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Nano Clay Additive Effect on Shear Strength of GFRP Joints

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Abstract

Adhesively bonding joints are widely used in various industries such as aviation, automotive and marine due to its advantages such as lightness, sealing ability, low cost, corrosion resistance and uniform stress distribution. Increasing the quality and durability of adhesives using various methods is a matter of interest both in science and engineering. This study investigates the role of the addition of Nano-clay particles to epoxy resin on the shear strength of single lap GFRP bonding joints. For this aim, Nano-silica particles were added in epoxy resin, 1%, 2%, 3% and 5% by weight. The experimental results obtained from lap shear test showed that the increase in shear strength was about 36, 91 and 63% for 1, 2 and 3 wt. respectively.

Keywords: Single-lap joints, Nano-clay particles, GFRP, shear strength

1. INTRODUCTION

Composite plates made of fiber reinforced polymer have been widely used since four decades ago for major and minor structures in many engineering applications, because they offer significant features over conventional structures made of metals only. These features include considerable reduction in weight, low maintenance and manufacturing costs and hence improving performance [1]. Joining composite materials by adhesives is preferable due to absence of stress concentration emerging in bolted and riveted joints as well as lack of defects induced by machining. The adhesive bonding offers excellent sealing, superior fatigue strength and good performance in raised temperature [2].

Adhesives are, in a simple sense, fluid or semi-fluid liquids which adherent materials using surface or chemical bonds, either natural or synthetic. Adhesion is basically the atomic and molecular interaction between two surfaces [2]. As well as the method's practical and low cost, mechanical, thermal and permeability of epoxy adhesives offer promising developments in an adhesive's properties.

Increasing the quality and durability of adhesives using various methods is a matter of interest both in science and engineering. Among these methods, the use of Nano-particles, such as Nano-fibers, carbon nanotubes, Nano-clays and graphite, as well as practicality and low cost, as well as mechanical, thermal and permeability of

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epoxy adhesives. It offers promising developments in its characteristics [3]. Nanoparticles exhibiting many unique mechanical properties have become one of the most attractive options in recent years to increase the strength of polymer materials and adhesives [4, 5]. In this regard, studies were made on the performance of adhesive bonds by adding many different nanoparticles such as aluminum oxide [6, 7] titanium oxide [8], Nano-graphite [9], carbon nanotube [10] and Nano-clay [11].

Khalili et al. [11] have investigated the mechanical properties of glass fiber composite to composite's single bond connections combined with the Nano-clay addition to the epoxy adhesive under static and dynamic loading in a study they performed, as a result, 1 wt. % of the Nano-clay particles showed maximum strength at tensile load.

Polymer clay nanocomposites (PCN) have recently attracted a great deal of academic and industrial interest, as the clay contribution on the nanometric scale dramatically increases the mechanical and thermal properties [12]. Montmorillonite nano-clay particles have been documented as the best reinforcing materials for PCNs, because they have high aspect ratio, low cost, and they consist of layered silicates that can be placed in separate nano-dimensions with polymer chains [13].

Jeyekumar et al. [14] have produced glass fiber composites using 1, 3, 5, 7% Nano-clay by weight. They supplied homogeneity dispersion and observe it in SEM. The samples were subjected to tensile and impact tests. Results show that addition of nano-clay 5% by weight increased tensile strength, flexural strength and impact strength by 23.66%, 53.86% and 29.65%, respectively.

Galimberti et al. [15] have investigated mechanical, barrier and thermal properties of composites produced using Nano-clay in a study they have done. It has been specified that the Nano-clay minerals increase the thermal properties of the adhesive.

According to the studies [16-17], if nano-clay addition into the polymer composites is less than 5 % by wt, it could get best result in dispersion, mechanical and thermal properties. Increasing the amount of Nano-clay will also increase the viscosity of the reinforced polymer system, and higher viscosity polymer will cause higher temperature during the sample fabricating.

In the light of progress made in joining technologies, adhesive bonding of composite materials has been become simpler in terms of alignment and consuming time. Many studies have been pointed out the significance of toughening and strengthening adhesives. Studies have shown that the addition of various low concentration Nano-particles to the resins of polymer composites is a good solution to improve mechanical and impact performance without sacrificing toughness or manufacturing process. Although studies on these new nanocomposites are common, there are a limited number of studies on the effect of Nano-clay addition on the adhesive when plate-like materials are combined with adhesive. The mechanical connections and the degradation processes of the adhesively bonded joints are very complex, too. And also many factors such as the type of adhesive, the type of adherent materials, the overlap length and the thickness of the adhesive affect the strength of the connections. Therefore, these effects need to be better understood by using different Nano-particles, different adherents and different adhesives. So, in this study, the effects of adding Nano-clay particles to commercial epoxy resin on the shear strength of GFRP single-lap joints are investigated. The overall aim of this study was to develop a relatively inexpensive and strong adhesive for common engineering applications.

