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Effect Of Nano Reinforced Adhesive AL Powder And Cnt On Bending Strength Of Hybrid Laminate Structure AL - CFRP

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A B S T R A C T

Amphibious aircraft are types of aircraft that can land on land and in water with floating components (floaters). Amphibious aircraft are capable of landing both on land and water using float-equipped structures. In its operation, it is likely to have a bending force on the floater. When the floater is replaced with a hybrid composite, it is likely to have a light load and high beding value bending value. During operation, the floater is subjected to significant bending forces. Replacing the floater with a hybrid composite results in a lighter structure with improved bending strength. This study aims to analyze the bending test of hybrid composites reinforced with carbon fiber and aluminum faceplates. This study aims to evaluate the bending strength of hybrid composites reinforced with carbon fiber and aluminum faceplates. The method used in this study is vacuum bagging, where the sample is combined with epoxy resin and mixed with carbon nanotube (CNT) nanoparticles and aluminum powder (AL). The study was conducted with adhesive resin, surface treatment and the addition of nano particles to determine the effect of the bending strength of the composite. This study aims to analyze the effect of surface treatment and nanoparticle addition on the flexural strength of the hybrid composite. The results showed that had a high bending value compared to the variation of specimens without surface treatment or nano particles. Specimens treated with surface modification and nanoparticles exhibited higher bending strength than those without either treatment. The highest bending stress value was obtained by the CNT variation of 133.89 MPa followed by the variation without nano particles of 98.59 MPa, then the variation without surface treatment of 91.76 MPa, and the one with the smallest value was the AL variation of 61.02 MPa. Macro photo analysis after bending test shows the presence of Mixed-mode defects in the specimen. This shows that specimens that have surface treatment and nano particles have better bonds and are able to fill the void in the empty area, so that the bending strength is good. This study provides an important contribution to understanding the variation of adhesives and nano particles on the bending strength of hybrid composites. This study offers preliminary insights into how variations in adhesives and nanoparticles influence the bending strength of a specific hybrid composite system.

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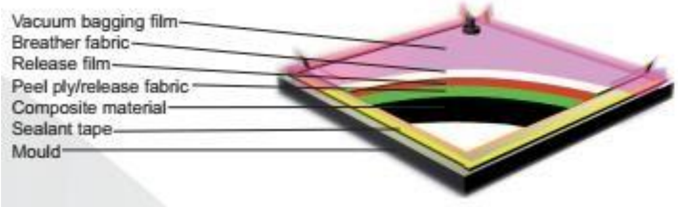
1. INTRODUCTION

Seaplanes have the ability to land on both sea and land surfaces. Currently, this aircraft is not very popular and is only used by a handful of people or certain groups. However, if it can be improved and developed optimally, this aircraft has the potential to be applied in Indonesia.The use of floters in seaplanes plays an important role in improving stability and performance when landing on water surfaces. Aerodynamically designed floters can reduce drag during flight and improve fuel efficiency in seaplanes. Studies on seaplane transportation show that an optimized floter can improve the aircraft's ability to cope with diverse water conditions(Irsabudi, Jatisukamto, and Sutjahjono 2021).[2}

Composite is a material that is formed from a combination of two or more materials so that a composite material is produced that has different mechanical properties and characteristics from the material that forms it. Composites have better mechanical properties than metals, higher specific stiffness (Young's modulus/density) and strength than metals. Certain composites exhibit superior mechanical properties compared to some metals, particularly in terms of specific stiffness (Young's modulus-to-density ratio) and strength-to-weight ratio. The objectives of forming composites are, Improving mechanical properties and / or certain specific properties, Facilitating difficult designs in manufacturing, Flexibility in shape / design that can save costs, and Making materials lighter[3]-[34]

