High-force Mechanical Dynamic Investigation of Natural Fiber Composite Sand[illegible]nels for Aerospace Design

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Received: 21 May 2024 | Revised: 4 June [illegible]4 | Accepted: 6 Ju[illegible]4

[illegible]OI: https://doi.org/10.48084/etasr.7903

ABSTRACT

In this paper, the non-destructive assessment of thermo-mechanical charac[illegible]stics of extremely rigid structures made up of natural composites fibers i[illegible]ucted. Higher-force dynamic mechanical investigation has allowed for new insights, which is [illegible]ossible with the regularly employed static and impact test methods. Natural fibers made up of co[illegible]site sandwic[illegible]nels with aluminum and aramid honeycomb cores are studied. Various panel cor[illegible]f equal stiff[illegible] and damping capabilities are compared over flight frequencies ranging from 1 to [illegible]Hz. It was d[illegible]vered that the exhaustion of the natural fiber sandwich panels depends on both the co[illegible]rial and[illegible] applied static load. Additionally, temperature sweeps were carried out, and it was discove[illegible] can identify variations in the post processing of the natural fiber laminated panels and show the [illegible]ations in the transition temperature of the matrix material.

Keywords-natural fibers; sandwich panels; [illegible]dynam[illegible]anical analysis; characterization design; MMC

I. INTRODUCTION

Engineers and developers in the aerospa[illegible] face constant pressure to increase fuel efficien[illegible]nd [illegible]imize structural performance. Due to their high[illegible]gidity [illegible] weight, natural fiber sandwich panels are [illegible]ently[illegible] in constructions sensitive to bending loads (s[illegible]ings and fuselage) [1, 2]. Those laminates are m[illegible]of sligh[illegible]t core raw material that is joined to high[illegible]stiffness natu[illegible]er sheets on both sides. The struc[illegible] bending loads are principally resisted by the face s[illegible]le the core offers compressive strength and stabili[illegible]the stru[illegible]o prevent the buckling caused by limit compression or to[illegible]The face sheets and cores are joined by[illegible]adhesive material, [illegible]esides the natural fiber laminate front[illegible]ngth or a secondary adhesive. Correct load transfer throu[illegible]out the[illegible]ire assembly is ensured by this adhesive bond. [illegible]tal, a[illegible]d (oft[illegible]known by the DuPontTM tradename [illegible]®[illegible]and po[illegible]ethane have all been utilized as core materia[illegible]se ma[illegible]als have also been employed in a variety of geomet[illegible]requently surfs and honeycomb structu[illegible]. Althoug[illegible]arbon and glass fiber textiles are frequ[illegible]y us[illegible]the front lengths (face sheets) are also made of a [illegible]ety of [illegible]sandwich materials [2, 4, 5]. The mech[illegible]al ch[illegible] of natural fiber sandwich plates have [illegible] under various loading scenarios, particularly under [illegible]resses. Because their properties are time and temperature[illegible]ent, intricate materials like polymers and polymer natura[illegible]fiber composites are improperly represented by static testing. Another loading condition that has [illegible]een frequently studied outside the static circumstances is [illegible]pact testing.

By employing drop impact testing, authors in [6] evaluated the dynamic interpretation of natural fibers with polyimide core sandwich honeycomb structures. They found that a surf core outperforms the honeycomb core of equivalent density when subjected to impact. However, it may be also prone to crushing under compressive pressures. Authors in [7] used drop impact testing to examine natural fiber composite panels made with polyurethane surf cores. Authors in [8] studied the dynamic characteristics of natural fiber sandwich panels made of aramid honeycomb subjected to impact. Authors in [9] used hammer strikes to induce force excitation and transducers for signal measurement to determine the thickness effects of phenolic resin on the properties of frequency dependent aramid honeycomb cores. They focused on loading scenarios with time scales much below 102 s (frequencies above 100 Hz).

While collision analysis is important for verifying structural interpretation in aerospace operations, higher-intensity vibrations during typical flight conditions happen at low frequencies. Such vibrations are caused by the propulsion system or by turbulence. Reducing vibration and noise can improve comfort and speed up flyer response times and performance [10–12]. Measurements of the typical vibrational frequencies seen during aircraft flying have been made in many studies. In-vibrations of aircraft of a Rockwell dual turbo engine prop airplane were captured in [13]. Authors in [14] measured the vibrations of a Boeing 757 jet engine and were able to create low and high intensity flying contours. It was discovered that the maximum intensities were in the range of 1 to 100 Hz in both investigations. The findings of the two experiments are shown in Figure 1 and are compared to the ASTM D4169 criterion for conviction Level II vibration weights observed in airplanes throughout payload transit [15]. Power Spectral Density (PSD), which measures the strength of these vibrations at each frequency, was used.

