

PAPER • OPEN ACCESS

Analysis of syntactic foam – GFRP sandwich composites for flexural loads

To cite this article: Daniel Paul *et al* 2018 *J. Phys.: Conf. Ser.* **991** 012064

View the [article online](#) for updates and enhancements.

Related content

- [A comparative study of a self strain-monitoring carbon nanotube film and carbon fibers under flexural loading by electrical resistance changes](#)
B Pinto, S Kern, J J Ku-Herrera *et al.*
- [Properties of polyurethane foam/coconut coir fiber as a core material and as a sandwich composites component](#)
M A Azmi, H Z Abdullah and M I Idris
- [Stereolithography fabrication and characterization of syntactic foams containing hollow glass microspheres](#)
T Roques-Carnes, Ph Marchal, A Gigante *et al.*

Recent citations

- [Development of a Software Package for Analysis of Heart Muscle Activity](#)
O Bezruckova *et al*



ECS **240th ECS Meeting**
Oct 10-14, 2021, Orlando, Florida

Register early and save up to 20% on registration costs

Early registration deadline Sep 13

REGISTER NOW

Analysis of syntactic foam – GFRP sandwich composites for flexural loads

Daniel Paul¹, R Velmurugan^{1*}, R Jayaganthan², N K Gupta³,
and A V Manzhurov^{4,5}

¹Department of Aerospace Engineering, Indian Institute of Technology Madras, Chennai, India

²Department of Engineering Design, Indian Institute of Technology Madras, Chennai, India

³Department of Applied Mechanics, Indian Institute of Technology Delhi, Delhi, India

⁴Ishlinsky Institute for Problems in Mechanics of the Russian Academy of Sciences, Moscow, Russia

⁵Bauman Moscow State Technical University, Moscow, Russia

E-mail: *ramanv@iitm.ac.in

Abstract. The use of glass microballoon (GMB) — epoxy syntactic foams as a sandwich core material is studied. The skins and foam core are fabricated and joined instantaneously unlike the procedures followed in the previous studies. Each successive layer of the sandwich is fabricated when the previous layer is in a semi-gelled state. These sandwich samples are characterized for their properties under flexural loading. The failure modes and mechanical properties are carefully investigated. The change in fabrication technique results in a significant increase in the load bearing pattern of the sandwich. In earlier studies, debonding was found to occur prematurely since the bonding between the skins and core is the weakest plane. Using the current technique, core cracking occurs first, followed by skin fiber breaking and debonding happens at the end. This ensures that the load carrying phase of the structure is extended considerably. The sandwich is also analytically studied using Reddy's higher order shear deformation theory. A higher order theory is selected as the sandwich can no longer be considered as a thin beam and thus shear effects also need to be considered in addition to bending effects.

1. Introduction

A syntactic foam is a material system composed of a matrix and hollow particles which are added to improve weight reduction and certain other properties. While most of the initial focus was on polymer matrices such as epoxy or vinyl ester [1,2], studies have recently been done even on metal matrices [3]. The lower weight of these syntactic foams enables us to use them in various applications, mainly in the aerospace and marine sectors. Their mechanical properties have been extensively studied. Another attractive use of syntactic foams is as the core in sandwich structures. These structures have been proposed as early as the 1990s [4]. Such sandwich composites have been fabricated and studied in the past both experimentally [5] and numerically [6]. The foam core is found to reduce the overall density of the composite while providing considerable stiffness under bending. Most sandwich structure cores studied have very low stiffness compared to the skin and models to analyse them have been discussed in literature [7]. Syntactic foam cores on the other hand, have considerably higher stiffness values.

In most of the studies on syntactic foam sandwich structures the skins and core are fabricated separately and combined at the end using a resin system. This caused premature debonding,



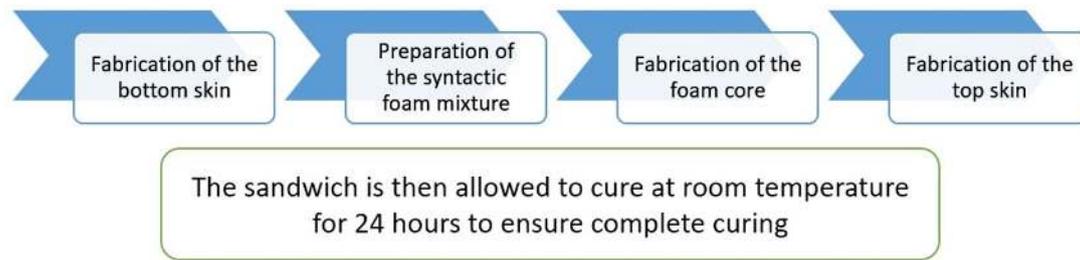


Figure 1. The stages involved in flexural failure of syntactic foam – GFRP sandwich composites.

