Data Article

Data characterizing flexural properties of Al/Al₂O₃ syntactic foam core metal matrix sandwich

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ABSTRACT

Microstructural observations and flexural property datasets are provided for aluminum alloy matrix syntactic foam core sandwich composites. The tests are conducted in three-point bending configuration. The data supplied includes methods used for conducting microscopy and mechanical testing. Raw load–displacement data, which is used to plot stress–strain graphs, obtained during the flexural test is also included. Images from a DSLR camera are stitched together to form a detailed failure sequencing video. Failure of specimens is captured in sequential images using a digital camera. These images are stitched together to develop a video for visualization of failure mechanisms. Calculations are also included for a theoretical model that is used to estimate the flexural properties of the syntactic foam core sandwich.

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Specifications Table

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Type of data: Tables and graphs (excel spreadsheets), videos (flexural failure mode) and micrographs.

How data was acquired: The following apparatus and relevant techniques were used for acquiring data: optical microscope, scanning electron microscope, digital SLR camera, universal testing machine, and split-Hopkinson pressure bar (in-house developed).

Data format: The raw data is in the Microsoft Excel file format and the calculated results are in tables.

Experimental factors: Flexural properties for syntactic foam core sandwich composite containing facesheets of one layer of carbon fabric on each side.

Experimental features: Experimental data for three-point bending is provided. Key properties such as flexural strength and modulus are derived from the data. Failure mechanisms can be determined from the image analysis of the videos.

Data source location: New York, USA.

Data accessibility: Data is included in this article.

Value of the data:

- The present dataset is the first one available on the flexural properties of metal matrix syntactic foam core sandwich composites.
- Data obtained in future studies on flexural properties of other metal matrix syntactic foam core sandwich composites can be compared with these results.
- Data available on other metal based sandwich composites can be compared to select the best material for an application. Designers of applications of these materials can use the data as input properties in their calculations.
- Studies on finite element analysis or theoretical modeling of sandwich composites can use this dataset as an input parameter or for result validation.

1. Data

The data included in this article is based on a detailed publication [1]. Micrographs obtained from optical and scanning electron microscopes are presented to show the material microstructure and quality. The micrographs are focused on particles, particle–matrix interface, precipitates in the matrix alloy and fiber–matrix interface in the facesheets.

Load–displacement data obtained for all specimens tested under three-point bending conditions is presented. The data and graphs can be processed to convert to stress–strain diagrams and calculate bending strength and modulus of the sandwich composite.

Images obtained through a digital camera during three-point bending of the sandwich composites are stitched together to develop a video for visualization of the failure process. The video playback speed does not represent the actual compression rate, which was slower.
2. Experimental design, materials and methods

Testing was conducted in a three-point bending configuration using an Instron 4469 universal test system, equipped with a 50 kN load cell. Bluehill 2.0 software was used to acquire load and displacement data. The three-point bend test specimens had total length, width and thickness of 110, 15 and 11 mm, respectively. The span length was selected as 80 mm. The loading anvils were cylindrical with 12.5 mm diameter.

Optical images of initial and failed specimens were captured using a Nikon D7000 digital SLR camera equipped with an AF-S VR Micro-Nikkor 105 mm f/2.8 G IF-ED macro-lens.

Prior to optical microscopy, standard metallographic procedures were followed for specimen preparation. The procedure included surface grinding using 200–1200 grit wheels and polishing using 6 and 1 μm diamond slurry. The polished surface was etched with one part nitric acid in 20 parts alcohol. In some cases, prior to SEM analysis, samples were sputtered with gold using a Leica sputter coating unit.

Microscopy was conducted using an optical microscope (Nikon Epishot 200) equipped with a Nikon DS-Fil digital camera. A Hitachi S3400N scanning electron microscope (SEM), equipped with secondary electron (SE) and back-scattered electron (BSE), detectors was used for microstructure and failure analysis.

3. Microstructure

Fig. 1(a) shows two representative alumina hollow particles (Al₂O₃-HP). These particles are spherical in shape. Fig. 1(b) shows the cross-section of the particle wall in a broken Al₂O₃-HP. Sub-micron size pores can be observed in the cross-section. The surface of the particle is shown in Fig. 1(c) and (d), where surface texture can be observed. The texture is formed during sintering of the small size particles during the manufacturing of Al₂O₃-HP. The texture can be helpful in promoting the particle–matrix interfacial bonding. Fig. 1(e) is an optical micrograph that shows the matrix microstructure having aluminum-rich grains surrounded by silicon rich precipitates. The matrix microstructure is uniform throughout the specimen. Finally, Fig. 1(f) is also an optical micrograph that shows fibers in the carbon fabric that is used in the facesheet region. Since the entire sandwich composite, including the core and facesheets, is fabricated in a single infiltration step, no discontinuity is observed in the core–skin interface region. In addition, the particle–matrix interface appears to be free from defects such as porosity.

