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Investigation of Effects of Graphene Nanoplatelets Addition on Mechanical Properties of 7075-T6 Aluminium Matrix Hybrid Fibre Metal Laminates

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In this study, hybrid fibre metal laminates (FMLs) are produced using 1 mm thick 7075-T6 quality Al plate, unidirectional carbon fibre fabric and epoxy resin in 4/3 stacking order. The effect of adding 0.5% GNP to pure epoxy resin and epoxy resin on the mechanical properties of hybrid FMLs is investigated. As a result of the experiments, it is observed that adding 0.5% graphene nanoplatelets (GNP) to the epoxy resin increased the tensile strength of hybrid FMLs by about 2.42% and the three-point bending strength by about 5%. After mechanical tests, interface microstructures of FMLs are examined under digital microscope and it is observed that 0.5% GNP addition positively affected the delamination between metal and fibre reinforcement in FMLs.

Key words: hybrid fibre metal laminate, 7075-T6 Al, graphene nanoplatelets, mechanical properties, delamination.

У цьому дослідженні гібридні металічні волокнисті ламінати (МВЛ) виготовляли з використанням алюмінієвих пластин якості 7075-T6 товщиною 1 мм, односпрямованої вуглецевої волокнистої тканини та епоксидної смоли в порядку накладання 4/3. Досліджено вплив додавання 0,5% графенових нанопластинок (ГНП) до чистої епоксидної смоли та епоксидної смоли на механічні властивості гібридних МВЛ. У результаті експериментів виявлено, що додавання 0,5% ГНП до епоксидної смоли збільшує міцність на розрив гібридних МВЛ приблизно на 2,42% і міцність на три-

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точковий згин приблизно на 5%. Після механічних випробувань досліджено мікроструктури інтерфейсу МВЛ під цифровим мікроскопом і виявлено, що додавання 0,5% ГНП позитивно впливає на розшарування між металом та армувальним волокном у МВЛ.

Ключові слова: гібридний металічний волокнистий ламінат, 7075-T6 Al, графенові нанопластинки, механічні властивості, розшарування.

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1. INTRODUCTION

Production of metal-matrix composite materials began in the early 1960s to meet the demand for existing materials that could not be used at high temperatures and for new materials with high resistance [1, 2]. Composites whose matrix element is metal and generally ceramic material is selected as reinforcement element are called metal matrix composites.

Reducing the weight of structural components is the main goal of different industrial sectors. This main purpose has led to an increase in the application areas of fibre composites for primary structural components. Fibre/metal laminated composites (FML), a new lightweight material group aimed at this goal, have been developed. Fibre metal laminated composites, which we can include in the layered composite materials class, which is a subgroup of the structural composite materials group, is a material group that is widely researched for its performance compared to existing structural materials [3, 4]. FML composites are materials that are widely used in today's modern warplanes and civil aviation industry due to their superior properties.

FML are hybrid composite materials which are produced by combining thin metal sheets and fibre reinforced polymeric materials. This new hybrid material consists of three main components: the metal alloy, FRPC (Fibre reinforced polymer composite) laminate, and resin (or matrix), which are variables. In FMLs, the desired mechanical properties can be optimized by changing components such as fibre reinforcements, orientation, thickness, placement, bonding system and metal sheet [5, 6]. In Figure 1, existing commercial products and composite material groups are shown as schematically [6, 7].

FMLs can also be classified according to the way metal and composite plates are laid outside. Symbolic representations such as 2/1, 3/2, 4/3 are used in FMLs. The first number in the symbol represents the number of metal plates and the second number represents the number of composite plates placed between metal plates [8, 9].

In line with rapid advances in nanomaterials, nanoparticle reinforcements are widely used in laminated composite materials to increase matrix or fibre interface adhesion. Graphene, which is the most

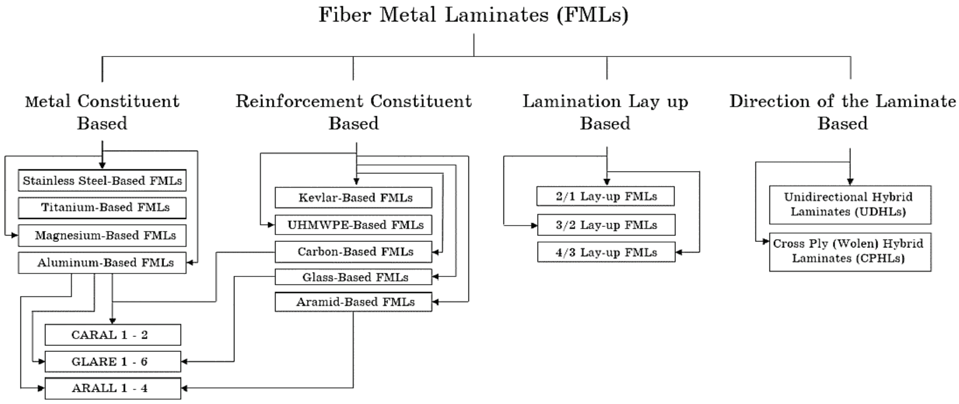


Fig. 1. Classification of FML composites according to the metal alloy used.

widely used nanoparticle reinforcement material in laminated composite materials, provides good mechanical, thermal and electrical properties [10, 11].

