Numerical analysis of aluminum foam sandwich subjected to compression loading

Muataz Hazza F. Al Hazza, Nor Amalina Endut, Erry Y. T. Adesta, Nur Asmawiyah Binti Ibrahim

Abstract---* *Demand using aluminum foam sandwich in various application of industry keep increasing. Hence, the reliable numerical models are still required and need to be enhanced by observing the mechanical behavior of the sandwich structure. Numerical analysis of aluminum foam sandwich that subjected to compression loading had been analyzed using LS-DYNA software. Three different thickness of aluminum foam (3.2mm, 5.6mm, 6.35mm) and three different thickness of aluminum sheet (0.4mm, 0.6mm, 0.8mm) had been selected to investigate their pattern of force-displacement curves and energy absorbed. The numerical results have been validated by experimental results for comparison. The findings show that simulation results exhibit good agreement with the experimental results in terms of their trend in force-displacement curves and deformation behavior of the sandwich structures. The increment in peak force and energy absorbed affected by increasing the thickness of foam and aluminum sheet

Keywords: aluminum foam sandwich; Numerical analysis; energy; LS-DYNA.

1. INTRODUCTION

The development for new materials in industries plays an important role in maintaining the market share through improving performance, safety and cost. One of the new materials that introduced to the market is metal foams. Metal foams are a new class of materials with low densities and novel physical, mechanical, thermal, electrical and acoustic properties [1]. One of the most commercially available metal foams is based on aluminum. However aluminum foam alone is not enough in many cases to replace the normal structural materials due to some features. Therefore, the need to improve and increase the applicability of those materials needs some improvement. Thus, a new technology had been introduced to replace traditional materials by using aluminum foam sandwich (AFS) due to lightweight and high energy absorption properties. Aluminum foam sandwich (AFS) is a product comprising a highly porous aluminum alloy foam core and two aluminum alloy face sheets. The layers are firmly attached to each other by metallic bonding [2].

Ruan et al. [3] reported that AFS is useful for lightweight components with good energy absorption properties. One of the most important features in structural parts in industry is the energy absorption behavior. One of the important tests that may help for understanding the mechanical behavior of AFS due to its relationship between the core and the skin thickness of the AFS and the peak force and energy absorbed is the compression test. Many researchers tried to investigate experimentally or by simulation the peak force and energy absorbed of AFS under the compression test.

Tarlochan, et al., [4] conducted compression test of composite sandwich structures in order to evaluate the peak load, absorbed crash energy, average crushing load and crush force efficiency. The mechanism of crushing of the sandwich structures and its relation to the energy absorption capabilities had been investigated. The sandwich structures are made of expanded polystyrene (EPS) foam and woven glass fiber fabric.

Idris et al., [5] performed uniaxial compression test by varying the effect of thickness and density in order to observe energy ab-sorption capability of aluminum foam. There were two types of closed-cell aluminium foam that used in this study which were ALPORAS and ALULIGHT. Aluminium foams were produced by direct foaming technique and powder metallurgy method. The findings that emerge from this study show that collapse strength and energy absorbed for both foams increases when increasing the density of foams.

Zhang et al. [6] performed compressive test by comparing the different types of aluminum which were aluminum foams, empty aluminum tubes and foam-filled tubes. It had been clearly shown that the higher the load plateau region of stress-strain curves will increase the capacity of energy absorption of aluminium foam.

In addition, Dou et al., [7] carried out the compression test for analyzing the mechanical behavior of aluminium foam sandwich with different thickness of foam core and face sheets. This finding highlights that sandwich structure have different deformation behavior under different loading rates.

However, there are still limited on the LS-DYNA simulation study of energy absorption which only focused on aluminum foam sandwich. To achieve reliable energy absorption behavior while maintaining the fundamental concept of energy absorption for automotive application, aluminum foam sandwich has been espoused for this current work. Hence, this current research will be focused on experimental and LS-DYNA simulation of energy absorption for aluminum foam sandwich in automotive application. Recently, researchers have been shown an increased interest in production of automotive industries.

