EFFECT OF NANOCOMPOSITE POWDERS ON THE STRENGTH OF JOINTS BONDED WITH EPOXY ADHESİVE INCLUDED VARIED PROPORTİONS

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Abstract - There is a considerable interest nanoparticles added structural adhesives, recently. Because, nanoparticles improve the mechanical properties of an adhesive and its joint. In this paper, the static strengths of adhesive joints incorporating Al2O3 , TiO2 and SiO2 nanoparticles (2wt%, 4wt% and 6wt% proportions in the epoxy adhesive) were compared to those adhesive joints without nanoparticles. Experiments were performed 20, 25 and 30 mm overlap lengths, respectively. DP460 epoxy adhesive, Al2O3 , TiO2 and SiO2 nanoparticles and AISI 304 stainless steel plates were used for manufacturing the single lap adhesive joints. The results of the experimental research revealed that average shear failure load was increased significantly nanoparticle-reinforced adhesive joints. The highest shear strength was obtained with 4 wt % nano-Al2O3 in epoxy adhesive, being almost four times higher than that of the without nanoparticles. As the shear strength increased, the locus of failure changed from interfacial to the mixture of interfacial and cohesive.

Key words - Adhesive joints, single lap joints, nanoparticles, shear strength

I. INTRODUCTION

Adhesively bonded joints have been commonly used in almost every sector of the industry e.g., automotive, marine industry, space and aeronautics, as they offer significant advantages in applications. Different approaches were employed in the past to improve the mechanical behavior of bonded assemblies. Ferreira et al. [1] concerned with a fatigue study of composite adhesive lap joints produced from a bi-directional woven E-glass fibres and polypropylene. The effects of layer orientation, lap joint length and water immersion on the fatigue behaviour were studied. The specimens were immersed in water during periods until ninety days for controlled temperatures of 20, 40 and 70 °C. The results shows that creep deformation within the temperature range of this study was probably the mainly cause of the dynamic stiffness reduction observed.

The tensile debonding and shear properties of composite interfaces reinforced by two different homogeneously dispersed nanofillers, carbon nanotubes and alumina nanopowder, are investigated by Meguid et al.[2]. The results reveal that varying the weight percentage of the nanofillers into the epoxy matrix adhesive favourably influences the debonding and shear characteristics of the interface.the results also Show that increasing the amount of the nanofillers beyond a certain weight fraction of the adhesive reduced the interface.

Nanoparticles affects unique properties such as increased chemical activity and physical properties [3-6]. So many researches [7-9] have shown great promise for obtaining much increased performance, such as mechanical, fatigue and thermal properties with adding low concentrations of nanoparticles into epoxy. However, a systematic study of the influence of nanoparticles addition on the interfacial adhesion between an epoxy and steel is not available and only a few papers have reported the influence of nanoparticles addition on adhesion [2]. Therefore, it is very interesting to consider the influence of nanoparticles additive on the adhesion and understand the interface in the metal–polymer system and the adhesion mechanism.

In this paper, the static strengths of adhesive joints incorporating Al_2O_3 , TiO_2 and SiO_2 nanoparticles (2wt%, 4wt% and 6wt% proportions in the epoxy adhesive) were compared to those adhesive joints without nanoparticles. Experiments were performed 20, 25 and 30 mm overlap lengths, respectively.

II. MATERIAL AND METHOD

2.1. Materials

In experiment, AISI 304 stainless steel plate of 2 mm thickness was used as adherend and DP460 which is Two-component structural adhesive (DP460) produced by 3M company was used as adhesive. The mechanical properties of AISI 304 stainless steel is given in Table 1. The nanoparticles added to adhesive have 20 nm size and are Al_2O3 , TiO_2 and SiO_2 nanoparticles

Quality	304(1.4301) - X5CrNi18-10
Ultimate Strength	515-720 MPa
Yield Strength, (% 0,2)	210 MPa (min)
Hardness, Rockwell (HB)	201

Table 1. The mechanical properties of AISI 304 stainless steel

2.2.Experimental

In this study, the mechanical behaviors of nonoparticles added adhesively bonded single lap joints were investigated experimentally. The parameters and joint geometry used in experiment are given in Table 2 and Figure 1, respectively. The single lap joints are classified to three groups according to overlap length. Each situation for all parameters was repeated three times experimentally.

