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INVESTIGATION OF THE EFFECT OF CLAY, GNP AND SiO_2 NANOPARTICLE ADDITIONS ON THE MECHANICAL PROPERTIES OF HYBRID FMLs

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Abstract. In this study, tensile and three-point bending tests of hybrid fiber metal laminated (FML) composites were performed according to ASTM D3039 and ASTM D7264 standards, and the effects of the addition of 1% clay, 1% GNP and 1% SiO_2 nanoparticles on the mechanical properties were investigated. As a result of the experiments, it was observed that the addition of 1% GNP improved the tensile strength properties of hybrid FMLs by 5.08%. In the three-point bending tests, it was observed that the addition of 1% clay was more effective and improved the bending strength values of the composites by 258.31%. In hybrid FML composites, the addition of nanoparticles to epoxy resin improved mechanical properties due to improved adhesion properties and crack bridging mechanisms between fiber and nanoparticles, and these improvements coincided with changes in microstructure.

Keywords: *Hybrid FML composites, GNP, SiO_2, clay, tensile test.*

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1. Introduction

Hybrid FML composites are multi-purpose engineering materials in which fiber and metal sheets are combined with the help of resin (Sinmazcelik *et al.*, 2011). Hybrid composites have unique properties that can meet different design needs more perfectly than traditional composites (Remmers *et al.*, 2001; Afaghi-Khatibi *et al.*, 2000). These composites have been developed as an alternative to single-reinforced composite materials (Remmers *et al.*, 2001). In Figure 1, the FML composites available in the industry are shown schematically.

The use of nanoparticles as a reinforcing material in composites aims to benefit from the unique properties of these particles (Hossein-Zadeh *et al.*, 2012). In hybrid FML composites, nanoparticles are used to increase adhesion between fiber-metal plates and prevent delamination (Alishahi *et al.*, 2013; Ayatollahi *et al.*, 2011). When similar studies are examined in the literature, it is seen that the addition of 1% by weight of different nanoparticles to the epoxy improves the mechanical properties of the composite materials (Ayatollahi *et al.*, 2011; De Cicco *et al.*, 2017; Kashfi *et al.*, 2019).

(Megahed *et al.*, 2019a) tested the effects of 1% different nanoparticle (SiO_2, Al_2O_3, TiO_2, clay) reinforcements on the mechanical properties of FMLs. In their experiments, they observed that 1% SiO_2 reinforcement significantly increased the tensile strength of FMLs. (Alsaadi *et al.*, 2021) emphasized that epoxy/kevlar composites and GNP

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composites used as reinforcement material in epoxy/carbon/kevlar composites have a positive effect on tensile, impact and bending strength. (Shokrieh *et al.*, 2014) investigated the effects of 1% GNP and 1% graphite nanoparticle reinforcement to epoxy resin on the mechanical properties of composites. In the study, they observed that the tensile strength of nanocomposites increased by 15.7% with the reinforcement of 1% GNP by weight, and the tensile strength value increased by 14% as a result of the addition of 1% graphite. (Wu *et al.*, 2019) stated in their study that bending strength and bending modulus of the composites produced by adding graphene oxide at different rates into aramid/epoxy composites increased and strengthened the interfacial bond between the matrix and the fiber.the tensile strength value increased by 14% as a result of the addition of 1% graphite. (Wu *et al.*, 2019) stated in their study that bending strength and bending modulus of the composites produced by adding graphene oxide at different rates into aramid/epoxy composites increased and strengthened the interfacial bond between the matrix and the fiber.

