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Enhanced Mechanical Evaluation of Natural Fiber Composite Sandwich Panels for Aircraft Structures

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Abstract: The non-destructive assessment of thermo-mechanical characteristics of exceptionally rigid structures composed of natural composite fibers, facilitated by high-force dynamic mechanical investigation, has unveiled new insights previously unattainable with conventional static and impact test methods. This groundbreaking study delves into the potential of natural fiber composite sandwich panels, featuring both aluminum and aramid honeycomb cores, designed for advanced multi-passenger airplane structures. By comparing various panel cores, the study evaluates equal stiffness and damping capabilities across critical flight frequencies ranging from 1 to 100 Hz. Remarkably, the research reveals that the fatigue behavior of these natural fiber sandwich panels is intricately dependent on both the core material and the applied static load. Furthermore, temperature sweeps conducted during the study provide an innovative approach to detecting variations in the post-processing of natural fiber laminated panels. These temperature sweeps also highlight changes in the transition temperature of the matrix material, offering deeper insights into the material's performance under different thermal conditions. The findings of this study underscore the crucial role of core material selection and processing conditions in enhancing the performance of natural fiber composites for aerospace applications. By leveraging dynamic mechanical analysis, researchers can gain a more holistic understanding of material behavior under realistic operational conditions, paving the way for the design and maintenance of lightweight, durable, and efficient aircraft structures. This research not only advances the field of natural fiber composites but also holds significant implications for the future of sustainable and high-performance materials in the aerospace industry.

Keywords: Natural fiber, Sandwich Pannels, Aero Dynamics, mechanical analysis, Characterization designing, MMCs.

1. Introduction

Engineers and developers in the aerospace industry face constant pressure to increase fuel efficiency and maximize structural performance. Due to its incredibly high rigidity and light weight, natural fiber sandwich panels are frequently utilized in constructions sensitive to bending loads (such as wings and fuselage) (Allen, 2013; Castanie *et al.*, 2020). Those laminates are made

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of slight weight core raw material that is joined to higher-stiffness natural fiber sheets on both sides. The structure's bending loads are principally resisted by the face sheets, while the core offers compressive strength and stabilizes the structure to prevent buckling caused by limit compression or torsion. The face sheets and cores are joined by an adhesive, besides throughout the curative of the natural fiber laminate front length or by using a secondary adhesive. A correct load transfer throughout the entire assembly is ensured by this adhesive bond. Metal, aramid (often known by the DuPontTM tradename Nomex®), and polyurethane have all been utilized as core materials and researched. These materials have also been employed in a variety of geometries, most frequently surfs and honeycomb structures (Castanie *et al.*, 2020; Zenkert, 1995). Although carbon and glass fiber textiles are frequently used, the front lengths (face sheets) are also made of a variety of natural fiber sandwich materials (Castanie, Zenkert, 1995; Soutis, 2005). The mechanical characteristics of natural fiber sandwich plates have been put to the test under various loading scenarios, particularly under static stresses. Because of their properties that are time and temperature-dependent, either intricate material like polymers and polymer natural fiber composites are improperly represented by static testing. Another loading condition that is frequently studied outside of static circumstances is impact testing, which accounts for a sizable fraction of studies.

