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To cite this article: N A Endut *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **290** 012084

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Compressive Behaviour and Energy Absorption of Aluminium Foam Sandwich

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Abstract. Development of materials in automotive industries plays an important role in order to retain the safety, performance and cost. Metal foams are one of the idea to evolve new material in automotive industries since it can absorb energy when it deformed and good for crash management. Recently, new technology had been introduced to replace metallic foam by using aluminium foam sandwich (AFS) due to lightweight and high energy absorption behaviour. Therefore, this paper provides reliable data that can be used to analyze the energy absorption behaviour of aluminium foam sandwich by conducting experimental work which is compression test. Six experiments of the compression test were carried out to analyze the stress-strain relationship in terms of energy absorption behavior. The effects of input variables include varying the thickness of aluminium foam core and aluminium sheets on energy absorption behavior were evaluated comprehensively. Stress-strain relationship curves was used for energy absorption of aluminium foam sandwich calculation. The result highlights that the energy absorption of aluminium foam sandwich increases from 12.74 J to 64.42 J respectively with increasing the foam and skin thickness.

1. Introduction

Recently, researchers have been shown an increased interest in production of automotive industries. Material selection plays vital role in order to meet the functional requirements of components [1]. In the past few years, metallic foams has been attracting considerable attention. One of the excellent metal foam that are used by previous researchers in automotive application is aluminium foam sandwich due to their unique properties such as low density, good energy absorption characteristics. Aluminium foam sandwich panels are good energy absorbers and lightweight which provide wide range of potential applications in automotive industries [2],[3]. Rajak et al.,[4] highlighted about to calculate energy absorbed of aluminium foam by performing compression test. For this study, the authors were investigated the effect of face sheets and core thickness due to empty mild steel sample and aluminium foam filled sample. It had been clearly shown that there were increasing trend for energy absorption of aluminium foam filled samples compared to empty mild steel samples at different strain rates. However, the study by Ansari et al., [5] were presented sandwich composites using polyurethane (PU) foam and acrylic sheet to analyze mechanical behavior by conducting



compression test. The input of this research were skin(acrylic sheet) thickness, core(polyurethane) foam thickness and strain rates values whereas the output were compressive strength and deformation behaviour. The compressive stress-strain curve of ideal foam are presented in figure 1.

As shown in the figure, For the first region, it refers to collapse stress, whereas for the plateau region, total deformation energy is absorbed at constant stress value. The final region which is densification region related to increasing of stress at constant strain value. At this region, the cell walls are in close contact each other [6].

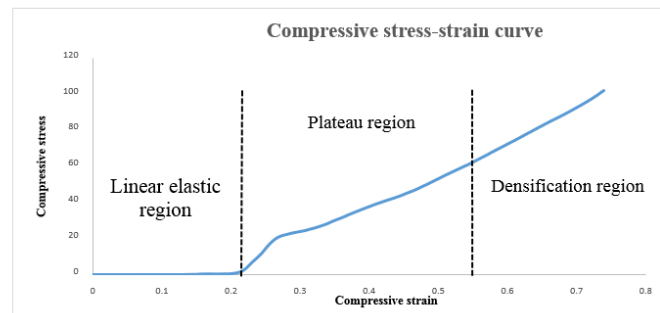


Figure 1. Compressive stress-strain curve of ideal foam [6].

Although there were many research had been done experimentally about mechanical behaviour of aluminium foam sandwich but researching into aluminium foam sandwich with respect to energy absorption characteristics is limited if any. Meanwhile, there were also some gaps that need to be fill by varying parameters and testing methods for energy absorption behaviour.