Fiber Metal Laminate (FML) is a hybrid composite material that combines a metal coating and fiber-reinforced polymer materials, such as glass and carbon fibers. FML has advantages such as high specific strength, corrosion resistance, and damage tolerance. The use of FML is widely applied to important aircraft components due to its lightweight yet strong nature, as well as its ability to withstand bending loads and compressive forces[45]. Aluminum powder is small-sized aluminum particles used as a base material in a variety of industrial applications, including the manufacture of alumina (Al2O3) nanoparticles(Surya Iwanata et al. 2022). Aluminum matrix composites reinforced with carbon nanotubes (CNT) has increased significantly over the past decade due to the



improved specific properties expected from these nanocomposites. Functionally graded materials (FGM) are also a rapidly growing field in materials science, offering the possibility to manufacture components with desired properties at specific locations to serve different applications. Fiber Metal Laminate (FML) is a hybrid composite material that combines metal sheets with fiber-reinforced polymer layers, such as glass or carbon fibers. FMLs are known for their high specific strength, corrosion resistance, and damage tolerance, making them suitable for critical aircraft components where both strength and lightweight characteristics are essential. Aluminum powder, composed of fine aluminum particles, is widely used in various industries and plays a key role in the synthesis of alumina (Al_2O_3) nanoparticles. Additionally, aluminum matrix composites reinforced with carbon nanotubes (CNTs) have gained attention due to their enhanced mechanical and physical properties. Functionally graded materials (FGMs) also offer the advantage of tailoring material properties at specific locations within a component. However, limited studies have examined the synergistic effects of combining carbon fiber-reinforced polymers with aluminum faceplates, CNT-enhanced adhesives, and surface treatment techniques—particularly in the context of hybrid laminate structures for floater applications in amphibious aircraft. Furthermore, bending performance data for such composite systems remains scarce, despite its relevance in structural loading conditions. This study aims to address this gap by evaluating the flexural behavior of these hybrid laminates under bending loads. [67].

Carbon Nanotubes (CNT) are tube-shaped nanoscopic structures composed of carbon atoms. CNTs have very small diameters, usually in the nanometer scale, and lengths that can reach several micrometers. CNT are used to strengthen the adhesive bond between aluminum substrates and carbon fiber reinforced polymers (CFRP). This technique involves the use of a CNT-containing resin pre-coating (RPC) to increase the interfacial shear bond strength, with an increase in interfacial shear strength of up to 30-100% depending on the surface profile of the aluminum substrate. This suggests that CNT play an important role in improving the mechanical properties of composites by forming fiber “bridges” that reduce the likelihood of premature adhesive failure[78].

Vacuum bagging is a technique used in the composite manufacturing process, particularly in the aviation and automotive industries. This method involves placing the composite material in an airtight plastic bag which is then vacuumed, creating negative pressure. This helps in deflating the composite material, ensuring even resin flow, and eliminating air bubbles that can affect the strength and structural integrity of the material[89].

Figure.1 vacuum bagging

Source : [910]

The bending test is a test method that involves bending the test material by applying a load at certain points. Usually, bending testing is divided into two types, namely three point bending and four point bending. In three point bending, the load is applied through two support points and one pressure point, while in four point bending there are two support points and two pressure points. Each type of test, both three point bending and four point bending, has its own advantages and disadvantages[9]11.

One of the standard methods for testing flexure in composite materials is by using ASTM D-790. The bending test process involves applying pressure to the top of the sample, while two supports are placed at the bottom. This test method falls under the category of three point bending.

$$\sigma = \frac{3\,P.L}{2b.d^2} \quad (1)$$

Information :

σ = bending strength (MPa)

P = force (N)

L = span length (mm)

b = specimen width (mm)

d = specimen thickness (mm)

Therefore, this study aims to fabricate and evaluate a hybrid composite consisting of carbon fiber, aluminum 1100 faceplates, and nano-reinforced adhesive with CNTs and aluminum powder, using surface treatment and vacuum bagging techniques, in order to assess its bending performance for potential application in seaplane floater structures.

2. METHODS

2.1 Tools and materials

The tools that will be used as support in the process of making hybrid laminate composites are very important to ensure the success and accuracy of each stage of the work. The tools used to support the fabrication of hybrid laminate composites were essential in ensuring the success and accuracy of each stage of the process. Bending tests are needed to measure the strength and durability of the resulting composites, while measuring cups and scales are used to precisely measure the materials to ensure the right ratio of resin and catalyst. A caliper is useful for measuring the dimensions of carbon fiber and aluminum to match the specified specifications. Vacuum bagging machines, hoses, and valves are needed to create optimal vacuum conditions during the resin curing process, while brushes are used to apply the resin mixture evenly on the carbon fiber. With these tools, it is expected that the process of making hybrid laminate composites can run effectively and efficiently.