2. EXPERIMENTAL STUDY

2.1. Materials

Clay is known to scientist for centuries; however its application as a reinforcing agent in polymers is relatively recent. Nano-clay type Montmorillonite (MMT) was used as a Nano-filler in this study to reinforce epoxy resin (Figure 1). MMT is hydrated alumina-silica clay

composed of a central alumina octahedral layer and two tetrahedral layers. MMT Nano clay was obtained from Grafen Chemical Industries, Turkey. MMT Nano-clay particles are at 1-10 nanometer sizes with dimethyl dialkylamine and their technical properties are shown in Table 1.

Table 1. Properties of nanoclay particles

Properties	
Loss in Drying (%)	<3
Mass Density (kg/m ³)	200-500
Lateral Width (μm)	0.5-2
Thickness (nm)	1-10



Figure 1. MMT Nano- clay particles

Fiber reinforced polymer (FRP) composite materials are widely used in aerospace, civil and structural industries because of several favorable properties such as low density, high specific strength and stiffness. In addition, the fatigue strength to weight ratios as well as fatigue damage tolerances of many composite laminates is excellent. Thus, FRP composites have emerged as a major class of light-weight structural material. In this study, Glass Fiber Reinforced Polymer G10-FR-4 plate in 2 mm thick was used. G10-FR-4 glass fiber reinforced polymer platters are thermosetting industrial fiberglass composite laminates made of epoxy resin-bonded continuous filament glass fiber material. G10-FR-4 GFRP plates commercially produced were bought from Kubar Pompa, Küçükparmak Mühendislik San. Tic. Ltd. Şti. Turkey. Its mechanical properties are given in Table 2.

MOMENTIVE-MGS L160 epoxy resin and MOMENTIVE-MGS H260S hardener were used as an adhesive material in the experiments which were supplied from DOST Chemical Industrial Raw Materials Industry, Turkey. Resin and hardener mixing ratios are 100:36±2 in weight and 100:43±2 in volume. This adhesive system has an excellent environmental resistance and bonds to a variety of substrates. The original properties, as provided by the manufacturer, are given in Table 3.

Table 2. Properties of GFRP

Properties	
Density (g/cm ³)	17.101
Buckling Strength (MPa)	357.00
Tensile Elastic Modulus (MPa)	23752
Pressure Resistance (N/mm ²)	371.20
Notch Impact Strength (Parallel to Lamination) (kJ/m ²)	117.79

Table 3. Physical properties of laminating resin and hardener (at 25 °C)

	MGS L160 resin	MGS H260 hardener
Density g/cm ³	1.13-1.17	0.93-0.97
Viscosity MPa	700-900	80-100
Epoxy equivalent gr/equivalent	166-182	-
Epoxy value equivalent/100gr	0.55-0.60	-
Refractor index	1.5480-1.5530	1.4980-1.4985
Amine value (mgr. KOH / gr)	-	450-500

2.2. Preparation of Adhesive Joint Samples

GFRP composite plates, were wiped with acetone, abraded with an abrasive paper, wiped with a dry cloth to remove released atoms, and then wiped again with acetone. Water proof silicon carbide abrasive paper grade P120D was used to prepare the bonding areas for adhesive bonding.

The epoxy resin was modified by different weight ratios of clay nanoparticles. For lap shear test, clay Nano-particles was added by 1, 2, 3 and 5 % wt. five samples for each epoxy mixture design were prepared and tested. Epoxy resin was firstly put on the cup and after required amount of Clay nanoparticle was added and mixed with mixed with a light load homogenizer at 22,000 rpm for 10 minutes. Hardener was added with 100:40 stoichiometric ratios to the mixture after getting homogeneous mixture and mixed with the same speed for 10 minutes. Finally, mixture was waited for 10 minutes to remove bubbles.

The adherents were prepared from GFRP composite plates by geotine machine as rectangular pieces with appropriate dimensions according to ASTM D5868 – 01 as shown in Figure 2. Single lap joints (SLJ) were created using two thin adherents; each one is 25 mm in wide and 100 mm in long. They were bonded with a 25 mm overlap length, resulting in an overall sample that is 25 mm wide by 175 mm long. The two adherents were of same material. The thickness of the adherents was 2 mm. The adhesive bond-line thickness was 0.1 mm.