2. Experimental procedures

For this research, aluminium foam sandwich was used for conducting the experimental work. Aluminium foam were attached together with aluminium sheets using mixing of epoxy resin and hardener with a ratio of 2:1 in terms of volume 100 ml of epoxy and 55 ml of hardener to fabricate aluminium foam sandwich. According to ASTM standard of C393, the preferable ratio for designing sandwich structure should be approximately less or equal to 0.10 in order to select the suitable thickness for core and skin as shown in equation 2.0 below .

$$\frac{t}{c} \leq \sim 0.10 \quad (2.0)$$

t: skin thickness, c: core thickness

Based on design of experiment (DOE), Taguchi design were developed with two level of thickness of core were used which were 6.35 and 10 mm, whereas three level of thickness of aluminium sheets were 0.4, 0.6 and 0.8 mm respectively. Table 1 shows the design of experiment for the a AFS in terms of aluminum core thickness and skin thickness.

Table 1. Input parameters

Nu of run	Core thickness, mm	Skin thickness, mm
1	6.35	0.4
2	10	0.4

3	6.35	0.8
4	10	0.6
5	10	0.8
6	6.35	0.6

For compression test, Universal Testing INSTRON machine was used to analyze the compressive behavior of aluminium foam sandwich (AFS) as shown in figure 2 (a) below. This machine was set up with 100 kN load cell [6] and speed of test with 1.5 mm/min. Figure 2 (b) shows the setup of compression sample. The compression samples were compressed between two steel loading platens to 50% and the compressive stress-strain curves were generated by using Bluehill 2 software.

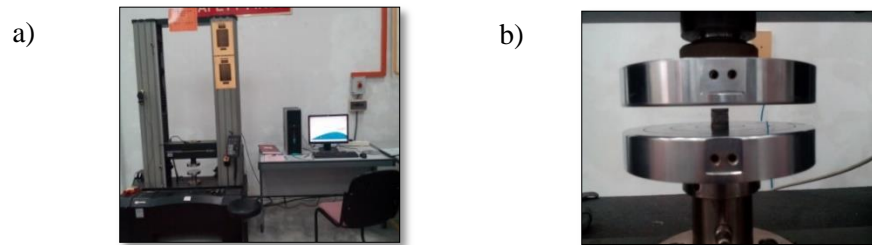


Figure 2. Compression test: (a) Universal testing machine INSTRON, (b) setup of compression sample.

3. Results and Discussion

The mechanical properties of aluminium foam sandwich (AFS) can be determined by conducting compression test. During compression test, the aluminium foam sandwich (AFS) samples will deform after undergoes some load. Energy is absorbed by aluminium foam core which approximately equal to one of AFS structure. This findings is supported by Dou et al., [7] which relate to the stress-strain relationship with relevant formulae. Based on this formulae, the energy absorbed of aluminium foam sandwich, AFS can be expressed in equation (3.0).

$$E = \int_0^{\epsilon} \sigma(\epsilon) d\epsilon \quad (3.0)$$

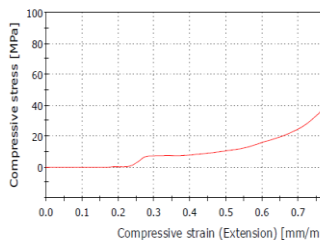
where E is energy absorbed of aluminium foam sandwich, σ is compressive stress and ϵ is compressive strain. It had been clearly shown on table 2 that there were increasing trend for compressive stress, compressive strain and energy absorbed based on area under curve when increasing the thickness of aluminium foam as a core.

Figure 3 depicts results of experimental work that obtained from compression. The sample have been compressed until 50% of its initial length Based on figure 3, the alteration point between plateau stress and rupture (densification) region are clear trend. As compressive stress increases, the compressive strain also increases due to densification region. It can be found that the energy absorbed of aluminium foam sandwich follows the same trends with the increasing of compressive strain and stress

Table 2: Compression test results.

