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Strength and Deformation Characteristics of Carbon Fibre Reinforced Composite Wrapped Aluminium Foam Beams

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Abstract: Sandwich structures fabricated from an aluminium skinned foam enclosed within a carbon fibre reinforced composite structure have the potential application for high-performance on- and off-road automotive vehicles. The deformations and failure of these types of structures are presented, and results indicate that the application of aluminium face sheets with aluminium foam (AF) aids to prevent the delamination of the outer layers of carbon fibre reinforced polymers (CFRP). The load carrying capacity has been increased by utilising a manufacturing method to maintain the adhesion between the core and the skins until the failure stage is reached. The core shear and de-bonded issue associated with this type of sandwich structure can be addressed by this manufacture method. The peak average flexure load capacity of an aluminium foam sandwich structure (AFSS) with a completely wrapped around CFRP skin was 2800 N with a mass of 191 g. This compares favourably with previously used AFSS without the skins, which had a peak average load of 600 N and a mass of 125 g. An initial finite element model for comparison purposes has been developed to represent the structure's behaviour and predict the associated failure loads. It is proposed that CFRP wrapped around AFSS enhances the structural performance without significant weight gain.

Keywords: composites; sandwich structures aluminium foam; automotive materials

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1. Introduction

The world is passing through economic and climate change with the rapid increase in the consumption of fuel and the emission of carbon, which requires the transport modes to consider the influence on the environment and cost-effectiveness, especially those related to high-performance products. There are numerous researchers who have investigated the mechanical behaviour of metallic foams and aluminium foam sandwich structures. All the cited research refers to aluminium foam sandwich structures that are made of closed-cell aluminium foam with aluminium skins. In previous works, Guglielmino, et al. [1] have collected data and mechanical properties on aluminium foam sandwich structures under shear and compression tests. Experimental results using a finite element analysis on aluminium foam under quasi-static compression and aluminium foam sandwich structures subjected to the quasi-static three bending loads have been reported by Nammi, et al. [2]. This work utilises the repeating unit-cell FE model to represent the performance of closed-cell aluminium foam under quasi-static loading. Bart-Smith, et al. [3] discussed an aluminium foam sandwich structure manufactured by the Alporas® core with two Al alloy face sheet materials to measure and analyse the three-point bending performance of aluminium foam sandwich structures. Yan, et al. [4] presented the mechanical properties of an aluminium foam sandwich structure with a carbon fibre fabric/epoxy resin face-sheet whilst carrying bending loads. The carbon fibre reinforcement increases the panel's strength by distributing the stress over a greater area and absorbing most of the shear strain that would have been transmitted to the core. This also increases the energy absorption of the aluminium foam sandwich structure with the incorporated carbon fibre reinforcement. The failure through de-bonding between the carbon fibre reinforced skins and aluminium foam sandwich structure had been observed. This was due to the aluminium foam not bonding with the CFRP skins which have a higher potential peak load capacity and increased rigidity. The delamination between the aluminium foam core and CFRP skins was detected at the early stage of the three-point bending tests by Yan, et al. [4], and this can be observed in Figure 1. The debonding issue currently restricts the use of this type of structure for potential automotive applications.

Figure 1. De-bonded AFS specimen subject to quasi-static load.

Further work investigated the use of metal skins that are applied as a reinforcement to the aluminium foam core. However, the metal skins increased the weight of the low-density aluminium foam core when acting as the sandwich structure, and therefore limits the application when a lightweight structure is sought after. Composite materials have been introduced as skins to sandwich structures supporting the cellular foam materials in order to keep the lightweight advantage. Sun, et al. [5] introduced carbon fibre reinforcement because of its high tensile strength, low weight, and chemical resistance properties. Zhu and Boay [6] described the performance of a sandwich structure fabricated from an aluminium honeycomb laminated with a carbon fibre epoxy under quasi-static bend tests and drop weight impact loading. Shi, et al. [7] also manufactured sandwich structures consisting of a carbon fibre fabric and aluminium honeycomb. The mechanical properties of the sandwich structure were studied using quasi-static loadings; however, this type of construction is limited as an energy absorber and has poor resistance to local impact loads, compared to a metallic foam system.

Previous work highlighted that a sandwich structure consisting of carbon fibre reinforcement face sheets with the cellular core is capable of taking full advantage of a combination of high strength skins and low density. This sandwich structure could provide much desired energy absorption capacity and beneficial damping properties. Even though the carbon fibre reinforcement enhances the foam material, the delamination between the carbon fibre face sheet and foam core during the process of quasi-static loadings tests was observed, and thus is the basis for further work presented here to alleviate this issue. In this work, a unique composite structure with the carbon fibre reinforced polymer (CFRP) wrapped around aluminium foam with a thin aluminium face sheet was applied as one structure. The number of layers of the CFRP was limited to four so as to compare with current automotive practices. The bonding between carbon fibres and the foam core with aluminium face sheets was utilised to produce a much-improved interface between the two materials and reduce the likelihood of premature failure.

This new sandwich structure was manufactured with a fully self-contained core, and tested under quasi-static loads applied, to compare with previous systems. This work explains the unique manufacturing method of wrapping CFRP around the core and demonstrates that this is a solution for delamination problems which occur at the early stage of flexure tests on specimens that are not wrapped or self-contained. A simplified finite element (FE) model of this sandwich structure was established based on the data from experimental materials, and used for comparison purposes.

This is the basis for a potential energy absorption system that has been fabricated from aluminium foam containing thin aluminium face sheets fully wrapped with CFRC skins. It is proposed as a system with the potential for replacing the current metallic hollow section structures utilised on high performance commercial vehicles.

2. Materials and Methods

The aluminium foam used in this work is AlMg3Si6 and the cover sheet alloy is Al 6082. The AFSS panels comprises of a foam containing TiH2 as a blowing agent with an aluminium alloy sheet as a core layer and two face sheets of aluminium alloy on both sides (see Figure 2).

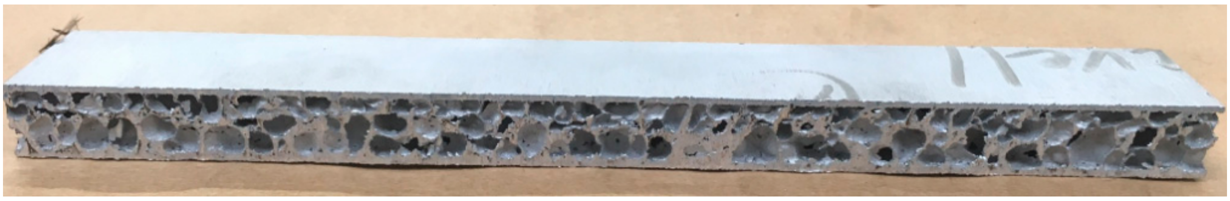


Figure 2. AFSS panel for this work.