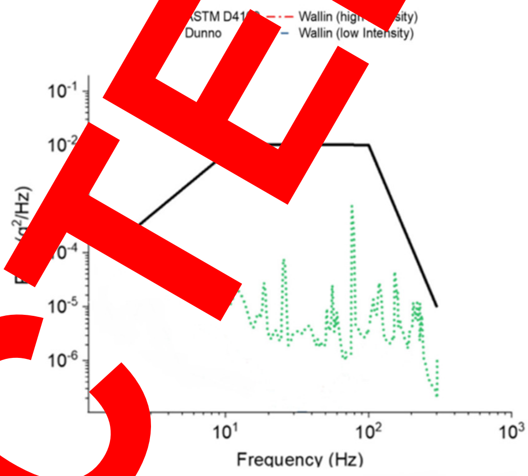
Dynamic Mechanical Analysis (DMA) is one method that may measure attributes in the lower-frequency region. The thermomechanical characteristics of plastics are frequently measured using DMA at various time intervals. In a standard dynamical mechanical analysis test, a sample is distorted by an oscillation with a small 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. As far as is known, the use of DMA on high-stiffness panels has not been studied yet, probably because most commercially available instruments only have lesser load capacities, in range of 30 to 50 N [16]. The current maximum load capacities are greater than 500 N due to the recent development of commercial higher-force DMA instruments [17].

The novelty of the current study is that it provides a thorough assessment of natural fiber sandwich panels for use in aerospace applications, with an emphasis on the panels' dynamic characteristics under practical low-frequency vibrations. This work opens a hitherto unexplored (due to instrument constraints) avenue by [illegible] the thermomechanical behavior of high-stiffness composites using DMA with high-force instruments. In order to identify configurations for impact resistance and [illegible], it also utilizes sophisticated drop impact testing across several core materials and geometries, including metal, [illegible], and polyurethane. This work creates new opportunities to improve the performance of aerospace materials by incorporating high stiffness composite structures [illegible] addressing the low-frequency vibrations characteristics of in-flight circumstances. It also fills important gaps in the literature.

II. MATERIALS AND METHODS

In this project, Dark Aero (Madison, WI) prototype natural fiber composite sandwich panels were employed. These panels are being tested for the [illegible] experimental model shown in Figure 2. The cell density [illegible] honeycomb cores made of aramid and 5056 Al was 3.1 lbs/ft^3 ([illegible] kg/m^3) and the cell size was 1/8 in. (3.2 mm). [illegible] natural fiber composite face sheets for the panels were made [illegible] epoxy resin, and vacuum melding was used to construct [illegible] to provide electrical insolation to [illegible] face sheet, layers of T700 12K compose natural fibers were employed in addition to the layers of transparent composite [illegible] fiber. All panels underwent an oven post-cure after a 2[illegible] room temperature cure. The aramid core panels were post-cured at 65 °C, whereas the aluminum core panels were post-cured at 90 °C.

After post-curing, a big [illegible] was cut into test samples with dimensions of [illegible] mm length and 15 mm breadth using a diamond blade wet saw. The aramid samples had a core thickness of 0.25 in and the aluminum 0[illegible] in and 0.25 in. Figure 3 depicts the evaluated specimens' configurations.



[illegible] Frequency comparison of several air vibration patterns.

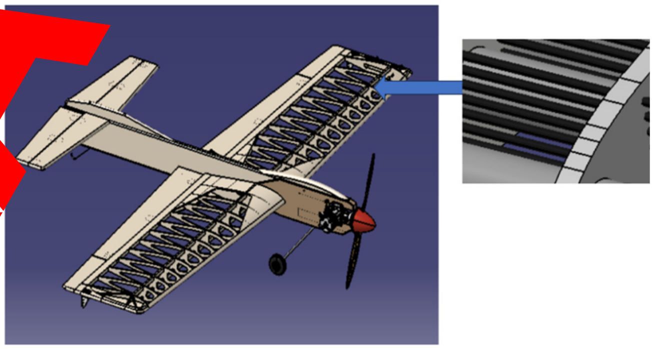


Fig. 2. Inside diagram of the Dark Aero 1 composite sandwich panels.