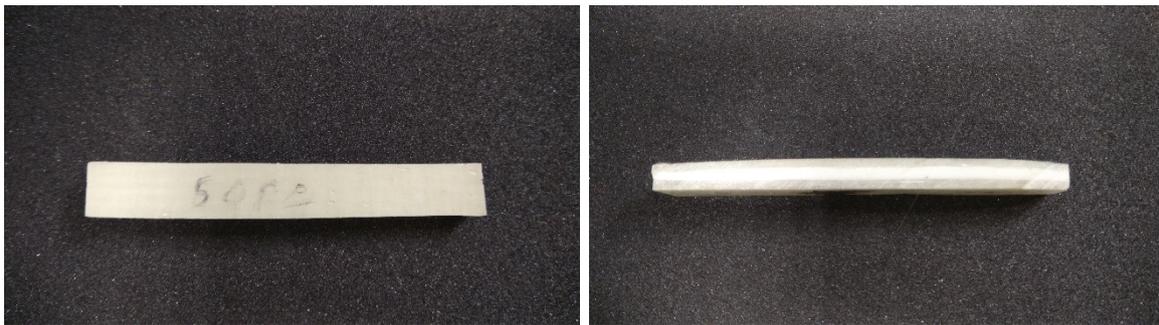


Figure 2. Different views of a sandwich sample after preparation.

leading to failure, under bending. In this study, the skins and core were fabricated together, thereby obtaining maximum load carrying capability from the sandwich before debonding takes place. Flexural tests were performed experimentally and the modes of failure were carefully observed. Analytical study was carried out and results were compared.

2. Experimental study

2.1. Fabrication of the sandwich composites

The materials used in the fabrication of the sandwich composites were 3M Scotchlite K15 type hollow glass microballoons, unidirectional stitched glass fiber mats, and a DGEBA-based epoxy resin system, Araldite LY556. A TETA-based hardener, Aradur HY951, was used as the curing agent. In previous studies, the skins were pre-fabricated and the foam core was then bonded separately. In this study, all the layers were fabricated simultaneously to ensure better bonding at the interfaces.

A predetermined quantity of GMB was mixed with epoxy system using a mechanical stirrer. The mixing was done at lower speeds and the mixture was heated at regular intervals while being stirred to prevent the breaking of the GMB and to reduce its viscosity. At the same time, the lower skin was fabricated by using a hand layup technique. As soon as the epoxy in the skin started gelling, the hardener was added to the GMB-epoxy mixture being stirred. The GMB-epoxy-hardener mixture was poured over the skin and allowed to gel into a semi-solid state. The top skin was then fabricated over the foam core. Both the upper and lower skins were comprised of three layers of glass fiber mats. Care was taken that the subsequent layers were fabricated before the layer preceding them gelled completely. The entire sandwich structure was allowed to cure for around 24 hours at room temperature. A sample with 3mm core thickness with a volume fraction of 0.5 is shown in figure 2.

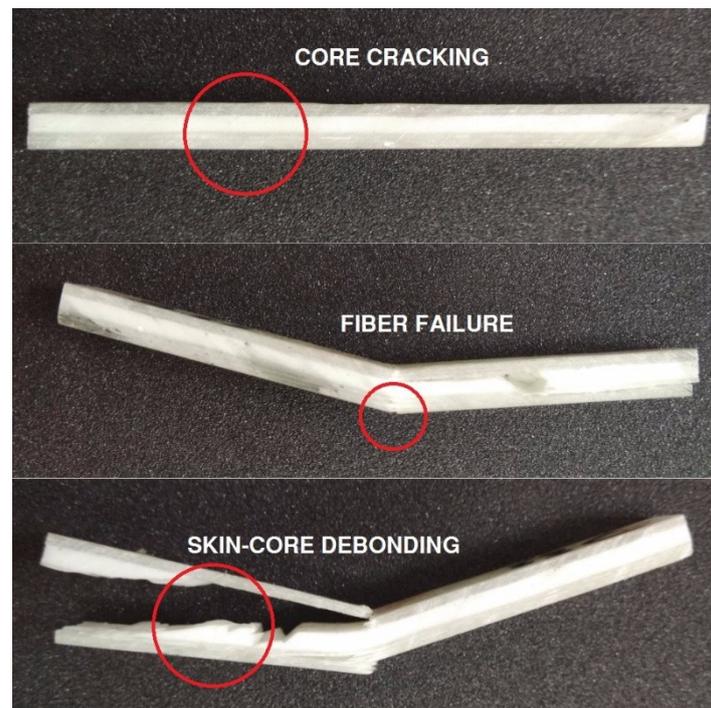


Figure 3. The stages involved in flexural failure of syntactic foam - GFRP sandwich composites.

