Experimental Optimization of Effective Parameters of Sandwich Panels With Aluminum Foam Core Under Low Velocity Impact

Mohammad Amin Torabizadeh (torabizadeh@yahoo.com)
University of Applied Science and Technology

Original Article

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Abstract

This paper introduces the application of Taguchi optimization methodology in optimizing the production parameters of aluminum foam sandwich panels (AFSP) with different skin layer under low velocity impact loading. The core material of AFSP is A356 aluminum foam reinforced with SiC particles produced using the CaCO3 foaming agent with 20, 30 and 40 mm thickness. The skin layer of plates are made of glass / epoxy with quasi-isotropic and cross-ply layout as well as pure aluminum layer. For the impact test, drop weight impact device used. Three types of spherical, parabolic and cone impactor used. The impact parameters that are chosen to be evaluated in this study are skin layer layout, impactor shape and core thickness of AFSP. While, the response factors to be measured are specific absorbed energy (SAE), maximum displacement (MD) and maximum impact force (MIF). Taguchi method used to check the effect of the production parameters on the response factors by creating orthogonal array (OA). The result from this study shows that the application of the Taguchi method can determine the best combination of production parameters. These results can provide the optimal impact response that are the largest SAE, smallest MD and smallest value of MIF. For the best SAE and MIF, A1–B1–C1 (cross-ply/conical/40 mm core) found. Meanwhile, the optimized combination of levels for all the three production factors from the analysis that provides the lowest MD found to be A3–B2–C1 (pure Aluminum/spherical/40 mm core).

1. Introduction

In recent decades, the use of AFSPs in the aerospace, automotive, renewable energy and civil engineering industries has expanded due to its unique mechanical properties. The behavior of these materials against impact loads is one of the biggest concerns in this regard. Impact loads can result from falling objects, causing significant internal damage and reducing the residual strength of the composite plates. On the other hand, many researchers are interested in reducing the weight of the structure, creating holes filled with air or inert gases inside the background material and producing a porous material known as "foam". Many metals and alloys, such as aluminum, steel, copper, nickel, lead, zinc, magnesium, and titanium, have the ability to foam through various manufacturing processes. The use of aluminum metal as a foam backing material, due to its lightweight and low melting point and due to its high rigidity, good corrosion resistance, high strength to weight ratio, excellent energy absorption capacity, recyclability as well as the ability to produce relatively homogeneous and isotropic cellular structures has attracted much attention in recent years [2-1]. The cellular structure of the metal foam, especially the aluminum foam, allows them to absorb a great deal of kinetic energy from the collision before it destroys the structure, and thus in cases where resistance against impact or penetration required, these materials act as energy absorbers. These properties have made aluminum foam used in the applications mentioned. Aluminum foam is also used as the core material in sandwich structures with different procedures under different loading such as impact.

Farahat and Ahmadi [1] have analyzed the behavior of aluminum foam under the impact of experimental loads while developing a low velocity drop weight device. In their results, they reported the behavior of aluminum foam including three steps, linear, Plato and fracture and increase in absorbed energy in these three steps, respectively. They also recommended A356 / SiC foam cell material to design appropriate energy absorbers. Qajar and Rasaf [2] investigated the effect of the impactor shape and the ambient temperature on the behavior of glass / epoxy composite plates under the impact of a drop weight. Their findings indicate that the maximum impact velocity decreases and the displacement increases as the ambient temperature increases, and that by decreasing the bending curvature, the impact time reduced, the maximum impact force is increased and the amount of surface damage reduced. Kameniro et al. [3] have investigated the effect of thickness and layout on the compressive strength after impact on composite plates. The results showed a decrease in the level of degradation by increasing the amount of energy absorbed. The thicker plates also had higher post-impact space resistance due to their increased flexural stiffness. They found that plates with non-orthogonal layout had better loading performance. Cheng et al. [4] investigated the behavior of sandwich composite plates with aluminum foam core under quasi-static influence and observed the behavior of samples in three stages of elastic, yield and failure. As the epoxy resin layer increased, the amount of energy absorbed increased. Croppi et al. [5] predict the behavior of sandwich composite plates with an aluminum foam core under impact load. They compared their experimental results using the analytical model. In their results, they cited the separation of aluminum from the core as the main cause of sample degradation. In addition, the amount of energy absorbed by the specimens depends on the mechanical properties of the foam core of the sandwich plates. Long et al. [6] characterized the degradation process of foam core sandwich composite plates under low velocity impact load using a finite element model. They have investigated the effects of impact energy, foam density and porosity on the porous layer. They found that the type of sample degradation influenced by the amount of penetrating impact. As before the penetration of the separation, plates occurred according to the composite laws and after the penetration of the degradation zone observed cyclic. Liu et al. [7] have studied the behavior of sandwich composite plates with an aluminum foam core and a metal composite surface. As the foam thickness increased, the energy absorption also increased. There was also a significant increase in the energy absorption by increasing the thickness of the composite layer. They also observed good agreement between the experimental results and the finite element model using the software. Liu and Zhang [8] also investigated the behavior of composite plates in the aluminum foam core under the influence of high-speed impact. They have evaluated the validity of their experimental results using finite element model and studied the effect of impactor shape and angle of impact. Their results showed an increase in the absorbed energy due to the increase in the thickness of the supernatant. In this case, the separation of the supernatant observed at the upper surface of the specimen, and especially around the impact site. They also reported an increase in the thickness of the aluminum foam core due to the non-separation of the top surface layer of the foam core. Kara et al. [9] investigated the flexural behavior of sandwich structures with aluminum foam core of different thicknesses. They found that sandwich composite plates were a good choice for the design of energy absorbers, and their performance was proportional to the increase in foam thickness and the type of fibers applied to the samples. Wang et al. [10] studied the behavior of sandwich plates under moderate velocity load using the experimental method. They observed that the material used in the core plays an important role in the deformation, the amount of energy absorbed, the mechanism of degradation, and the rate of impact on the plate. They identified polypropylene honeycomb cores as the optimal choice for post-traumatic deformity. Han and Chow [11] investigated the behavior of sandwich composite plates with an aluminum foam core and a metallic surface by comparing the experimental results of the drop weight test. Their results showed that with the impact energy of 50 J, only the top surface of the plate was degraded, with the energy of 70 J in addition to the destruction of the top effect of the bumping penetration, and ultimately with the impact of 100 J of the bumping effect. Very good agreement between experimental and numerical results reported. Rajanish et al. [12] have investigated and analyzed sandwich composite plates with a foam core and a crisp metal surface. They compared the results of collision force, absorbed energy, and shape of the degradation in two ways that showed good agreement.