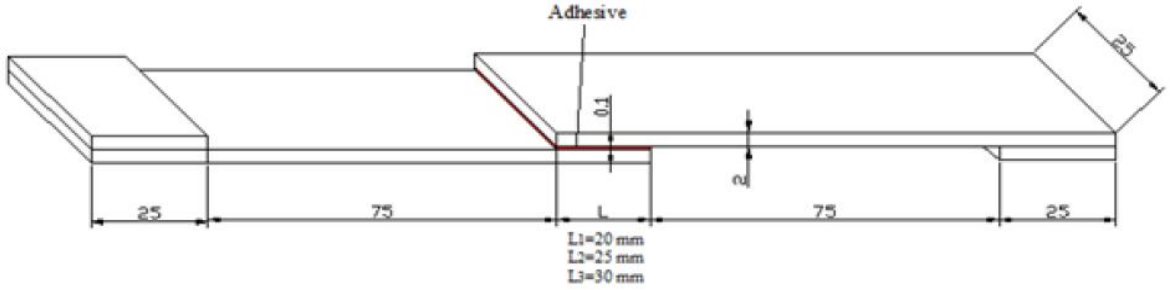


Figure 1. The Single lap joint geometry

Type	Overlap length (mm)	Nanoparticle	Adding prop.(wt%)
Type- I-a	20	Pure adhes.	-
Type- I-b	20	Al_2O_3	% 2
Type- I-c	20	Al_2O_3	% 4
Type- I-d	20	Al_2O_3	% 6
Type- I-e	20	TiO_2	% 2
Type- I-f	20	TiO_2	% 4
Type- I-g	20	TiO_2	% 6
Type- I-h	20	SiO_2	% 2
Type- I-ı	20	SiO_2	% 4
Type- I-j	20	SiO_2	% 6
Type- II-a	25	Pure adhes.	-
Type- II-b	25	Al_2O_3	% 2
Type- II-c	25	Al_2O_3	% 4
Type- II-d	25	Al_2O_3	% 6
Type- II-e	25	TiO_2	% 2
Type- II-f	25	TiO_2	% 4
Type- II-g	25	TiO_2	% 6
Type- II-h	25	SiO_2	% 2
Type- II-ı	25	SiO_2	% 4
Type- II-j	25	SiO_2	% 6
Type- III-a	30	Pure adhes.	-
Type- III-b	30	Al_2O_3	% 2
Type- III-c	30	Al_2O_3	% 4
Type- III-d	30	Al_2O_3	% 6
Type- III-e	30	TiO_2	% 2
Type- III-f	30	TiO_2	% 4
Type- III-g	30	TiO_2	% 6
Type- III-h	30	SiO_2	% 2
Type- III-ı	30	SiO_2	% 4
Type- III-j	30	SiO_2	% 6

Table 2. The parameters used in experiments

It is necessary to remove the substances such as paint, oil and dust on the surface before bonding. For this purpose, steel sheets were degreased with acetone, sandblasted, washed in running tap water and dried in an oven for 20 min at 65 ºC, before bonding. Steel sheets were bonded with the DP460 two-constituent (2/1 mixing ratio) structural liquid adhesive (3M Scotch-Weld), by curing at room temperature in a press under 0.1 MPa pressure for a day (Fig.2). Three samples of each joint type were produced. For nanoparticle added joint, before bonding, nanoparticle was weighted (Fig. 2) according to adding proportion. Then added to adhesive and was mixed The test specimens were produced to have a thickness of 2 mm and an overlapping length of 20, 25 and 30 mm. Experiments were carried out in a universal tensile test machine with a drawing speed of 1 mm/min at a room temperature of 24 ºC and in 35% humid environment one week after the production of the specimens

III. RESULTS AND DISCUSSION

The average tensile failure loads of single lap joints bonded with pure adhesive and Al_2O_3, TiO_2 and SiO_2 nanoparticles added adhesive are given in Figure 4-6. When the figures are investigated it can be seen that the addition of nano-Al_2O_3 and nano-TiO_2 into epoxy adhesive increases the strength of the joints until 4 wt % proportion, then decreases. Whereas the addition of nano-SiO_3 into epoxy adhesive increases the strength of the joints until 6 wt % proportion.

