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A study of tensile test on open-cell aluminum foam sandwich

N A Ibrahim[1], M H F Al Hazza[1], E Y. T. Adesta[1], Atiah Bt. Abdullah Sidek[1] and N A Endut[1]

[1]Department of Manufacturing and Materials Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia

Email: muataz@iium.edu.my

Abstract. Aluminum foam sandwich (AFS) panels are one of the growing materials in the various industries because of its lightweight behavior. AFS also known for having excellent stiffness to weight ratio and high-energy absorption. Due to their advantages, many researchers, shows an interest in aluminum foam material for expanding the use of foam structure. However, there is still a gap need to be fill in order to develop reliable data on mechanical behavior of AFS with different parameters and analysis method approach. Least of researcher focusing on open-cell aluminum foam and statistical analysis. Thus, this research conducted by using open-cell aluminum foam core grade 6101 with aluminum sheets skin tested under tension. The data is analyzed using full factorial in JMP statistical analysis software (version 11). ANOVA result show a significant value of the model which less than 0.500. While scatter diagram and 3D plot surface profiler found that skins thickness gives a significant impact to stress/strain value compared to core thickness.

1. Introduction

Demand for the use of aluminum foam sandwich (AFS) is rapidly increasing in various applications because of their lightweight material, high specific stiffness and strength and also excellent energy absorption [1]. Sandwich panels with porous structure core material had been used in many application in industries such as lightweight construction, aerospace industry, ship building, railway industry, machine construction and biomedical industry [2]. Earlier researchers had found several new classes of material that can be used in diverse applications and one of them are metallic foams. There are two types of metallic foam structure which is open-cell and closed-cell aluminum foam as shown in the figure 1 below.

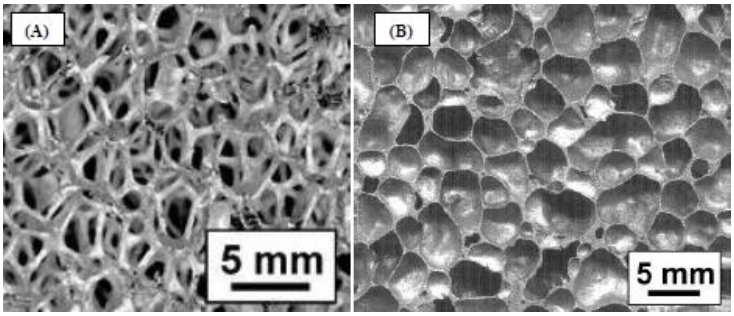

Figure 1. Open-cell metallic foam (a) and Closed-cell metallic foam (b) [3]

At the beginning of creation of foam structure, previous research had developed foam structure material using polymer. However, polymer foam has many limitations such as low heat resistance. Hence, in order to fix the limitation, previous researchers had developed metallic foam. Nevertheless, foam itself is weak, so sandwich structure consist of metallic foam as core and different type of metal as a faces was develop.

It is important to determine the mechanical behavior of new sample produce for identifying their suitable application. Therefore, many researchers had prepared the research on metal foam with different types of skin material and testing method. There are researches had been done for tensile test on steel foam only [4], tensile test on closed-cell metal foam [5], compression and tensile on closed-cell aluminum foam [6], impact test on aluminum foam [7], tensile test on aluminum foam only [8-9] and many more. Most of the previous researchers focusing on closed-cell metal foam compared to open-cell metal foam.

To increase the area of the metallic foam material application and for future use, there is a need for researchers to create many reliable data on the mechanical behavior of the material [4]. After many years, the development of data for aluminum foam sandwich properties are growth in variety parameters and application and most of them focusing on closed-cell aluminium foam. Least of them focusing on the tensile test of open-cell aluminum foam sandwich and also statistical analysis method. Therefore, the aim of this paper were to present analysis of the tensile test data on open-cell aluminium foam sandwich using full factorial in JMP statistical analysis software.

2. Experimental procedures

The paper discussed about the analysis of the tensile test data of aluminum foam sandwich panels using full factorial method. Figure 2 below shows the flowchart that need to be follow in order to conduct the research.

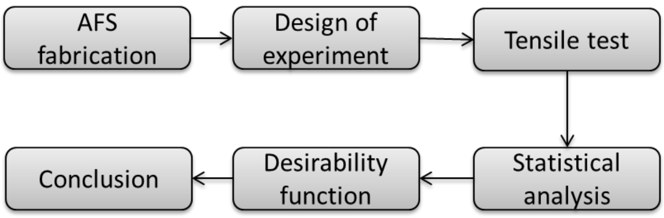

Figure 2. Steps of the research

The AFS panels were prepared by attaching the open-cell aluminum foam core with aluminum skin sheets using adhesive bonding of epoxy resin mixed with hardener with ratio 2:1. The dog-bone specimens of aluminum sheets and foam core were shaped with an electrical discharge machine (wire cut). The shape and ratio of the sandwich structure were designed based on ASTM standard of C393.