Based on previous studies, little has been done to examine the effect of impactor type, skin layer layout and the core thickness on impact response of AFSPs. Since the geometry of the bump may change depending on the type of application, In order to fully understand the behavior of AFSP against impact loads, their response to other impactor shapes must be studied. In addition, as noted in previous studies, the skin layer layout plays an important role in this type of loading and consideration should be given to the effect of the type of skin layer of sandwich plate. Therefore, this study investigates the effect of impactor type, core thickness and skin layer layout of AFSP under impact loads. Also by using Taguchi optimization methodology, optimized production factors derived for the best response of SAE[1], MD and MIF. For this purpose, Three types of conical, parabolic and spherical impactor shapes as well as three types of aluminum, cross-ply and quasi-isotropic composite coatings are used. Also specimens made in three different core thickness (20, 30 and 40 mm).

Footnote:

[1] The specific absorbed energy is obtained by dividing the absorbed energy by the sample weight (Jul/gr)

2. Materials, Method Of Production And Manufacture Of Samples

In this study, the cast aluminum A356 with the chemical composition listed in Table 1 selected as the base metal. SiC particles with a purity of 98 wt% and an average particle size of 11 μm were prepared as the reinforcing phase which plays a stabilizing or viscosifying role in the foam production process.

Table 1. Chemical composition of cast aluminum alloy A356

Si	Mg	Fe	Cu	Ti	Zn	Mn	**Composition**
6.81	0.35	0.19	0.09	0.07	0.02	0.01	**Weight percent**

Heating of SiC particles performed for one hour at 951 ° C and then for 2 hours at 651 ° C to remove contaminants and adsorbed gases resulting in improved wettability of SiC particles by aluminum melt. Calcium carbonate powder with purity of 99.5 wt% and average size of 5 μm was used as foaming agent. The powder also heated to 211 ° C for 2 hours to remove moisture and surface contamination and to increase the wettability properties and consequently better distribution of these particles in the aluminum melt. In order to produce the foam product, a composite ingot of aluminum foil with a certain amount of SiC particles first produced and cast by eddy molding at a temperature between 711 and 651 ° C. The ingot then stirred at 651 ° C and re-melt at 1411 rpm. At this stage, 1% by weight of magnesium added to the melt and then stirred for a minute by adding the calcium carbonate powder. After a few minutes and after producing CO2, the foam released from the furnace and cooled in ambient air. 3% by weight of calcium carbonate powder and 11% by volume of SiC particles used at this stage to produce the products. Figure 1 shows a sample of aluminum foam made by the above method.

Glass fibers as a unidirectional fabric used to make the composite skin layer with different layout. Each layer has a thickness of 0.2 mm and a mass of 200 g / m ^{2}. These types of fibers currently considered for various applications in industry. Epoxy resin ML503 and Hardener HA11 also used in the domestic industry. The mechanical properties of the composite plates along with the resin used presented in Table 2.

In this study, the hand layup method used to prepare composite plates and the surface thickness of all skin layers considered 2 mm. The dimensions of the specimens are 120 mm × 120 mm. these dimensions selected based on the fixing device used. Figure 2 shows an example of an AFSP with a pure aluminum skin layer. Geometric dimensions and weight of specimens listed in Table 3.

Table 2. : Mechanical Properties of unidirectional composite layer [13]

Value	Mechanical properties
19.94	Longitudinal tensile modulus (GPa)
5.830	Transverse tensile modulus (GPa)
2.110	Shear modulus (GPa)
700.11	Longitudinal tensile strength (MPa)
570.37	Longitudinal compressive strength (MPa)
69.85	Transverse tensile strength (MPa)
122.12	Transverse compressive strength (MPa)
68.89	Shear strength (MPa)

Table 3: Weight of specimens (gr) with different skins and core thickness

Core thickness (mm)			Skin layer
20	**30**	**40**	
278	393	455	Cross-ply
301	425	476	Quasi-isotropic
388	479	578	Pure Aluminum

3. Drop Weight Test Machine

One of the most important factors affecting the impact phenomenon is the initial energy of the projectile. In this study, a low velocity impact performed by a drop-weight device. This may be due to the collapse of the working tool during maintenance on the composite structure. For this purpose, a test machine manufactured by Iran Sayesh Company used. The projectile mounted on a track with very low friction that can fall freely. In this study, the manufacturer recommended to ignore low friction rates on the rails and equipment. The overall mass of the impactor and its accessories (load cell, bearings, etc.) is 7 kg, which can fall to a height of 1 meter above the target. The load cell capacity is 10 kN and with a data frequency of 25 kHz. The mass and height of the projectile can varied, so different kinetic energies can applied. In this experiment, for all specimens, the impactor and accessories changed to 17 kg by increasing the weight of 10 kg and falling from the height of 70 cm on the target sample. Figure a-3 shows the overview of the device used. As shown in Fig. 3, square specimens placed on a special stand and then reinforced by a hollow square clamp with four screws. All four edges of the specimen clamp to 10 mm wide and are free 100 × 100 mm wide. The impactor falls exactly at the midpoint of the sample free space. (Figure b-3) All tests performed according to ASTM D7136 [14]. To prevent reoccurring impacts on the specimen, a pneumatic jack is used which acts quickly after the first impact and stops the impactor to prevent secondary impacts. (Figure c-3)

