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Effect of nano-particle dispersion methods on mechanical behavior of Al-GFRP bonded joints under bending moment

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***Abstract*- Reinforcement of adhesives by adding nano particles is an important issue for enhancing mechanical performance of bonded lap joints. In this paper, functionalized graphene nano platelets (GNPs) and nano silica particles were added to the structural epoxy adhesive at three weight percentages by implementing four dispersion procedures. The effect of dispersion procedures were investigated on static behavior of nano-reinforced adhesive Al-GFRP single lap joints subjected to four-point bending. Experiments revealed that, for a constant wt% of functionalized GNPs, using magnetic stirring and ultrasonic probe resulted in the greatest static failure load. But for nano silica particles, the maximum failure load was obtained by implementing the magnetic stirring and bath sonication procedure. Moreover, increasing the wt% of each nano particle in the adhesive enhanced the static failure load of the corresponding joint.**

***Keywords* –** Single lap joint, Bonded joint, Nano adhesive, Graphene nano platelet, Nano silica, Four-point bending

I. INTRODUCTION

Application of bonded joints especially metal to composite parts, has been increased in automotive, boat structures, marine, aeronautics, and wind turbine blades in recent years [1- 4].

The bonded components may be loaded by lateral forces perpendicular to the surfaces of adherends. This leads to a bending moment over the bonding area, and consequently, induces peeling stresses. These stresses are the major cause of failure in adhesively bonded joints [5]. Many researches were investigated the influence of geometrical parameters of the SLJ and type of materials on their mechanical strength under merely static four-point bending [6,7]. Zamani et al. [8] experimentally investigated the fatigue behavior, and influence of various maximum fatigue loads and load ratios on crack initiation of metal to composite SLJs.

Reinforcing the adhesive using nano particles can be an advantageous manner to improve the mechanical behavior of the joint. For this purpose, achieving a suitable method to better disperse the reinforcement particles is important. In this paper, functionalized graphene nano platelets (GNP-OH) and nano silica particles were added to the structural epoxy adhesive Araldite 2015 in order to investigate the influence of four dispersion procedures on mechanical strength of metal to composite single lap joints.

II. EXPERIMENTAL PROCEDURE

Materials and methods

Aluminum 2024-T3 and glass fiber reinforced plastic (GFRP) strips with 25 mm width were used as adherend materials. Uniaxial GFRP plates were fabricated using vacuum infusion process. The composite plates were cured initially at room temperature for 24 hr, and post-cured at 70^{o}C for 12 hr. Two part epoxy adhesive, Araldite 2015 was used to bond the adherends.

Preparation of Specimens

The surfaces of aluminum and GFRP strips were initially washed with acetone, the aluminum surfaces were abraded with #120 mesh sandpaper, both adherends were washed in distilled water, and they were dried in an oven at 45^{o}C for 25 min. The strips were bonded together under special clamps with 0.1 mm average thickness of adhesive layer [8]. Finally, the SLJs were cured initially at room temperature for 24 hr, and post-cured at 80^{o}C for 30 min [8].

Nano particles dispersion Methods

To investigate the significant effect of dispersion procedure of the nano particles on improving the mechanical properties of the joint, 0.5, 1, and 1.5 wt% of them were added to the adhesive using four different procedures. Because of the high adhesive viscosity, for all procedure, 20 gr epoxy resin was mixed with 20 gr acetone. The first step of all methods is mixing the epoxy resin and acetone by 1:1 weight ratio for 10 min by a magnetic stirrer at 180 rpm. The four dispersion methods were implemented as follows: Method I: 1) Adding specified values of nano particles to the resin and acetone mixture, and stirring for 60 min at 1200 rpm by a mechanical stirrer. Method II: 1) Adding the specified values of nano particles to the resin and acetone mixture, and stirring them for 60 min at 180 rpm using a magnetic stirrer. Method III: 1) Adding the specified values of nano particles to the resin and acetone mixture, and stirring them for 30 min at 180 rpm by a magnetic stirrer, 2) Stirred them by a bath-sonication device with 37 kHz ultrasonic frequency (Elma S40H, Elmasonics) for 1 hr. Method IV: 1) Adding the specified values of nano particles to the resin and acetone mixture, and Stirring them for 30 min at 180 rpm using a magnetic stirrer, 2) Stirring them using sonication probe (Top Sonics co.) with sonication power of 80 W, 1 second on/off cycle, and 1 hr duration. After the dispersion step, the mixture of resin, acetone, and nano particles were cured in a vacuum oven (VACIOTEM, JP SELECTA) at 70^{o}C for 3 hr in order to gently release the air bubbles and evaporate the acetone from the mixture.