The AFSS panels [8] were manufactured by the Austrian company Mepura Metallpulver GmbH. The panels are manufactured by rousing a foaming agent, typically TiH2, into an aluminium alloy and adjusting the pressure while cooling. This method produces a type of aluminium foam named cymat and the material is normally referred to as Al-Sic, for which the base mechanical properties are as shown in Table 1.

Table 1. Mechanical properties of aluminium foam.

Type	Relative Density (kg/m^3)	Young's Modulus (GPa)	Shear Modulus (GPa)	Compressive Strength (MPa)	Tensile Strength (MPa)
Closed-cell aluminum foam	0.6 ± 0.1	2.0 ± 0.5	0.001–1.0	1.0–7.0	2.0–3.0

The aluminium skins are aluminium 6082. The main mechanical properties consist of: density (2.71 kg/m^3), Young's modulus (71 GPa), and yield strength (280 MPa). M79 200T2 prepreg was used as the carbon fibre reinforced polymer surface for the sandwich structure. 200T2 is a type of prepreg consisting of a 2×2 twill weave pattern. The main properties of the resin matrix, as well as prepreg, are presented in Table 2. These outer skins are HexPly® M79 carbon fibre reinforcement with the twill weave pattern, which is more drappable and is therefore a suitable choice for this type of application. HexPly® M79 is a low temperature cured CFRP system. The curing process takes place at 80 °C in an oven for 8 h. Figure 3 shows the typical cure cycle of CFRP based on the out-of-autoclave (OOA) method. KMS industry [9] described the automobile industry as constantly looking for methods to make vehicles cheaper, lighter, faster, and stronger. Based on these ideals, the potential application environment requires OOA as a more economical and time-efficient method for the automobile industry, rather than the autoclave method. The autoclave method needs a more specialised facility and much more investment to achieve the high-quality curing of the composite, which is not generally accepted for general use by the automobile industry.

Table 2. Cured Prepreg Mechanical Properties (HexPly® M79, 2014).

Mechanical Parameters	0° Tensile Strength [MPa]	0° Tensile Modulus [GPa]	0° Compression Strength [MPa]	0° Compression Modulus [GPa]
Value	955	60	750	57

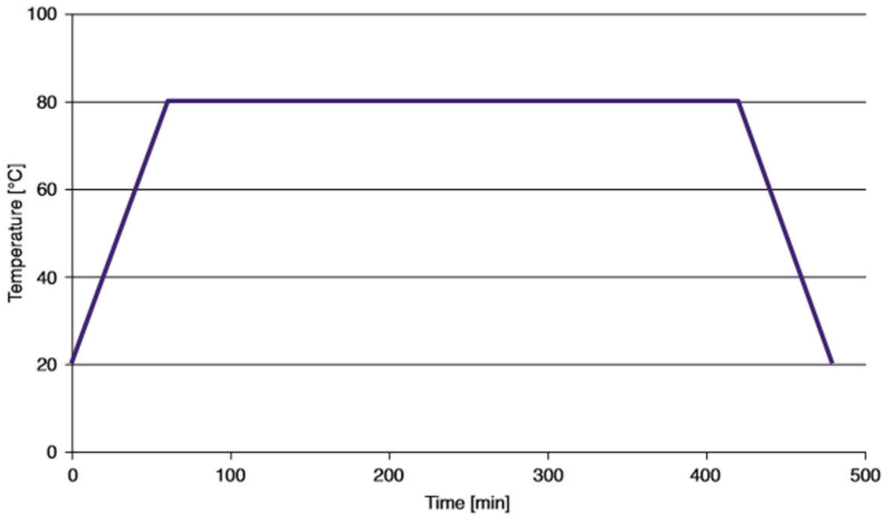


Figure 3. Typical cure cycle (HexPly® M79, 2014).

3. Experimental Results and Discussion

There are three stages of experimental testing that have been designed for the purposes of this work. The first stage was to replace the AF with AFSS and make comparisons between the AFSS and the AFSS laminated CFRP. The second stage was to compare AFSS laminated CFRP with an AFSS wrapped CFRP system and third stage was to compare the larger sized AFSS and AFSS wrapped CFRP systems.

The initial testing stage used beams with the dimensions 150 mm long × 20 mm wide for the AFSS utilizing a standard beam test set up. To compare with actual automotive systems, the size of the beam was increased to 400 mm in length × 40 mm wide for the AFSS in order to simulate the requirements of typical automotive components. Four layers for the CFRP skins producing a 1 mm thickness were used in the initial stage to replicate the research outcome of Yan, et al. [4] and further investigate the de-bonding issues previously described. The total wrapping of the four layers of CFRP skins were applied to remedy the de-bonded issue with limited increase on the overall weight.

3.1. Experimental Investigation of AFSS and AFSS Laminated Four Layers CFRP

Yan, et al. [4] showed that the three-point bending flexural test provides, not only the mechanical properties of the structure in bending, but also showed the deformation and failure mechanism of a foam sandwich structure (as presented in Figure 1). The three-point bending loading is a type of quasi-static loading which represents an initial assessment of the energy absorption capability of the AF with a CFRP sandwich structure. An AFSS panel is introduced here to remedy the deboning issue between aluminium foam core and CFRP skins (see Figure 2). Due to the flat aluminium skin of AFSS, this provides a much-improved contact area with the CFRP skins. Table 3 lists the geometric parameters of the samples subjected to the three-point bending setup. The length and width of each sample is 150 mm × 20 mm for both AFSS and AFSS laminated with four layers CFRP skins in Figure 4; the other dimensions are shown in Table 3.

Table 3. Mass and beam depth for bending tests.

	H (mm)	Mass (g)
AFSS 1	13	28
AFSS 2	13	26
AFSS 3	13	28
AFSS Laminated CFRP-1	15 ± 0.25	46.2
AFSS Laminated CFRP-2	15 ± 0.25	39.6
AFSS Laminated CFRP-3	15 ± 0.25	45.5

Figure 4. (**a**) 150 mm long AFSS panel only; (**b**) AFSS laminated with four layers of CFRP.

The average increase in mass of AFSS laminated with a CFRP to AFSS is only 1.7 times. In the loading set up, the distance between the two support rollers was 100 mm and the loading rate was set at 2 mm/min. The load-displacement curve relating to the AFSS and AFSS laminated CFRP skins under the bending load is shown in Figure 5. The peak load of each sample is used to determine the characteristics of two sandwich structures. The average peak load of AFSS laminated CFRP skins is 2.9 times higher than AFSS with an increase of 1.7 times mass compared with AFSS, therefore, producing a 70% increase in specific strength. However, the peak load value of AFSS laminated CFRP sample 2 is close to AFSS sample 1, as shown in Figure 5.