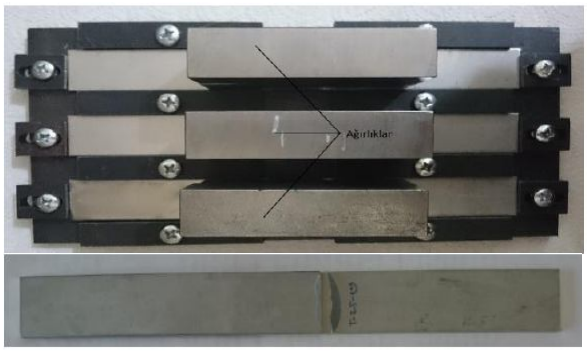


Figure 2. Test Specimens

The reason of this is that addition of nanoparticles into epoxy adhesive changes its chemical property,

resulting in carboxyl groups. Carboxyl group, which was used to improve the adhesion of a commonly used epoxy coating [10], showed the highest interaction with metal than other functional groups [11,12].

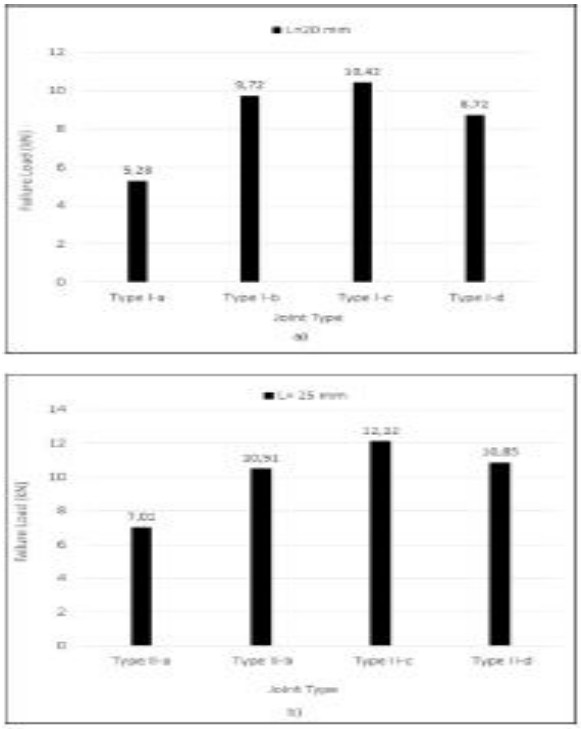
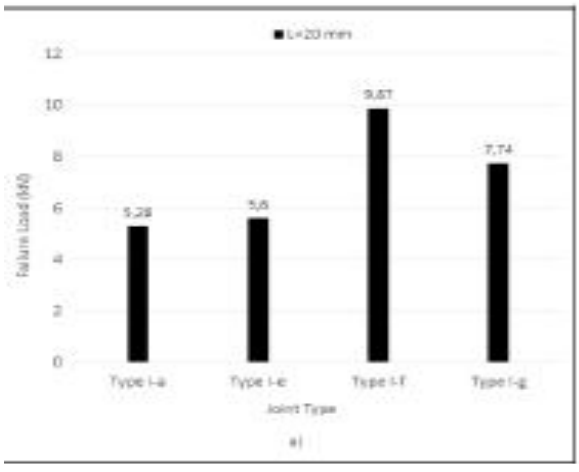
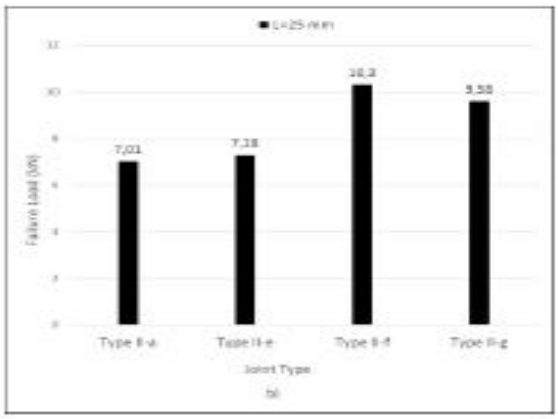