Rafiee *et al.* [12] found that the addition of 0.1% GNP to epoxy increased the Young's modulus in composites by 31% and tensile strength by 40%. Sydlik *et al.* [13] in their study observed that the addition of carbon nanotubes to the epoxy resin at a rate of 1% provided an improvement in the tensile strength of approximately 50%. Zhou *et al.* [14] studied the effect of carbon nanofibers on mechanical properties in carbon fibre/epoxy composites. They added 1%, 2% and 3% carbon nanofibre to the epoxy resin by weight, and they carried out the bending, tensile and fatigue tests of the composites. They achieved the highest improvement in strength by 2% by weight. They stated that the tensile and bending strengths increased by 11% and 22.3%, respectively, compared to the pure composite and the fatigue strength improved significantly.

Our main aim in this study is that commercially produced (Aramid reinforced aluminium laminates-ARALL, Carbon fibre reinforced aluminium laminates-CARALL, Glass and aramid fibre aluminium laminates-GLARE); to produce hybrid laminated composite materials with GNP addition 7075-T6 Al matrix as a domestic alternative to fibre metal laminated composite materials widely used in aviation, defence and space industries.

2. EXPERIMENTAL/THEORETICAL DETAILS

2.1. Materials and Method

FMLs in this study 1 mm thick 7075-T6 Al sheet with 2 layers of car-

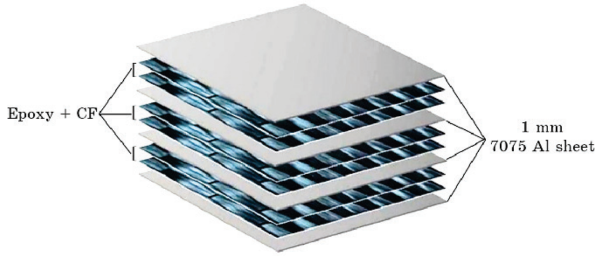
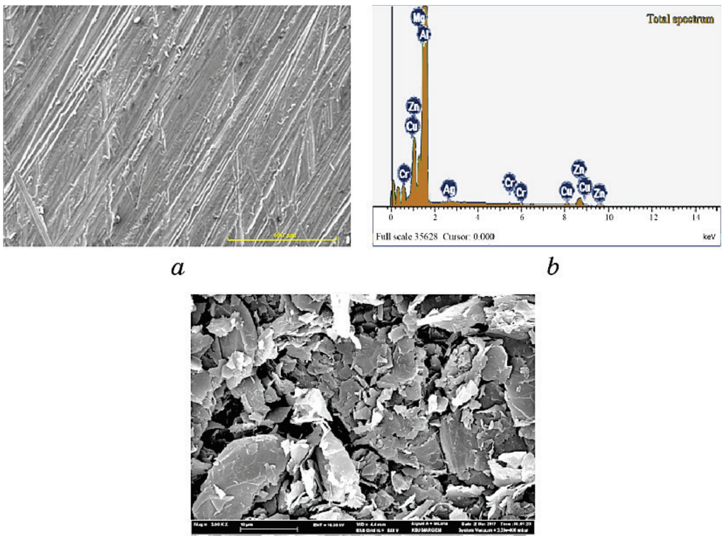


Fig. 2. The sequence of the composite material produced is given schematically.

bon fibre fabric reinforcement between Al/KF 0°–KF 0°/Al/KF 0°–KF 0°/Al/KF 0°–KF 0°/Al stack produced in order. The carbon fibre fabric used in this composite material is unidirectional. The fibre directions are placed parallel to the roll direction of the aluminium sheet. The stacking order and symbolic representation of the produced FML composites is shown in Fig. 2.

For the production of FMLs in scanning electron microscopy, the microstructures of 1 mm thick 7075-T6 Al sheet used as matrix material and GNP with a diameter of 3 nm and 1.5 μm (500 $m^2 \cdot g^{-1}$, 99.5% purity) as filling material and also the EDS analysis results of the 7075-T6 aluminium sheet are given in Fig. 3.



a *b*

c

Fig. 3. SEM images of materials used in FML production. Microstructure of 7075-T6 aluminium sheet (*a*), EDS analysis result of 7075-T6 aluminium sheet (*b*), GNP microstructure (*c*).

