International Journal of Adhesion & Adhesives 41 (2013) 33–40

Contents lists available at SciVerse ScienceDirect

International Journal of Adhesion & Adhesives

journal homepage: www.elsevier.com/locate/ijadhadh

Mechanical characterization of adhesive joints with dissimilar substrates for marine applications

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ARTICLE INFO

Article history:
Accepted 14 September 2012
Available online 22 October 2012

Keywords:
Adhesive bonding
Sealant
Hybrid joint
Single lap joint
Analysis of variance

ABSTRACT

The simplicity and efficiency of the adhesive joints have increased more and more their use in many fields. In ship construction the need to join different materials, such as the bonding of the hull/deck, the sea chest, the portholes, the windshields, the panels of cabins, etc. leads to choosing increasingly the adhesive joints. In this work we have evaluated the effects of both SMP (Silyl Modified Polymer) based adhesives and sealants on single lap joints (SLJs) with dissimilar substrates. Three pairs of single lap joints were taken into account among dissimilar adherends: stainless steel (AISI 316) with PMMA (or Altuglas®) and monolithic composite laminates bonded with glass or PMMA. Before tensile testing some SLJ samples were subjected to a three-dimensional computed tomographic analysis to evaluate how the presence of possible defects in the adhesive layer affects the failure mode. A design of experiments was defined in order to quantify the effect of the considered factors and their correlation. The obtained maximum tensile stress values confirm the data provided by the manufacturer, approximately between 2 and 2.5 MPa, showing generally cohesive fracture. Finally the considered SMP adhesives and sealants are well suited for the chosen different substrates, although special attention should be placed on the glass–GFRP joint as it is confirmed by statistical analysis.
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1. Introduction

In recent years adhesive joints have captured a large slice of the industrial market thanks to their many advantages over mechanical fasteners, such as relatively high strength/weight ratio and reduced costs. Also the choice of the single lap joint (SLJ) for the adhesive's effectiveness evaluation is the most common, mainly, due to its simplicity and handiness. The joint strength is influenced by many factors such as the type of adhesive, the type of adherend, the overlap length and the bondline thickness. In any case, to achieve the full capacity of the adhesive, the type of failure has to be cohesive in the adhesive and not interfacial [1–3].

In the marine field the adhesives and sealants are used in many applications: to bond the hull/deck [4], the channels running through the teak-made deck staves, the sea chests, the exhaust systems, the air intakes, the portholes, and the windshields; inside the boat the panels of cabins, the toilets and the engine compartment are glued and sealed [5,6].

Elastomeric bonding joints offer high peel strength, impact resistance and flexibility. Interest in this class of adhesives (see Fig. 1) is on the rise because these joints are more forgiving than other adhesives. The low modulus gives a more uniform stress distribution and a more uniform stress transfer. The high tear propagation strength of elastomers, even where the adhesive layer has started to tear, prevents sudden catastrophic joint failure. This forgiving behaviour means that damaged adhesive joints can be identified and repaired before total failure. In contrast to rigid adhesive joints, elastomeric adhesive layers deform under applied loads. This property is extremely useful for damping vibrations and absorbing impact loads. Exposure to heat may result in differential thermal expansion, causing adhesively bonded components to move relative to each other [7]. Elastomeric adhesives are well suited to join materials with different coefficients of linear expansion; thanks to their flexibility they avoid thermal stress [8].

Theoretical analysis and experimental data in the literature, generally, are related to rigid and strong adhesives in structural joints. However, the advantageous properties of flexible adhesives in sustaining large strains and distributing peel forces on the bonded substrates have led to their use also for structural joining applications. They present important advantages in terms of

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0143-7496/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijadhadh.2012.10.005

damping, impact, fatigue, and safety. There might be situations where the adhesive is required to retain joint integrity during large deformations of the adherends. In this case the flexible adhesives, characterised by low modulus and large extensions to failure, are widely used. They have glass transition temperatures at or below the service temperature and therefore operate in the rubbery phase. Hence their deformation is characterised by large elastic strains with little evidence of plastic deformations [9].

Silicone and polyurethane adhesives cure from the moisture in air and form low strength structural joints. Both act as adhesives and sealants. The silicone sealants are particularly appreciated for their elastic behaviour; they can absorb movements of the joint without tearing away from the substrate, or without tearing apart itself [10]. Polyurethanes have good mechanical properties, good adhesion on various substrates, short drying times and can dampen the vibrations. The MS polymers are the latest generation of polymers; they come from the polyurethanes with enhanced properties. These innovative, environmentally friendly, moisture curing MS polymers are solvent- and isocyanate-free adhesives and sealants. They essentially combine the strength of polyurethanes with the weathering resistance of silicones and represent the latest generation on high-performance adhesive/sealants. MS polymers offer a wide range of physical properties. They combine a low modulus with a high movement capability holding discrete tensile strength. O'Connor and Kingstom have studied the weatherability of polyurethane, silicone and SMP sealants by applying the ASTM C793 to observe cracking and colour changes. In long-term weathering studies outdoor as well as with xenon arc, ongoing tests of SMP sealants show promising results. The xenon arc specimen performed very well, with only minor chalking and a small colour change. The outdoor specimen similarly displayed some minor chalking and a colour change due to dirt pick-up. After exposing the sealant to UV light (xenon arc) for 200 h in a weatherometer the specimens of the analysed sealants have been subjected to peel test. In general they showed retention of their original peel strength as well [11–13].