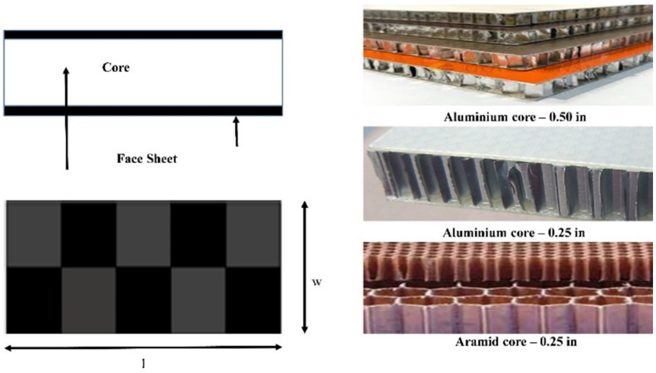


Fig. 3. Dimensions and components of the panels utilized in this study.

III. RESULTS AND DISCUSSION

A high force dynamic mechanical analyzer and 500 N load cells were utilized to conduct a DMA of the natural fiber composite panels. The three-point bending method was used over 40 mm span for all tests. The initial round of tests was carried out in isothermal conditions. 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 10 cycles for each strain level. The damping capacity of the various natural fiber composite sandwich panels was assessed in a range of sweeps from 0.1 Hz to 100 Hz under realistic flying circumstances.

To further explore the impact of the 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 measurement results were averaged using the same sampling procedure. In a second set of experiments, the dynamic characteristics were measured with a temperature ramp with strain amplitude of 0.10% [17].

Findings were made using a 4 K temp step, averaging across 8 cycles of loading. In Figure 4(a), the natural fiber composite sandwich panels' linear behavior during the dynamic strain sweep can be noticed. 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 can be seen even with loading throughout the [illegible] and symmetric stacking. The absence of buckling [illegible] as wrinkles of core material shear crimps, and the [illegible] behavior would be expressed as an e deviation. Figure [illegible] demonstrates the higher force needed to undertake the DMA [illegible] these rigid composite sandwich panels. The [illegible] to the aluminium core samples are more than the [illegible] normal range of 30–40 N with dynamic [illegible] above [illegible] 0.50 in core Al produces 300 N forces. [illegible] the [illegible] the aramid 0.25 in core required the least [illegible] force, but at 1% strain it was closer to the cap with a [illegible] force of roughly 25 N. The isothermal [illegible] sweep [illegible] 5) shed light on the nature of the sandwich composites [illegible] a range of time scales. At [illegible] 10 and 100 Hz, all three panel layouts show an [illegible] initiating at around 20 Hz. This is in [illegible] with the [illegible] that contribute to a crucial level of vibration [illegible] during a normal flight. To serve as a [illegible] of reference, the usual values of Al alloys and solid [illegible] 1 [illegible] in the range of 0.01 and 0.001, respectively [illegible] At [illegible] static strains, there is a difference in the [illegible] that [illegible] visible as a vertical shift in the [illegible] made [illegible] Al with 0.25 in thickness. The damping ability [illegible] increasing static tension, yet the [illegible] get [illegible]. The massive sandwich panel [illegible] which is [illegible] in thick, has a minor effect at low frequencies [illegible] becomes more effective at higher frequencies. [illegible] these [illegible], the Al core material may [illegible] transformation that is the cause of these [illegible] sandwich panels made of aramid with 0.25 in thickness [illegible] effect from static strain on its damping characteristics. [illegible] to Figure 4, the aramid core material is far less rigid than Al core, so geometric deformity in the aramid core would probably have less impact on the damping and bending [illegible] 6 displays another portrayal of the [illegible]. The stress-strain reaction of a sample to the [illegible] of a load is shown by the Lissajous [illegible]. The loss of [illegible] of loaded and unloaded materials that [illegible] viscoelastic [illegible] causes a lag in the strain-stress [illegible] a [illegible] that is entirely elastic will have [illegible] no [illegible] a solid strain-stress curve, a [illegible] damping [illegible] substantially behaves viscously and [illegible] lag area. Sweeps of frequency carried out [illegible] of [illegible] for the multi panel designs are [illegible] for the sake of clarity. The entire [illegible], as well as a magnified view of [illegible] which amplifies the distinct lag [illegible] at high and [illegible] that can be attributed to the [illegible] in damping seen in Figure 5. Figure 4 exhibits that [illegible] circular shape supports a linear [illegible].