4. Impactor Shape, Skin Layer Layout And Core Thickness

As previously mentioned, this study investigates the effect of the impactor shape, skin layer layout and core thickness of plates. Since spherical impactor is the most common type, this geometric shape of impactor used in most studies. As explained earlier, the geometrical shape of the impactor can be very effective in the parameters of impact load assessment. Therefore, in this study, three types of conical, parabolic and spherical pickers are used. All three impactor with a diameter of 13 mm and a penetration height of 60 mm are made of hardened CK45 steel. Figure 4 shows these three types of impactor.

In addition, in the leading study, the effect of the type of skin layer of AFSPs also examined. In the evaluation of other previous studies, most of the sandwich plates studied with metal or simple composite surfaces and less attention paid to the effect of composite layout of skin layer. Therefore, in this study, in addition to fabricating specimens with aluminum, orthogonal and quasi-isotropic composite surfaces evaluated. Figure 5 shows a sample composite plate screen. In this study, the effect of ore thickness on sandwich plate behavior evaluated. For this purpose, the specimens made with three core thicknesses of 20, 30, and 40 mm.

5. Experiments And Taguchi Approach

Design of experiments (DOE) is one of the most powerful techniques to improve quality and increase productivity. In this way, through some experiments, conscious changes made to the system to examine their impact on the performance characteristics of system response to them. The design of experiments is the systematic manipulation of a number of variables in which the effects of these manipulations evaluated and from which conclusions are drawn, the results implemented. In the late 1940s, Dr. Taguchi introduced new statistical concepts and later proved to be valuable tools for quality control and improvement. Since then, many Japanese artisans have used this technique to improve products and process quality.

The Taguchi method is quite different from the conventional methods of testing. Taguchi's methodology focuses on designing experiments and performing a limited number of experiments, while in the conventional methods all possible combination should be tested. Orthogonal arrays (OA) used in this method dramatically reduces the number of tests required by identifying a set of robust strategies in designing the experiments and analyzing the results. To consider the three control factors considered in this study, a standard Taguchi-based design, L27, which shown in Table 1 is used. This basic design uses three control elements; each of them has three levels. In addition, this design is capable of examining the interaction between the factors. From the standard design (Table 4), nine experimental runs need to conduct with the combination of levels for each control factor (A–C).

Table 4: The basic Taguchi L_9 orthogonal array

Control factors and levels			Run
C	**B**	**A**	
1	1	1	1
2	2	1	2
3	3	1	3
2	1	2	4
3	2	2	5
1	3	2	6
3	1	3	7
1	2	3	8
2	3	3	9

In this study, three major factors that have more effects on the behavior of the plates considered: skin layer layout, impactor shape and core thickness. Three levels for each factor were selected (shown in Table 5) as factor levels.

Table 5: Parameters, codes, and level values used in Taguchi method

Levels			Code	Factors
3	**2**	**1**		
Cross-ply	Quasi-isotropic	Pure Aluminum	A	Skin layer
Spherical	Parabolic	Conical	B	Impactor shape
40	30	20	C	Core thickness (mm)

Table 6 shows the results of experimental tests of response factors based on the Taguchi method selected parameters from Table 4.

Table 6: Modified orthogonal array using basic Taguchi

Specific Absorbed Energy (J/gr)	Max. Impact force (KN)	Max. Displacement (mm)	Control factors and levels			Run
			C	B	A	
0.181	7.51	5.67	1	1	1	1
0.178	8.84	3.83	2	2	1	2
0.258	8.54	3.98	3	3	1	3
0.153	8.67	3.54	2	1	2	4
0.221	8.41	4.78	3	2	2	5
0.146	8.01	5.12	1	3	2	6
0.148	8.22	4.34	3	1	3	7
0.102	7.78	6.32	1	2	3	8
0.103	8.99	3.62	2	3	3	9

5.1. Signal-to-noise ratio analysis

Signal-to-noise ratio (SNR or S/N) is a measure used in engineering that compares the level of a desired signal to the level of background noise. SNR defined as the ratio of signal power to the noise power, often expressed in decibels. The larger-the-better (LB), the smaller- the- better (SB), and the nominal-the-better (NB) are the three types used to analyze the S/N ratio.

The average effects of the factors were calculated and shown in Tables 7. This table include comparing the relative value of the effects based on the delta statistics, which called ranks that is the difference between the lowest and the highest averages for the factor chosen. Core thickness appears as the first effective factor for SAE and impactor shape is as the first one for MD and MIF. The Taguchi analysis of SAE value versus skin layer, impactor shape and core thickness reveals that delta statistics of the core thickness is 2.58, that of impactor shape is 1.16 and skin layer layout is 0.63. This shows that the most significant factor for SAE of AFSP is core thickness, followed by impactor shape and the skin layer layout is the least factor. In case of MD of AFSP, the delta statistics of the impactor shape is 3.81, skin layer layout has a value of 1.31, while that of core thickness is 0.39. This means that the most principle factor for MD of the AFSP is impactor shape, followed by skin layer layout and core thickness. For the MIF, the delta statistics of the impactor shape is 1.12, that of the skin layer layout is 0.4, while that of core thickness is 0.09, this implies that the most important factor here is impactor shape, followed by skin layer layout and the least factor here is core thickness.