Single lap joint is the most popular configuration used in engineering applications such as automotive, wood and plastic, and aerospace industries. Single lap samples are practical, economical and easy to produce. Single lap joints can improve joining efficiency of dissimilar materials. The single lap joint is vastly utilized in adhesive bonding and has been the subject of significant research in the last decades. It also allows easy control and measure of the bond thickness. The simple and efficient design of a single lap joint often enables to evaluate the mechanical properties of the adhesive bonded joints [18].

An aluminum mold (Figure 3) was used to produce SLJs consistent. The mold was machined as stepped base to obtain the required thickness of the bond-line (i.e., 0.1 mm). The aluminum mold was previously coated by release agent to prevent samples from attaching to its surface. SLJs samples were prepared first by applying the adhesive onto one substrate. The second substrate was then placed accordingly to obtain the desired

overlap length and excess resin was wiped from the edges. The substrates were then bonded together and carefully cured at a room temperature for 7 days.

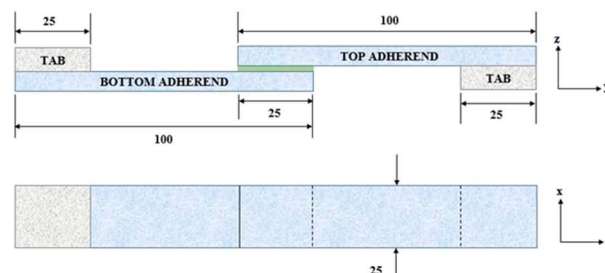


Figure 2. Dimensions of single lap joint according to ASTM D5868 – 01

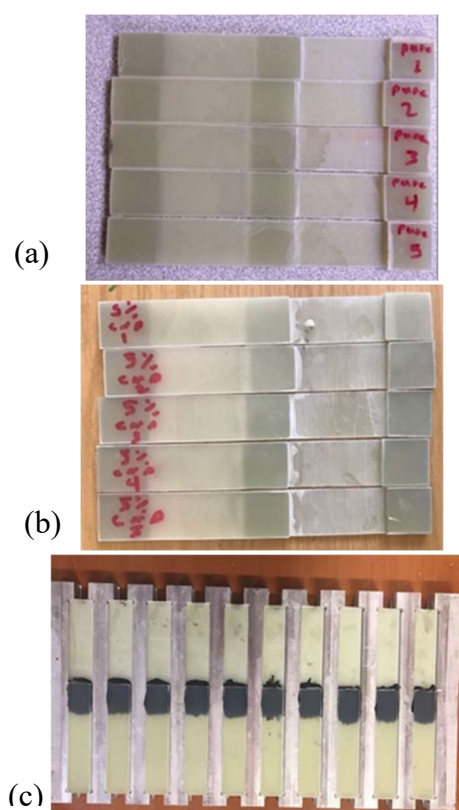


Figure 3. Production of single lap joint samples with the help of aluminum mold (a) Neat epoxy samples, (b) Nano-clay samples, (c) Mold

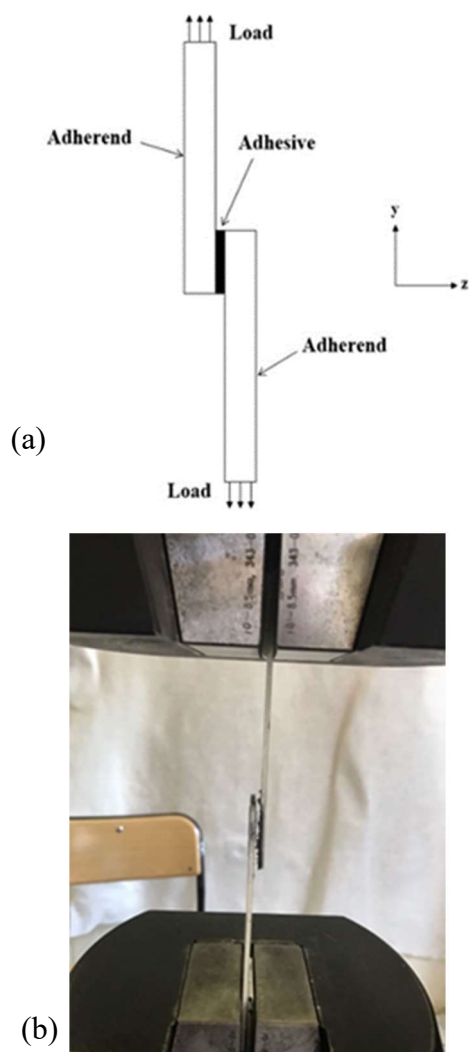


Figure 4. Lap shear test, (a) Schematics of the test set-up, (b) test sample under lap shear loading till fracture

SHIMADZU universal tensile testing machine with 300 kN loading capacity was used to perform tests. Samples were pulled at extension rates of 1.0 mm/min until failure, based on ASTM D3165 – 07 standards as shown in Figure 4.