Figure 3 below shows the final sandwich panels ready to be test under tension using Universal INSTRON machine with 100KN load.

Figure 3. Tensile specimens of AFS

In order to conduct the test, design of experiment was developed in JMP statistical analysis using full factorial method for maximizing the input parameters combination. Six runs with input parameters combination of two levels of foam core thickness and three levels skins thickness have been generated as tabulated. The results from tensile test then documented in table in order to conduct the statistical analysis in JMP statistical analysis software. The AFS panels were tested under tensile test for two times using Universal INSTRON machine in order to have result that is more consistent. The relationship between input parameters with the stress/strain result was analysed.

3. Results and Discussion

The stress/strain values of tensile test were compiled in the table 1 below.

Table 1. Result compilation of tensile test of AFS sandwich

Run	Skin thickness (mm)	Core thickness (mm)	Average Stress (MPa)	Average Strain (mm/mm)
1	0.4	6.35	13.9495	0.0045
2	0.6	6.35	22.7035	0.009
3	0.8	6.35	27.7995	0.016
4	0.4	10.0	9.1935	0.005
5	0.6	10.0	15.864	0.0125
6	0.8	10.0	20.419	0.018

Based on the data above, statistical analysis was conducted for determining the relationship between input variables of skin and core thickness on stress/strain result. Table 2 and 3 below show the analysis of variance and summary of fit models for relation between input variables and stress value of AFS panels after loaded in tension.

Table 2: Analysis of variance (ANOVA)

	DF	Sum of Squares	Mean Square	F Ratio
Model	3	218.93194	72.9773	49.0431
Error	2	2.97605	1.4880	Prob > F
c. Total	5	221.90799		0.0200*

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Table 3. Summary of Fit

Summary of Fit	
RSquare	0.986589
RSquare Adj	0.966472

It is found that the result for ANOVA analysis of stress, there are 0.02% chance of error that the model could be occur due to noise which can be accepted since the value of 'Prob > F' less than 0.05. Next, for summary to fit model shows the differences between RSquare and RSquare adjusted and RSquare is always increased when the factors increase while the RSquare adjusted is increased when the bad factors were removed such as slippage between the grip and sample. Based on the results obtained, the RSquare value is reasonably agree with RSquare adjusted which is 0.986589 and 0.966472 respectively and it is acceptable since the value are close to 1. While table 4 and 5 below show the ANOVA and summary of fit model analysis of strain output.

Table 4. Analysis of variance (ANOVA)

	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.00015663	0.000052	61.1220
Error	2	0.00000171	8.542e-7	Prob > F
c. Total	5	0.00015833		0.0161*

Table 5. Summary of fit

Summary of Fit	
RSquare	0.989211
RSquare Adj	0.973026

Based on tables above, it can be seen that the chance of error of the model for strain also less than 0.05 which 0.0161%. For RSquare and RSquare adjusted also reasonably agree with each other and the value are almost 1 which is 0.989211 and 0.973026 respectively. In order to find out more about the effect of skins and cores thickness on stress/strain value, the scatter diagram had been generated in JMP statistical analysis software. Figure 4 below shows the scatter diagram of relationship between input and output variables.

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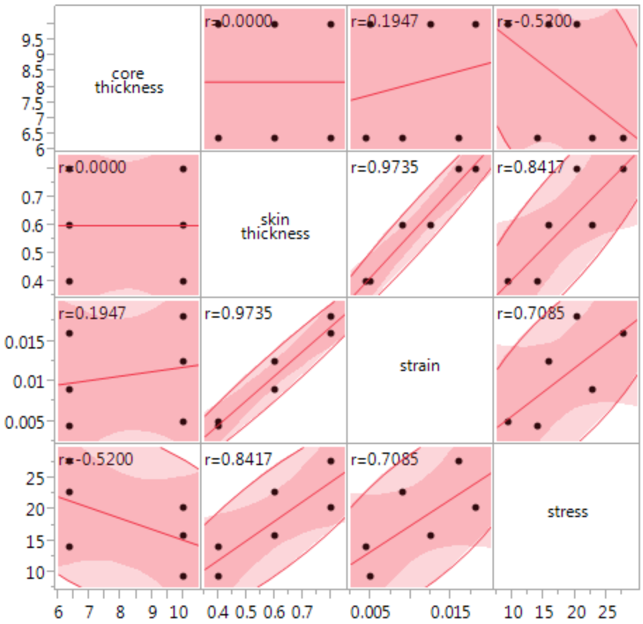
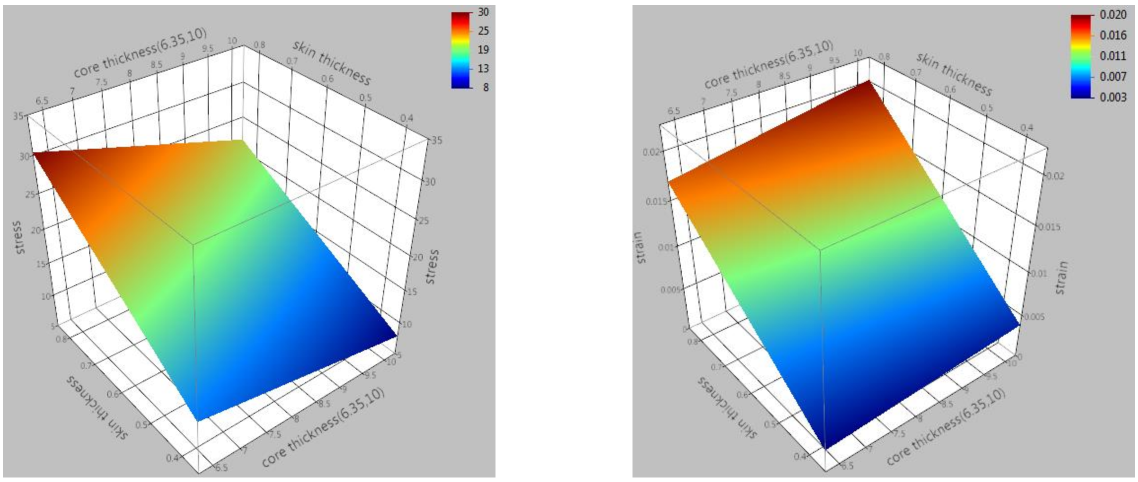