Table 7. Taguchi analysis: SEA, MD and MIF versus different factors, Table for S/N ratios

Response variable	Specific Absorbed Energy (LB)			Max. Displacement (SB)			Max. Impact Force (SB)		
Factors	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
1	36.62	36.88	37.46	-12.93	-15.09	-12.92	-18.19	-17.80	-18.36
2	36.29	35.72	36.56	-13.76	-11.28	-12.92	-18.41	-18.92	-18.44
3	35.98	36.28	34.88	-12.45	-12.78	-13.31	-18.59	-18.47	-18.40
Delta	0.63	1.16	2.58	1.31	3.81	0.39	0.40	1.12	0.09
Rank	3	2	1	2	1	3	2	1	3

5.2. Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures used to analyze the differences among group means in a sample. ANOVA developed by statistician and evolutionary biologist Ronald Fisher. The ANOVA based on the law of total variance, where the observed variance in a particular variable partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether two or more population means are equal, and therefore generalizes the t-test beyond two means. In this study, statistical significance of the impact load parameters affecting the SAE, MD and MIF investigated by ANOVA. The influence of core thickness, skin layer layout and impactor shape on the total variance of the results undertaken for a level of significance of .5%, i.e. for a level of confidence of 99.5%. The ANOVA table also contains the F- values and the percent distribution. By comparing the F-values with the values in the table, one can understand the importance of the factors. If the F-value obtained from a parameter is greater than the calculated value, that particular parameter has a significant effect on the response variable. The main effects of the variables considered for the raw data and the SNR data plotted. Response parameter curves used to investigate the parametric effects on response characteristics. Analysis of variance of raw data and SNR data performed to identify important variables and quantify their effects on response characteristics. The most cost-effective values (optimal settings) of the production variables in terms of mean response characteristics created by analyzing the response curves in Figures 6-8 and Tables 8-10.

Table 8. ANOVA for means for SAE

Source	DF	Seq SS	Adj SS	Adj MS	F	P	R-Sq	R-Sq (Adj)
Core thickness	2	561.572	561.572	280.876	620.66	0.002	99.9 %	99.5 %
Skin layout	2	34.050	34.050	17.025	37.62	0.026		
Impactor shape	2	115.092	115.092	57.546	127.16	0.008		
Residual error	2	0.905	0.905	0.453				
Total	8	711.799						

Table 9. ANOVA for means for MD

Source	DF	Seq SS	Adj SS	Adj MS	F	P	R-Sq	R-Sq (Adj)
Core thickness	2	0.1480	0.1480	0.07401	0.142	0.413	98.6 %	94.5 %
Skin layout	2	0.8388	0.8388	0.41941	0.805	0.110		
Impactor shape	2	6.4247	6.4247	3.21234	61.68	0.016		
Residual error	2	0.1042	0.1042	0.05208				
Total	8	7.5157						

Table 10. ANOVA for means for MIF

Source	DF	Seq SS	Adj SS	Adj MS	F	P	R-Sq	R-Sq (Adj)
Core thickness	2	0.00667	0.00667	0.003333	1.56	0.390	99.8 %	99.1 %
Skin layout	2	0.21740	0.21740	0.108700	50.95	0.019		
Impactor shape	2	1.72287	1.72287	0.861433	403.80	0.002		
Residual error	2	0.00427	0.00427	0.002133				
Total	8	1.95120						

5.3. Estimation of optimum response characteristics

Specific absorbed energy

The larger-the-better characteristic used to determine the largest SAE that would be the ideal situation for this study. Meanwhile, the larger SNR projected as the best response given in plate manufacturing which would be the ideal situation. Fig. 6 shows the graphs used to determinate the optimal values of parameters from this experimental test. In this Figure, the factor of skin layer layout of the plate (A) at level 1 (cross-ply) shows the best result. In addition, the best results for impactor shape (B) observed at the level 1 (conical). Meanwhile, the core thickness of the plate (C) gives the best results at the level 1 (40 mm). There are no conflicts to determine the optimal skin layer layout, impactor shape and the core thickness of the plate and the criteria of the largest response and highest SNR followed. Therefore, the optimal combination of levels for all three factors of production provides the best SAE found to be A1-B1-C1.

Maximum displacement

In this response factor, the-smaller-the-better characteristic used and the smallest MD value would be the ideal situation The SB characteristic used to determine the smallest MD that would be the ideal situation for this study. Fig. 7 shows the graphs used to determinate the optimal values of parameters from this experimental test. In this

Figure, the factor of skin layer layout of the plate (A) at level 3 (pure Aluminum) shows the best result. In addition, the best results for impactor shape (B) observed at the level 2 (spherical). Meanwhile, the core thickness of the plate (C) gives the best results at the level 1 (40 mm). Therefore, the optimal combination of levels for all three factors of production provides the best MD found to be A3-B2-C1.

Maximum impact force

In the last response factor, the-smaller-the-better characteristic used and the smallest MIF value would be the ideal situation The SB characteristic used to determine the smallest MIF that would be the ideal situation for this study. Fig. 8 shows the graphs used to determinate the optimal values of parameters from this experimental test. In this Figure, all the control factors (A, B and C) at the level 1 provides the best results (cross-ply, conical and 40 mm respectively). Therefore, the optimal combination of levels for all three factors of production provides the best MIF found to be A1-B1-C1.

In order to validate the results obtained from the Taguchi method, three validation tests performed for each response characteristics (SAE, MD and MIF) at optimal levels of the production variables. The results given in Table 11. Results show good agreement between actual data from experimental tests and those predicted by current model. So optimal values of production parameters predicted in Table 11 are valid.