Figure 4. Tensile failure loads of single lap joints bonded with pure and Al_2O_3- nanoparticle added adhesive for 20, 25 ve 30 mm over lap length.





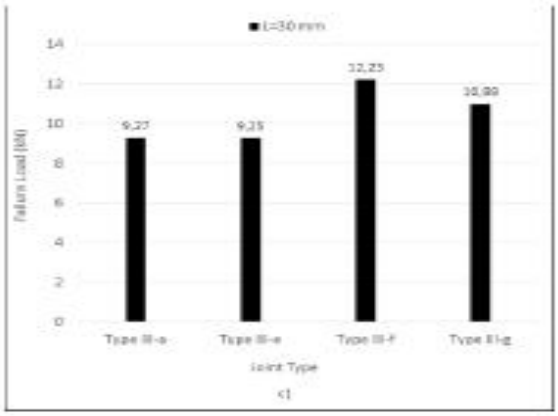
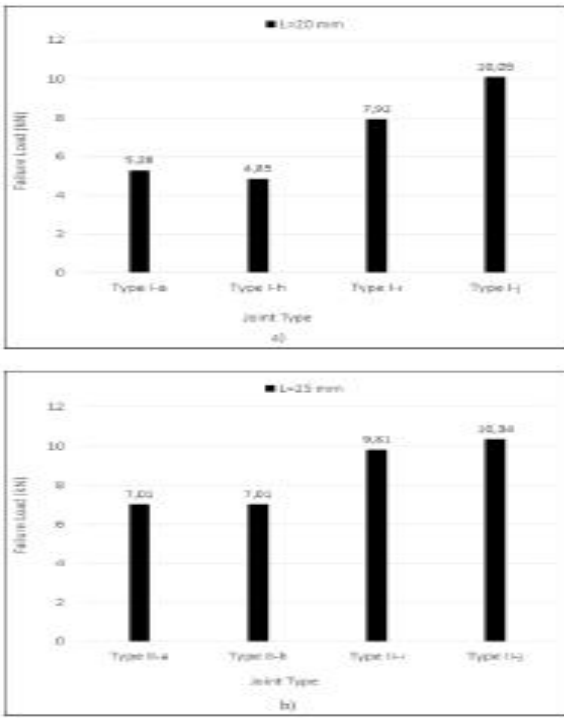


Figure 5. Tensile failure loads of single lap joints bonded with pure and TiO_2 -nanoparticle added adhesive for 20, 25 ve 30 mm over lap length.

When figures are investigated, it is shown that, average tensile failure loads increase with increase in overlap length, but the increase ratio in failure loads decreases.



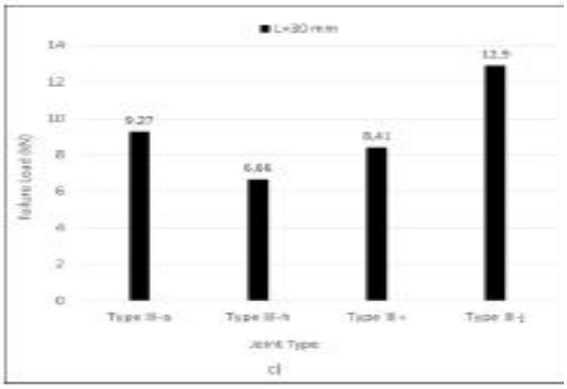


Figure 6. Tensile failure loads of single lap joints bonded with pure and SiO2-nanoparticle added adhesive for 20, 25 ve 30 mm overlap length.