2.2. Mechanical tests

Flexural tests were performed on a 5 kN Instron Universal Testing Machine (UTM) fitted with a three-point bending fixture. Rectangular samples were used for the tests. The gauge length was fixed at 50 mm.

2.3. Results and discussion

To compare the method of fabrication used in this study, samples were also fabricated by preparing the core and the skins separately and bonding them. Both were subjected to bending loads in order to understand the modes of failure in each section. The stages of failure observed in a sandwich specimen prepared instantly as described in this study are shown in figure 3. There were three easily distinguishable modes of failure in the sandwich structure: core failure (cracking), skin fiber breakage, and skin-core debonding. Initially, both the skin and the core carried the load applied. The core failed first as it had lower strength compared to the skin. This is the first, sudden drop seen in the stress-strain curve. Even though cracks developed in the core, it was held intact by the skins and the structure was able to take further loads. As the specimen was bent further, the skin fibers on the tensile side of the specimen started breaking. This resulted in sudden drops in the load carried alternated by regions where the load could still be carried by the remaining intact specimen. The final failure happened when the skin and core debonded due to shear failure. It was observed that the core surface after debonding was not smooth which indicated that the bonding between the foam and the skin was very strong. This was a result of the fabrication technique used where the entire specimen was allowed to cure as one single unit instead of fabricating each layer of the sandwich and bonding them at the end. In specimens prepared by bonding together the individual sandwich layers at the end, it is seen that the first mode of failure is the debonding of the skin and the core, which led to very low overall strength as the debonding occurred before the maximum load-bearing capacity of the skin had been reached.

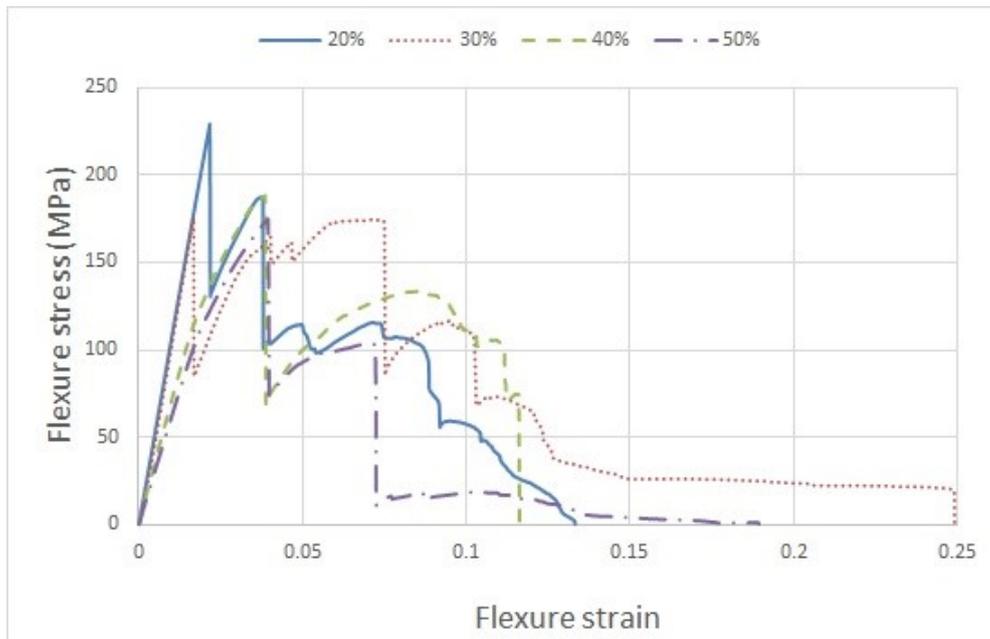


Figure 4. The flexural stress-strain curves of sandwich composites with varying foam volume fraction (core thickness equal 3 mm).

The results of the flexural tests for various core volume fractions of the sandwich composites are shown in figure 4. It can be seen that as the core volume fraction increases, the modulus and strength of the foam showed a slight decrease. Figure 5 compares the sandwich flexural moduli to those of the pure syntactic foams. The increase in modulus compared to the pure foam is due to the higher stiffness of the glass-fiber reinforcement. Despite the decrease in properties, the foam core helps in reducing the density of the composite significantly. The density of the fiber reinforced epoxy alone was found to be 1.646 g/cc while a sandwich containing a core having a GMB volume fraction of 50% had a reduced density of 1.155 g/cc. This helps in reducing the weight of the overall structure being fabricated.