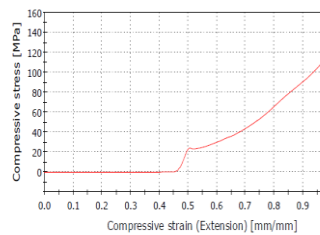
Run	C,mm	F,mm	Compressive strain,mm/mm				Compressive stress, N/mm ²				Energy absorbed , J			
			1	2	3	Average	1	2	3	Average	1	2	3	Average
1	6.35	0.4	0.39	0.39	0.39	0.389	91.88	91.91	93.57	92.45	12.5	11.9	13.8	12.74
2	10	0.4	1.3	1.31	1.36	1.322	153.7	153.6	153.4	153.59	29.2	27.4	34.5	30.36
3	6.35	0.8	0.6	0.6	0.6	0.598	95.2	94.97	94.92	95.03	23.1	23.4	23.2	23.22
4	10	0.6	1.26	1.24	1.24	1.249	292	290.3	291.1	291.13	37.5	39.9	38.6	38.65
5	10	0.8	1.64	1.63	1.67	1.645	321.6	317.2	318.5	319.12	62.3	66.7	64.3	64.42
6	6.35	0.6	0.45	0.47	0.45	0.458	88.04	86.78	87.21	87.34	20.7	19.4	21.4	20.51

The result was consistent with [8] which also stated that increasing the foam thickness and density of foam will increase the collapse strength and energy absorbed. The sample for run 5 with core thickness of 10mm and skin thickness of 0.8mm shows the highest value of energy absorbed. Meanwhile, compressed aluminium foam sandwich shows that breaking process of cell wall initiated from cylindrical surface to the central axis along the radius direction. This finding reflects the findings of Y-G. Li et al., [9].



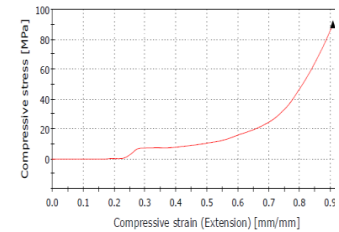
Run 1 with maximum stress=89.927 MPa, strain=0.206 mm/mm, energy absorbed=19.340 J

(a)



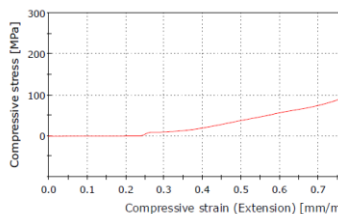
Run 2 with maximum stress=142.460 MPa, strain=1.039 mm/mm, energy absorbed=35.007 J

(b)



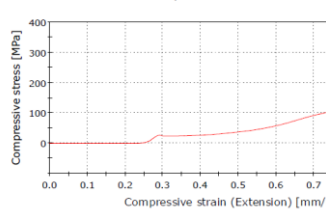
Run 3 with maximum stress=92.450MPa, strain=0.789mm/mm,energy absorbed=30.493 J

(c)



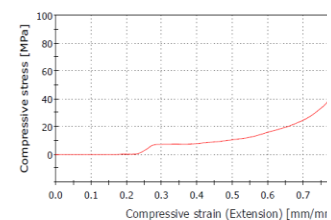
Run 4 with maximum stress=280.57 MPa, strain=1.098 mm/mm, energy absorbed=46.630 J

(d)



Run 5 with maximum stress, 310.850 MPa, strain=1.356 mm/mm, energy absorbed=56.505 J

(e)



Run 6 with maximum stress, 90.346 MPa, strain=0.307 mm/mm, energy absorbed=24.398 J

(f)

Figure 3. Compressive stress-strain curves.

4. Conclusion

For this paper, samples of aluminium foam sandwich with two levels of core thickness and three levels of face thickness have been fabricated. After that, experimental work through compression test has been conducted in order to generate the stress-strain curve. Hence, this current study will help to provide the reliable experimental data that can be used to analyze energy absorption behavior of aluminium foam sandwich in automotive application. Important conclusions that can be drawn from this work are the absorbed energy in compression test increases with increasing foam and face sheet thickness of aluminium foam sandwich which is 64.42 J. Moreover, equation (3.0) provides plausible estimate for energy absorbed of aluminium foam sandwich.

Acknowledgement

The authors would like to express their sincere appreciation to the Research Management Centre, International Islamic University Malaysia and the Ministry of Higher Education, MOHE for financially providing and supporting fund for the research under science fund with the No: FRGS 15-247-0488.

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