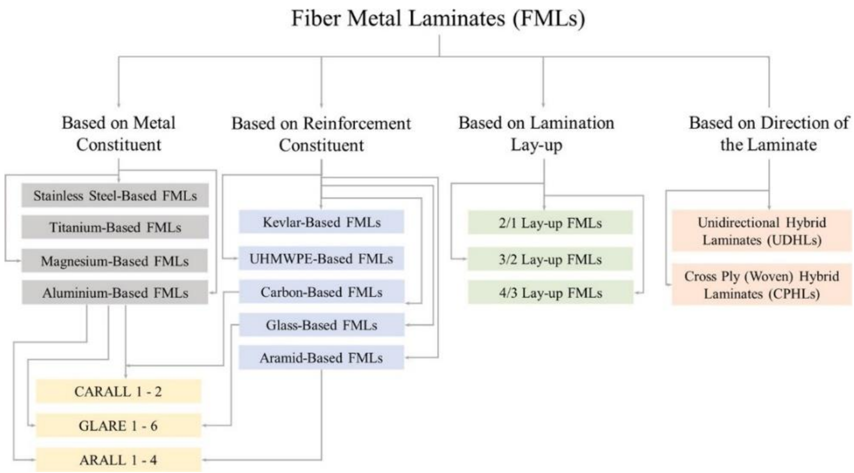

Fig. 1. Classification of FML composites
(Sinmazcelik *et al.*, 2011; Remmers *et al.*, 2001; Afaghi-Khatibi *et al.*, 2000)

Megahed et al. (2019b) observed that the reinforcement of 1% by weight carbon and SiO_2 nanoparticles significantly improved the tensile strength of glass/epoxy composites. Ferreira et al. (2012) investigated the effects of 3% clay nanoparticle reinforcement to epoxy resin on the fatigue behavior of composites in kevlar fiber composites produced by hand lay-up method. As a result, it was observed that the clay nanoparticle additive increased the rigidity of the material by decreasing the bending and tensile strength of the composite.

Since the presence of metals in FMLs provides high toughness to the composite structure, it improves the impact resistance, and the fibers prevent crack propagation under dynamic loads (Afaghi-Khatibi *et al.*, 2000; Abouhamzeh *et al.*, 2015). This brings FML composite materials to the fore as it significantly increases fatigue performance and damage tolerance in structures (Cortés & Cantwell, 2004; Logesh *et al.*, 2015; Domingues *et al.*, 2003).

As can be seen from the literature reviews above, nanoparticle reinforcements positively affect the mechanical properties of hybrid FMLs. According to these results, it was aimed to produce and mechanical test hybrid FML composites reinforced with GNP, SiO_2 and clay nanoparticles in order of 4/3 stacking.

2. Material and method

2.1. Material

Hybrid FMLs were produced in accordance with the 4/3 stacking procedure (Al / CF 0° - CF 0° / Al / CF 0° - CF 0° / Al / CF 0° - CF 0° / Al). In the production of composites, 7075-T6 aluminum sheets cut in 1mm thickness and 10x10cm dimensions as matrix material, 0.5mm thick unidirectional carbon fiber fabric with 300 gr/m^2 fiber density and MGS L326 coded epoxy resin were used as reinforcement phase between metal matrix elements. In addition, 18 nm thick clay (99.95%), 3 nm thick graphene (99.5%) and 15 nm thick silica (99.50%) were added to MGS L326 epoxy at a rate of 1% to be used in the production of nanoparticle reinforced FML composites. SEM photographs of epoxy resin and nanoparticles with different geometric shapes are shown in Figure 2.

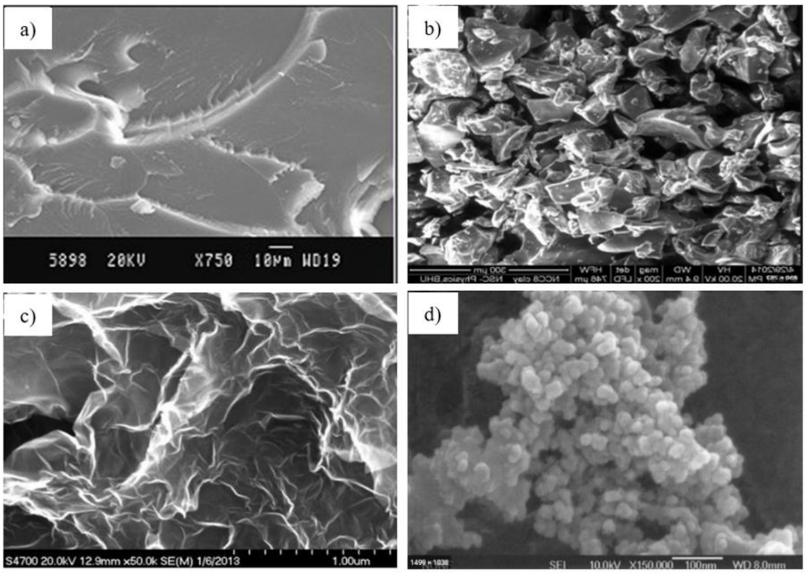

Fig. 2. SEM images of epoxy resin and nanoparticles: (a) epoxy resin, (b) clay nanoparticle, (c) GNP, (d) SiO_2 nanoparticle