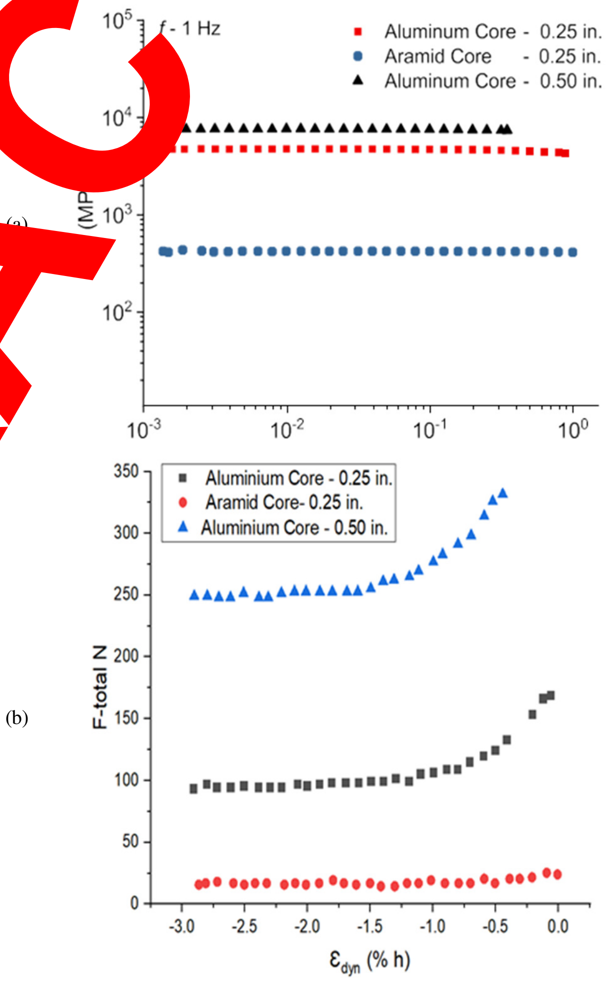


Fig. 4. Total force needed for each level of strain.

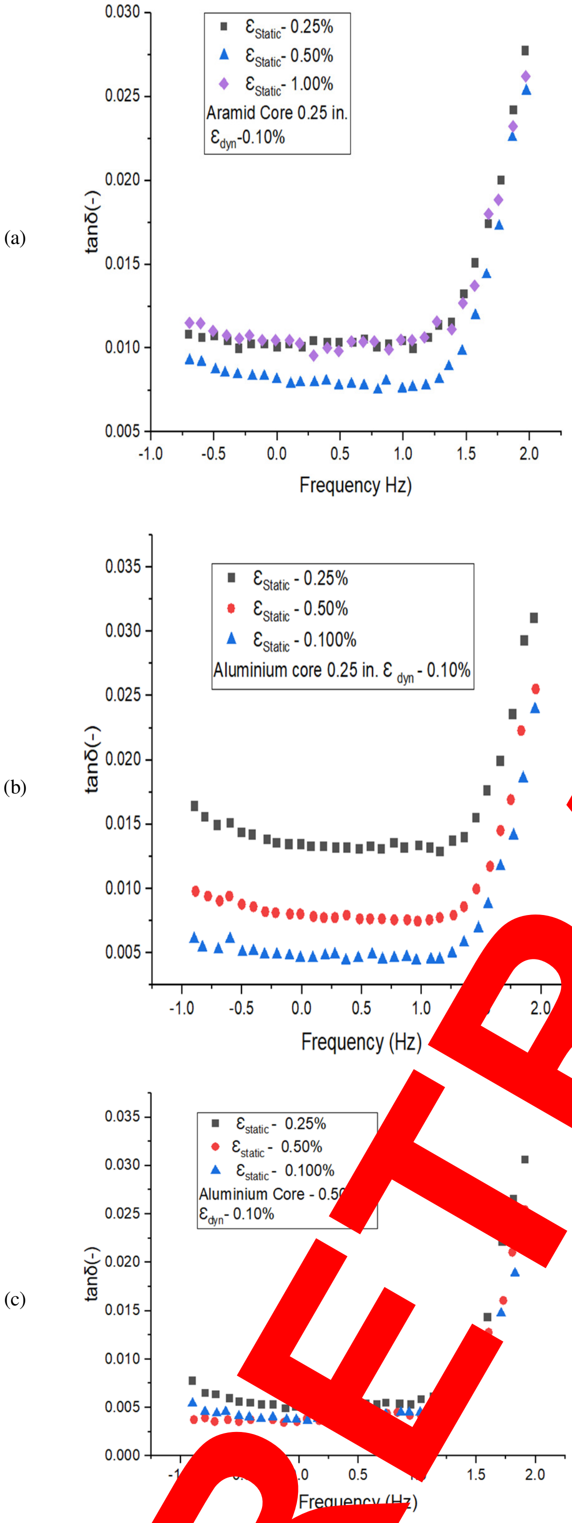
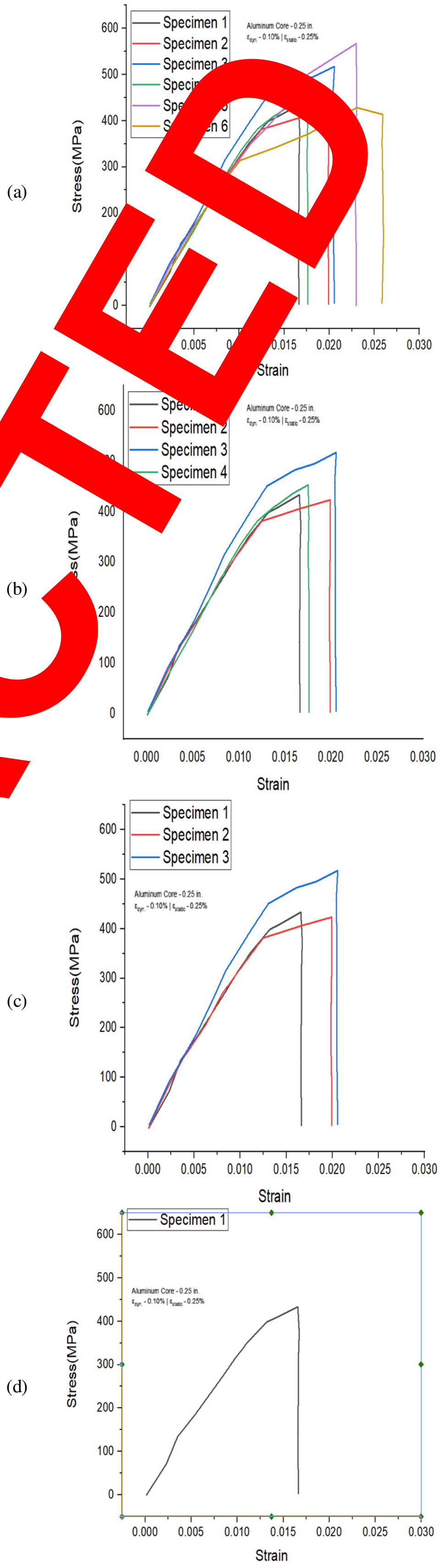


