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Mechanical behavior of metallic fiber-reinforced adhesive under dynamic loading

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Abstract

The mechanical behavior of metallic fiber reinforced adhesively bonded Single Lap Joints (SLJ) under dynamic loading has been studied. The effect of different fiber spacing along the joint width on the strength of SLJs was investigated experimentally. The experimental tests were conducted on non-reinforced and reinforced adhesives joints fabricated using Araldite 2015 adhesive. The experimental results indicated that introducing the metallic fibers in the adhesive layer improved the shear strength of SLJs. This improvement was observed to be maximum under higher loading rates. Additionally, the improvements were found to be de-pendent on the spacing between the metal macrofibers for which lower fiber distancing result-ed in higher failure load improvements.

Keywords: Dynamic loading; Failure analysis; Metal fiber; Single lap joint.

1. Introduction

Adhesive joints have attracted considerable attention in various industries due to their advantages compared to traditional methods of joining. High fatigue life, preventing the galvanic corrosion between the adherends, more uniform stress distribution in the bonding area are among these advantages. Single lap joints (SLJ) has been commonly used for bonding adherends due to its simple geometry and practically easy fabrication method. However, this type of

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adhesive joint suffers from intensified stresses at both ends of the bond line, which reduces the overall strength of the joint. In order to improve the mechanical behavior of SLJs or in general adhesive joints, several methods have been proposed by researchers in the past decades, which can be categorized in two main group; optimization of adherends geometries (Boss et al., 2003; Fessel et al., 2009; Campilho et al., 2001; Rincon Troconis et al., 2013; Ayatollahi et al., 2017a; Razavi et al., 2018a,b, 2019) and improving the mechanical properties of adhesives (Kinloch et al., 2003; Zhai et al., 2006; Fereidoon et al., 2010; May et al., 2010; Ayatollahi et al., 2017b; Kanar et al., 2018; Razavi et al., 2018c,d; Akpinar et al., 2018). In order to improve the mechanical properties of currently available adhesives, extensive researches were conducted on the toughened adhesive using nano, micro and macro additives.

Dealing with macro additives, Khoramashad and Razavi (2014) suggested application of metallic fibers in the bonding layer of adhesive joints. They studied the effect of incorporating aluminum fibers on the overall shear strength of SLJs. According to their results the reinforced joints not only experienced an increase in strength, but also the displacement at failure was increased. A shear strength improvement of 133.9% was reported for the reinforced adhesive joints with smallest fiber spacing compared to a non-reinforced SLJ. Later it was revealed that only incorporation of metallic fibers along the length of adhesive joint can improve the mechanical behavior and lateral fibers don't result any improvement in the overall behavior of the adhesive joint (Nemati Giv et al., 2018). The flexural behavior (Esmaeili et al., 2018) and fracture behavior (Razavi et al., 2017) of metallic fiber reinforced adhesives were then studied in other published researches. It was reported that incorporation of metallic fibers improves the stress distribution in adhesive layer beside the fact that relatively higher thermal conductivity of the reinforcing fibers compared to the adhesive, can result in better heat transfer during curing resulting in less residual stresses in adhesive layer (Khoramashad and Razavi, 2014).

In the current research the mechanical behavior of metallic fiber reinforced adhesive joints is evaluated under dynamic loading. The reinforced adhesive joints are produced using a new fabrication fixture enabling production of the joints with different fiber spacing and the results were compared with that of non-reinforced joints. Three different loading rates were considered for conducting experiments.

2. Experimental procedure

The SLJs were fabricated using Araldite® 2015 adhesive, steel adherents and 0.5 mm Forta 304/4301 austenitic stainless-steel reinforcing fibers. The technical data and material properties of Araldite 2015 are reported in Table 1. Reinforcing fibers with a diameter of 0.5mm are made of Forta 304/4301 austenitic stainless steel with an ultimate tensile strength of 650 MPa. Three different reinforcement fiber spacing of a = 0.4, 0.9 and 1.9 were considered in fabrication of reinforced SLJs, in which a is the dimensionless fiber spacing parameter based on distance between the fibers divided by the adhesive layer thickness (see Fig. 1). In addition to the reinforced specimens, non-reinforced adhesive joints were fabricated as control specimens.