Table 11. Predicted response values and results of actual values

Performance responses	Optimal combination of parameters	Predicted response values	Actual values from experimental tests
Specific Absorbed Energy (J/gr)	A_1 B_1 C_1	81.99	82.40
Max. Displacement (mm)	A_3 B_2 C_1	3.24	3.62
Max. Impact Force (KN)	A_1 B_1 C_1	7.53	7.51

Figure 9 illustrates sandwich samples with different procedures tested using spherical impactor. Since the analysis of specimen damage and its mechanism of destruction is not the subject of this article, it is merely a case report. As can be seen, the spherical impactor have entered the plate with aluminum and quasi-isotropic surfaces from the top but stopped in the foam core of the plate while for cross-ply skin layer, impactor passes through the bottom plate. In addition, the surface damage of the sample with a quasi-isotropic skin layer is greater than the surface damage of the sample with cross-ply skin. This phenomenon is due to the higher impact force in this case. The separation of skin layer saw in the cross-ply sample, which not observed in the quasi-isotropic case. Also in the evaluation of impact depth, in this case, the maximum penetration belongs to the plate with cross-ply skin layer and the lowest one is to the plate with pure aluminum surface.

6. Conclusions

In this study, the effect of impactor type, core thickness and skin layer layout of AFSP under impact loads investigated. In addition, by using Taguchi optimization methodology with a basic L_9 OA, optimized production factors (skin layer layout, core thickness and impactor shape) derived for the best response of SAE, MD and MIF. It proved that the Taguchi parameter design is an efficient way to determine the optimal combination of production parameters for the largest SAE and lowest MIF and MD. Additionally following comments highlighted:

- The most important factor for best SAE of AFSP is core thickness, followed by impactor shape and the skin layer layout. These parameters for MD and MIF of the AFSP is impactor shape, followed by skin layer layout and core thickness.
- The optimized combination of levels for all the three production factors from the analysis that provides the best SAE, MD and MIF are A1–B1–C1, A3–B2–C1 and A1–B1–C1 respectively.
- The spherical impactor have entered the plate with pure aluminum and quasi-isotropic surfaces from the top but stopped in the foam core of the plate while for cross-ply skin layer, impactor passes through the bottom plate
- The surface damage of the sample with a quasi-isotropic skin layer is greater than the surface damage of the sample with cross-ply skin. This phenomenon is due to the higher impact force in this case.
- Maximum penetration of impactor belongs to the plate with cross-ply skin layer and the lowest one is to the plate with pure aluminum surface.

7. List Of Abbreviations

Abbreviation	Explanation
AFSP	aluminum foam sandwich panels
SAE	specific absorbed energy
MD	maximum displacement
MIF	maximum impact for
OA	orthogonal array
DOE	Design of experiments
SNR	Signal-to-noise ratio
LB	larger-the-better
SB	smaller- the- better
NB	nominal-the-better
ANOVA	Analysis of variance
P	Percentage of participation
MS	Mean squares
SS	sum of squares
DF	degree of freedom
F	Ratio of variance

8. Declarations

Funding (Not applicable)

Code availability (Not applicable)

Conflicts of interest:

There is no conflicts of interest to disclose.

Availability of data and material

All data, models, and materials generated or used during the study appear in the submitted article.