Materials In the manufacture of hybrid laminate composites, some of the main materials used include carbon fiber, aluminum 1100, carbon nanotubes, AL Al powder, epoxy resin, catalyst, wax mold, plastic bagging. Carbon fiber fabric with an areal weight of 220 gsm is a lightweight reinforcement material commonly used in aerospace and automotive composites. It typically features a plain or twill weave, with a dry thickness of about 0.2–0.25 mm. Based on standard T300 fibers, it offers a tensile strength of around 3.5–4.0 GPa and a modulus of elasticity of 230–240 GPa, resulting in excellent specific stiffness. Its low weight and flexibility make it suitable for outer layers or complex contours, though additional layers are often required for structural applications. Vacuum bagging or resin infusion is recommended to ensure proper resin distribution and minimize voids, enhancing mechanical performance.Aluminum 1100 with a thickness of 1 mm serves as a structural component that provides additional stability to the laminate. Carbon nanotubes and AL powder were added to improve the mechanical properties and conductivity of the composite. The bonding process of these materials is done using epoxy resin mixed with catalysts to ensure optimal hardening. During the manufacturing process, wax molds are used to prevent the resin from sticking to the mold, while plastic bagging and dodol glue serve to maintain vacuum conditions and prevent air leakage during curing. With the combination of these materials, it is expected to produce composites that have better strength and durability. The fabrication process utilized carbon fiber fabric, aluminum 1100 sheets, epoxy resin, catalyst, carbon nanotubes (CNT), aluminum powder, and standard vacuum bagging equipment. Carbon fiber and aluminum sheets were cut to specified dimensions according to ASTM D790. The aluminum surfaces were roughened to enhance bonding, and a pre-coating of resin mixed with CNTs or Al powder was applied. Materials were assembled layer by layer and sealed in a vacuum bag. Vacuum pressure was applied for three hours to ensure proper resin distribution and air removal. The laminate was then cured under pressure for 24 hours using a steel plate.

2.2 Vacuum bagging process

Before performing the vacuum bagging process, there are several important steps that must be taken to ensure the quality of the hybrid laminate composite that will be produced. Before the vacuum bagging process was performed, several preparatory steps were taken to ensure the quality of the resulting hybrid laminate composite. First, 220 series carbon fiber is prepared and cut according to ASTM D790 standard to get the right size. Plain weave carbon fiber fabric with an areal weight of 220 gsm was used as the reinforcement material. The fabric was cut into test specimens measuring 150 mm in length, with a thickness of 3.0–3.5 mm and a span length of 120 mm, in accordance with ASTM D790 for flexural testing. Next, 1100 series aluminum with a thickness of 1 mm is prepared and the surface is roughened using a portable sandpaper grinder to improve adhesion. The pre-coating process was carried out by applying a mixture of resin and acetone on the aluminum surface, where acetone was mixed with carbon nanotubes and AL powder to improve mechanical properties. The pre-coating process was carried out by first dispersing carbon nanotubes and aluminum powder into acetone to ensure uniform distribution. This nanoparticle-acetone mixture was then blended with epoxy resin and applied onto the surface of the aluminum sheets to enhance interfacial bonding and mechanical performance. After that, a 30x40 cm glass was prepared as a base for vacuum bagging, and wax mold was used as a lubricant to prevent the resin from sticking to the glass. All these steps are crucial to ensure that the resin and other materials can interact well during curing, resulting in a strong, high-quality composite. Plain-weave carbon fiber fabric with an areal weight of 220 gsm was used as the reinforcement material. Each composite specimen consisted of four plies of woven carbon fiber, arranged in a [0/90] layup orientation. The fibers were cut into strips measuring 150 mm in length and 12.7 mm in width, as specified by ASTM D790 for flexural testing. Aluminum 1100 sheets, 1 mm thick, were used as faceplates with dimensions of 150 mm × 12.7 mm to match the carbon fiber layers. Prior to bonding, the aluminum surfaces were abraded using 400-grit sandpaper to improve adhesion and were degreased with ethanol to remove contaminants.