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Modeling of metallic foam is a decisive view in order to accomplish accurate numerical simulation. Material model that are available in LS-DYNA signify good way to predict the behavior of foam itself. There were types of modelling the metallic foams in LS-DYNA. Good constitutive model is vital to validate the modelling of foams. For designing the automotive structure, it requires the numerical study by using LS-DYNA in order to predict the behavior of the structure [8]. Due to the increasing demand for metallic foams especially aluminum foams in automotive industry, it is necessary for validation of the constitutive model. However, several challenges exist in modelling the foam since the foam itself is a cellular material and the volume changes during loading as a result of cell walls collapsing. Furthermore, aluminum foam shows diverse behavior in tension compared to compression by showing elastic deformation phase followed by fracture as shown in figure below. Hence, this study had been done to evaluate the constitutive model for aluminum foam [9].

Finite element (FE) simulation of polymeric foam using LS-DYNA and ABAQUS software have been extracted in this study by performing compression test. Force and deformation behaviour in compression test by observing the multiple loading and unloading of polymeric foams were presented. Several available material models available in LS-DYNA for various types of foams. There-fore, for this study, MAT57 was used for low density foam be-cause it can control the shape of loading and unloading curves [10]. MAT 154 which is Deshpande Fleck Foam offers reasonable results and had been successfully implemented in LS-DYNA since foam itself is a porous structure that related to the density [9]. In this current study, compression test had been conducted to investigate the effect of core and skin thickness on the peak force and energy absorbed. The trend of force-displacement curves and deformation modes have been validated using LS-DYNA simulation.

2. RESEARCH METHODOLOGY

The research methodology is based on merging both experimental and simulation work in order to validate the results and can be concluded in steps as shown in Figure 1.

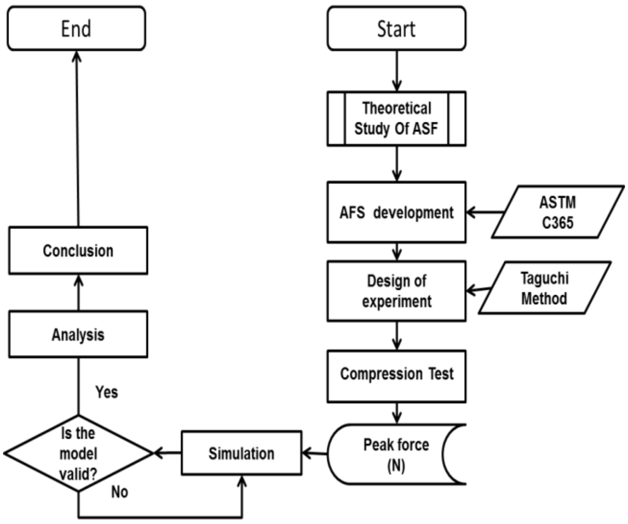

Fig. 1: Research methodology Flowchart

3. DESIGN OF EXPERIMENT

The design of experiment for compression test as well for the simulation was developed using Taguchi orthogonal arrays L^9. Table 1 is concluded the independent factors and the experimental levels. Three levels of core thickness (3.2 mm, 5.6 mm and 6.35 mm) and three levels of skin thickness (0.4 mm, 0.6 mm and 0.8 mm) have been used for two independent factors of ASF: core thickness and the skin thickness.

Table 1: Design of experiment

	L1	L2	L3
core thickness (mm)	3.2	5.6	6.32
skin thickness (mm)	0.4	0.6	0.8

Table 2 is concluded the different combination that conducted for the experiments

Table 2: Taguchi orthogonal arrays $L^9$for compression test

Sample	Skin thickness, mm	Core thickness, mm
1	0.4	3.2
2	0.6	3.2
3	0.8	3.2
4	0.4	5.6
5	0.6	5.6
6	0.8	5.6
7	0.4	6.35
8	0.6	6.35
9	0.8	6.35

4. EXPERIMENTAL PROCEDURE

Experimental test was conducted using SHIMADZU AG-X 250 machine at constant crosshead speed of 0.5 mm/min based on ASTM C365 as shown in figure 2 below.