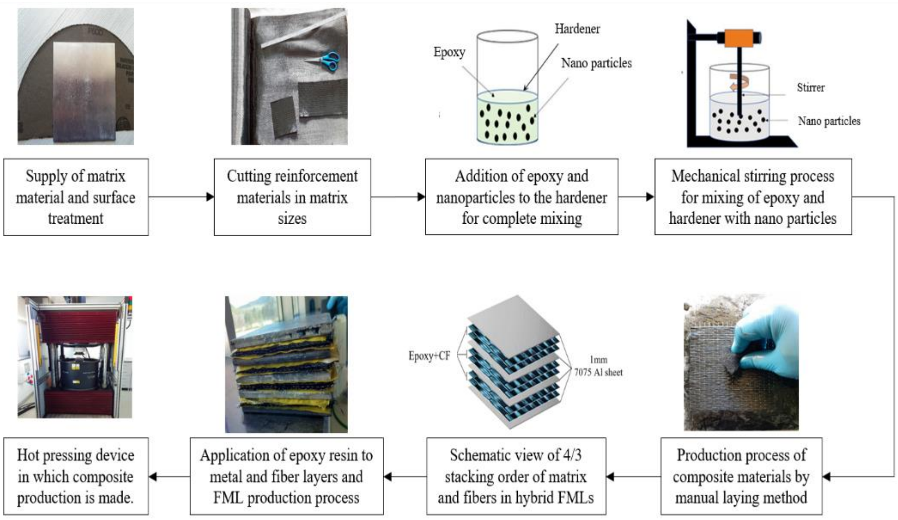

Fig. 3. Production processes of hybrid FML composite materials

The materials, which were stacked using the manual placement method, were pressed in a hot press device at 120°C for 3 hours and under 1 ton pressure. After 3 hours, the composite materials were removed from the device and allowed to cool at room temperature for 24 hours. Production processes of hybrid FML composite materials are given in Figure 3.

2.2. Mechanical Characterization

In order to determine the mechanical properties of the composites, tensile tests according to ASTM D3039 standard and three-point bending tests according to ASTM D7264 standard were applied. Tensile tests of composite specimens were performed at a tensile speed of 1 mm/min^{-1} and three-point bending tests were performed at a bending speed of 1 mm/min.3D models of composite samples belonging to tensile and bending tests are given in Figure 4.

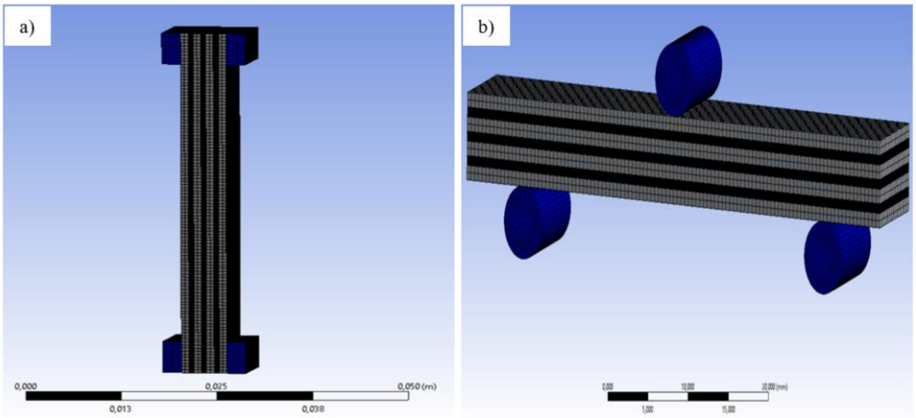

Fig. 4. 3D configuration of FMLs test samples: (a) 3D model of tensile test, (b) 3D model of three-point bending test

2.3. Optical Characterization

After the tests applied to determine the mechanical properties of hybrid FML composites, NIKON digital microscope was used to determine the interfacial adhesion properties of the samples.