3. RESULTS AND DISCUSSION

3.1. Shear Test Results

Single lap adhesive bonded joints were prepared with epoxy/Clay nanoparticle (CNP) composite adhesives and tested under lap shear loading in tension. The joints based on different weight ratios of CNP were tested and compared with control samples of neat epoxy. Two parameters fundamentally dominate the adhesive strength: (a)

mechanical characteristics of the epoxy resin and CNP and (b) adhesion properties and viscoelastic behavior of epoxy resin. In previous researches on adhesively joints of epoxy [19], it was noticed that the mechanical properties of the joints increased with the increase of Nano particle content, but, at the same time, their viscoelastic behavior has been changed from liquid-like to solid-like. Thus, it was likely that epoxy containing high weight content of CNP will not have good adhesion properties. The results of lap shear tests in tension on the adhesive joints prepared with epoxy containing different amounts of CNP were obtained and presented in load-displacement diagram (Figure 5). The maximum shear strength of SLJs (Figure 6) is estimated using the average maximum shear stress shown in Figure 5.

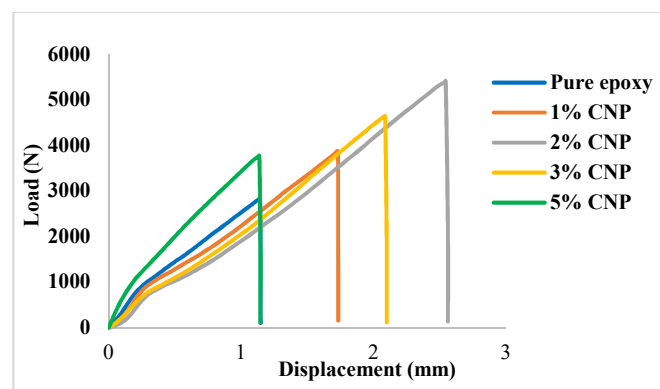


Figure 5 Load-displacement curves for SLJs reinforced with different amounts of CNP and subjected to tensile loading

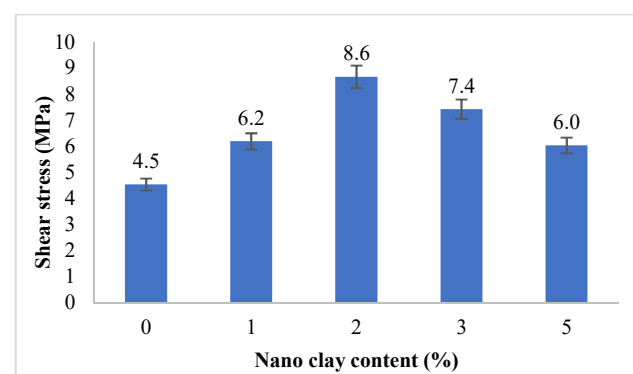


Figure 6. Maximum shear strength of SLJs versus CNP weight content

The variations of standard deviation for the results shown in Figure 6 were 0.276 to 0.661 MPa for composite epoxy. The influence of CNP incorporation into the adhesive layer on the shear

strength of SLJs was studied comparatively by the results of adhesive joints reinforced and unreinforced with CNP. It can be seen that the shear strength of adhesive joints increased with the addition of CNP, but above 2 wt. % of CNP, the shear strength decreased. The shear strength values for pure epoxy and epoxy reinforced with 1, 2, 3, and 5 wt. % of CNP were 4.532, 6.187, 8.653, 7.417, and 6.026 MPa, respectively. The results obtained from the lap shear test can be given in Table 4 1 to 2% by weight of nano-clay was added to the epoxy resin, the shear strength increased by about 36% and 91%, respectively. When CNP content exceeded 2 wt. %, the shear strength of adhesive joints decreased with the increase of Nano clay amount. This can be attributed to the aggregation of particles which causes stress concentration and crack growth in the adhesive layer and lead to sudden failure under lower stresses. However, the results showed that the bonded joints with Nano-clay particle reinforced adhesive, for all epoxy/Nano-clay contents considered in this study, have shear strength higher than that of control samples. The increase in shear strength was about 36, 91, 63, and 33% for 1, 2, 3, and 5 wt. % of CNP.