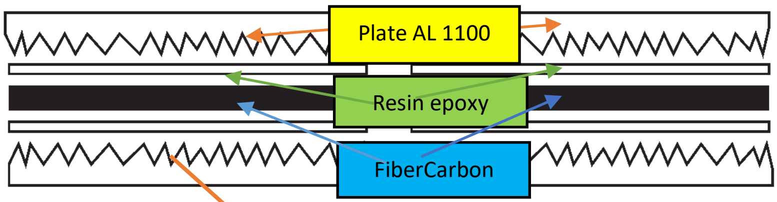
For the nano-reinforced adhesive, carbon nanotubes (CNTs) and aluminum powder were first dispersed in acetone using ultrasonication for 30 minutes at 100 W to ensure uniform particle dispersion. The nanoparticle-acetone mixture was then blended with epoxy resin at a ratio of 1:10 (nanoparticles to resin by weight). The resulting mixture was applied as a pre-coating layer on the aluminum surface to enhance interfacial bonding.

All layers were assembled in sequence, and vacuum bagging was performed for 3 hours under full vacuum (~-0.8 bar) to remove entrapped air and ensure resin flow. Curing was completed by pressing the specimen under a steel plate for 24 hours at room temperature. The final laminate thickness was between 3.0 and 3.5 mm.

2.3 Variable variations

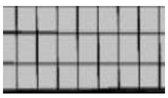
a. Variation 1

b. Variation 2



Adhesive resin, AL powder, *carbon fiber*, alumunium 1100, and *surface treatment square.*