3. Results and Discussion

3.1. Mechanical Properties of hybrid FMLs

In Figure 5 graphically shows the results of tensile tests of composite material specimens according to ASTM D3039 standard. As can be seen from the graph, the tensile strength of the composite samples produced with epoxy resin is 911.4 MPa. As a result of the experiments, it was determined that the addition of 1% clay nanoparticles into the pure epoxy resin improved the tensile strength of composite materials by approximately 3.63%. (Binu *et al.*, 2016) investigated the effects of clay nanoparticles used in different proportions on the mechanical properties of glass fiber reinforced composites. In their experiments, they showed that the addition of 1% clay nanoparticle positively changed the tensile strength of the composites. As seen in the graph, it was determined that 1% SiO_2 and GNP reinforcement compared to epoxy increased the tensile strength of composites by approximately 5.08% and 1.83% compared to FMLs produced with pure epoxy. It has been reported that SiO_2 nanoparticles used as reinforcement material positively affect the mechanical properties of composite materials (Balagna *et al.*, 2017; Cavaliere *et al.*, 2018). Askin and Turen (2019) investigated the effect of 1% GNP additive on the mechanical properties of the composite in 2024-T3 Al matrix FMLs. As a result of the studies, they observed that the addition of GNP increased the tensile strength of the composite samples by approximately 9%.

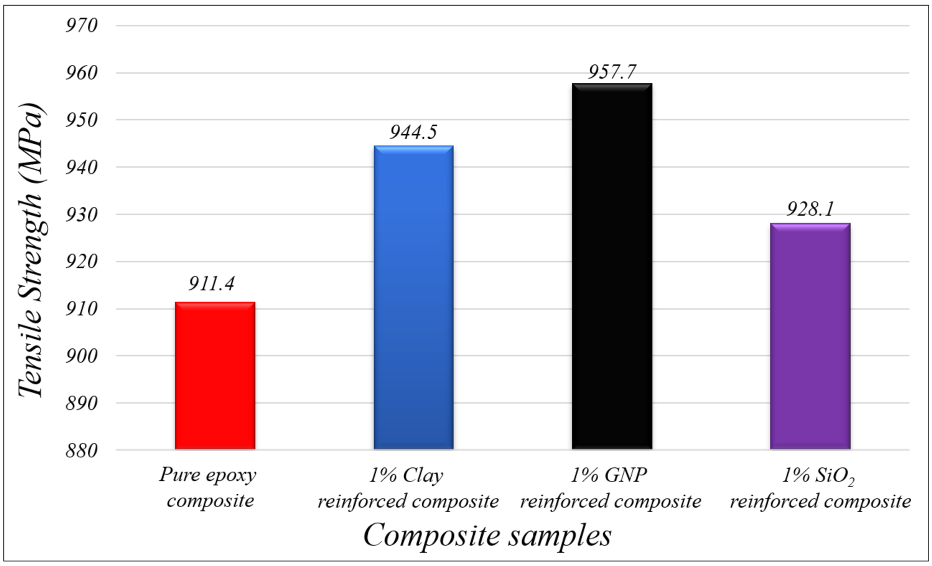

Fig. 5. Tensile test results of hybrid FMLs

The most critical disadvantage of hybrid FML composites in service conditions is the delamination problem. This problem may be caused by contaminations that may remain in the components during production or the metal and composite plates have different poisson ratios, so they are prone to delamination at high loads or cyclic loads (Park *et al.*, 2010; Asundi & Choi, 1997). If the nanoparticles used as reinforcement material in hybrid FML composites can be dispersed homogeneously in the epoxy matrix, they can contribute positively to the adhesion properties of the composite by slowing the progression of the crack that starts to form between the fiber-metal plates (Agwa *et al.*, 2017). The increase in tensile strength as a result of tensile tests of composite materials may be due to this situation (Figure 5). The positive results found in the tensile strength of FMLs overlap with the reference information and no contradiction was observed.

Three-point bending tests of hybrid FMLs were performed according to ASTM D7264 standards, and their bending strengths were calculated with the help of Equation (Eq 1) given below.

$$\sigma_{bend} = 3F_{max} \cdot L/2b \cdot d^2 \qquad (1)$$

where $\sigma_{bend} -$ bending strength value of composite sample, (MPa), F_{max} - maximum force load damaging the specimen, (N), $L -$ the distance between the supports, (mm), $b -$diameter of test specimen, (mm), $d -$ test specimen thickness, (mm).