Table 1. Araldite® 2015 technical data according to the product's datasheet.

Density	~1.4[g/cm^3]
Viscosity (25ºC)	Thixotropic
Mixing ratio (by weight)	1:1
Pot life at 25ºC, 100g	~30-40 min
Shear modulus (at 25ºC)	0.90 GPa
Young's modulus	2.00 GPa
Tensile strength	30.0 MPa
Elongation at tensile break	4.4%

To ensure that the reinforcement fibers are correctly placed, orientated and spaced within the adhesive layer, an assembly fixture made of precision-machined steel parts was designed and employed (see Fig. 2). The dynamic tests were conducted at room temperature (20ºC) and at a relative humidity of 26% under different loading rates of 0.20, 10 and 50 mm/min. At least three samples were tested for each case.

3. Results and discussion

The experimental results obtained from the static and dynamic tests are presented in Table 2. According to the static results (i.e. loading rate: 0.2 mm/min), the failure loads of reinforced adhesive joints with fiber spacing of a = 0.4, 0.9 and 1.9 were 61%, 73% and 34% higher than that of non-reinforced joints. This improvement was slightly enhanced for the reinforced adhesive joints tested under 10 mm/min loading rate. For this case, the highest failure load improvement of 76% was observed which belonged to the reinforced adhesive joints with fiber spacing of a = 0.9. Application of 50mm/min rate, which is one hundred times higher than that of static loading, resulted in considerably higher failure loads for both non-reinforced and reinforced adhesives. The failure load improvements for the fiber spacing of a = 0.4, 0.9 and 1.9 were 73%, 84% and 49%, respectively. Once again, the highest failure load under this loading rate was observed for the samples with fiber spacing of a = 0.9.

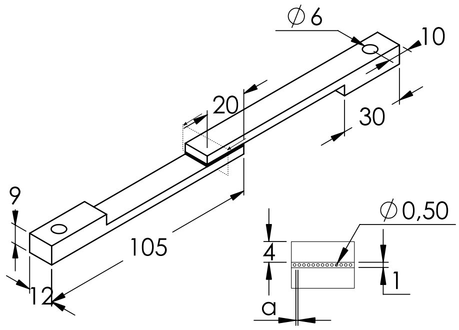

Fig. 1. Schematic view of the adhesively bonded joints (dimensions in mm).

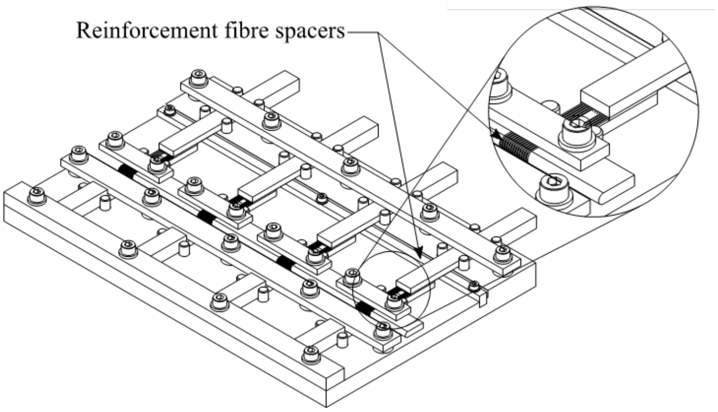

Fig. 2. Schematic view of the joint production fixture.

Table 2. The details of experimental failure loads obtained from the tested adhesive joints.