Adhesive resin, *carbon fiber*, alumunium 1100, and *surface treatment amplas.*



c. Variation 3	d. Variation 4

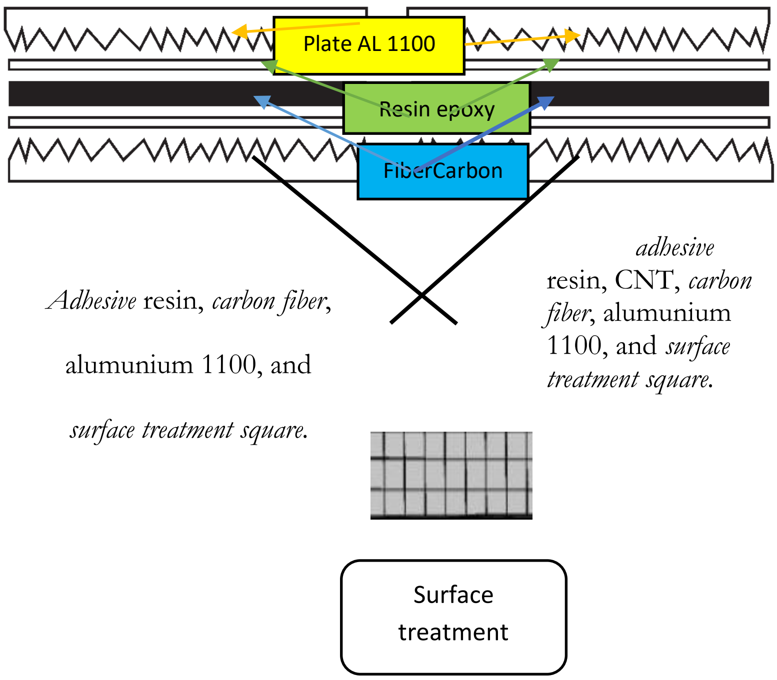


Figure.2 Variation surface treatment

<table>
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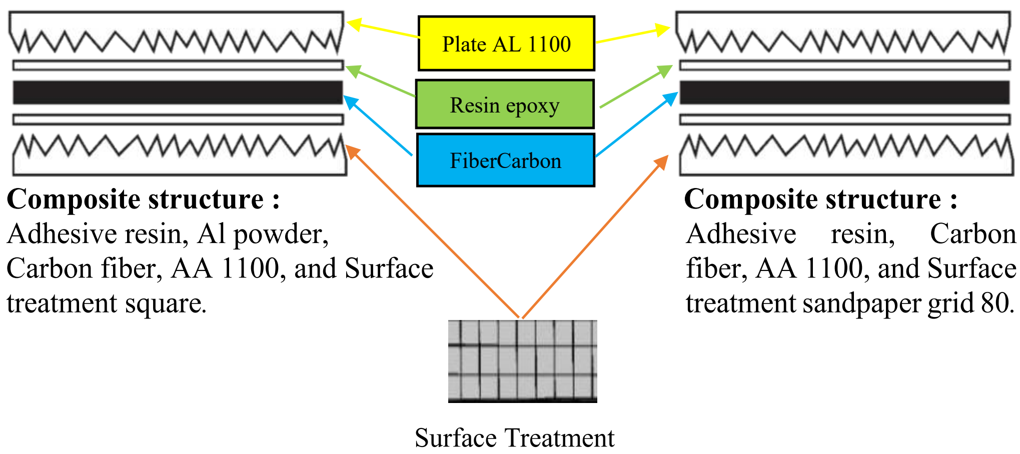
<tr><td colspan="2">
</td></tr>
<tr><td>c. Variation 3</td><td>d. Variation 4</td></tr>
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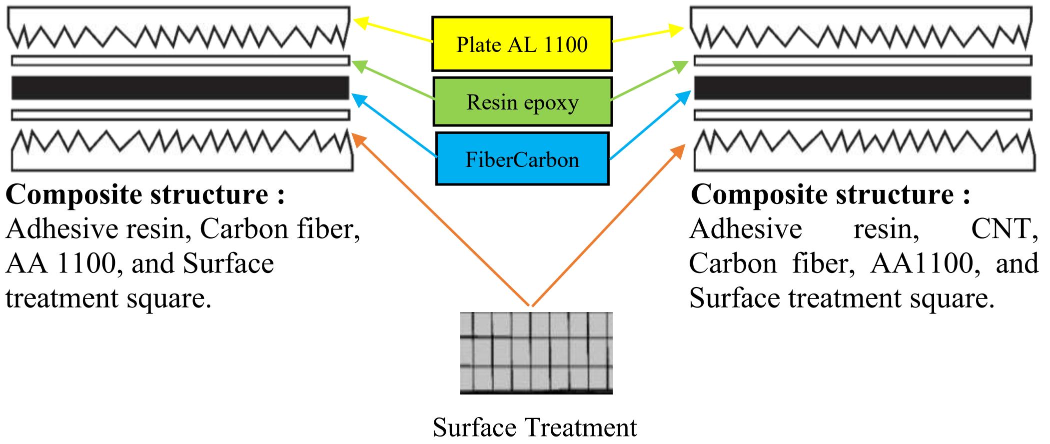


Figure.2 Composite composition used for research variation

2.4 Variable Fix variation

Vacuum bagging is a technique used in the composite manufacturing process, where raw materials are placed in vacuum bags to remove air and improve the quality of the final product. This process helps in distributing the resin evenly and reduces defects in the product. Precoating is the initial step where the surface of the material is coated with resin before the vacuum bagging process, which aims to improve adhesion and reduce the amount of resin required. The use of nano particles in this process can improve the mechanical and thermal properties of the composite. Nano particles, such as silica or carbon nanotubes, can strengthen the material structure and provide better resistance to temperature and pressure. By integrating this technology, the final product is not only lighter but also stronger and more durable, making it ideal for applications in the automotive and aerospace industries.

3. RESULT AND DISCUSSION

The following are the results of vacuum bagging, where this process successfully created composites that have optimal strength and durability. After vacuuming for 3 hours, the resin became semi-dry and when the vacuum was turned off, the specimen was removed and pressed with a steel plate for 24 hours. The final result shows a solid structure and is ready to be tested using the bending method, thus confirming the performance of the hybrid laminate composite that has been made**.** This test is determined by the formula 16 x h, and h is the specimen thickness. The average specimen thickness is 3.0 - 3.5 mm. Then the distance between spans is 16 x 3.3 = 52.8 mm.

Figure.3 Bending test

The three-point bending test for hybrid composite specimens according to ASTM D790, several key parameters are essential for evaluating their flexural properties. The specimen dimensions typically used are 150 mm in length, with a span of 15 mm from each end when placed on the testing fixture, resulting in a total span of 120 mm for the load application. The flexural strength is calculated based on the maximum load applied at the center of the specimen, while the flexural modulus is determined from the slope of the initial linear portion of the load-deflection curve. The test is usually conducted at a controlled crosshead speed, often around 1.3 mm/min, and requires a span-to-thickness ratio of at least 16:1 to ensure accurate results.

