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Corresponding author: NIEKE Philipp
e-mail of corresponding author: p.nieke@auckland.ac.nz

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Title

Mechanical Properties of Additively Manufactured Titanium Alloy Sandwich Structures for Thermal Protection

Authors

Philipp NIEKE[1], Vladimir Yotov [2], Guglielmo S. Aglietti[3], Nicholas J. Rattenbury[4], John E. Cater[5]*

** Corresponding author*
[1] The University of Auckland, Department of Engineering Science, Auckland, New Zealand, p.nieke@auckland.ac.nz
[2] The University of Auckland, Space Institute - Te Pūnaha Ātea, Auckland, New Zealand, vladimir.yotov@auckland.ac.nz
[3] The University of Auckland, Space Institute - Te Pūnaha Ātea, Auckland, New Zealand, g.aglietti@auckland.ac.nz
[4] The University of Auckland, Department of Physics, Auckland, New Zealand, n.rattenbury@auckland.ac.nz
[5] University of Canterbury, Department of Mechanical Engineering, Christchurch, New Zealand, john.cater@canterbury.ac.nz

Abstract

In recent years sandwich structures with lightweight lattice cores have been considered for active and passive thermal protection systems for aerospace applications [1]–[5]. Metal additive manufacturing provides a relatively fast method of physically realising such complex structures with the advantage of a low and controllable core density [6], [7]. While most studies determine the heat transfer characteristics of these systems, the performance under dynamic mechanical loads such as vibration has not yet been studied extensively [1]. Thus, this contribution focuses on the vibration testing and correlation with numerical modal analysis of six cylindrical sandwich samples with an open-cell lattice core. The lattice core is based on a body-centered-cubic (BCC) unit cell with an edge length of 5 mm. To study the influence of the lattice properties, three relative core densities (resulting from nominal strut diameters 0.5 mm, 0.8 mm, and 1.0 mm) and two lattice thicknesses (15 mm and 25 mm) were manufactured using Electron Beam Melting in Grade 5 Titanium (Ti-6Al-4V). The same sample geometries were previously thermally tested in the arc-heated facility L2K at the German Aerospace Center [8]. In this study, low-level random vibration tests were performed within a frequency range from 20 Hz to 2000 Hz on a 1D shaker in the axial and lateral directions successively. A 0.575 kg dummy mass was mounted on top of the samples, such that the assembly would have natural frequencies (NFs) sufficiently lower than the maximum excitation frequency and the measured transfer functions could be used for accurate mechanical property identification by curve-fitting an analytical solution. Finite element analysis (FEA) was used to estimate the NFs and size the dummy mass a priori. Two pairs of orthogonal bending modes, an axial mode and a torsion mode were identified in the specified frequency range, that is, the 6 principal modes of the dummy mass. The natural frequency of the bending mode was successfully measured for all samples. For the axial mode, the exact NFs could only be determined for three of the samples, as they were above 2 kHz for the rest. Depending on the lattice parameters the NFs ranged from 180 Hz to 804 Hz and from 752 Hz to 1468 Hz, respectively. The equivalent Young's moduli and structural damping of the homogenized lattice cores were calculated under the assumption of a damped six-degree-of-freedom spring-mass system, and were subsequently cross-correlated against FEA. The derived values were compared to analytical predictions for metal foams [9] and BCC lattices [10].

Keywords

mechanical properties, thermal protection system, additive manufacturing, lattice structure, Ti-6Al-4V, vibration testing, modal analysis

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