPa) of single joints after holding in lap shear.



It was observed that the simple joint with a thickness of 0.1 mm had a resistance 9.3% higher than the joint with a thickness of 0.25 mm. The values obtained were 14.18 ± 1.30 MPa, 12.97 ± 2.39 MPa, and 12.23 ± 1.63 MPa, respectively, from the smallest to the largest thickness. When comparing the resistances of the 0.25 mm and 0.5 mm joints, it was found that doubling the thickness did not affect the increase or decrease in resistance under the conditions studied in this article.

The failure mode of simple joints subjected to shear is shown in Figure 3.

Figure 3: Failure mode on metallic substrate after lap shear test.

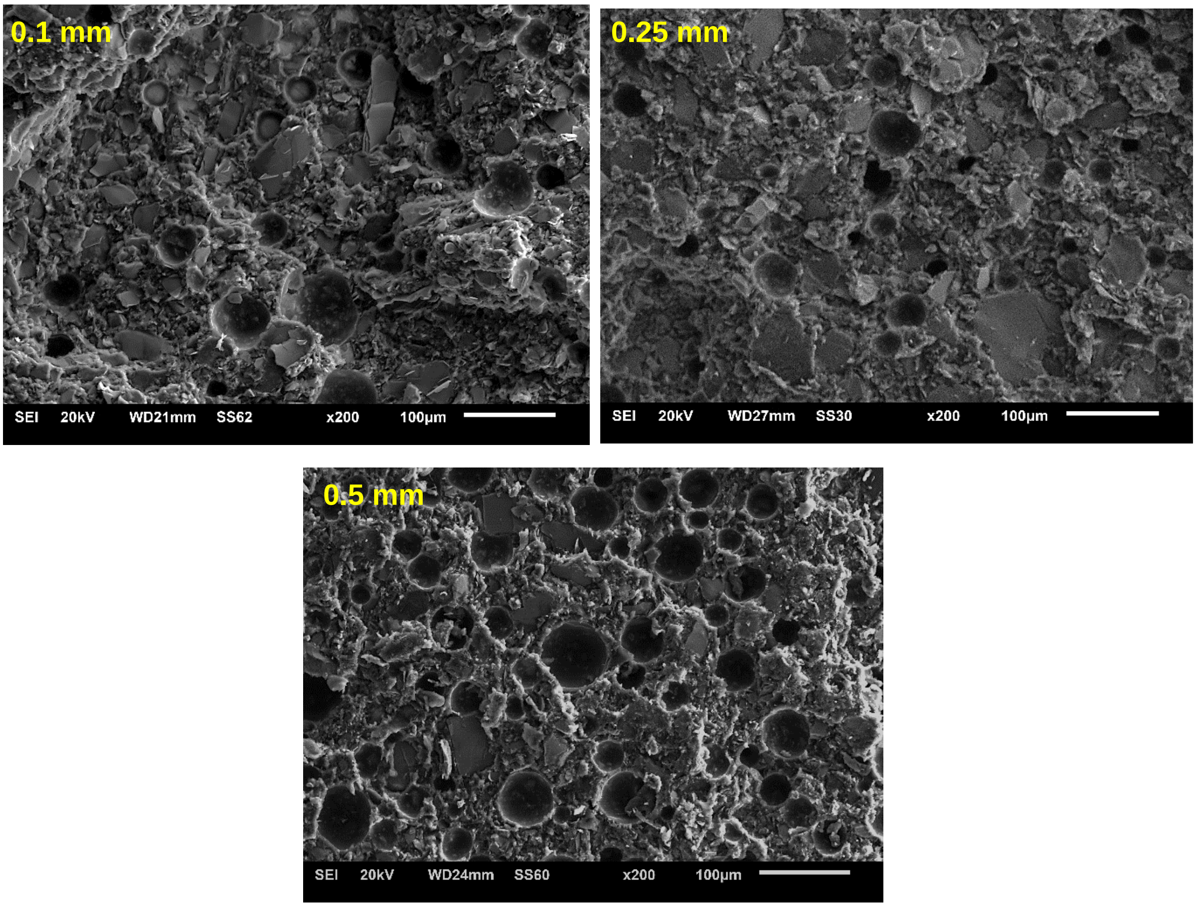


When evaluating the failure mode of the single joints after shear (Figure 3), a rough profile was observed in all three cases, indicating a fracture in the bulk, approximately in the middle of the adhesive layer. There was also a thin layer of adhesive residue covering the substrate.

The ISO/DIS10365 standard [12] was used to evaluate the fracture pattern observed in simple sheared joints with 0.1, 0.25 and 0.5 mm thickness failure with stress whitening of the adhesive (SWCF).

Figure 4 shows the images obtained by SEM of the fracture surface of the joints after the lap shear test.

Figure 4: Scanning electron microscopy of the fracture area after lap shear testing.



A significant presence of spherical voids was observed in the SEM images of the fracture surfaces of the sheared joints. The technical data sheet of the adhesive indicates the presence of glass spheres to control the adhesive thickness of the bond line during prototyping or evaluation of the adhesive [13].

4. CONCLUSION

The purpose of this study was to evaluate the lap shear mechanical strength of simple joints bonded with a two-part epoxy structural adhesive in three thicknesses, 0.1, 0.25, and 0.5 mm. It was found that the 0.1 mm adhesive thickness in the single joint showed greater resistance to lap shear. The failure mode in the joints with the three thicknesses showed failure with stress whitening of the adhesive and the SEM analyzes showed the existence of spherical voids due to the presence of glass spheres in the composition of the studied adhesive.

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