Three-point bending test results of hybrid FMLs are given in Figure 6. It is seen that the bending strength of FML samples produced with epoxy resin is 128.02 MPa. It was observed that the addition of 1% clay nanoparticles into the epoxy resin improved the bending strength of hybrid FMLs by 258.31%, reaching 459 MPa. Bahari et al. (2016) investigated the effects of clay nanoparticle additive at different rates (0%, 1%, 3%, and 5%) on the impact and bending properties of 2024-T3 Al matrix laminated composites. As a result, it was found that the effect of clay nanoparticles on the bending and impact strengths of composites was obtained by using 3% by weight modified clay nanoparticle. When we examined the results of our experiments, it was observed that the addition of 1% GNP improved the bending strength value of hybrid FMLs by 204.44%, and the same rate of SiO_2 nanoparticle reinforcement improved the bending strength value of the composites by 173.22%. Ávila et al. (2010) investigated the effects of graphene additive at different rates (0.5%, 1%, 1.5%) on the bending strength properties of composite materials. As a result of their experiments, they observed that the added graphene had an effect on the bending strength, and the highest bending strength was obtained with the addition of 0.5% graphene. They emphasized that the graphene added at higher rates could not be distributed homogeneously in the structure and caused agglomeration. Nayak et al. (2014) general findings in the studies examining the mechanical effects of nano SiO_2 added into epoxy resin in hybrid epoxy/glass fiber composites are that SiO_2 reinforcement into the resin improves mechanical properties such as impact resistance, tensile and bending strength. The information we have obtained from the literature confirms the data in this study.

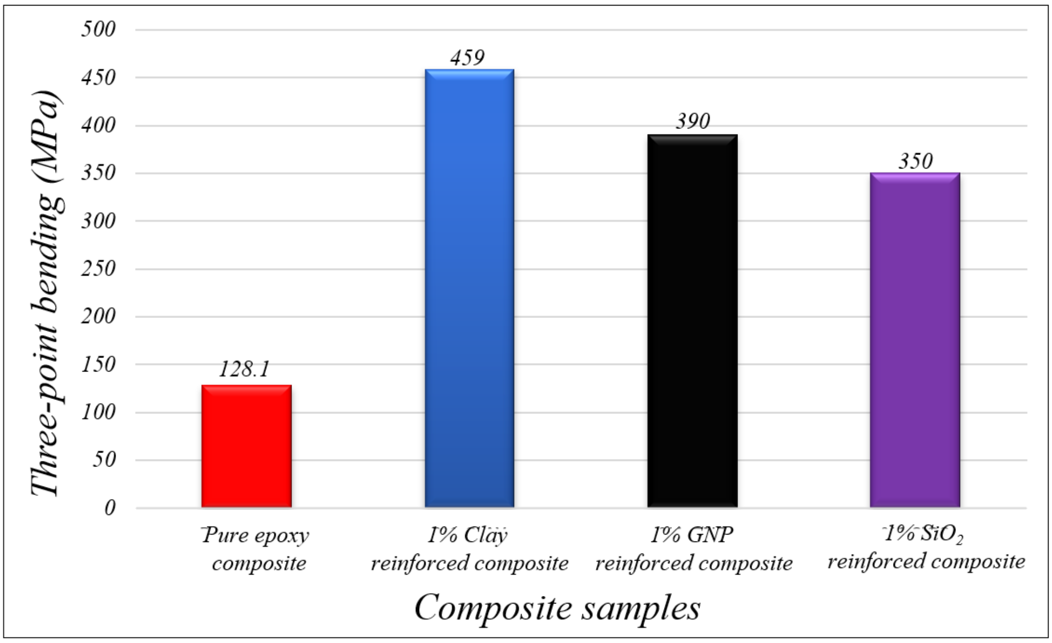

Fig. 6. Three-point bending test results of hybrid FMLs

3.2. Optical Characterization of hybrid FMLs

After the tensile tests of the hybrid FMLs according to the ASTM D3039 standard, images of the damaged surfaces of the samples were taken with a digital microscope to detect the delamination formed in the samples and to examine the damaged interfaces (Figure 7). It was observed that the delamination between the metal and fiber reinforcing elements was more pronounced in the hybrid FML s produced with pure epoxy resin than in the composites reinforced with different nanoparticles (Figure 7a). The positive contribution of nanoparticle addition to the adhesive properties in hybrid FML composites is clearly determined from the difference between the amount of delamination after the tensile test (Figure 7 b, c,d).