Figure 6 shows the issues of delamination on some of the samples and problems with the core of AFSS with a CFRP skin, which had the main influence on the failure mechanism during the bending test. The damage at the left side of the sample was observed under the bending loading from the top surface, because the connection between the pores of closed-cell AF was at the edges of the porous foam core, the walls collapsed, and the closed-cell foam core showed shear failure prior to the skin cracking or delaminating. There were three samples of the same dimensions and shape. After subjecting them to the bending loads, all of the samples showed signs of the aluminium foam core shearing as shown in Figure 6. This phenomenon needed a solution so that the core could continuously carry the load up to the structure's failure.

3.2. Experimental Set Up of AFSS with Wrapped around CFRP Skins

After investigating the de-bonded issues between the aluminium foam core and CFRP skins, as shown in Figure 6, this could be alleviated by using the AFSS between the aluminium foam and totally wrapping the outside surface with a CFRP skin. Therefore, the CFRP skin is now totally wrapped around the outside surface to prevent the initial shear of the aluminium foam core. HexPly® M79 was used as the reinforcement which incorporates a twill weave, thus the degree of wrapping around could not follow the 00/00 direction in all cases. The direction of wrapping HexPly® M79 is therefore 0/180/0/180/0 for the twill weave to cover all around the surface of the sandwich structure. The layout method assists in enhancing the strength in the primary load direction, which means the load can be carried in two directions compared with a unidirectional (0°) lamination. This method is more beneficial because the direction of the load in a vehicle during an accident is generally unknown. Hence, the CFRP skin wrapped around the core to face will also improve the out of plane load capacity condition. The four layers of CFRP (HexPly® M79) were assigned to wrap around AFSS sheets. Figure 7 shows the direction of wrapping of the first and third layers of CFRP around the AFSS.

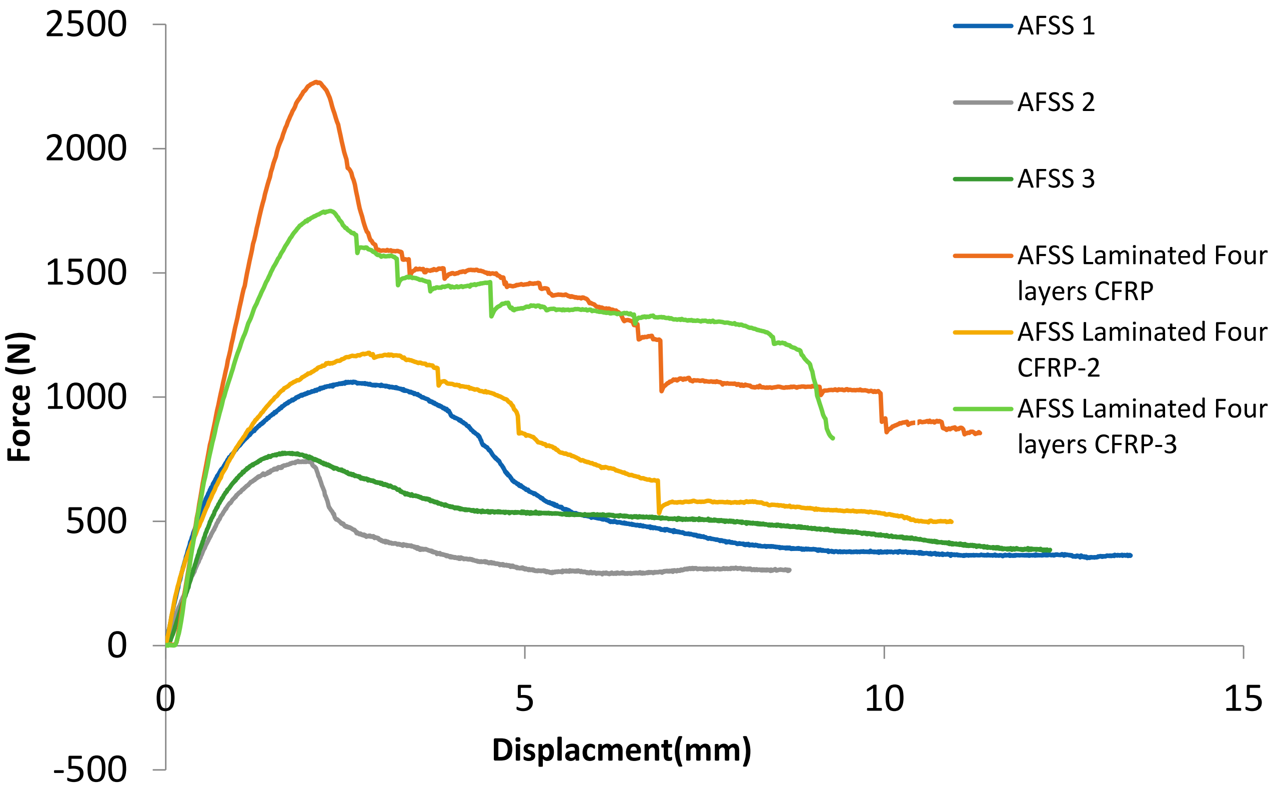


Figure 5. Load-displacement curved of AFSS and AFFSS with four layers CFRP.

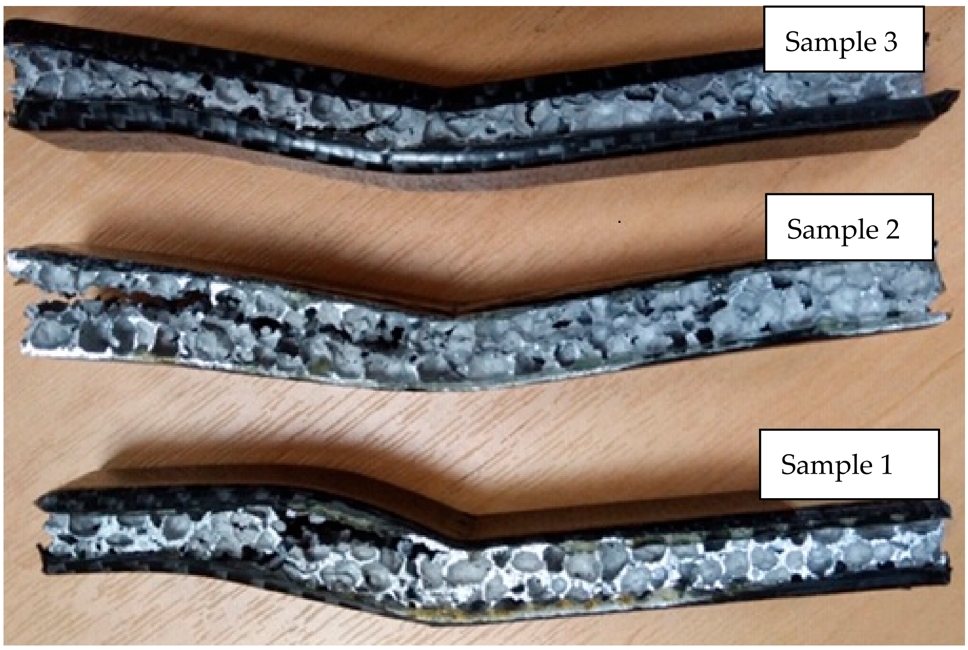


Figure 6. AFSS laminated CFRP samples after carried the bending load.