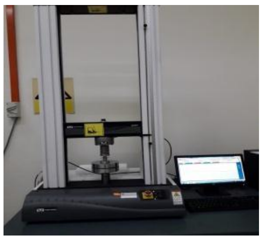

Fig.2: SHIMADZU AG-X 250 compression machine

Each experiment have been repeated for three times, table 3 is concluded the results for Peak force (N) for each run and

Table 3: Summary of peak force for different runs

Sample	Peak force, N			Average
	1	2	3	
1	653.399	661.539	656.26	657.066
2	732.411	729.32	724.97	728.900
3	766.089	762.411	763.11	763.87

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4	801.955	805.78	803.674	803.803
5	810.2	812.562	815.256	812.673
6	823.45	825.324	830.22	826.331
7	856.78	862.952	858.34	859.357
8	913.854	916.759	918.76	916.458
9	928.349	932.562	935.452	932.121

5. FINITE ELEMENT MODELING

Numerical analysis of the aluminum foam sandwich was performed using LS-DYNA software. The model in the simulation were designed same as experimental work which consist of upper, lower aluminum sheets and aluminum foam. The aluminum foam was modelled using solid section while for aluminum sheets as shell section. The meshed model for aluminum foam sandwich has been illustrated in figure 3 below. As shown in figure 3, the blue color was defined as upper and lower skin of aluminum sheet whereas for yellow color was defined as aluminum foam.

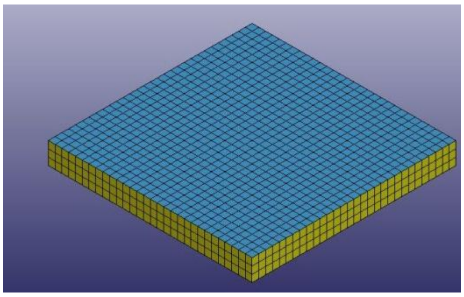


Fig.3: Meshed finite element model of aluminium foam sandwich

Automatic surface to surface tied and interior contact has been used to define the contact condition of the sandwich structure. Bottom nodes of sandwich were fixed in all degree of freedom while the top of the sandwich structure was constrained in Z-direction by applying the prescribed motion set in boundary condition. Two different types material had been selected which were Deshpande Fleck Foam (MAT 154) for aluminium foam and piecewise linear plasticity (MAT 24) for aluminum sheet. From the simulation results, the pattern of force-displacement curves have been plotted for validation purposes with experimental test.

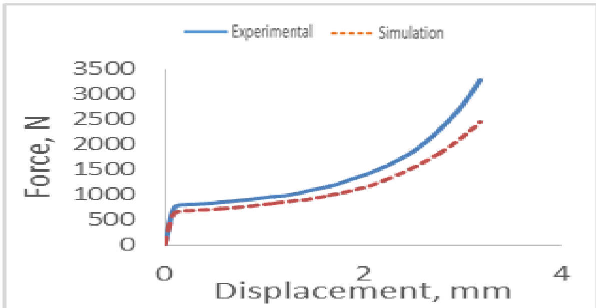
6. RESULTS AND DISCUSSION

The numerical model of aluminium foam sandwich that subjected to compression loading was validated using experimental results. The comparison of peak force between experimental and simulation results have been illustrated in table 3. Based on table 4, good agreement between experimental and simulation results had been achieved by calculating the percentage difference. Table 3 below displays the comparison of force-displacement curves between experimental and simulation results with different thickness of core (3.2mm, 5.6mm, 6.35mm) and skin thickness (0.4mm, 0.6mm, 0.8mm). The experimental and simulation results were plotted to show both the trend of the relationship between the force and the displacement in addition to compare between the simulation results and the experimental results for all runs.