By employing drop impact testing, Baral *et al.*, 2010 evaluated dynamic interpretation of natural fiber with polyimide cores sandwich structures of honeycomb. They found that a surf core outperforms equivalent density of honeycomb core when subjected to impact., however it may be also prone to crushing under compressive pressures. further investigation is [He *et al.*, 2016] used to drop impact testing to examine the conduct of natural fiber composite panels made with polyurethane surf cores. They discovered that greater surf core thicknesses enhance impact interpretation by expanding the Stiffness in bending of a monolithic natural fiber composite sandwich panel. To build models for forecasting based on the thickness and density of the face sheet. The analysis of (Xie *et al.*, 2020) dynamic characteristics of natural fiber sandwich panels made of aramid honeycomb subjected to impact. Zhou *et al.*, 2018 used transducer for signal measurement by giving acceleration response signal and hammer strikes to induce force excitation to determine resin thickness effects of phenolic on the properties of cores of aramid honeycomb that are frequency dependent. These impact studies were focused on loading scenarios with time scales much below 102 seconds (frequencies above 100 Hz). In addition, while collision analysis is important for verifying structural interpretation in aerospace operations, higher-intensity vibrations proficient during typical flight requirements happen at low frequencies, similar vibrations caused by the propulsion system or airframe sound brought on by airflow which is caused by turbulent. It has been suggested that reducing vibration and noise can improve comfort and speed up flyer response times and performance (Woods, 1967; Ingvarsson & Daniel, 1999). Measurements of the typical vibrational frequencies seen during aircraft flying have been made in numerous research. In-vibrations of aircraft of a Rockwell dual turbo engine prop airplane were captured by Dunno and Batt (Dunno & Gregory, 2009) during multiple flights. Vibrations of Boeing 757’s jet engine airplanes measuring over three carries on a, Wallin (Wallin, 2007) was able to create low and high intensity flying contours. The data recorder was affixed to a cargo container. The maximum intensities were discovered in the range of 1 to 100 Hz in both investigations. The findings of two experiments are shown in Figure 1 and are compared to ASTM D4169 criterion for conviction Level II vibration weights observed in airplanes throughout payload transit (Redmann *et al.*, 2021). The power spectral density (PSD), which measures the strength of these vibrations at each frequency, is used. DMA is one method that may measure attributes in this lower-frequency region, in contrast to impact testing. The thermomechanical characteristics of plastics are frequently measured using DMA at various time intervals. In a standard dynamical mechanical analysis test, a sampling is distorted by an oscillation with a little amplitude and a predetermined frequency and strain. A measurement of viscoelastic characteristics is obtained by recording both the strain's application force and the material's reaction after the load has been delivered. The linear viscoelastic area, a region with low strain amplitudes, is characterized by strain independence of the viscoelastic properties. The use of DMA on high-stiffness panels has not been published in the literature, according to a thorough review of the research, which is probably because most commercially available instruments only have less load capacities in range of 30 to 50 N (Menard & Noah, 2020). current maximum load capacities greater than 500 N due to the recent development of commercial higher-force DMA instruments (Redmann *et al.*, 2021). This opens new characterization possibilities and uses, structures made of high-stiffness composite for the aerospace industry.

2. Investigative Techniques

2.1. Materials

In this project, DarkAero (Madison, WI) prototype natural fiber composite sandwich panels were employed. These panels are being tested for the multi crew experimental shown in figure 2. The cell density of the honeycomb cores of aramid and 5056 al was 3.1 lbs/ft3 (50 kg/m3) and the cell size was 1/8 in. (3.2 mm). The natural fiber composite face sheets for the panels were made of epoxy resin, and vacuum molding was used to construct them. In order to provide electrical insolation to each sheet of face, layer of

T700 12K compose natural fiber was used in addition to layer of transparent compose E-glass fiber. All panels underwent an oven post-cure after a 24-hour room temperature cure. The aramid core panels were post-cured at 65°C, whereas the aluminium core panels were post-cured at 90°C.

In Section 2.3, the effects of the various post-cure schedules are investigated and discussed.After post-curing, a big panel section was cut into test samples are prepared with dimensions of 50 mm in length and 15 mm in breadth using a diamond blade wet saw. The aramid samples had a core thickness of 0.25 inches and the aluminium were evaluated 0.50 inches and 0.25 inches. Figure 3 depicts the multiple specimens' configurations that were evaluated.

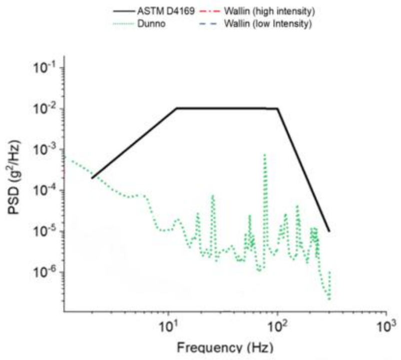

Figure 1: A frequency comparison of several air vibration patterns

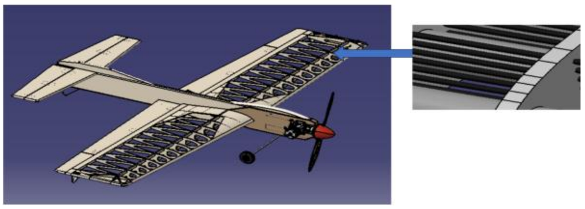

Figure 2: A inside diagram of the Dark Aero 1 building's composite sandwich panels

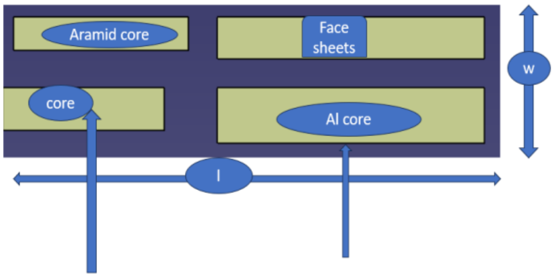

Figure 3: shows Dimensions and components of the panels utilized in this study.