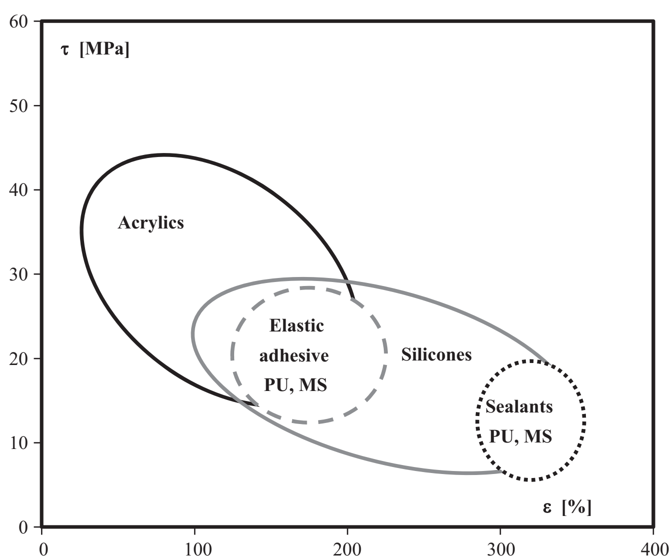

Fig. 1. Elastomeric adhesives.

They withstand the most stringent requirements for high performance bonding and elasticity under severe aging and UV weathering conditions without cracking or yellowing when subjected to extended UV-light exposure. After drying time they can be sanded and painted.

Some studies about the correlation between natural ageing and accelerated exposure can be found in the literature, confirming the strong efforts of the scientific community to overcome this problem, and good results are obtained [12,16].

In this work we have evaluated the effects of two kinds of SMP (Silyl Modified Polymer) based adhesives and sealants on single lap joint properties. Three pairs of SLJs were taken into account with dissimilar adherends: stainless steel with PMMA (or Altuglas®) and monolithic composite laminates bonded with glass or PMMA. The single-lap joint test has been chosen to evaluate the joints resistance.

Finally a statistical data analysis was performed to quantify the effect of the considered factors (i.e. kind of adhesive and couple of substrates) and their correlation.

2. Experimental set-up

2.1. Materials

The used substrates were

- *Glass (thickness 4 mm)*: soda–lime glass contains 60–75% silica, 12–18% soda and 5–12% lime;
- *PMMA (thickness 5 mm)*: known under commercial mark Altuglas®, it is an acrylic sheet that can be used for a wide range of applications such as design, construction, and transport;
- *AISI 316 (thickness 2 mm)*: austenitic stainless steel can be hardened by cold working and it has better corrosion resistance than AISI 304.
- *GFRP (thickness 6 mm)*: a glass fiber-reinforced plastic composite realized by the hand lay-up technique laminating a gelcoat

Table 1
Technical data of adhesives and sealants.

Technical data	A1	A2	B1	B2
Skin forming time 20 °C/50% RH (mm)	≈ 15	≈ 15	≈ 10	–
Open time 20 °C/50% RH (min)	< 35	< 35	< 15	≈ 45
Open time 35 °C/80% RH (min)	–	–	–	≈ 30
[a]Cure in depth after 24 h (20 °C/50% RH) (mm)	≈ 3	≈ 3	≈ 3	≈ 3
Shore A hardness	≈ 55	≈ 55	≈ 65	≈ 60
Volume change (%)	< 3	< 3	< 3	\
Tensile stress (100%) (MPa)	≈ 2.0	≈ 1.7	≈ 2.2	≈ 2.3
Tensile stress at break (MPa)	≈ 3.0	≈ 2.6	≈ 2.9	≈ 3.6
Shear stress (MPa)	≈ 2.5	≈ 2.5	≈ 2.3	≈ 2.5
Elongation at break (%)	≈ 225	≈ 250	≈ 225	≈ 450

[a] The cure in depth (mentioned on technical data sheets as curing speed) is the average curing speed of very thinly applied sealants that are in direct contact with air (humidity). When applying thick layers of sealants, the curing rate (humidity hardening), under normal circumstances i.e. 20 °C/50% RH, will equate to about 3 mm during the first 24 h. With increasing sealant thickness, the curing speed significantly slows down. This is due to the fact that the necessary humidity in the surrounding area will have more difficulty in penetrating through the cured surface.

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