3. Analytical study

Analytical studies were carried out using the higher order shear deformation theory proposed by Reddy [8]. A higher order theory was chosen since the sandwich composite being studied cannot be considered as a thin beam and thus will have shear effects in addition to pure bending. This is visibly noticed during the experimental bending tests where the core and the skin shear off at higher loads.

The displacement field is considered to be of the form

$$\mathbf{u}_1(x, y, z) = \mathbf{u}(x, y) + z\Psi_x(x, y) + z^2\xi_x(x, y) + z^3\zeta_x(x, y), \quad (1)$$

$$\mathbf{u}_2(x, y, z) = \mathbf{v}(x, y) + z\Psi_y(x, y) + z^2\xi_y(x, y) + z^3\zeta_y(x, y), \quad (2)$$

$$\mathbf{u}_3(x, y, z) = \mathbf{w}(x, y), \quad (3)$$

where the last two terms in (1) and (2) are the higher order terms which account for the shear effect which is not considered in first-order theories; Ψ_x and Ψ_y are the rotations of the normal to the mid-plane about the y and x axes, respectively. Using the constitutive and equilibrium equations leads us to form a stiffness matrix which involves a large number of coupling terms other than the usual A , B , and D matrices obtained in simpler theories. After simplifying the

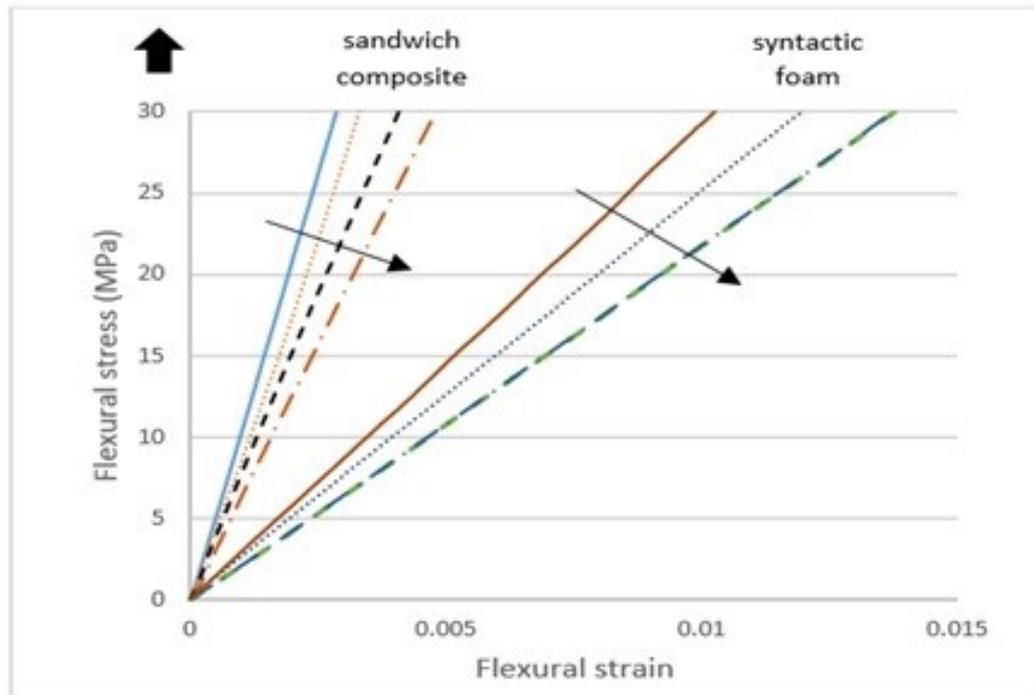


Figure 5. The initial portion of the flexural stress-strain curve compared with pure syntactic foam curves. The arrows depict increasing core volume fraction.

equations for symmetry and special material properties, assumed displacements and rotations are substituted into the equations in Fourier series fashion. Care is taken that these satisfy the boundary conditions. The unknowns in our study are the vertical displacement, w , and the rotations, Ψ_x and Ψ_y . The set of equations obtained is then solved using any equation solving software to obtain the displacement field at a given load. This can be used to calculate the modulus of the sandwich beam. The results obtained for specific volume fractions are shown in figure 6. They were found to be following the same trend as the experimental results.