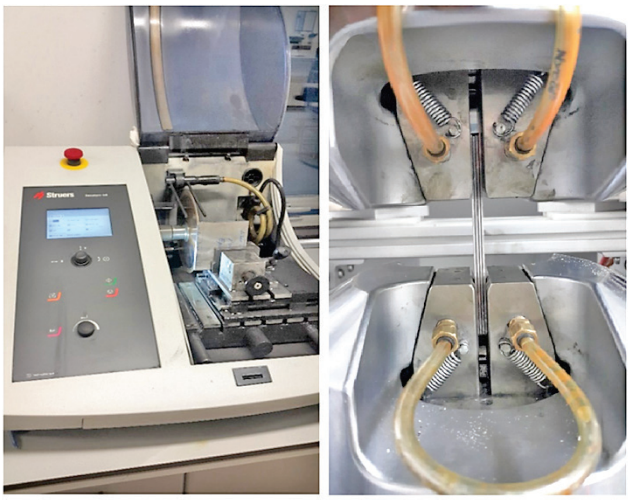
The unidirectional carbon fibre fabric, which is used as a reinforcement element between metal sheets, is made of 12k carbon fibre yarn and is preferred in applications where high performance, unidirectional rigidity and strength are required. MGS-L326 epoxy and MGS-H265 hardener used in the production of fibre metal finished composites Dost Kimya Co. Ltd. provided.

In the first stage, pure epoxy resin and hardener (100:25) are homogeneously mixed to produce hybrid FML composite materials. Nanocar Co. Ltd. The 0.5% GNP nanofilling material provided by the company for subsequent production processes is homogeneously mixed with the epoxy resin with the help of an ultrasonic homogenizer.

After all the preparations required for lamination are completed, the materials are cured in a hot pressing device at 120°C less than 1 ton of pressure for 3 hours. After 3 hours, the material taken from the hot pressing device is left to cure at room temperature for 24 hours.

2.2. Tensile Test

In order to determine the mechanical properties of the hybrid FMLs the tensile test is carried out in accordance with ASTM D3039/D3039M-17 standard, on a MTS branded 100 kN tensile test machine at 1 mm/min tensile speed. Tensile tests of FMLs are carried out according to the above-mentioned standard by taking 3 samples for the tensile test from each hybrid FML plate produced. The samples required for the tensile test of FMLs are cut from the main plate using Struers Secotom-50 precision cutting device. A visual of the adhesive shear process and



a *b*

Fig. 4. Cutting samples from FMLs (*a*), tensile test of FMLs (*b*).

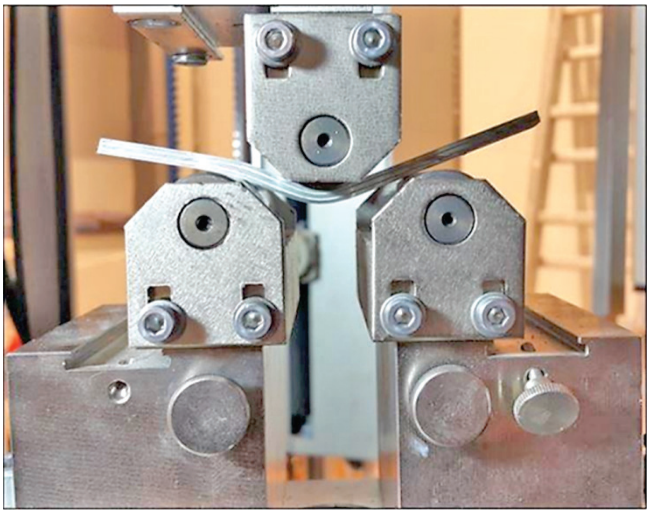


Fig. 5. Bending test.

tensile test specimens in FML is given in Fig. 4.

2.3. Three Point Bending Test

Three point bending test is applied to determine the bending strength properties of the hybrid FML composites produced. The three point bending test is carried out in accordance with ASTM D7264, in a ZWICK brand 60-ton electromechanical test device within at a bending speed of 1 mm/min with a distance between the supports to be 20 mm. Tests are carried out by removing 3 bending samples of 10×10 mm from each hybrid FML composite plate. Bending test specimens are obtained by cutting from the base plate on a precision cutting device. The visuals of the three point bending test are shown in Fig. 5 is also seen.