Table 4. Lap shear test results of SLJs with various amounts of CNP

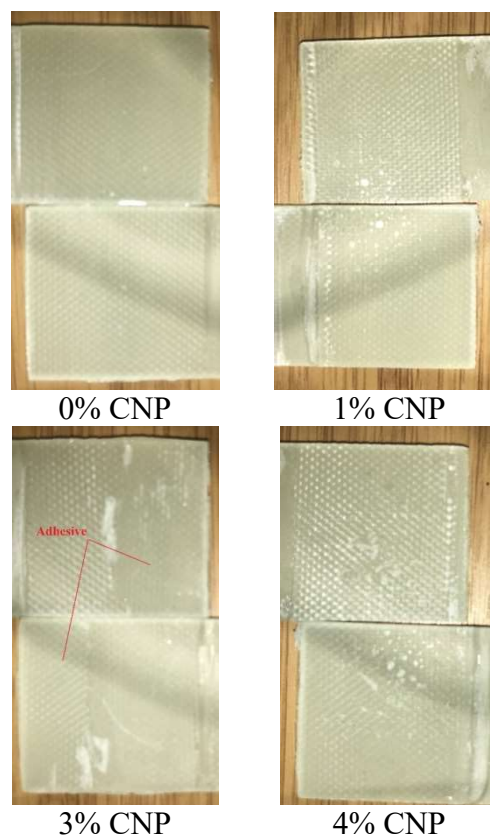
Sample code	Epoxy + Hardener (%)	Clay (wt. %)	Max. Force (N)	Max. Shear stress (MPa)	Max. Shear strain (%)
T ₀	100	0	2832.472	4.532	4.573
T ₁	99	1	3867.078	6.187	6.927
T ₂	98	2	5408.394	8.653	10.187
T ₃	97	3	4635.823	7.417	8.355
T ₅	95	5	3766.573	6.026	4.554

3.2. Failure Modes of Adhesively Single Lap Joints

There are two fundamental failure modes in adhesive bonded joints: adhesive failure and cohesive failure. Adhesive failure is an interfacial failure caused by complete separation between the adhesive and the adhered at one side. Cohesive failure is taken place in the adhesive layer only when a thin layer of adhesive still stuck on both sides. A combination between the two modes of

failure can be obtained if the joint is neither strong enough to fail cohesively nor very weak to fail adhesively [20]. Nano-particles have the ability to fill micro voids of the substrate surfaces, emerging new points of contact and hence great opportunity to improve the adhesion strength is offered.

After the tensile tests, when the specimens are visually inspected, the difference in adhesion type deterioration is remarkable between the pure epoxy samples and the Nano-clay doped samples see Figure 7. In the unadulterated samples, the adhesiveness of the adhesive is low and there is a large amount of adhesion damage in the sample surfaces. Increasing the ratio of Nano-clay in the adhesive causes the damage type to turn into cohesion damage. While at 1.0 %, 2.0 % and 3 % Nano-clay doped joints, cohesion damage is observed in large proportions, adhesion damage is also present. In the case of 5% Nano-clay doped samples, as can be seen in Figure 7, the roughness on the surface of the adhesive increases, and in this respect, the adhesive property of the adhesive decreases.





5% CNP

Figure 7. Fracture surfaces of SLJs after shear test

4. CONCLUSION

This work was undertaken primarily to determine the influence of various weight percentages of clay Nano-clay particles utilized to reinforced adhesively bonded single lap joints under shear loads. The overall aim of this study was to develop a relatively inexpensive and strong adhesive for common engineering applications. The experimental results showed excellent improvements in the mechanical properties with addition of the Nano-clay particles. Based on those results, it can be concluded the following:

- The addition of Nano-clay particles efficiently improves the chemical compatibility between epoxy adhesive and composite substrate surfaces and hence more efficient wetting of surface which causes increasing shear strength of the joint.
- The inclusion of Nano-clay particles into the epoxy resin resulted in more ductile behavior and this gives more uniform stress distribution across the joint and results higher strength.
- The maximum shear stresses value 8.653 MPa was obtained with the 2 % by wt addition of CNP, resulting in percentage increase in shear stress of about 91% compared to the neat epoxy resin joints.
- The experiments have shown that there is a powerful correlation between the joints strength and the failure mode. Increasing the ratio of Nano-clay in the adhesive causes the damage type to turn into cohesion damage. While at 1.0 %, 2.0 % and 3 % Nano-clay

doped joints, cohesion damage is observed in large proportions, adhesion damage is also present.

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