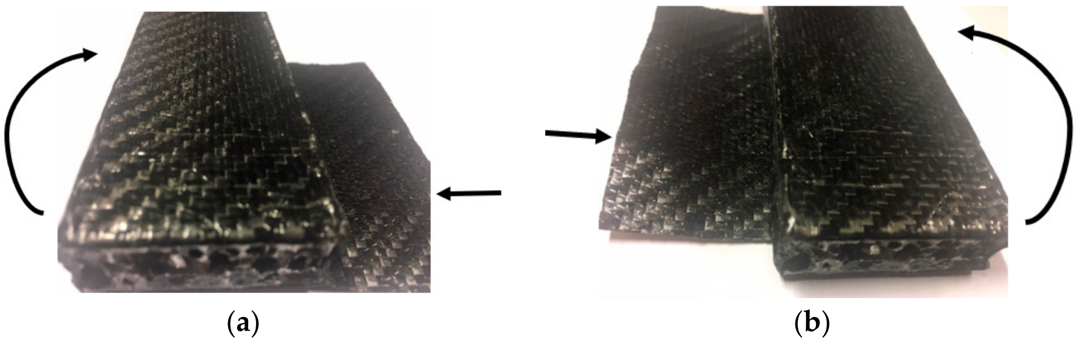


Figure 7. (**a**) Wrapping direction for first and third CFRP layers; (**b**) wrapping direction for second and fourth CFRP layers.

The samples were cured as before with the same method (OOA), cure time, and temperature conditions. The parameters of AFS wrapped around four layers were 150 mm × 22 mm × 15 mm with an average mass of 51.6 g; three samples were used to compare with the AFSS laminated with four layers of CFRP. The distance between the two rollers was 100 mm and the loading rate for the three-point bending load was 5 mm/min.

The three-point bending testing results between the AFSS laminated CFRP and AFSS wrapped around CFRP with the same number of layers are presented in Figure 8. The peak load values of the three samples of AFSS wrapped around CFRP skins are all close to 3000 N, which means that the aluminium foam did not shear at the initial stage; the peak load occurred due to the CFRP cracking under the bending load. The foam core shearing issue of AFSS laminated CFRP has now been alleviated by applying the wrapping process.

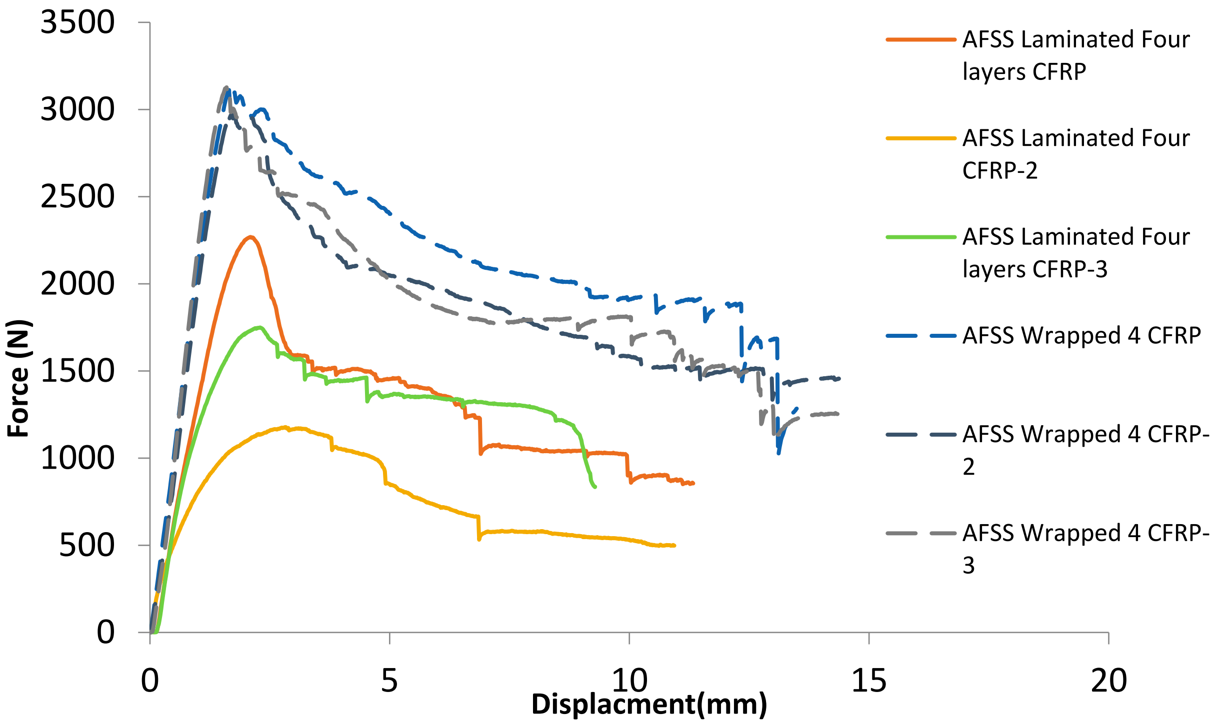


Figure 8. Load displacement curved of AFSS and AFSS wrapped around four layers CFRP.

The CFRP wrapping around AFSS manufacture method provides a solution to producing a high strength, low mass structure. The average peak load of AFSS wrapped around CFRP is 1.8 times higher than AFSS laminated with the same number of layers with only 1.2 times the increased mass, which is detailed in Table 4. The performance of AFSS wrapped around CFRP can be optimised by increasing the layers of CFRP or reducing the thickness of aluminium skins to decrease the mass, but more importantly, the de-bonded issue could be fixed by incorporating a thin flat aluminium skin for the CFRP wrapped around the AF cores.

Table 4. The comparison between AFSS and AFSS laminated four layers of CFRP.