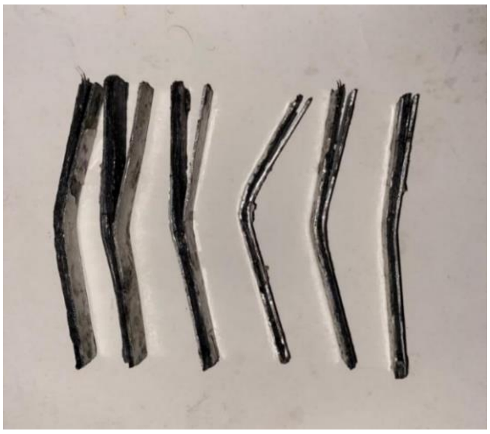
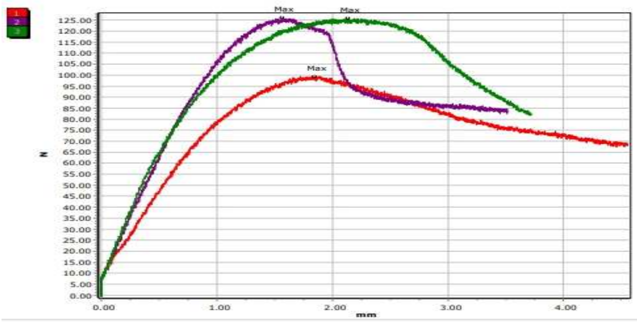


Figure.4 Specimen after bending test

From the graph above, it can be seen that AL 1 and AL 2 have maximum force values of 130.52 N and 116.99 N, respectively. The density between the line spacing of AL 1 and AL 2 graphs is quite uniform when compared to AL 3, which shows that the maximum force point has decreased to 83.91 N. Therefore, it is expected that in the future the manufacturing process should be paid more attention to produce better material quality and improve overall product performance.

Test Num.	Material	Width (mm)	Thickness (mm)	Displacement (mm)	Maximum Force (N)	Bending Stress (MPa)
1	KASAR-1	10.00	3.30	1.85	99.55	72.40
2	KASAR-2	10.00	3.30	1.56	126.16	91.76
3	KASAR-3	10.00	3.30	2.13	125.86	91.54
Average	0.0000	10.00	3.30	1.85	117.19	85.22991

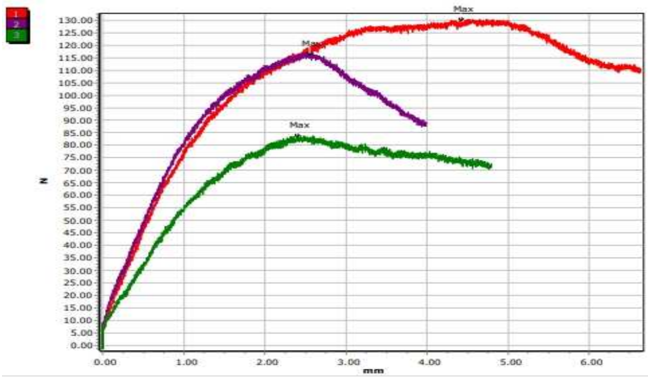


b. Variation 2

From the graph above, it can be seen that rough 2 and 3 have maximum force values of 126.16 N and 125.86 N. The density between the line spacing on the rough 2

3.1 Graphics

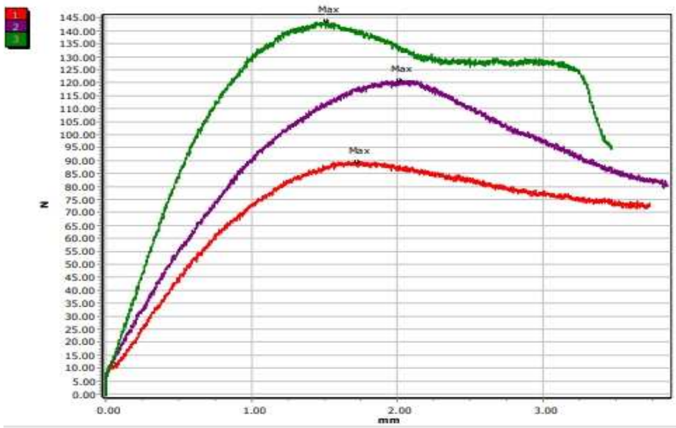
Test Num.	Material	Width (mm)	Thickness (mm)	Displacement (mm)	Maximum Force (N)	Bending Stress (MPa)
1	AL-1	10.00	3.30	4.42	130.52	94.93
2	AL-2	10.00	3.30	2.55	116.99	85.08
3	AL-3	10.00	3.30	2.40	83.91	61.02
Average	0.0000	10.00	3.30	3.12	110.47	80.34505



a. variation 1

and 3 graphs is more uniform compared to rough 1 whose maximum force point decreases to 99.55 N. It is hoped that in the future, it is necessary to pay attention to the right manufacturing process