Conclusions

Syntactic foam – GFRP sandwich composites were fabricated using an instantaneous method. Flexural tests were performed, which showed failure modes different from specimens made by the normal method. The modes of failure were studied in detail and it showed three modes of failure in the following order of occurrence: core failure (cracking), skin fiber breakage, and skin-core debonding. The effect of increasing core GMB volume fraction on the overall properties was studied. Though the stiffness and initial failure of the sandwich samples decreases with an increase in GMB volume fraction, the drawback is compensated by a corresponding decrease in overall sandwich density.

Analytical study was done using a higher order shear deformation theory to model the sandwich composite studied which ensured the shear effect in the thicker composite was taken into account. The values for the skins and core properties individually were obtained from experiments and from analysis. The analytical results were very close to the experimental values obtained.

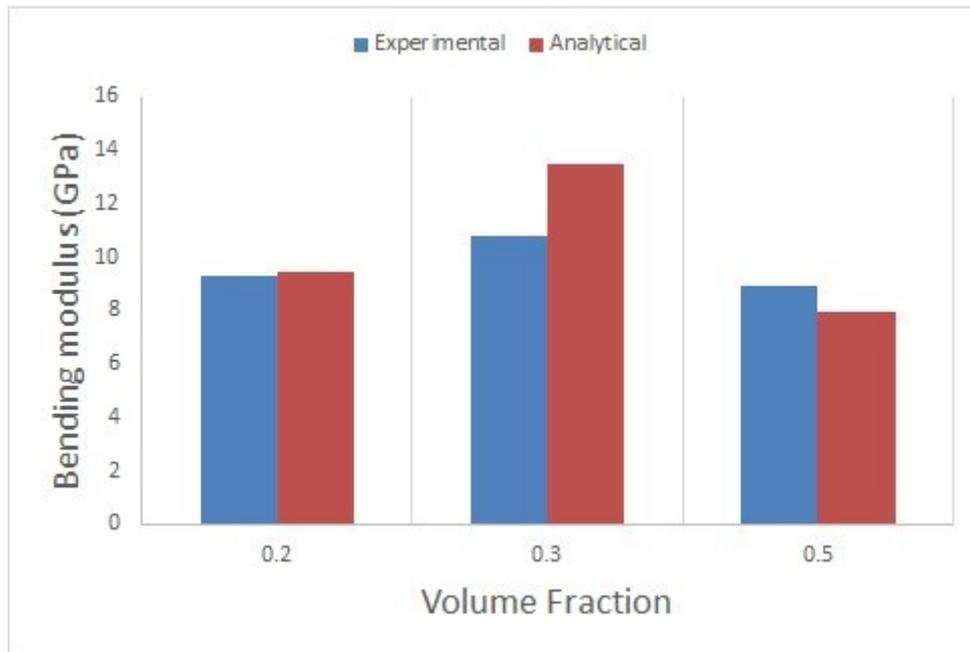


Figure 6. Comparison of analytical results with experimental values.

Acknowledgments

This study was financially supported by the Federal Agency for Scientific Organizations (State Registration Number AAAA-A17-117021310381-8) and by the Department of Science and Technology (DST) of India and the Russian Foundation for Basic Research (project No. 17-51-45054) through the Indo-Russian collaborative project scheme.

References

- [1] Gupta N, Ye R, and Porfiri M 2010 Comparison of tensile and compressive characteristics of vinyl ester/glass microballoon syntactic foams *Compos. Part B: Engng* **41** (3) 236–45
- [2] Wouterson E M, Boey F Y, Hu X, and Wong S C 2005 Specific properties and fracture toughness of syntactic foam: Effect of foam microstructures *Compos. Sci. Technol.* **65** (11) 1840–50
- [3] Omar M Y, Xiang C, Gupta N, et al. 2015 Syntactic foam core metal matrix sandwich composite: compressive properties and strain rate effects *Mater. Sci. Engng: A* **643** 156–68
- [4] Hiel C, Dittman D, and Ishai O 1993 Composite sandwich construction with syntactic foam core: a practical assessment of post-impact damage and residual strength *Composites* **24** (5) 447–50
- [5] Gupta N and Woldeesenbet E 2005 Characterization of flexural properties of syntactic foam core sandwich composites and effect of density variation *J. Compos. Mater.* **39** (24) 2197–212
- [6] Corigliano A, Rizzi E, and Papa E 2000 Experimental characterization and numerical simulations of a syntactic-foam/glass-fibre composite sandwich *Compos. Sci. Technol.* **60** (11) 2169–80
- [7] Hu H, Belouettar S, and Potier-Ferry M 2008 Review and assessment of various theories for modeling sandwich composites *Compos. Struct.* **84** (3) 282–92
- [8] Reddy J N 1984 A simple higher-order theory for laminated composite plates *J. Appl. Mech.* **51** (4) 745–52