Sample	Mass (g)	Peak Load (N)	Average Mass (g)	Average Peak Load (N)
AFSS Laminated CFRP-1	46.2	2100	44 ± 3.0	1600 ± 500
AFSS Laminated CFRP-2	39.6	1100		
AFSS Laminated CFRP-3	45.5	1600		
AFSS Wrapped around CFRP-1	50.7	3011	52 ± 1.0	3017 ± 82.5
AFSS Wrapped around CFRP-2	53	2940		
AFSS Wrapped around CFRP-3	52	3100		

3.3. Larger Sized AFSS with Wrapped around CFRP Skins

To simulate the potential for this application in a commercial vehicle, the components were scaled up to represent realistic components using the same fabrication method. This was carried out to support the results obtained from the smaller samples and to see if the process could be upscaled without any loss of strength or the premature failure between the skin and the core.

Table 5 shows the manufacture process of the AFSS wrapped around with four layers of XPREG® XC110 (3K) carbon fibre reinforcement polymers (CFRP) which have a fibre volume fraction of 45% [10]. This material is currently employed in many motorsports vehicle systems. The '3K' means 3000 carbon fibre filaments as one bundle. The weave style of carbon fibre in XPREG® XC110 is the twill, in which one or more warp fibres alternate up and down two or more weft fibres in a continuous routine. A broken diagonal or a straight 'rib' as the visual effect can be noticed in this weave manner shown in Figure 9.

Table 5. Mechanical properties of XPREG® XC110 (3K) prepreg system.

Type	Density (kg/m^3)	0° Tensile Strength (MPa)	0° Tensile Modulus (GPa)
XPREG® XC110 3K	1440	521	55.1

Figure 9. The weave style of fibre for XPREG® XC110 epoxy system.

The prepreg carbon fibre was cut to the right size and laminated on the aluminium skins at the two sides of the AFSS panel. The out-of-autoclave was chosen to cure the prepreg carbon fibre. The XPREG® XC110 is proposed to be cured in OOA (vacuum bag at full pressure), however, it is also available to be cured in a typical autoclave with a hot press [10]. The minimum pressure for the vacuum is 10 mbar. The multi-stage temperature cycle with the final 120 °C temperature was used to accurately control and obtain best results, expressed in Figure 10.

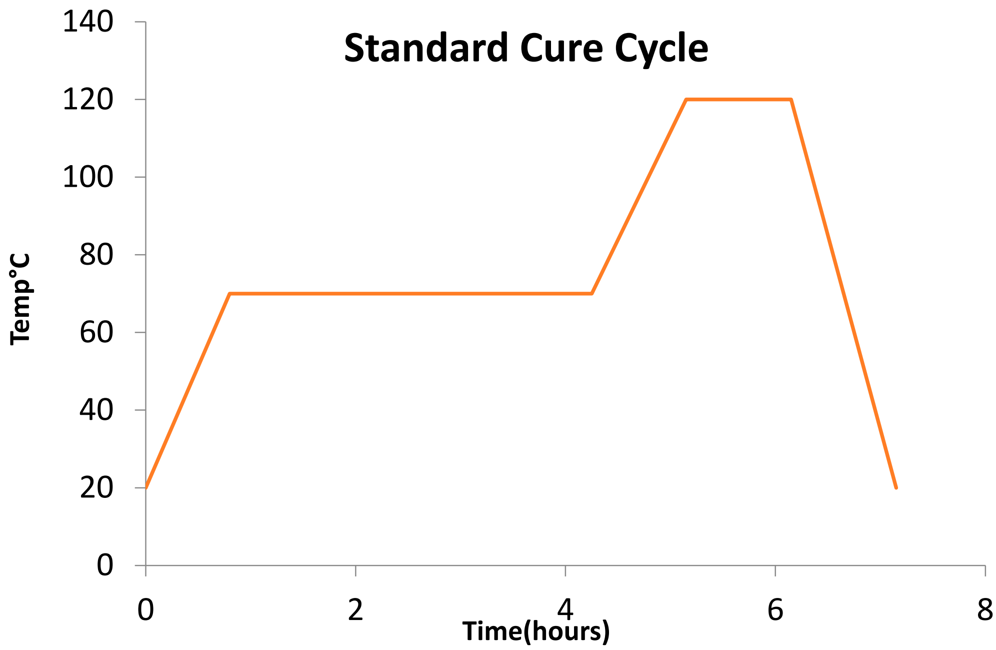


Figure 10. Process and temperature for curing CFRP on the AFFS T.

Bending testing was carried out on a DENISON MAYES® T42B4 universal test machine due the larger loads and sizes of supports required. The larger sized aluminium foam with aluminium skins was carried out under a three-point bending test with the same span ratio as for the smaller standard samples. Table 6 indicates the geometrical parameters used for carrying out the bending tests. The CFRP (XPREG® XC110 3K) were also wrapped around the closed-cell AFSS to form another form of structure, and subjected to a three-point bending test. The size of this new structure is the same as the AFSS (Figure 11A), but the thickness is different (Figure 11B). The span between the two rails was set at 200 mm.

Table 6. Geometrical properties for bending tests large scale.

	L (mm)	W (mm)	H (mm)	Weight (g)
AFSS	400	40	13	124.9
AFSS Wrapped around Four Layers of CFRP (XPREG® XC110 3K)	400	40 ± 1	15 ± 0.5	191

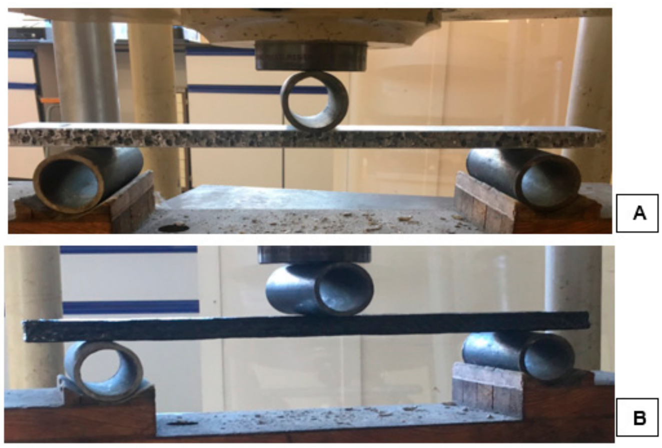


Figure 11. The large scale three-point bending test on (**A**) closed-cell AFSS and (**B**) closed-cell AFSS wrapped around four layers of CFRP (XPREG® XC110 3K).