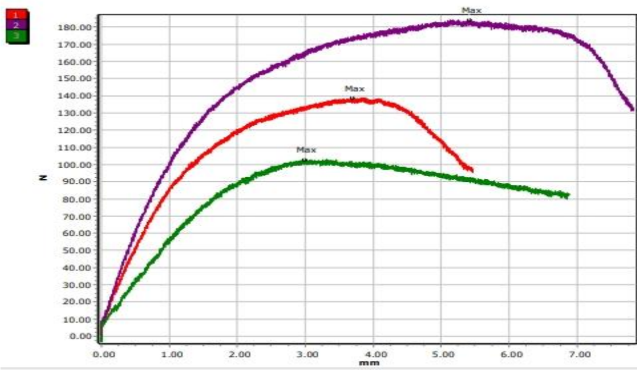
Test Num.	Material	Width (mm)	Thickness (mm)	Displacement (mm)	Maximum Force (N)	Bending Stress (MPa)
1	GARIS-1	10.00	3.40	1.72	89.77	61.51
2	GARIS-2	10.00	3.40	2.01	121.05	82.93
3	GARIS-3	10.00	3.40	1.51	143.91	98.59
Average	0.0000	10.00	3.40	1.75	118.24	81.01128



c. Variaton 3

From the graph above, it can be seen that lines 1, 2, and 3 have a maximum force value of 89.77, 121.05 N and 143.91 N. where the density between the distance of the graph lines of the three specimens still varies, and it is hoped that in the future it should pay attention to the right manufacturing process.

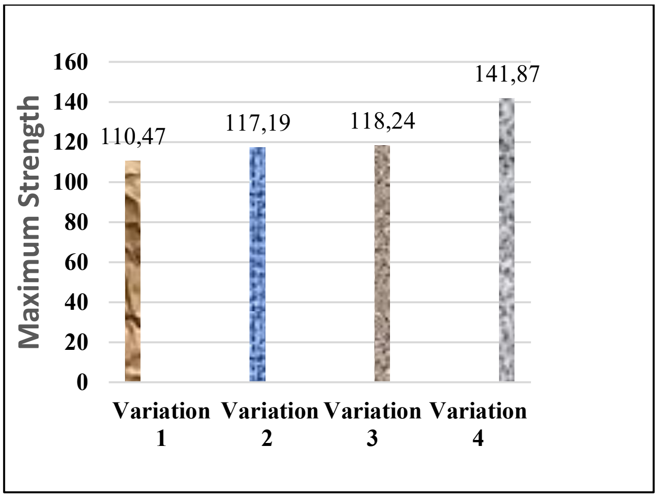
Test Num.	Material	Width (mm)	Thickness (mm)	Displacement (mm)	Maximum Force (N)	Bending Stress (MPa)
1	CNT-1	10.00	3.30	3.69	138.79	100.94
2	CNT-2	10.00	3.30	5.42	184.10	133.89
3	CNT-3	10.00	3.30	2.99	102.71	74.69
Average	0.0000	10.00	3.30	4.03	141.87	103.176



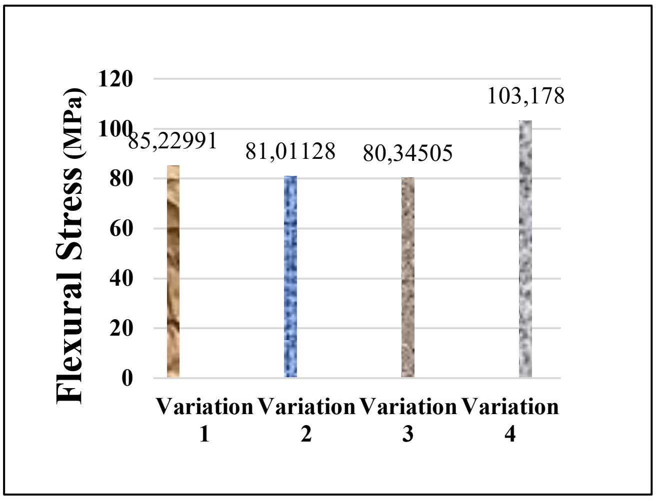
d. Variation 4

From the graph above, it can be seen that CNt 1, 2, and 3 have maximum force values of 138.79, 184.10 N and 102.71 N. where the density between the distance of the graph lines of the three specimens still varies, and it is hoped that in the future it should pay attention to the right manufacturing process.