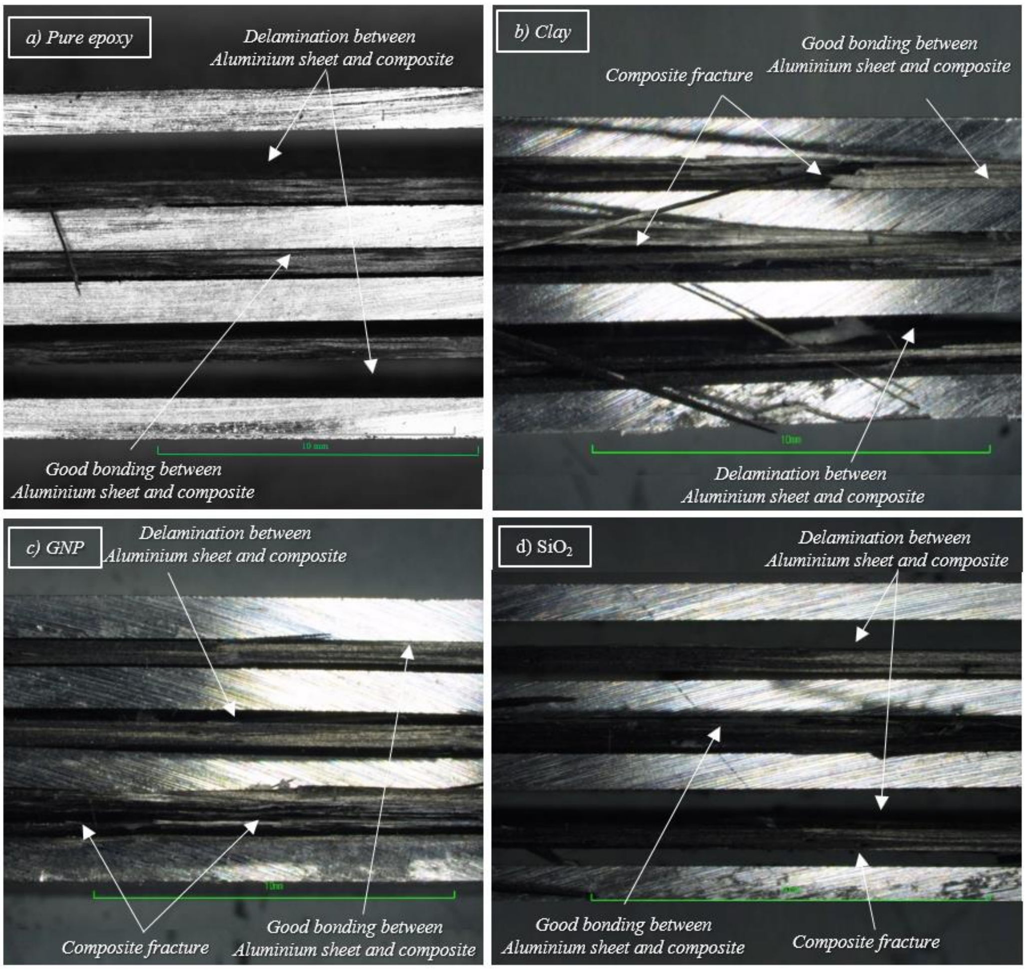

Fig. 7. Interface images of epoxy resin and nanoparticle added hybrid FMLs after tensile test at 24X magnification: (a) Epoxy resin FMLs, (b) hybrid FMLs with 1%glay nanoparticle addition, (c) hybrid FMLs with 1%GNP addition, (d) hybrid FMLs with 1%SiO_2 nanoparticle addition

When we compare the literature studies with our experiments, it can be seen that the most common problem in hybrid FML composites is the adhesion surfaces between the metal and the fiber sheet. The physical state of the bond between the surface sheets significantly affects the mechanical properties of FMLs (Nassier *et al.*, 2020). The increase in tensile strength values of hybrid FMLs is also related to this situation.