3.4. Discussion of Test Results for Larger Samples

The response between closed-cell aluminium foam with aluminium skins and closed-cell aluminium foam with skins wrapped around four layers CFRP (XPREG® XC110 3K) under bending is shown in Figure 12. In the case of the unwrapped structure, the foam collapsed at the centre of the span under the bending load and, at the peak load, the aluminium skin at the top face of aluminium foam yielded and the load bar indented nearly halfway through the section as shown in Figure 12A. The stiffness of aluminium foam with aluminium skins was increased by utilising a CFRP wrapped totally around the core. This enabled an increased bending load without the total collapse of the top surface under the peak load, as shown in Figure 12B. The cracking of CFRP was a consequence of the aluminium foam not collapsing and the skins of CFRP just wrinkling, which then means that this structure could significantly absorb more energy and load compared with aluminium foam with aluminium skins under similar flexure tests without a large increase in mass.

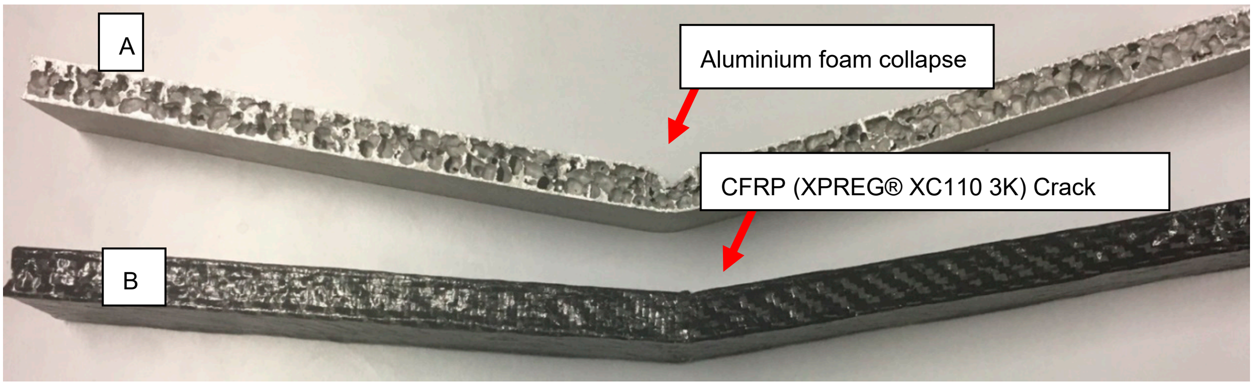


Figure 12. The shape of samples after three-point bending test; (**A**) closed-cell aluminium foam with aluminium skins; (**B**) closed-cell aluminium foam with aluminium skins wrapped around four-layers CFRP (XPREG® XC110 3K).

The graphs in Figure 13 show comparisons with the three-point bending tests results between AFSS and AFSS wrapped around four layers CFRP. The four layers CFRP significantly increased the stiffness of the closed-cell aluminium foam and the ability to carry bending load. It can be observed from the peak load at the linear elastic region. The aluminium foam recorded the peak load value of 600 N but the beam with the wrapped four layers CFRP increased the peak load to around 2800 N. The load-displacement curve of closed-cell aluminium foam with aluminium skins wrapped around four layers CFRP indicated the closed-cell aluminium foam absorbed more energy after cracking initiated in the CFRP. The structure continued to support the loading from the testing machine instead of failing through the bending loading, as occurred previously. The CFRP produces a structure that is much stiffer and stronger than aluminium foam with aluminium skins as shown in Figure 13.

Table 7 summarises the large sized samples subjected to bending load. The peak load of AFSS wrapped around four layers CFPP is four times higher than AFSS, with the mass increasing by 50%. The ratio of load/mass is also shown in Table 7. The sample with a wrapped around CFRP is three times higher than the AFSS only. These results show that the process of wrapping around provides a significant improvement to the load carrying capacity compared to the standard AFSS system, with only a moderate increase in the weight.

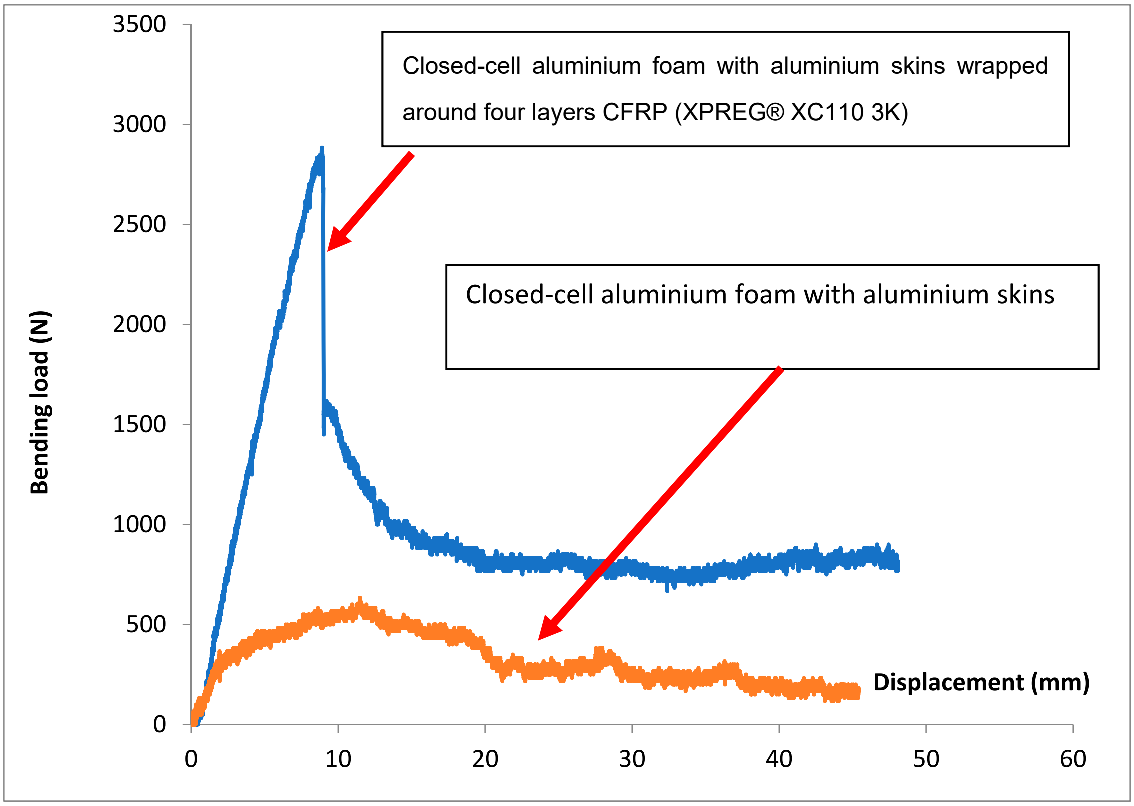


Figure 13. Comparison of the typically three-point bending tests results between closed-cell aluminium foam with aluminium skins and closed-cell aluminium foam with aluminium skins wrapped around four layers CFRP (XPREG® XC110 3K).