2.2 Mechanical Dynamic Analysis

A HighForce dynamically mechanical analyser and 500 N load cell were used to conduct a dynamic mechanical analysis natural fiber composite panel (DMA). The three-point bending method is used over 40 mm span for all tests. In isothermal conditions, the initial round of tests was carried out. To confirm the maximum loads and linear elastic strain an initial dynamically strain sweep between 0.01% and 1% was performed. The findings were averaged over ten cycles for each strain level. The damping capacity of the various natural fiber composite sandwich panels was assessed in a range of sweep from 0.1 Hertz to 100 Hertz under realistic flying circumstances.

To further explore the impacts of applied loads, additional frequency sweeps were performed with varying static strain values of 0.2, 0.5 and 1.00% height of strain. The frequency of dynamic strain for all sweeps was set to 0.10 % entrenched on the outcome of the previous strain sweep studies. The results of measurements were averaged using the same sampling procedure. In a second set of experiments, dynamic characteristics were measured using a temperature ramp with strain amplitude of 0.10% [Redmann *et al*., 2021].

Findings were made using a 4 K temp step, averaging across 8 cycles of loading. In Figure 4 (left), we can see the natural fiber composite sandwich panels' linear behaviour during the dynamic strain sweep. The storage modulus (E) demonstrates that the elastic feedback remains constant even at roughly 1% dynamic strains, which is a pretty high strain rate. This illustrates even loading throughout the skin layers and symmetric stacking. The absence of modes of buckling, such as wrinkles of core material shear crimps, this nonlinear behaviour would express as an E deviation, is also evident. Again, Figure 4 (right) demonstrates the higher force need to undertake the DMA on these rigid composite sandwich panels. The forces applied to both aluminium core samples are more than the DMA apparatus' normal range of 30–40N With dynamic stresses above 0.1% of al - 0.50 inches core produces 300 N forces. During the strain sweep, the Aramid - 0.25 in. core required the least amount of force, but at a rate of strain of one percentage would be close to the cap with a whole force of 25 roughly.

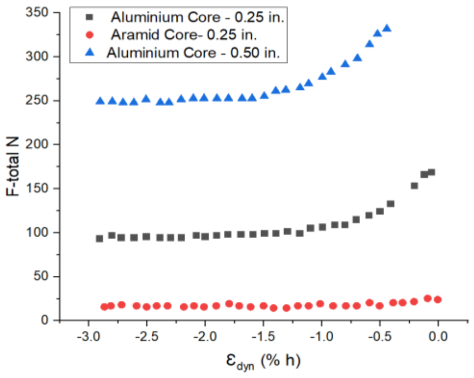

Figure 4: total force needed for each level of strain

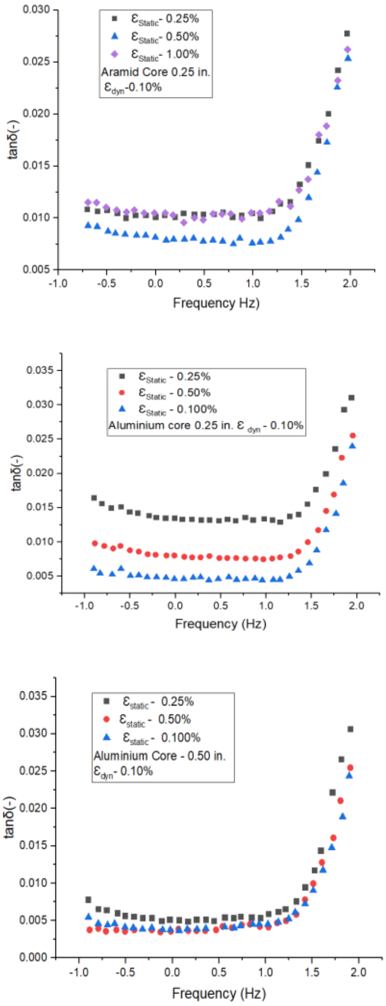

Figure 5: frequency sweeps for the nature composite sandwich panels.