4. Flexural characterization

The raw data from the acquisition software can be found in the attached Microsoft Excel file titled “Flexural Results-DIB”. In this file, the work sheet named “Load–displacement” contains the raw data obtained from the flexural test machine and the work sheet named “Stress–strain” contains the stress–strain data. The flexural stress (σ), flexural strain (ε_f) and the modulus of elasticity (E_B) are calculated from the force–displacement curves using

\[ \sigma = \frac{3Fl}{2bd^2} \]  
\[ \varepsilon_f = \frac{6Dd}{F} \]  
\[ E_B = \frac{l^3m}{4bd^4} \]

where F, b, d and l refer to load (N), specimen width (mm), specimen thickness (mm) and support span (mm) respectively. Additionally, m and D refer to slope of the tangent to the initial straight line
portion of the force–displacement graph and maximum deflection of the center of the beam (mm), respectively. The stress strain curves are plotted in Fig. 2. The elastic parts of the curves show consistency.
Flexural strength is defined as the peak after the elastic region of the stress–strain curve and the flexural strain is defined as the strain at which the flexural strength is obtained. The modulus is calculated as the slope in the elastic region. The results are presented in Table 1.

5. Failure mode

Sequential shots of the sandwich composites were taken during the three-point bend test. These are stitched together to create Video 1. It is observed in the video that within the elastic region, the initial structure of the material is preserved. Closer to the compressive strength, crack initiation occurs on the tensile side of the specimen. Although the exact location of the crack initiation depends on factors that include the localized concentration of alumina particles and the presence of defects in the particles close to the fabric layer of the specimen, it consistently begins very close below the loading anvil on the tensile side. Once the skin is fractured, the load is transferred to the core and the crack rapidly propagates to the compressive side. Differences in the compressive strengths are attributed to the random distribution of the particles in the matrix and the role they play in energy absorption during crack propagation. Facesheet wrinkling is observed in the specimens on the compressive side.

6. Theoretical predictions

The following beam theory (adapted from Allen et al. [2]) assumes that the core and face-sheets of the sandwich composites are homogenous. A sandwich beam of span \( l \), width \( b \), core thickness \( H \), homogenous face-sheets of thickness \( t_f \), and an overhang of \( s \) is supported by cylindrical rollers of
radius $R$. A load $F$ is applied to the top surface of the sandwich through a cylindrical loading anvil of radius $R$. The moduli of the face-sheets and the core material are represented by $E_f$ and $E_c$ respectively. The parameters related to the carbon fabric facesheets should be treated cautiously. The mechanical properties are known to degrade in the presence of a multi-axial stress states such as those imposed beneath a loading roller, which allows to neglect the face-sheet beneath the loading roller in subsequent calculations in accordance with previous analysis [3,4]. The relative deflection $\delta$ of the central roller with respect to the supports is given by

$$\delta = \frac{F l^3}{48(El)} + \frac{Fl}{4(AG)}$$

where flexural rigidity, $(El)$ is calculated by

$$(El) = \frac{E_f bt^3}{12} + \frac{E_f bt_f d^2}{4} + \frac{E_c b H^3}{12}$$

and $d$ is the total thickness of the sandwich. The panel rigidity, $(AG)$ is summarized as

$$(AG) = \frac{G_c d^2 b}{H}$$

where $G_c$ is the core shear modulus. The core shear modulus is found by

$$G_c = \frac{E_c}{2(1+\nu)}$$

where the core modulus, $E_c$ was taken to be 4.15 GPa [5] and its Poissons ratio was assumed to be that of Aluminum [6]. Using the relevant input parameters, the theoretical linear force-displacement relationship was determined. The theoretical calculation is presented in the work sheet labeled “Theoretical” in the attached Microsoft Excel file named “Flexural Results-DIB”.

Video 1 shows that upon fracture of the bottom face-sheet, the sandwich rapidly fails. Using mechanics of a composite beam [7], we can calculate the maximum load the carbon fabric can withstand before failure. This will be taken as the theoretical prediction for the collapse load of the sandwich composite and represented by

$$y = A_1 y_1 + n A_2 y_2, \quad n = \frac{E_f}{E_c}$$

$$I_t = I_1 + n I_2$$

$$\sigma_{f, \text{max}} = \frac{n Mc}{I_t}$$

$$M = \frac{P l}{2} \times \frac{l}{2}$$

The calculation for this part is provided in Appendix A. The final collapse load is given as 1782.9 N.
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The views and conclusions contained in this paper are those of the authors and should not be interpreted as presenting the official policies or position, either expressed or implied, of the ARL or the U.S. Government unless so designated by other authorized documents.

Appendix A

See Fig. 3

\[ n = \frac{E_c}{E_a} = \frac{234.42 \text{ GPa}}{4.15 \text{ GPa}} = 56.48 \]

\[ y = \frac{A_1 y_1 + n A_2 y_2}{A_1 + n A_2} = \frac{(10.38)(15)(5.5) + (56.48)(0.305)(15)(10.837)}{(10.38)(15) + (56.487)(0.305)(15)} = 8.82 \text{ mm} \]

\[ l_t = \frac{1}{12} (15)(10.38)^3 + (15)(10.38)(3.32)^2 + \frac{1}{12} (56.48)(0.305)^3(15) + (56.48)(0.305)(15)(2.01)^2 \]

\[ l_t = 4160.1 \text{ mm}^4 \]

\[ \sigma_c = \frac{nMc}{l_t} \Rightarrow M = \frac{(\sigma_c)l_t}{nc} = \frac{(4.27 \times 10^9)(4160.1 \times 10^{-12})}{56.48 \times (8.82 \times 10^{-3})} \]

Recall that : \[ M = \frac{P}{2} \times (40 \times 10^{-3}) \]

\[ P = 1782.9 \text{ N} \]

Appendix B. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.dib.2015.09.054.

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