2.4. Optical Analysis

NIKON brand shuttle pix portable digital stereo microscope is used to examine the interface properties of the produced FML samples after mechanical tests.

3. RESULTS AND DISCUSSION

3.1. Tensile Test

The tensile test results of hybrid FMLs performed at 1 mm/min tensile speed according to ASTM D3039 standard are shown graphically in

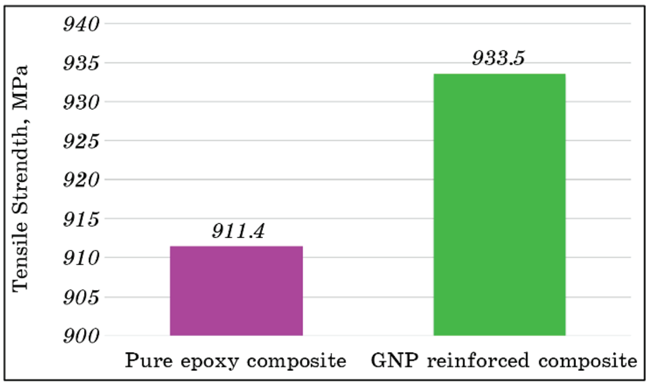


Fig. 6. Tensile test results of FMLs.

Fig. 6. When the graph is examined, it is seen that FML produced with pure epoxy resin has a tensile strength of 911.4 MPa, and the tensile strength of FML composite produced with 0.5% GNP added epoxy resin has increased by approximately 2.42% and reached 933.5 MPa. Amal Nassar and Eman Nassar [15] are examined the mechanical properties of glass fibre-based laminate composites with different fibre types and observed that the maximum tensile strength is 312 MPa in composites with 0.5% GNP by weight.

When the interface microstructure of FMLs is examined after the tensile test, it is seen that the GNP addition is homogeneously distributed in the matrix and as a result it had a positive effect on preventing delamination and increasing tensile strength (Fig. 6).

3.2. Three Point Bending Test

In this study, the bending strength of FML composites is calculated according to equation (1) and the results are given graphically in Fig. 7

$$\sigma_{\text{bend}} = 3F_{\max}L/2bd^2, \quad (1)$$

σ_{bend}—bending strength, (MPa); $F_{\max}$—maximum force load causing damage, (N); L—distance between bearings, (mm); b—width of the test sample, (mm); d—thickness of the test sample, (mm).

FMLs produced with pure epoxy are calculated according to the formula (1) and it is seen that the bending strength is 128.02 MPa. On the other hand, it is observed that 0.5% GNP addition increased the bending strength of FML composite by 5% and reached 133.9 MPa. Bulut [16] investigated changes in mechanical (impact, bending, tensile) behaviour by adding 0.1%, 0.2%, and 0.3% GNP by weight to epoxy to

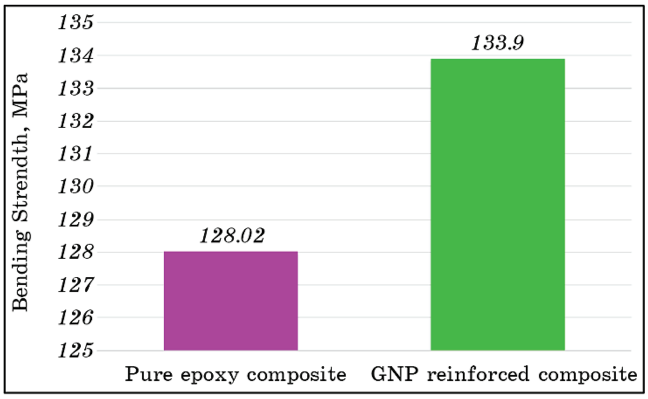


Fig. 7. Bending test results of FMLs.

basalt/epoxy laminate composite materials. He observed that the addition of 0.1% GNP in the intermediate phase between epoxy and fibre significantly increased bending strength by up to 273.9 MPa.

It has been observed that the addition of 0.5% GNP in FMLs contributes positively to the fibre/metal interface adhesion and thus significantly increases the bending strength. The microstructure analysis performed after the bending test explains this situation.

3.3. Optical Analysis

40X magnification digital microscope interface images of FMLs produced in 4/3 stacking order with pure epoxy and 0.5% GNP added resin are shown in Fig. 8. When the microstructures of FMLs are examined, it is seen that the lamination process between metal and carbon fibre layers is successful.