2.3. Iso Thermal Frequency Sweep

The isothermal frequency sweep results (figure 5) shed light on the nature of the sandwich composites over a range of time scales. At frequencies between 10 and 100 Hz, all three panel layouts show an increase in damping with a beginning at around 20 Hz. This is in line with the frequencies that contribute to a crucial level of vibration intensity during normal flight. To serve as a point of reference, the usual values of al alloys and solid epoxy at 1 hertz are in the range of 0.01 and 0.001, respectively (Lakes, 2009). At various static strains, there is a difference in the damping that is most clearly visible as a vertical shift in the sandwich panel made of aluminium that is 0.25 inches thick. The damping ability decreases with increasing static tension, yet the variances get smaller frequencies. The massive sandwich panel made of aluminium, which is 0.50 inches thick, has a minor effect at low frequencies but becomes more effective at higher frequencies. Under these bending loads, the aluminium core material may have undergone a geometric transformation that is the cause of these consequences. Sandwich panel made of Aramid that is 0.25 inches thick exhibits no effect from static strain on damping characteristics. According to the preceding section's illustration (Figure 4), the aramid core material is far less rigid than aluminium cores, so geometric deformity in the aramid core would probably have less of an impact on the damping and bending behaviour. In figure 6 shows another portrayal of above-mentioned findings. The stress-strain reaction of a sampling to the application and removal of a load is shown by the Lissajous curve. When loaded and unloaded materials that exhibit viscoelastic behaviour lose energy, causing a lag in the strain-stress curve. while a specimen that is entirely elastic will have little to no damping and a solid strain-stress curve, while a specimen with damping force substantially behaves viscously and have a significant lag area. Sweeps of frequency carried out with a strain rate of 0.25 percent for the multi panel designs are shown in Fig. 6 for the sake of clarity. The entire loading-unloading curve is given, as well as a magnified view of the crest loading section, which amplifies the distinct lag behaviour at high and low and frequencies that can be attributed to the increase in damping seen in Figure 5. Additionally, figure 4 figure shows straightforward circular shape supports a linear viscoelastic behaviour.

2.3 Temperature Dynamic Analysis

Figure 7 displays the results of temperature sweeps using DMA for natural fiber composite sandwich panels of the same thickness that had varied core materials. The natural fiber composite plates made with the al basis were post cured at high temp than the natural fiber composite structures made with cores of panels(65°c) of aramid was described in Section 2.1. The temperatures of the epoxy resin arrangement employed as the grind in the front sheets make it quite evident how these various post-curing regimens have an impact on the final product. At high peak in the loss of (E) modulus at 153°celsius for the al-based 0.25-inches panel and at 119°C for the aramid-based 0.25-inches panel indicates the Tg. This considerable Tg difference is in line with measurements made for epoxy laminates that underwent various thermal treatments (Polanský *et al.*, 2009; Stark *et al.*, 2015). The crest in the lost modulus for the al 0.25 inches panel is undoubtedly caused by the transition of the epoxy material. The phenolic resin used to coat the aramid core and the epoxy matrix used for the composite front sheet make up two polymeric materials employed in the aramid core material, which makes the transition more challenging. The glass transition of the two materials emerge to imbricate based on the longer assume in the Ecurve close to 140°celsius (Wu *et al.*, 2002).

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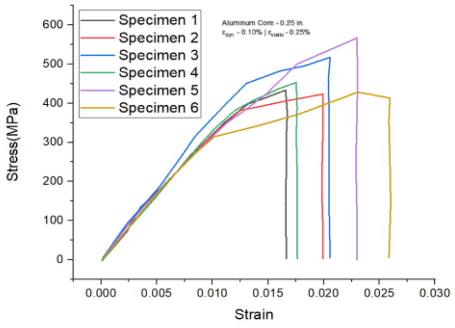