In Figure 8, interface digital microscope images of damaged areas of hybrid FMLs with added epoxy resin and 1% clay, 1% GNP and 1% SiO_2 nanoparticles are given after bending tests performed according to ASTM D7264 standard. Since the adhesive properties are weaker in FMLs produced with epoxy resin, delamination occurred earlier between the metal and composite layer, carbon fiber damage was observed at a minimum level, and therefore the amount of deformation is negligible (Figure 8a). In nanoparticle reinforced FMLs, on the other hand, since the bond at the fiber-metal interface is stronger, the amount of deformation and damage occurred more in carbon fiber composites (Figure 8 b,c,d). The positive changes in the bending strength of hybrid FMLs depend on this situation (Figure 6).

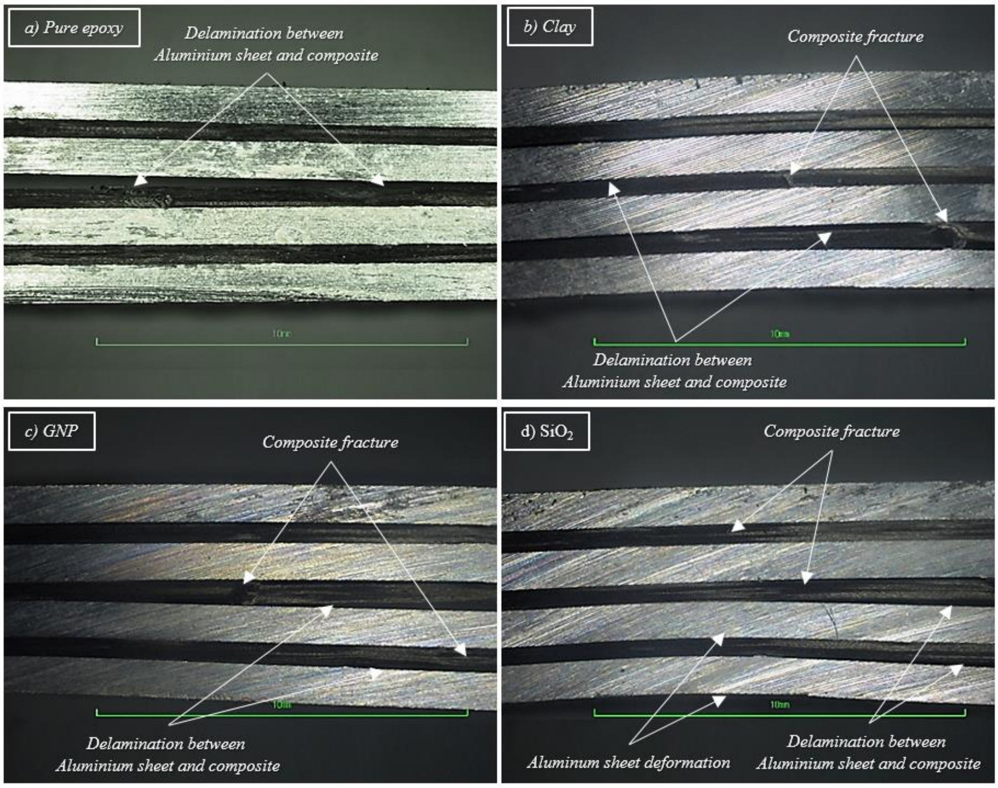

Fig. 8. Interface images of epoxy resin and nanoparticle doped hybrid FMLs after three-point bending test at 24X magnification: (a) Epoxy resin FMLs, (b) hybrid FMLs with 1%glay nanoparticle addition, (c) hybrid FMLs with 1%GNP addition, (d) hybrid FMLs with 1%SiO_2 nanoparticle addition

5. Conclusion

In this study, the results of this study are given below, considering that the addition of 1% clay, 1% GNP and 1% SiO_2 nanoparticles to the epoxy resin in hybrid FML composites will affect the tensile and bending strength properties:

- It was determined that 1% GNP additive in FML composites improved the strength value obtained as a result of the tensile tests of the samples by 5.08% compared to other nanoparticles.
- It was determined that the additive of clay nanoparticles was the most effective on the-point bending properties of hybrid FML s and improved the bending strength values by 258.31%.

It was observed that the improvement in the tensile and bending strength values of the hybrid FML composite samples was due to the additive of 1% clay, GNP and SiO_2 nanoparticles into the epoxy resin. It has been stated in previous experiments in the literature that nanoparticles added to the epoxy resin have a good effect on the mechanical properties due to their chemical bonding and anti-cracking properties between the matrix and the fiber.

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