Data Article

Data characterizing compressive properties of Al/Al$_2$O$_3$ syntactic foam core metal matrix sandwich

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A B S T R A C T

Microstructural observations and compressive property datasets of metal matrix syntactic foam core sandwich composite at quasi-static and high strain rate (HSR) conditions (525–845 s$^{-1}$) are provided. The data supplied in this article includes sample preparation procedure prior to scanning electron and optical microscopy as well as the micrographs. The data used to construct the stress–strain curves and the derived compressive properties of all specimens in both quasi-static and HSR regions are included. Videos of quasi-static compressive failure and that obtained by a high speed image acquisition system during deformation and failure of HSR specimen are also included.

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S p e c i f i c a t i o n s  T a b l e

<table>
<thead>
<tr>
<th>Subject area</th>
<th>Materials engineering</th>
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<td>More specific subject area</td>
<td>Material characterization/Mechanics of composite materials</td>
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Type of data | Tables and graphs (excel spreadsheets), videos (quasi-static and high strain rate failure) and micrographs
---|---
How data was acquired | Following techniques were used for acquiring data: optical microscope, scanning electron microscope, high speed camera, universal testing machine, and split-Hopkinson pressure bar (in-house developed).
Data format | Raw data in csv format and analyzed results in tables
Experimental factors | Compressive properties at quasi-static and high strain rate compression for syntactic foam core sandwich composite containing carbon fabric facesheets.
Experimental features | Experimental data for quasi-static and HSR compression is provided. Key properties such as the yield strength, plateau stress and modulus are derived from the data. Failure mechanisms can be determined from the image analysis of the videos.
Data source location | Brooklyn, NY, USA
Data accessibility | Data is included in this article.

Value of the data

- The present dataset is the first one available on metal matrix syntactic foam core sandwich composites.
- Data obtained in the future studies on 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 make selection of 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 input parameters or for result validation.

1. Data

Original micrographs obtained from optical and scanning electron microscopes are presented to show the material microstructure and quality.

Load–displacement data obtained for all specimens tested under compression is presented. The data and graphs can be processed to convert to stress–strain diagrams and calculate various properties of interest in the sandwich composite. Quasi-static failure features of the specimens are shown in videos.

High strain rate compression tests are very short duration tests. A high speed camera is used to capture the HSR compressive behavior of the specimens. A video is developed at slower playback speed in order to provide better visualization of failure process.

2. Experimental design, materials and methods

Quasi-static compression testing was conducted 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 from the machine. Dow Corning 111 Valve Lubricant & Sealant was applied to the surfaces in contact with the system’s platens to minimize friction and prevent barreling effects.

HSR compression testing was conducted with an in-house developed split-Hopkinson pressure bar (SHPB) set-up. The stress, strain rate and strain were obtained during the test.
Optical images of failure features in quasi-static compression were captured using a Nikon D7000 DSLR camera equipped with an AF-S VR Micro-Nikkor 105 mm f/2.8 G IF-ED macro-lens. Images under HSR compression were taken with an NAC Memrecam HX-5 high speed camera with an acquisition rate of 50,000 frame/s.

Fig. 1. (a) Surface texture of an alumina hollow particle, (b) cross-section of the wall of an alumina hollow particle, (c) the skin–core interface region shows no discontinuity in the matrix, (d) a higher magnification image of fibers showing a clean interface, and (e) optical micrographs of the matrix between alumina particles, where aluminum rich dendritic structures are surrounded by silicon rich precipitates.

Optical images of failure features in quasi-static compression were captured using a Nikon D7000 DSLR camera equipped with an AF-S VR Micro-Nikkor 105 mm f/2.8 G IF-ED macro-lens. Images under HSR compression were taken with an NAC Memrecam HX-5 high speed camera with an acquisition rate of 50,000 frame/s.
Optical micrographs were taken with an optical microscope (Nikon Epiphot 200) fitted with a Nikon DS-Fil digital camera. Other micrographs were taken with a scanning electron microscope (SEM) equipped with secondary electron (SE) and back-scattered electron (BSE) detectors. Standard metallographic procedures were used in specimen preparation, which included surface grinding from 200 to 1200 grit wheels, polishing of the specimen using 6 and 1 µm slurry and etching with a solution of one part nitric acid in 20 parts alcohol. In some cases, prior to SEM analysis, specimens were coated with gold using a Leica sputtering unit.

2.1. Microstructure

Fig. 1(a) and (b) shows the surface texture and cross-section, respectively, of an Al2O3-HP (alumina hollow particle). Porosity present in the walls of these particles can be observed in these images. While surface texture and porosity help in improving the particle–matrix interfacial bonding, porosity leads to degradation in the mechanical properties of particles. Fig. 1(c) shows the transition region from the syntactic foam core to the skin. Since the composite is infiltrated in one step, instead of attaching the skins separately, no discontinuity is observed in the matrix. Fig. 1(d) shows complete penetration of melt in the fiber tow. No interfacial debonding between fibers and matrix is observed in this figure. Fig. 1(e) illustrate the matrix microstructure, showing aluminum-rich dendritic networks surrounded by needle-like Al–Si precipitates. The particle–matrix interface appears to be free from defects such as porosity. The matrix microstructure is uniform throughout the specimen.