After the tensile test, the interface microstructures of the FML

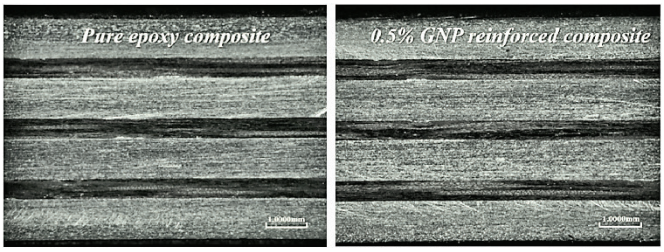


Fig. 8. 40X magnification digital microscope interface images of FMLs produced with pure epoxy (*a*) and 0.5% GNP added resin (*b*).

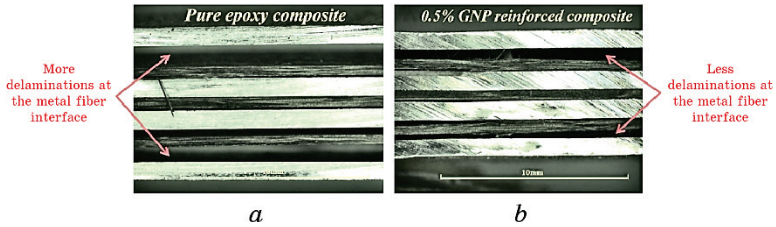


Fig. 9. Interface images of FMLs produced with pure epoxy (*a*) and 0.5% GNP added resin (*b*) at 24X magnification after tensile testing.

composite samples are examined under a digital microscope and it is observed that the delamination between metal and fibre reinforcement is much more pronounced in FMLs produced with pure epoxy resin compared to GNP reinforced FMLs (Fig. 9).

Metal surfaces of FMLs are examined with the help of a digital microscope after delamination in the tensile test phase (Fig. 10). When the images are examined, it is determined that the adhesive mechanism developed, and the fibre residue is more in GNP added FMLs. Therefore, the addition of GNP increases the fibre metal interface bond strength in FMLs mesh this situation proves the increase in tensile strength.

After the bending test, the interface microstructures of the FML composite samples are examined under a digital microscope and it is observed that the delamination between metal and fibre reinforcement is more pronounced in FMLs produced with pure epoxy resin compared to the GNP reinforced FML composite (Fig. 11). Basically, it is clear that the GNP reinforcement contributes positively to the difference between the adhesion properties of FMLs and the amount of deformation after the bending test. This change in the microstructure explains the tensile test results graphically given in Fig. 7.

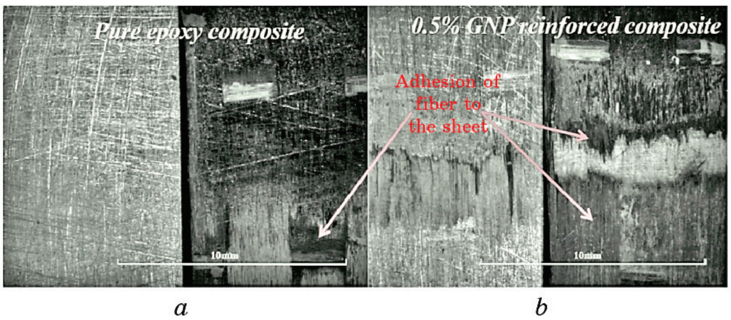


Fig. 10. Interface images of metal layers at 20X magnification after delamination of FML produced with pure epoxy (*a*) and 0.5% GNP added resin (*b*).

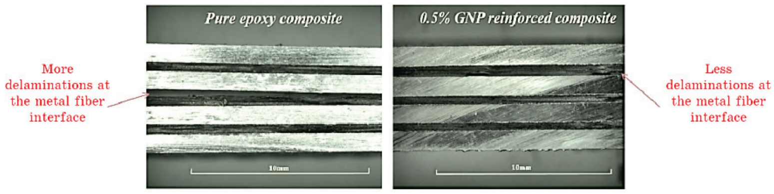


Fig. 11. Interface images of FMLs produced with pure epoxy (*a*) and 0.5% GNP added resin (*b*) at 24X magnification after flexural strength testing.

4. CONCLUSION

In this study, the effects of 0.5% GNP reinforced hybrid FMLs on their mechanical properties are experimentally investigated and the following results are seen.

1. It is observed that the addition of 0.5% GNP to the epoxy resin increased the tensile strength of FMLs by 2.42% .
2. As a result of the bending tests, an increase of approximately 1.17% is observed in the bending strength of 0.5% GNP reinforced FMLs compared to FMLs produced with pure epoxy.
3. When microstructures are examined in FMLs, it is observed that the addition of 0.5% GNP to epoxy resin positively affected the nanoparticle carbon fibre 7075-T6 Al sheet interaction and significantly increased mechanical properties as a result of interfacial bonding.

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