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Figures

Figure 1

Sample of aluminum foam manufactured

Figure 2

Sandwich Aluminum Composite Plate (a) Front View (b) Side View

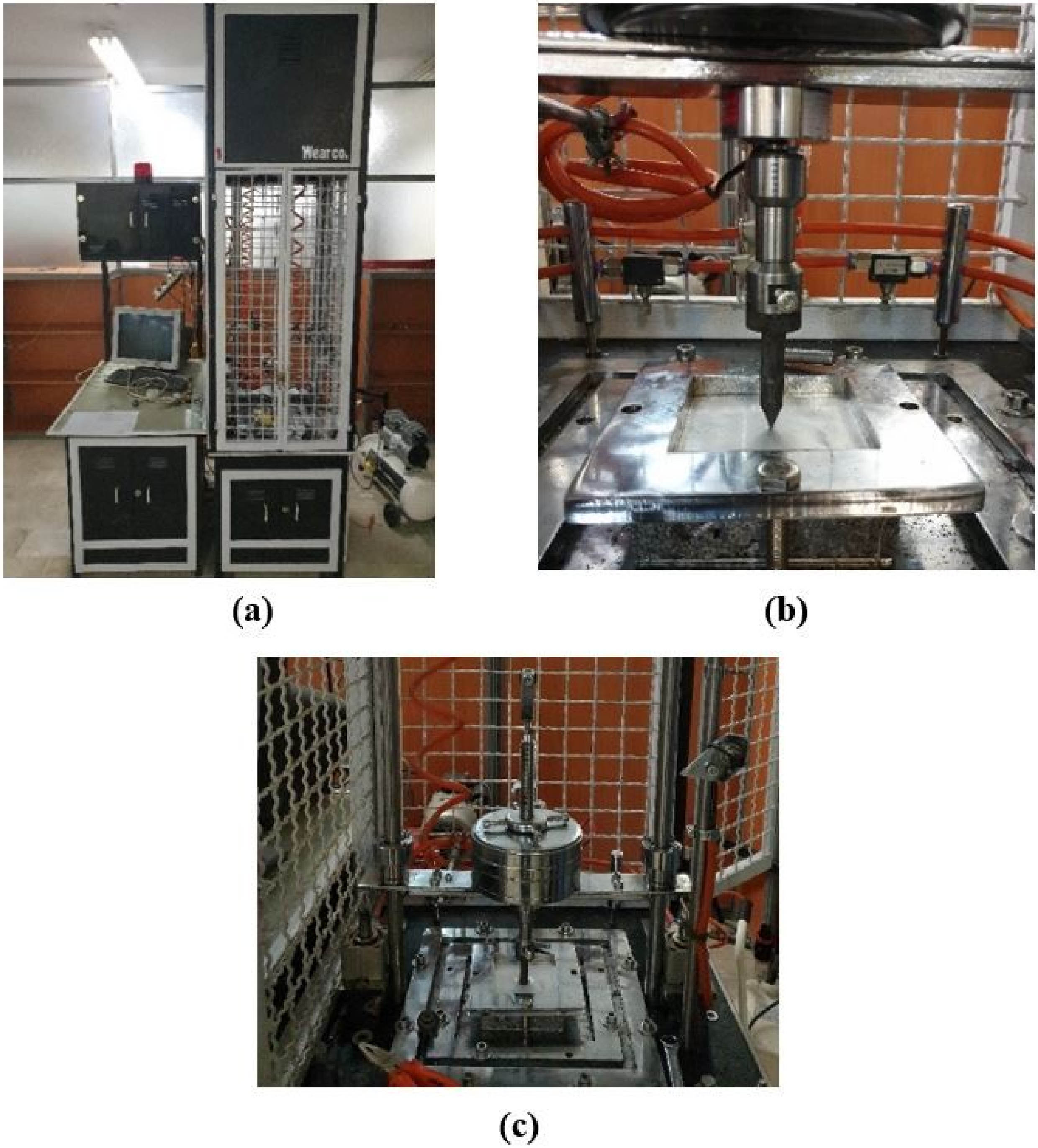

Figure 3

Drop weight machine (a) Overall scheme of the device (b) Moment of impact on the specimen (c) Pneumatic jack equipment for secondary impact prevention