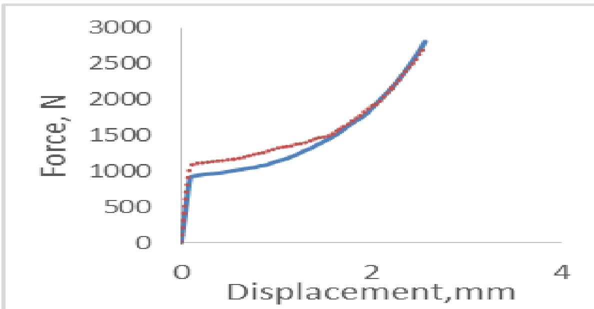
Table 3: Comparison of peak force value between experimental and simulation results

Run	Skin thickness, mm	Core thickness, mm	Peak force, N	Peak force, N	% difference
1	0.4	3.2	657.066	634.56	3.4
2	0.6	3.2	728.900	720.08	1.2
3	0.8	3.2	763.87	745.23	2.44
4	0.4	5.6	803.803	766.30	4.66
5	0.6	5.6	812.673	772.43	4.95
6	0.8	5.6	826.331	786.78	4.79
7	0.4	6.35	859.357	920.36	7.09
8	0.6	6.35	916.457	857.62	6.42
9	0.8	6.35	932.121	899.65	3.48

Figure 4, is clearly show that the trend of force-displacement curves in simulation results is very close with experimental results for all various thicknesses of core and skin. The force-displacement curves were plotted. Then, continued with simulation for further validation by investigating the different thickness of aluminum foam and aluminum sheet. It is apparent from the trend of force-displacement curves that consist of linear elastic region, plateau region and densification region.



a. Skin 0.4mm, core 3.2mm



b. Skin 0.4mm, core 5.6mm

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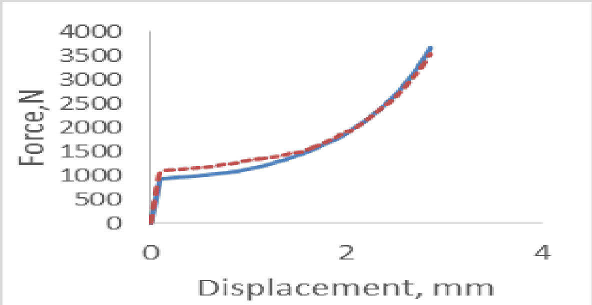
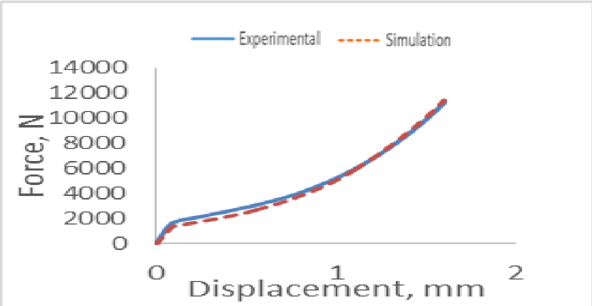
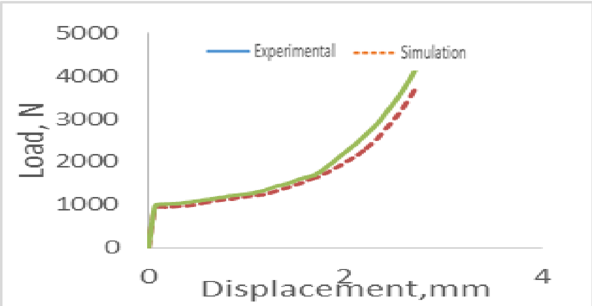