Tested joints	Loading rate					
	0.2 mm/min		10 mm/min		50 mm/min	
	Failure load (kN)	Improvement*	Failure load (kN)	Improvement	Failure load (kN)	Improvement
Non-reinforced	3.85	-	4.74	-	5.40	-
a = 0.4	6.20	61	7.70	63	9.35	73
a = 0.9	6.66	73	8.36	76	9.92	84
a = 1.9	5.16	34	6.26	32	8.05	49

*Improvement: (Failure load$|_{\text{reinforced joint}}$ - Failure load$|_{\text{non-reinforced joint}}$) / Failure load$|_{\text{non-reinforced joint}}$ ×100

It can be observed that increasing the loading rate from 0.2 mm/min to 50 mm/min increases the failure load of the non-reinforced adhesive by 40%. This behavior was intensified by incorporation of metallic fibers, showing the proper ability of this type of reinforced joints for the components subjected to dynamic loadings. Incorporation of metallic fiber reinforced adhesive joints results in better load transfer between the adherends as a result of load sharing function of the fibers. According to the results presented in this research, higher load bearing improvements were observed for the case of dynamic loading. This can be due to dominant cohesive failure in the adhesive joints, which have been tested under higher loading rates. Additionally, better thermal conductivity of metallic fibers compared to the base adhesive results in better temperature distribution in the adhesive layer during curing procedure, which consequently provides a more uniform curing condition with less residual stresses (Khoramishad and Razavi, 2014). The effects of the incorporation of metallic fibers on the overall dynamic behavior of SLJs was assessed in this paper by varying the fiber spacing and the results provided helpful understanding of how this key geometry parameter affect the load bearing capacity of the SLJs.

4. Conclusion

The dynamic behavior of metallic fiber reinforced adhesively bonded SLJs was experimentally studied. The distance between the reinforcing fibers was considered as the key parameters in analyses. According to the viscoelastic behavior of the adhesive, higher failure loads were obtained for the joints tested under loading rates of 10 mm/min and 50 mm/min compared to the static loading (i.e. loading rate of 0.2 mm/min). The experimental results of longitudinally reinforced adhesives showed 73% enhancement of static load bearing capacity while 84% enhancement of dynamic load bearing capacity was obtained under loading rate of 50 mm/min. This different improvement values were assumed to be due to different failure mechanisms in the reinforced SLJs under static and dynamic loadings, which requires further studies.

References

Akpinar, I.A., Gültekin, K., Akpinar, S., Gürses, A., Ozel, A., 2018. An experimental study on composite adhesives reinforced with different types of organo-clays. Journal of Adhesion 94 (2), 124-142.

Araldite 2015 - Data sheet, www.intertronics.co.uk, vol. 1, no. 1. Huntsman Advanced Materials, Basel, Switzerland, pp. 1–6, 2007.

Ayatollahi, M.R., Samari, M., Razavi, S.M.J., da Silva, L.F.M., 2017a. Fatigue performance of adhesively bonded single lap joints with non-flat sinusoid interfaces. Fatigue & Fracture of Engineering Materials & Structures 40(9), 1355−1363.

Ayatollahi, M.R., Nemati Giv, A., Razavi, S.M.J., Khoramishad, H., 2017b. Mechanical properties of adhesively single lap-bonded joints reinforced with multi-walled carbon nanotubes and silica nanoparticles. Journal of Adhesion 93(11), 896-913.

Boss, J.N., Ganesh, V.K., Lim, C.T., 2003. Modulus grading versus geometrical grading of composite adherends in single-lap bonded joints. Composite Structures 62(1), 113-121.

Campilho, R.D.S.G., Pinto, A.M.G., Banea, M.D., Silva, R.F., da Silva, L.F.M., 2001. Strength Improvement of Adhesively Bonded Joints Using a Reverse-Bent Geometry. Journal of Adhesion Science and Technology 25(18), 2351–2368.

Esmaeili, E., Razavi, S.M.J., Bayat, M., Berto, F., 2018. Flexural behavior of metallic fiber-reinforced adhesively bonded single lap joints. Journal of Adhesion 94(6), 453-472.