Mechanical testing

The static four-point bending tests on the SLJ specimens were carried out using Zwick/Roell Amsler HB 100 testing machine by means of a new designed and constructed four-point bending fixture [8]. The static tests were performed at 5 mm/min crosshead speed. A configuration of SLJ specimen and the position of loading and supporting rollers are presented in Fig. 1a and 1b respectively.

Altogether, 12 testing cases were considered. For enough reliability, each testing case was repeated for five times. Therefore, 60 static tests were performed at room temperature and relative humidity of 50%.

III. RESULTS AND DISCUSSION

The load-displacement curves of reinforced Al-GFRP SLJs for 1 wt% of GNP-OH particles are shown in Fig. 2. In this figure, the first dispersion method has the least, and the method IV has the greatest static failure loads. Besides, the load carrying capacity of the joint decreased in the method I, because of abundant air bubbles and method II, for the reason of the flocculated nano particles. In addition for neat and GNP-OH reinforced at various wt% on method IV the static failure load was enhanced by increasing the wt% of the nano particles, and the greatest static failure load was obtained by adding 1.5 wt% of GNP-OH particles. The load-displacement results of the four dispersion methods at 1 wt% of nano silica particles showed that the greatest static failure load was obtained for the method III, and the least for method I. Consequently, the mechanical strength of the last was decreased in compare with non-reinforced SLJ specimens. It was also found that the static failure load was raised by increasing wt% of particles according to the load-displacement curves of nano silica reinforced SLJs for various wt% in accord with the method III.

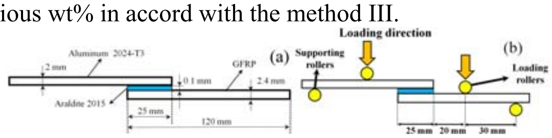

Fig. 1. (a) Geometrical dimensions of Al-GFRP SLJ, (b) Schematic of loading and supporting distances in four-point bending

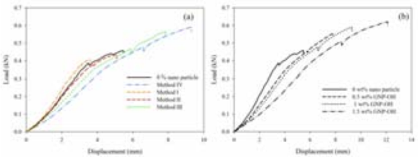

Fig. 2. Load-displacement curves of SLJs under four-point bending; (a) various dispersion methods for 1 wt% of GNP-OH , (b) non-reinforced, and GNP-OH reinforced

IV. CONCLUSION

Four dispersion methods, for GNP and nano silica particles at 0.5, 1, and 1.5 wt%, were applied to fabricate nano composite adhesives. Static four-point bending tests on neat and nano reinforced adhesive aluminum to GFRP single lap joints (SLJs), were performed. It was found that, for all wt%, GNP reinforced SLJs achieved to their greatest static failure load for method IV (magnetic stirring and ultrasonic probe) while the nano silica reinforced SLJs reach to their maximum static failure load by method III (magnetic stirring and sonication bath). For each nano particle, the static failure load was improved by increasing weight percent of nano particles. Beside, for method IV, the static failure load of GNP reinforced SLJs were greater than nano silica reinforced ones at 0.5, and 1 wt%. Conversely, for the same dispersion method and 1.5 wt%, the static failure load of nano silica reinforced joint was 2.3% more than the GNP reinforced joint. For method III of dispersion, the static failure load of nano silica reinforced SLJs were 7.5, 5.7, and 11.6% larger than GNP reinforced joints at 0.5, 1, and 1.5 wt%, respectively. For the methods I and II, the static failure loads of the reinforced joints were smaller than the non-reinforced SLJs because of an increase in air bubbles and nano particle agglomeration. Reinforcement of SLJs by 1 wt% nano silica in accord to method II was the only approach that resulted in approximately equal static failure load of neat SLJ.

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