2.2. Compressive characterization

To achieve an initial nominal strain rate of $10^{-3}$ s$^{-1}$, a constant cross-head displacement rate of 0.63 mm/min was applied. Specimens were tested in both edgewise and flatwise orientations and had dimensions $15 \times 15 \times 11$ mm$^3$. The edgewise orientation refers to the specimen position where the skins are oriented in the direction of the applied load. The skins are positioned perpendicular to the applied load in the flatwise orientation. Five specimens were tested for each orientation and the average and standard deviations are calculated and presented in Tables 1 and 2. The raw data obtained during the test can be found in files with nomenclature similar to Specimen_RawData_1_EW.csv, where “1” refers to specimen number and “EW” or “FW” refer to edgewise or flatwise orientation.

After acquiring the force–displacement data using Bluehill 2.0 software, stress–strain curves were plotted for each specimen. As shown in Fig. 2(a) and (b), the curves show consistency and are in good agreement with each other. Tables 1 and 2 provide the edgewise and flatwise compressive properties, respectively. The compressive strength refers to the peak at the end of the elastic region and yield strength is defined at 0.2% strain. The plateau stress is defined as the average value of the strain at the intercept point of the line with a gradient in the plateau stress region and the line tangent to the last section of the stress–strain curve. The edgewise compressive modulus is 22.43% higher than the flatwise value; but the compressive strength of the flatwise is 18.18% higher than the edgewise value. The yield strength and plateau stress are also higher in the flatwise orientation.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Edgewise quasi-static compressive properties.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>Modulus (GPa)</td>
</tr>
<tr>
<td>1</td>
<td>1.59</td>
</tr>
<tr>
<td>2</td>
<td>1.59</td>
</tr>
<tr>
<td>3</td>
<td>1.55</td>
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<tr>
<td>4</td>
<td>1.55</td>
</tr>
<tr>
<td>5</td>
<td>1.54</td>
</tr>
<tr>
<td>Avg.</td>
<td>1.57 ± 0.02</td>
</tr>
</tbody>
</table>
The raw data for the HSR compression is provided in files that are labeled as Specimen 1.csv, where “1” is the specimen number in accordance with the numbers listed in the first column of Table 3. This raw data is processed to obtain the HSR compressive properties presented in Table 3. The compressive strength and elastic energy were computed for each of the 19 specimens. The average compressive strength and average elastic energy are higher in the quasi-static region. The sandwich composite in the present study attained a compressive strength of 77.88 ± 4.58 (MPa/(g/cm³)) relative to density.

### Table 2
Flatwise quasi-static compressive properties.

<table>
<thead>
<tr>
<th>Density (g/cc)</th>
<th>Modulus (GPa)</th>
<th>Compressive strength (MPa)</th>
<th>Yield strength (MPa)</th>
<th>Plateau stress (MPa)</th>
<th>Densification strain (mm/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1.56</td>
<td>2.44</td>
<td>148.86</td>
<td>136.07</td>
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<td>9</td>
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<td>10</td>
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<td>2.28</td>
<td>143.70</td>
<td>142.45</td>
<td>77.81</td>
</tr>
<tr>
<td>Avg.</td>
<td>1.56 ± 0.02</td>
<td>2.27 ± 0.13</td>
<td>141.31 ± 4.72</td>
<td>136.27 ± 4.20</td>
<td>85.99 ± 5.61</td>
</tr>
</tbody>
</table>

Fig. 2. (a) Stress–strain curves for quasi-static compression in the edgewise orientation and (b) in the flatwise orientation.

The raw data for the HSR compression is provided in files that are labeled as Specimen 1.csv, where “1” is the specimen number in accordance with the numbers listed in the first column of Table 3. This raw data is processed to obtain the HSR compressive properties presented in Table 3. The compressive strength and elastic energy were computed for each of the 19 specimens. The average compressive strength and average elastic energy are higher in the quasi-static region. The sandwich composite in the present study attained a compressive strength of 77.88 ± 4.58 (MPa/(g/cm³)) relative to density.

### 2.3. Failure mechanism

In the quasi-static region, sequential shots were taken of samples in their edgewise and flatwise orientations. These have been stitched to create Video 1, Video 2 and Video 3, which show the failure mechanism in detail. They do not however, represent real-time compression as the playback frame rate is not in real time.

It is observed that within the elastic region, the initial structure of the material is preserved. In the flatwise orientation, failure is initiated by particle cracking whilst in the edgewise orientation, failure is initiated with carbon fiber fracture. In the stress drop region after the peak, shear bands start to form and particles along this band fail preferentially. The videos also show different stages of the plateau region and the densification of the material. The brittle Al₂O₃-H₃ particles fracture under shear stress and become compressed into their own voids. Once they are completely crushed, the material reaches the densification region. Particle failure of this kind has been recorded in aluminum matrix
syntactic foams (AMSFs) in previous studies [1,2]. Video 4 shows the compression of the syntactic foam core sandwich at high strain rate. The failure characteristics are similar at all high strain rates.

Acknowledgments

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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. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.dib.2015.09.046.

References