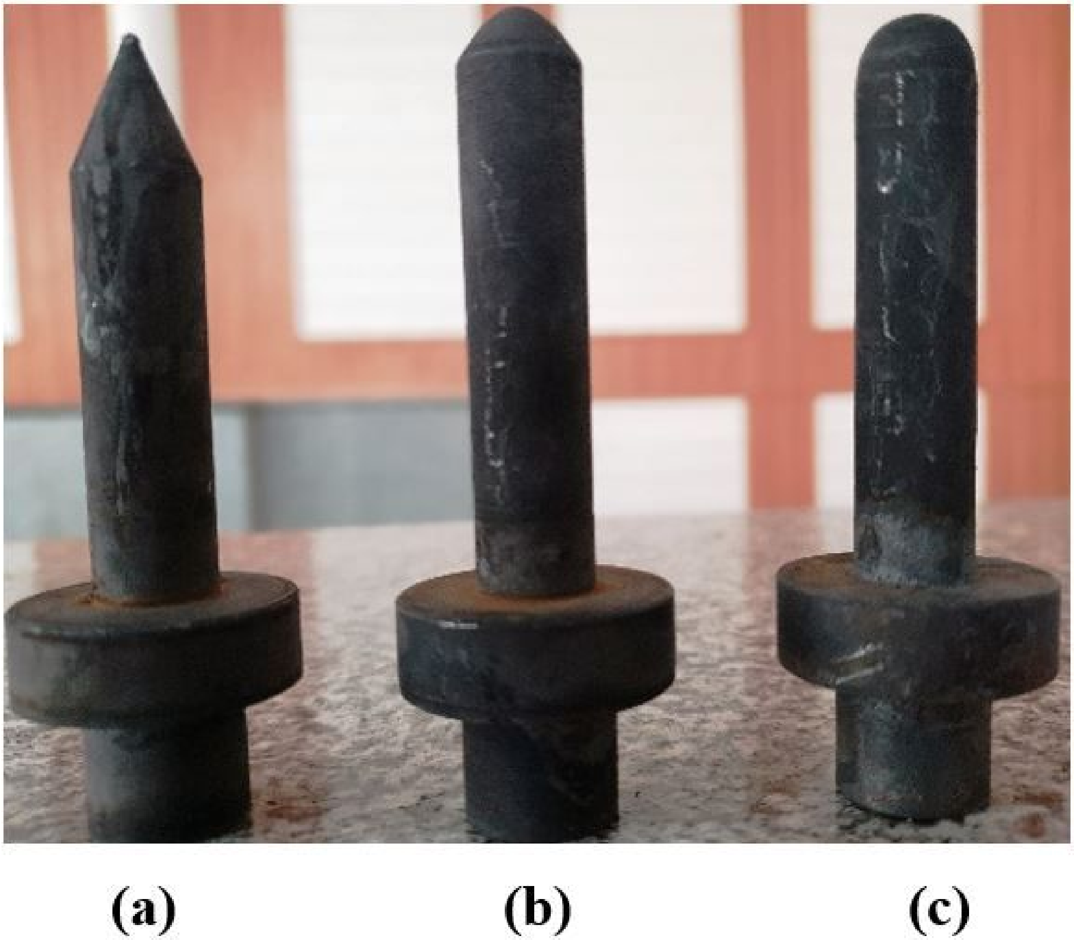

Figure 4

Three impactor shapes used (a) conical (b) parabolic (c) spherical

Figure 5

sandwich composite plate with quasi-isotropic surface

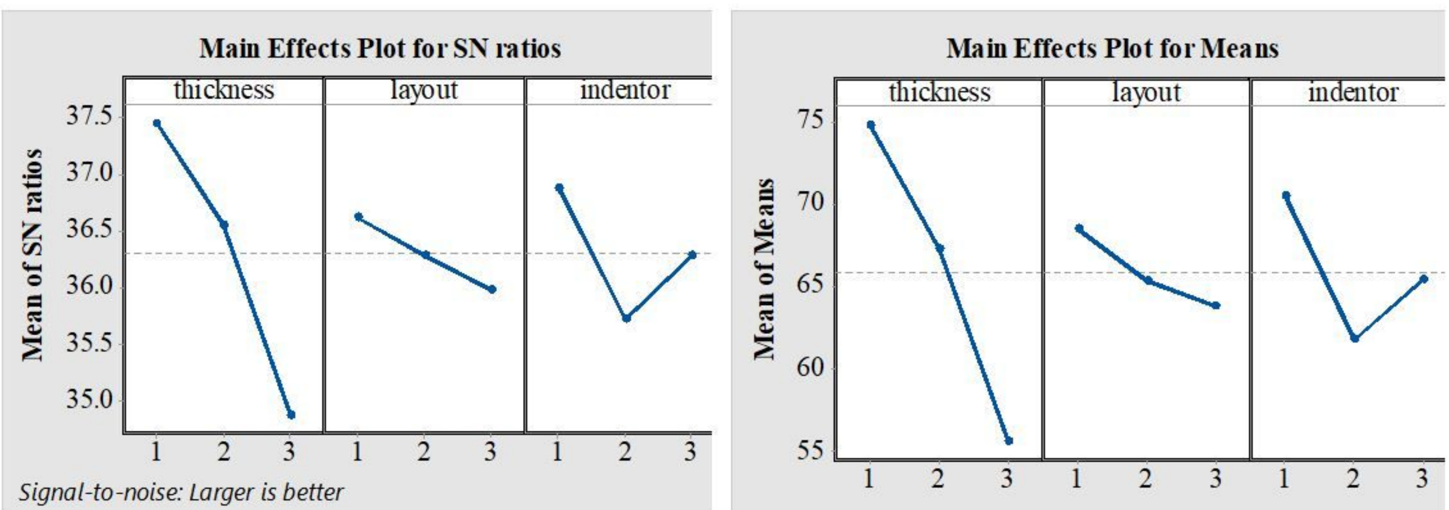

Figure 6

SEA means and SNR effects for each production factors

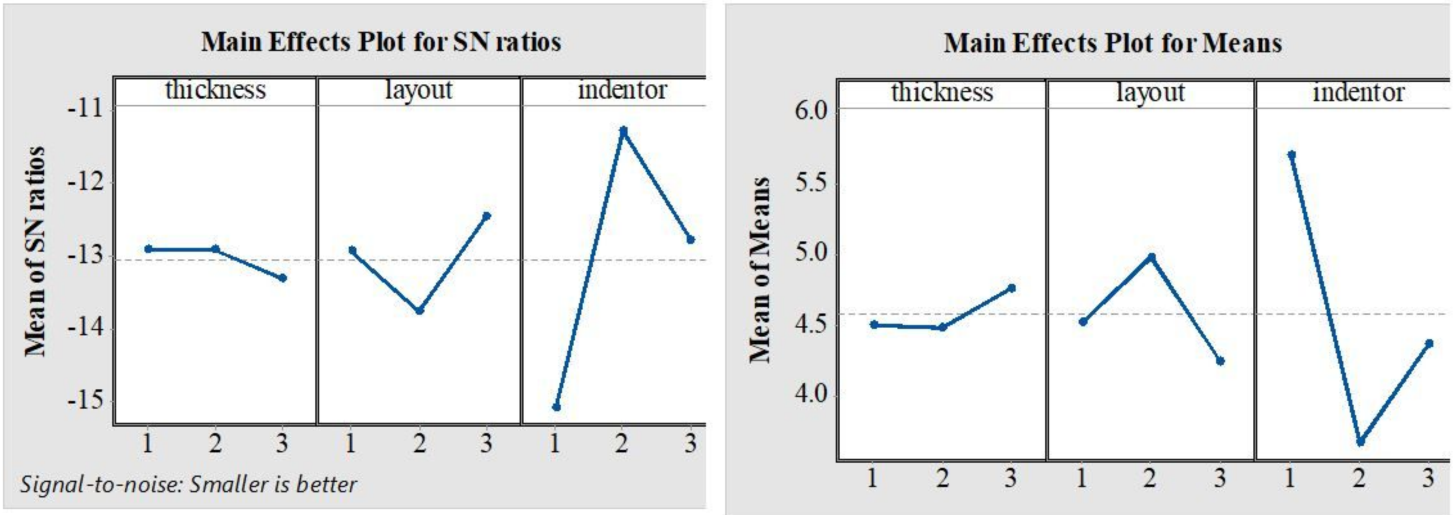