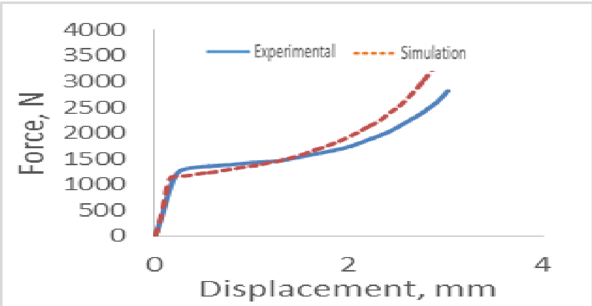
c. Skin 0.4mm, core 6.35mm



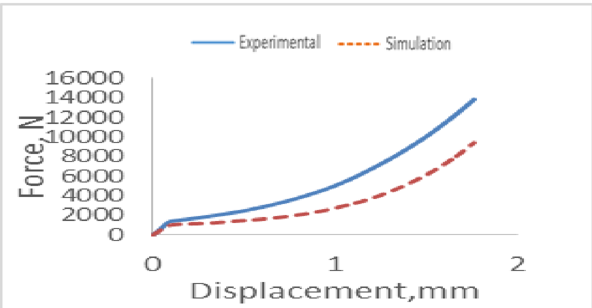
d. Skin 0.6mm, core 3.2mm



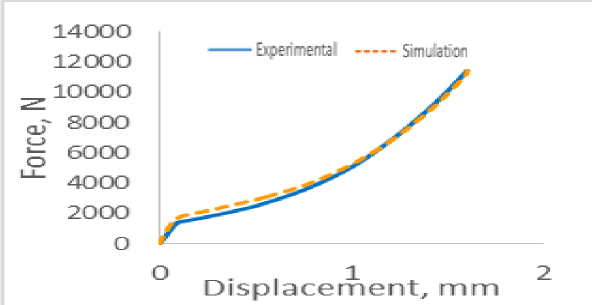
e. Skin 0.6mm, core 6.5mm



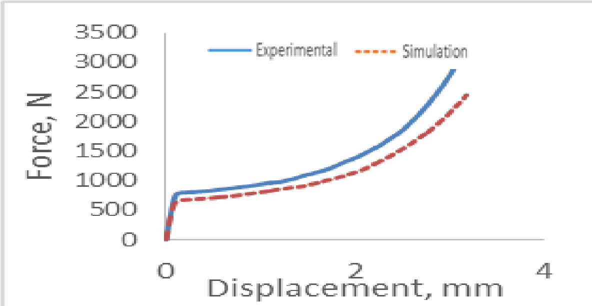
f. Skin 0.4mm, core 3.2mm



g. Skin 0.8mm, core 3.2mm

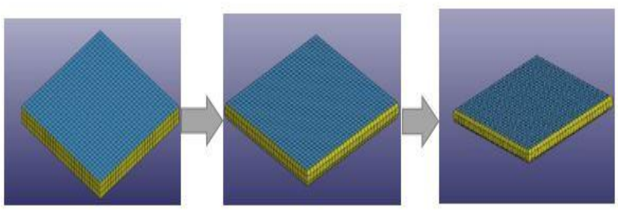


h. Skin 0.8mm, core 6.5mm



i. Skin 0.4mm, core 3.2mm

Fig.4: Comparison of force-displacement curves in experimental and simulation



(a) (b) (c)

Fig.5: Deformation behavior of AFS in simulation; (a) linear elastic region, (b) plateau region, (c) densification region

Figure 5 illustrated the deformation of aluminum foam sandwich that subjected to compression loading. It can be seen that the deformation behavior of AFS in the simulation reveal three distinct region which were linear elastic region, plateau region and densification region. Initially, the upper skin of AFS starts to deform. Next, the plateau region has been occurred whereby in this stage the upper skin and foam compressed each other. Finally, all layers of the sandwich structure have been compressed to 40% deformation from its initial thickness of the AFS.

7. CONCLUSION

1. The findings of the current study were consistent with the findings by [11] which echoed that increasing the foam and skin thickness will increase the plateau stress and peak force of the sandwich structure due to the densification of foam cell wall.

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2. The effect of thickness of aluminium foam as core and thickness of aluminium sheet as skin had been analyzed numerically. It clearly showed that by increasing the skin and core thickness, the peak force and energy absorbed increase as well. Meanwhile, the pattern of force-displacement curves in experimental and simulation agreed to each other.

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