Images of failure surfaces of the joint bonded with pure adhesive and with 4wt% nano-Al_2O_3 additive adhesive are given Figure 7. It can be seen from images that the interface failure of the joint bonded with pure adhesive is adhesion failure, for adhesive removed from adherend surfaces and failure occurred at interface between adhesive and steel surface. However, the interface failure of the joint bonded with nanoparticle added adhesive is cohesion failure, for the adhesive layer present on adherend surfaces and failure occurred at interface between adhesive. In this case, it can be said that the addition of nanoparticle in adhesive increases the adhesion force occurs between adhesive and adhesion surface and this case gives rise to higher joint strength.

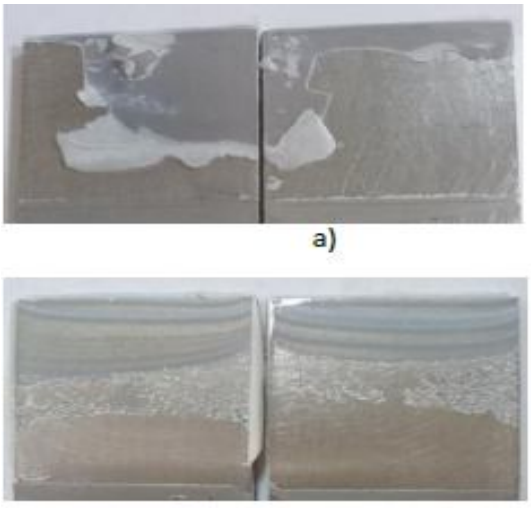


Figure 7. a) İmages of failure surfaces of the joint bonded with pure adhesive b) İmages of failure surfaces of the joint bonded with 4wt% nano-Al2O3 additive adhesive

Type	Overlap Length (mm)	Failure Load (kN)	Average Failure Shear Stress (MPa)
Type--I-a	20	5.28	10.56
Type--II-a	25	7.01	11.2
Type--III-a	30	9.27	16.1

Table 3. The failure loads and failure shear stresses of the joint bonded with pure adhesive.

Type	Overlap Length (mm)	Failure Load (kN)	Average Failure Shear Stress (MPa)
Type--I-c	20	10.42	20.84
Type--II-c	25	12.12	19.39
Type--III-c	30	12.97	17.29

Table 4. The failure loads and failure shear stresses of the joint bonded with 4wt% nano-Al2O3 additive adhesive.

Failure shear stresses of the joint bonded with pure adhesive and with 4wt% nano-Al_2O_3 additive adhesive are given in Table 3 and 4. When tables are examined it can be said that, the increase in overlap length increases the average failure shear stresses of the joint bonded with pure adhesive, while the increase in overlap length decreases the average failure shear stresses of the joint bonded with additive adhesive.

CONCLUSIONS

In this study, effects of addition of nanoparticle in adhesive on the strength of adhesively bonded single lap joints, which were subjected to tension, were investigated experimentally. The following results were obtained from these experimental studies:

1. The addition of nano-Al_2O_3 and nano- TiO_2 into epoxy adhesive increases the strength of the joints until 4 wt % proportion, then decreases. Whereas the addition of nano-SiO_3 into epoxy adhesive increases the strength of the joints until 6 wt % proportion. The reason of this is that addition of nanoparticles into epoxy adhesive changes its chemical property, resulting in carboxyl groups. Carboxyl group, which was used to improve the adhesion of a commonly used epoxy coating, showed the highest interaction with metal than other functional groups.
2. -The interface failure of the joint bonded with pure adhesive is adhesion failure, however, the interface failure of the joint bonded with nanoparticle added adhesive is cohesion failure.
3. -The addition of nanoparticle in adhesive increases the adhesion force occurs between adhesive and adhesion surface and this case gives rise to higher joint strength.
4. The increase in overlap length increases the average failure shear stresses of the joint bonded with pure adhesive, while the increase in overlap length decreases the average failure shear stresses of the joint bonded with additive adhesive.

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