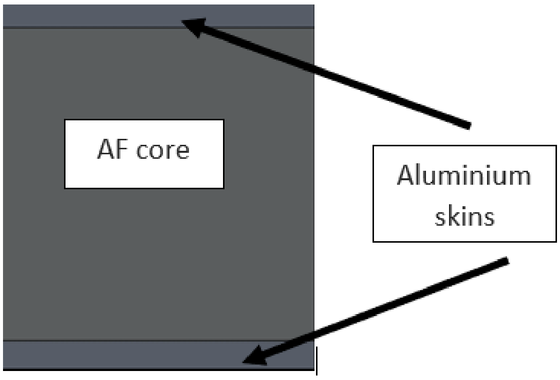
Table 7. The summary of the bending tests results.

	Peak Load (N)	Mass (g)	LOAD/MASS
AFSS	600	124.9	4.8
AFSS wrapped around four layers CFRP	2800	181	15.5

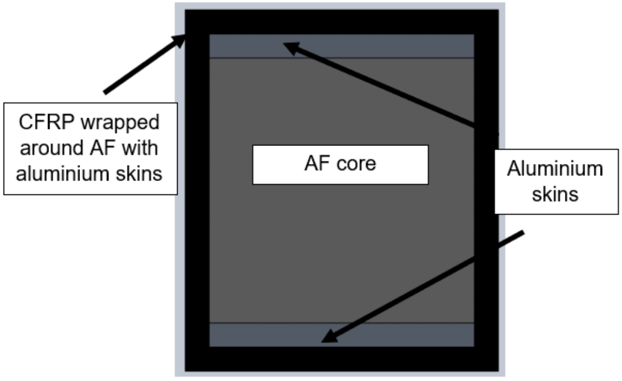
4. Finite Element (FE) Modelling of Three-Point Bending on the Large Scale AFSS and AFSS Wrapped with a CFRP

A simplified finite element analysis was performed to replicate the behaviour of the beam up to potential failure under flexure load. The position of the load and constrains were set as the same as the experimental test set up.

The FE model and simulation conditions can replicate the performance of the aluminium foam with aluminium skins (large scale) subjected to a three-point bending load. The FE model used to simulate the process of the sandwich structure of aluminium foam with aluminium skins wrapped around four layers CFRP by finite elements analysis was developed from two Solidworks® CAD models designed for this simulation, as shown in Figure 14a,b. The FE model of aluminium foam was simplified as a volume without pores, but with the same non-linear behaviour as the actual foam. However, the actual aluminium foam is filled irregularly with pores due to the manufacturing process which can be quite random, and here we have assumed an average. The same thickness of 1 mm of CFRP is applied on all surfaces as shown in Figure 14b.



(a)



(b)

Figure 14. (**a**) The CAD model for the FE simulation of AFSS; (**b**) AFSS wrapped around four-layer CFRP (XPREG® XC110 3K).

The direction of the load and boundary conditions for the FE model simulation are shown in Figure 15. The positions of the load and constraints were the same as the conditions of the experimental test shown in Section 3.3. The solid geometry set for the FE model includes AF and aluminium skins. The load parameter was derived from the test result and the load applied on an area on the top face of this FE model. The constrains were set at the bottom face of the FE model to simulate a frictionless roller system.

Figure 15. Schematic of boundary conditions and load direction.

The experimental stress-strain curves of CFRP and the foams were incorporated in the FE model to simulate the behaviour of the structure's ability to carry the flexure load.

Figure 16 indicates the comparison between the experiment test and simulation. The simulation results reflect the sandwich structure properties of aluminium foam with aluminium skins. The trend of the simulation curve is close to the experimental test result. The displacement of the experimental test was higher than the simulation, which is not surprising, and in part due to the solid shape used for the aluminium core, which in reality is comprised of the pores in the actual sample and the local random indentations.

The value of the maximum load was set at 1500 N. The displacement was recorded as 4.6 mm from the experimental test. The reason for the significant difference in displacement between the FE model (wrapped around the CFRP) and the testing sample is the pores filled around the AF core in the actual beam; however, the solid structure was selected for an FE model to simplify it and reduce the calculation time for the simulation results. The failure flexure load of larger AFSS wrapped around CFRP was 2800 N. The same maximum load was applied to the FE model to determine the displacement between the experimental testing sample and FE model. Figure 17 shows that the displacement of the FE model was 10 mm under the 2800 N (peak load obtained by the experimental result) and the testing result is 8.5 mm.

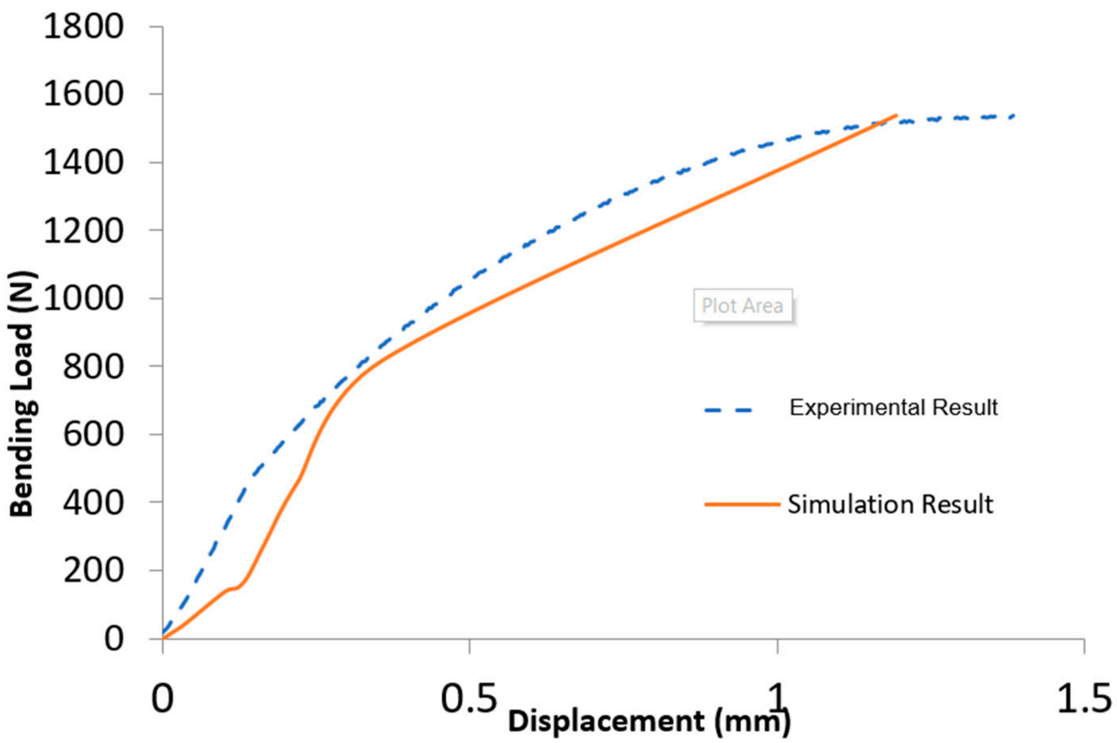


Figure 16. Comparison simulation and experimental of AFSS.