Figure 7

MD means and SNR effects for each production factors

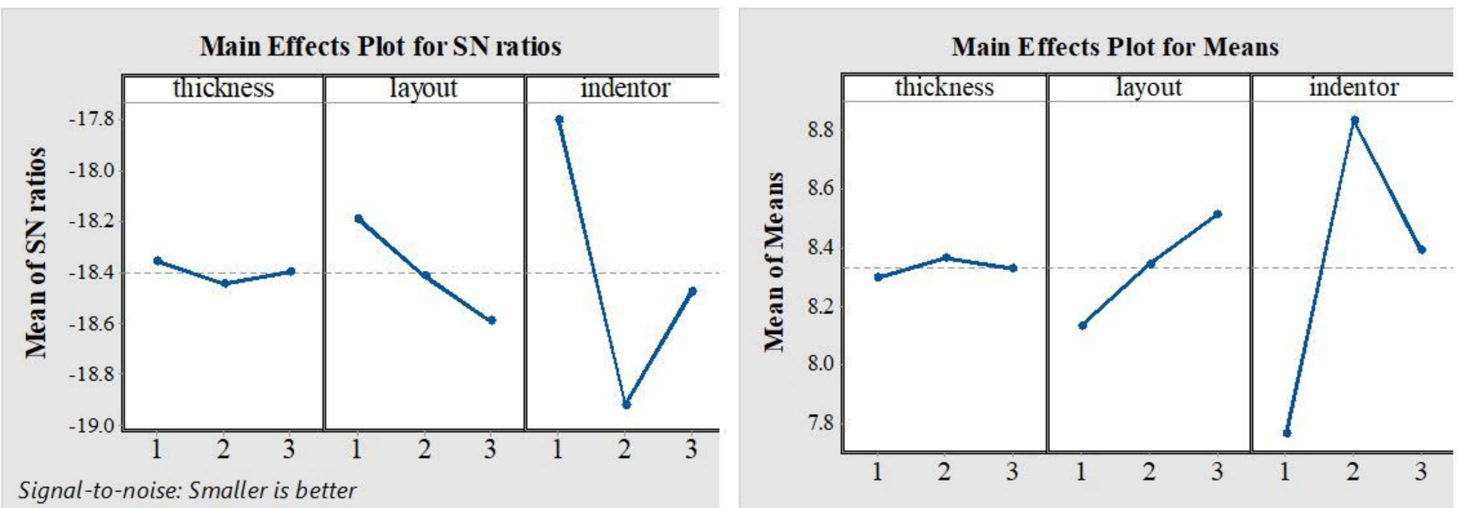

Figure 8

MIF means and SNR effects for each production factors

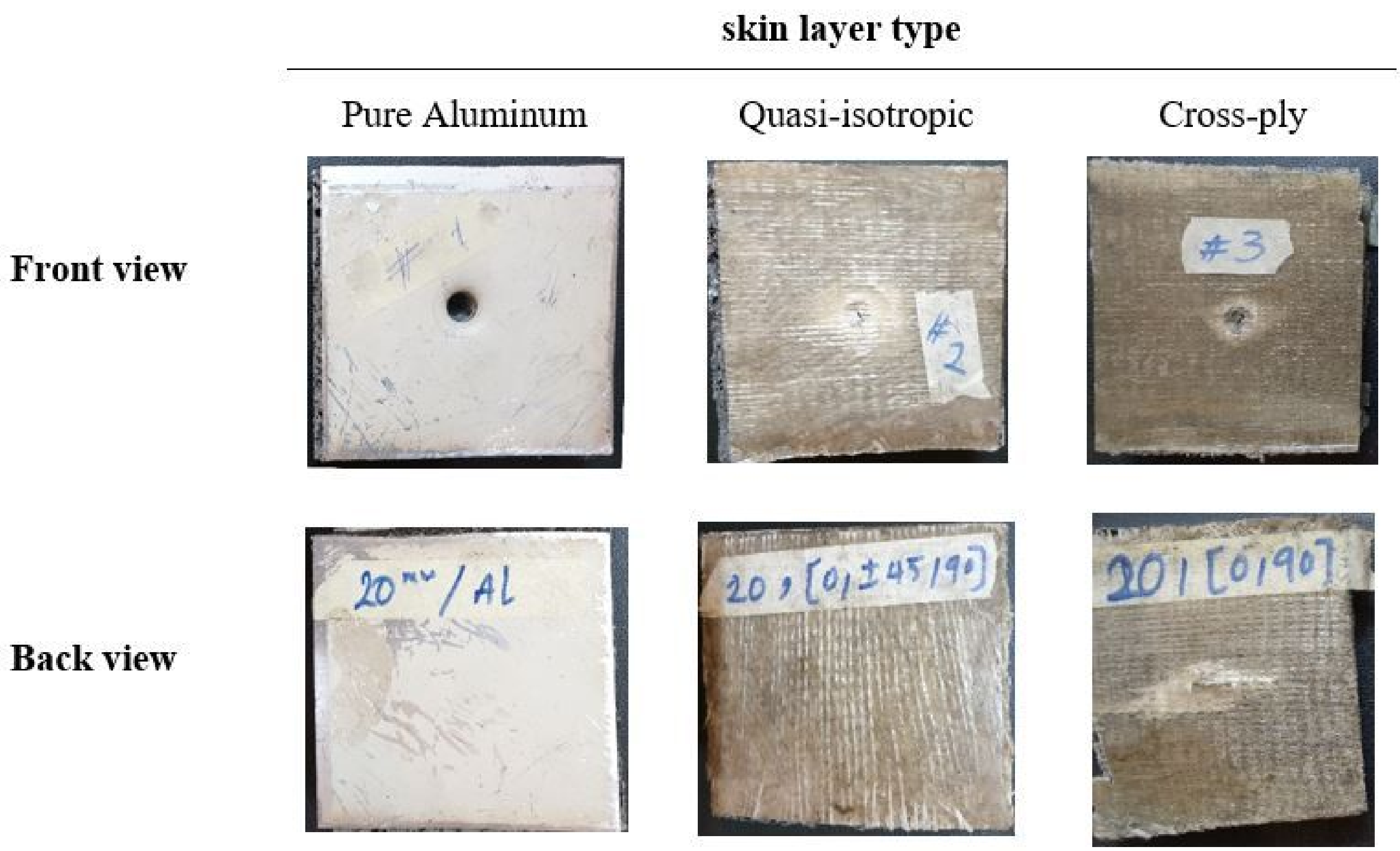

Figure 9

Front and back view of specimens after drop weight test with spherical impactor