Fereidoon, A., Kordani, N., Rostamiyan, Y., Ganji, D.D., Ahangari, M.G., 2010. Effect of carbon nanotubes on adhesion strength of e-glass/epoxy composites and alloy aluminium surface. World Applied Science Journal 9, 204–210.

Fessel, G., Broughton, J.G., Fellows, N.A., Durodola, J.F., Hutchinson, A.R., 2009. Fatigue performance of metallic reverse-bent joints. Fatigue and Fracture of Engineering Materials and Structures 32, 704–712.

Kanar, B., Akpinar, S., Akpinar, I.A., Akbulut, H., Ozel, A., 2018. The fracture behaviour of nanostructure added adhesives under ambient temperature and thermal cyclic conditions. Theoretical and Applied Fracture Mechanics 97, 120-130.

Khoramishad, H., Razavi, S.M.J., 2014. Metallic Fiber-Reinforced Adhesively Bonded Joints. Int. Journal of Adhesion and Adhesives 55, 114-122.

Kinloch, A.J., Lee, J.H., Taylor, A.C., Sprenger, S., Eger, C., Egan, D., 2003. Toughening structural adhesives via nano-and micro-phase inclusions. Journal of Adhesion 79, 867–873.

May, M., Wang, H.M., Akid, R., 2010. Effects of the addition of inorganic nanoparticles on the adhesive strength of a hybrid sol–gel epoxy system. International Journal of Adhesion and Adhesives 30(6), 505–512.

Nemati Giv, A., Ayatollahi, M.R., Razavi, S.M.J., Khoramishad, H., 2018. The effect of orientations of metal macrofiber reinforcements on mechanical properties of adhesively bonded single lap joints. Journal of Adhesion 94(7), 541-561.

Outokumpu, "Forta 304/4301 EN 1.4301, ASTM TYPE 304 / UNS S30400 stainless steel grade details." [Online]. Available: http://steelfinder.outokumpu.com/Properties/GradeDetail.aspx?OKGrade=4301&Category=Forta. [Accessed: 24-Jan-2017].

Razavi, S.M.J., Ayatollahi, M.R., Esmaeili, E., da Silva, L.F.M., 2017. Mixed-mode fracture response of metallic fiber-reinforced epoxy adhesive. European Journal of Mechanics - A/Solids 65, 349–359.

Razavi, S.M.J., Esmaeili, E., Samari, M., Razavi, S.M.R., 2018a. Stress analysis on a non-flat zigzag interface bonded joint. Journal of Adhesion 94(3), 199-217.
Razavi, S.M.J., Berto, F., Peron, M., Torgersen, J., 2018b. Parametric study of adhesive joints with non-flat sinusoid interfaces. Theoretical and Applied Fracture Mechanics 93, 44-55.
Razavi, S.M.J., Ayatollahi, M.R., Nemati Giv, A., Khoramishad, H., 2018c. Single lap joints bonded with structural adhesives reinforced with a mixture of silica nanoparticles and multi walled carbon nanotubes. International Journal of Adhesion and Adhesives 80, 76-86.
Razavi, S.M.J., Esmaeely Neisiany, R., Ayatollahi, M.R., Ramakrishna, S., Nouri Khorasani, S., Berto, F., 2018d. Fracture assessment of polyacrylonitrile nanofiber-reinforced epoxy adhesive. Theoretical and Applied Fracture Mechanics 97, 448-453.
Razavi, S.M.J., Ayatollahi, M.R., Samari, M., da Silva, L.F.M., 2019. Effect of interface non-flatness on the fatigue behavior of adhesively bonded single lap joints 233(7), 1277-1286.
Rincon Troconis, B.C., Frankel, G.S., 2013. Effect of Roughness and Surface Topography on Adhesion of PVB to AA2024-T3 using the Blister Test. Surface and Coatings Technology 236, 531-539.
Zhai, L., Ling, G., Li, J., Wang, Y., 2006. The effect of nanoparticles on the adhesion of epoxy adhesive. Materials Letters 60(25-26), 3031–3033.