Figure 4. Scatter diagram of relationship between skins and cores thickness on stress/strain value.

Based on the figure above, it shows that skin thickness gives a high positive correlation to the stress/strain value with 84% and 97% correlation respectively. The value of correlation are contrast with the core thickness which is fairly effect the stress/strain value with value less than 50% correlation. This shows that skin thickness give more effect to stress/strain result compared to core thickness. For further analysis of relationship between cores thickness and skins thickness on stress/strain value, 3D plot surface profiler had been generated. Figure 5a and 5b below show the 3D plot surface profiler for inputs with stress and strain respectively.



a. Core thickness, skin thickness and stress b. Core thickness, Skin thickness and strain

Figure 5. 3D plot surface profiler

Based on the figure 5a above, it can be seen that the stress value increases when the skin thickness increases and core thickness decrease. While according to figure 5b, it shows that the strain value were increasing when both skin and core thickness increase. Lastly, for finding the optimum input parameters combination that will contribute the maximize output, desirability function analysis had been used. Figure 6 below shows the prediction profiler for analysing the desirability function.

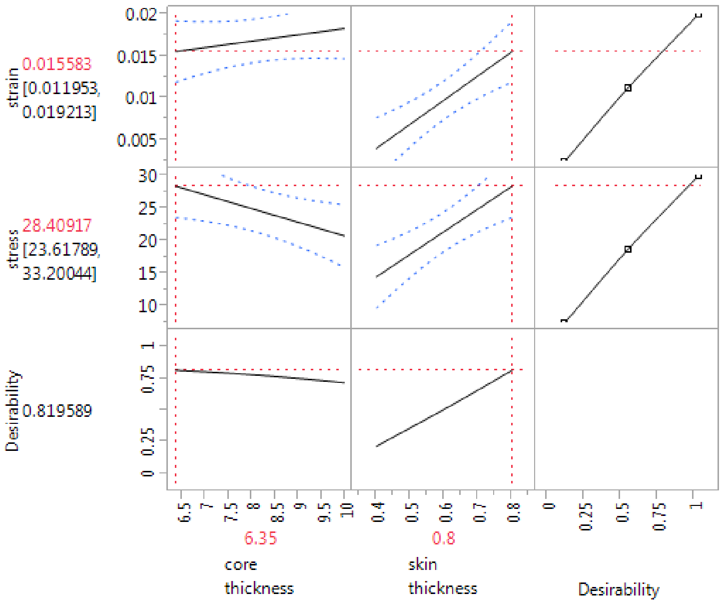


Figure 6. Prediction profiler

Based on the prediction profiler above, the desirability function analysis shows that the optimum input parameters combination for finding the maximize stress was skin thickness of 0.8 mm and core thickness of 6.35 mm with 81% desirability which means that as the skin to core ratio increase, the value of stress/strain also increase. Previous researcher also found the tensile modulus increase as the skin to core ratio increase [10].

4. Conclusion

In summary, it can be can concluded that, the tensile test was successfully conducted. The stress/strain data from tensile test were compiled and analyzed using statistical analysis. According to the ANOVA and summary of fit models, it shows that the results were acceptable with error less than 0.05. Based on scatter diagram, it confirms that skins thickness give the major effect on the stress/strain value compared to core, which fairly effect the stress/strain result. Lastly, according to 3D surface profiler plots, it show that the stress/strain value increase as the skin thickness increase and core thickness decrease which agree with the scatter diagram.

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