Fig. 5. Fr[illegible]y swe[illegible] of the nature composite sandwich panels.



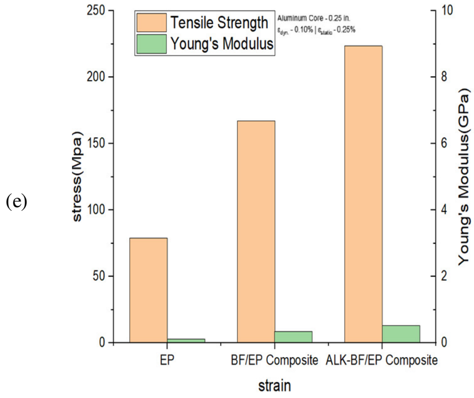


Fig. 6. Curves of multi panel contours, with an enlargement of the peak loading portion and the lag of the entire loading and unloading cycle.

IV. CONCLUSION

Dynamic Mechanical Analysis (DMA) may be used to assess a number of material characteristics at different temporal temperatures. The results of this investigation imply that in order to define higher stiffness structures, such as sandwich plates made of natural fiber composites, loads orders of magnitude greater than those generated by standard equipment are required.

Using the high-force DMA, the temperature and frequency behavior of many panel shapes were investigated. Understanding the damping behavior under flight circumstances and ensuring proper panel manufacture and curing are two areas in which this information can be very helpful. The biggest advantage of this approach is the ability [illegible] analyze a section of completed natural fiber sandwich panels made of composite rather of relying just on aggregate testing of the several components utilized by their manufa[illegible].

It is worth noting that the increased length to depth ratio of the Al 0.50 in plates, which greatly increases deformation [illegible] to transverse shear, means that bending [illegible] no longer the dominant source of stress. As a consequence, [illegible] possible to compute the loss and moduli storage values erroneously, which might lead to an inaccurate estimation of the structure [illegible] true stiffness.

Although the testing equipment [illegible]yed in this experiment is not commercially available, a w[illegible]an length fixture (100 to 200 mm) might be used to generate a loading situation where bending is [illegible]dominant. Still, the frequency patterns and transition points hold [illegible]e and provide valuable insights into the behavior [illegible] dense [illegible]e materials.

ACKNOWLEDGMENT

The authors extend their app[illegible] to the Deanship of Scientific Research [illegible]hern Border University, Arar, KSA for funding this research work through the project number "NBU-FFR-20[illegible]2402-0[illegible]".

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