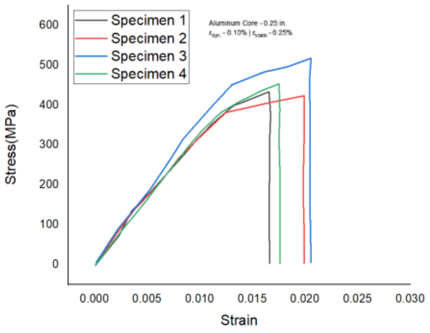

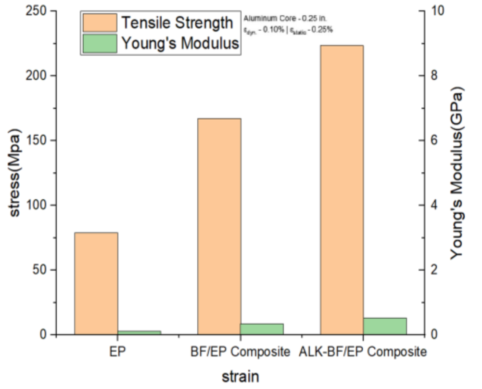

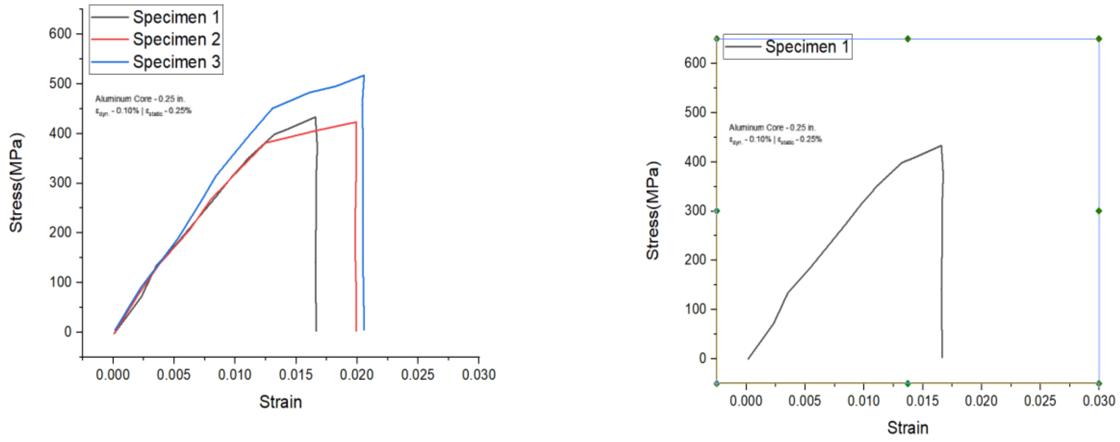

Figure 6: shows curves of multi panel contour, with an enlargement of the peak loading portion on the right and lag of the entire loading and unloading cycle on the left.

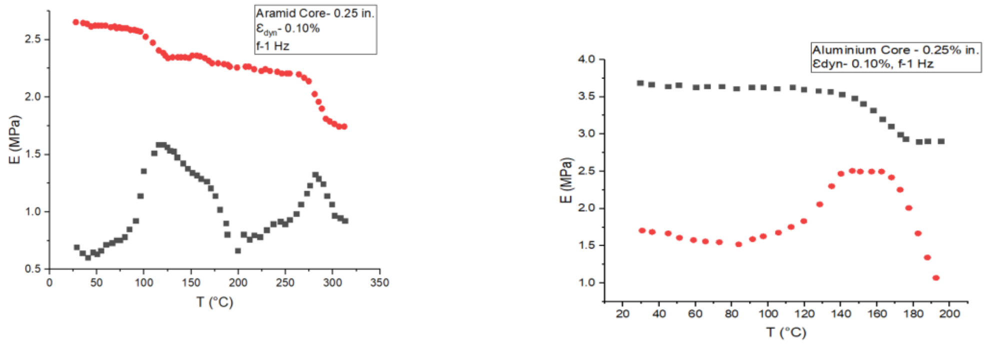

Figure 7: Constant frequency temperature sweeps by comparing the two core materials

3. Conclusion

Several material properties can be determined using mechanical dynamically analysis at various timescale temperatures. All the findings of this study suggest that loads that are orders of magnitude higher than those produced by conventional equipment are necessary to define higher stiffness structures, like natural fiber composite sandwich plates. The temperature and frequency behaviour of multiple variant panel contours were examined using the high-force DMA. This knowledge is especially useful for comprehending damping behavior under flight conditions and guaranteeing correct panel production and post-curing. To analyse a portion of finished natural fiber sandwich panels of composite rather than depending just on aggregate tests of the many components used in their fabrication may be this method's most significant benefit.

It is significant to observe that the stress is no more dominated by bending because of the higher length to depth ratio of the Al 0.50 inches plates, which significantly increases deformation caused by transverse shear. As result, the complete values of the lost and moduli storage might be calculated incorrectly, and the structure's real stiffness may be estimated incorrectly. Although there are no commercially available options for the testing apparatus utilized in this investigation, a larger span length fixture (100 to 200 mm) could be used to provide a bending-dominated loading condition. The frequency patterns and transition points, however, are still true and offer important information on how thick core materials behave.

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