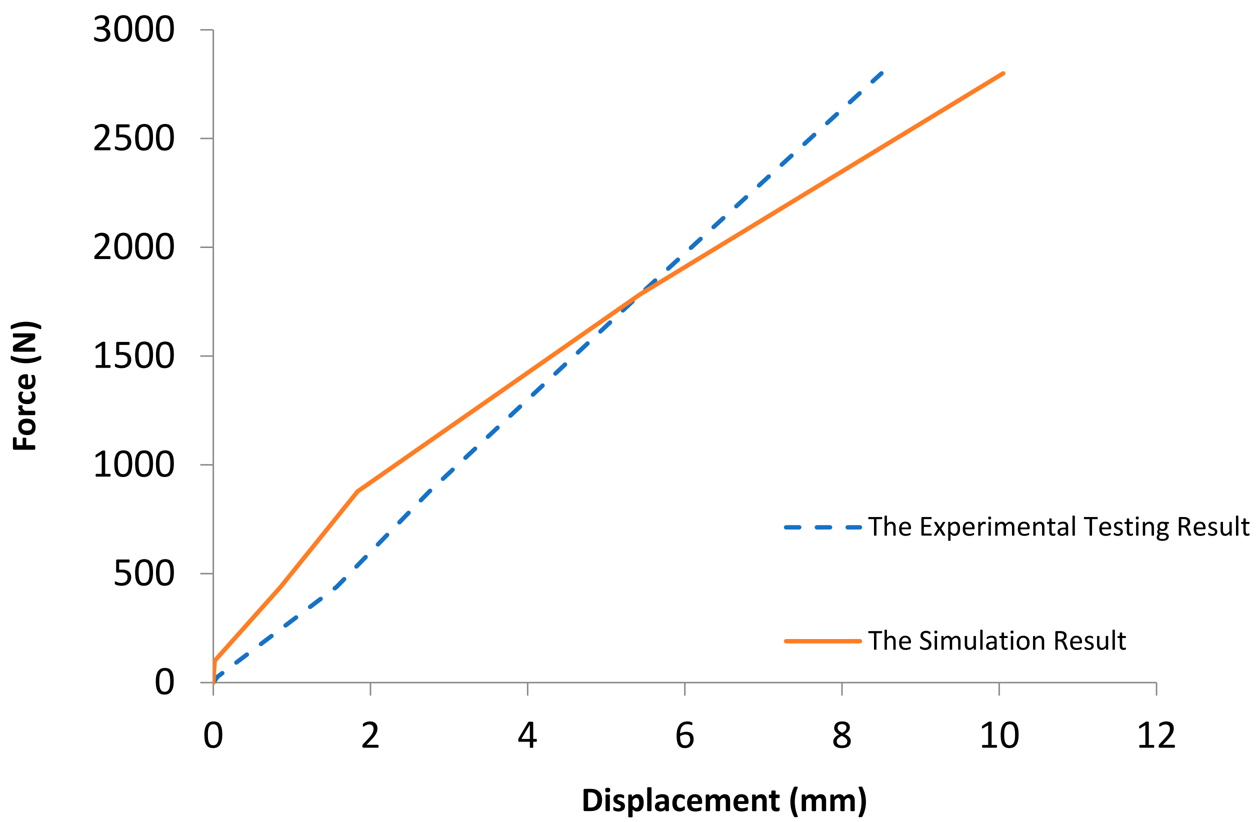


Figure 17. Comparison between simulation and experimental of AFSS wrapped around CFRP.

5. Conclusions

A lightweight and high strength with good energy capacity under the impact energy have been the goal for the automotive industry for a long time. The combination of aluminium foam and carbon fibre was chosen as a sandwich structure to meet the lightweight and greater energy absorption capacity, however, the delamination between the aluminium interface, even in the elastic region, is an issue for the application of this type of sandwich structure for an energy absorption system. Therefore, changes to the manufacturing processes to produce a fully wrapped system have been proposed.

Hence, a purpose-built sandwich structure fabricated from an aluminium skinned foam enclosed within a carbon fibre reinforced composite structure have been investigated for the potential application for high-performance on and off-road automotive vehicles.

The initially proposed sandwich structures had limitations due to early debonding between the core and the skins. However, when AFSS replaces AF bonded to CFRP, this potentially eliminates the de-bonded issue initially stated by Yan, et al. [4]. These debonding and delamination problems reduce the mechanical properties of these types of sandwich structures and restrict the use of such systems in automotive structural applications.

To address this issue, a system that encompasses a completely wrapped CFRP around an AFSS provides a potential solution to the de-bonded problem between AFSS and CFRP skins in sandwich structures which commonly occur on surface bonded sandwich structures. Once the improvement to the manufacturing process to optimise the wrapping of the CFRP skins was achieved, the aluminium foam cores could reach their potential as an energy absorbing system and support a larger carrying capacity compared to an AFSS only system without showing signs of delamination until close to the failure loads.

The load carrying capacity of completely wrapped beams was increased by utilising this new manufacturing method to maintain the adhesion between the core and the skins until the failure stage is reached. The core shear and de-bonded issue associated with this type of sandwich structure can be addressed by this manufacturing method.

In the present work, mechanical and performance of four layers only of CFRP wrapped around an AFSS system have been studied to follow many automotive systems, although this can be further investigated to optimise the lay up within the current design envelope, but cost may be the governing factor.

The approach here of designing a structure which completely wraps the CFRP around the AF provides a solution to the premature failure issues. An energy absorbing structure fabricated by AFSS completely wrapped around with CFRP skins was thus used to maintain the energy absorption characteristics of the structure under flexure load. The peak average flexure load capacity of AFSS with a completely wrapped around CFRP skin was on average 2800 N with a mass of 191 g. This compares favourably with AFSS without the skins, which had an average load of 600 N and a mass of 125 g.

A simplified FE model with perfect contact between the AF core and CFRP skins was defined for the model to reduce the solution time and simplify the AF structure. The simulation results, however, show that this contact definition could represent the performance of a sandwich structure up to the failure stage. However, the overall stiffness of the FE model is 5% higher than the experimental sample at the same flexure load. It is proposed that when a CFRP is wrapped around the AFSS, this significantly enhances the structural performance without substantial weight gain.

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