3.2 Average table graph of each specimen



Average bending strength graph



Average flexural stress graph

The average maximum force and flexural stress values for each specimen variation are shown in Figure X and summarized in Table X. Among the four tested configurations, the specimen reinforced with carbon nanotubes (CNT) exhibited the highest average maximum force of 141.87 N and flexural stress of 103.18 MPa. In contrast, the specimen using aluminum powder (Al) without surface treatment recorded the lowest values, with a maximum force of 110.47 N and flexural stress of 80.34 MPa. The superior performance of the CNT-reinforced composite is attributed to the high aspect ratio and nanoscale size of the CNTs, which enable effective load transfer and improved stress distribution within the resin matrix. The CNTs also enhance interfacial bonding between the carbon fiber, aluminum faceplates, and epoxy, effectively filling micro-voids and reducing delamination. Additionally, the application of surface treatment (sanding and precoating) on the aluminum faceplates contributed to improved adhesion, further increasing the bending resistance.

On the other hand, the lower mechanical performance observed in the Al powder variation can be linked to the relatively larger particle size of aluminum, which may have limited its ability to penetrate microvoids or interface effectively with the resin. Moreover, without CNTs or optimized surface modification, the bonding between the resin and aluminum substrate was less effective, resulting in lower energy absorption during bending. Quantitatively, the incorporation of CNTs increased the maximum bending strength by approximately 19.98% compared to the untreated baseline, while the addition of Al powder contributed only a 6.57% improvement. These results highlight the significance of nanoparticle type and surface treatment in enhancing flexural performance, which is critical for composite applications subjected to bending loads, such as in seaplane float structures.

In this study, an increase in flexural strength was observed in specimens reinforced with CNTs compared to those without nanoparticles or with Al powder only. While the flexural test does not directly measure interfacial strength, previous studies have demonstrated that CNTs can enhance bonding between resin matrices and fiber or metal surfaces due to their high surface area, aspect ratio, and ability to form mechanical interlocks [13]- [1516]. CNTs may also bridge microcracks and suppress interfacial failure under mechanical loading. Therefore, the observed improvement in bending strength may be attributed to enhanced interfacial bonding, potentially facilitated by the uniform dispersion of CNTs within the adhesive layer. However, as this study did not include interfacial shear tests, SEM imaging, or microstructural characterization, this mechanism cannot be confirmed directly. The interpretation is thus based on mechanical trends and should be viewed in light of supporting literature. Extensive research has shown that the incorporation of CNTs in composite systems can significantly improve interlaminar shear strength, which correlates with enhanced flexural performance. For instance, Bekyarova et al. (2007) reported a 27% increase in interlaminar shear strength when multi-walled carbon nanotubes (MWCNTs) were incorporated into carbon fiber/epoxy composites, highlighting the positive influence of CNTs on fiber/matrix interface quality. Similarly, Qian et al. (2008) observed a significant increase in interfacial shear strength by grafting CNTs onto fiber surfaces, further supporting the notion that CNTs improve bond performance under mechanical stress [1516]-[1617].

4. CONCLUSION

Based on the results of the flexural test research on FML specimens reinforced with AL powder and carbon nanotubes (CNT), it can be concluded that the specimens with CNT reinforcement showed the best results, with the highest maximum strength of 141.87 N and the highest flexural strength of 103.178 MPa. The effective bonding properties of the nano adhesive allow the particles to fill the gaps between rough surfaces, resulting in a stronger bond. Although all specimens experienced a mixed type of failure, where adhesive failure was more predominant in specimens with CNTs and AL, there were other factors that also affected the strength and strain of the specimens, causing the final results to not be fully optimized. These findings confirm the importance of selecting the right reinforcing material to improve the performance of composites in engineering applications.

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