Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 33, No. 2, 2023, April, pp. 121-125
Journal homepage: http://iieta.org/journals/rcma

Analysis of Impact Loading Response on the Composites Materials as a Function of Graphite Filler Content Using Taguchi Method

Drai Ahmed Smait[1], Farag Mahel Mohammed[2], Hamid A. Al-Falahi[3], Hussam Lefta Alwan[2], Sameer Alani[1*]

[1] Department of Medical Physics, The University of Mashreq, Research Unit Centre, Baghdad 10011, Iraq
[2] Department of Electromechanical Engineering, University of Technology-Iraq, Baghdad 10081, Iraq
[3] Department of Chemical and Petrochemical Engineering, University of Anbar, Ramadi 31001, Iraq

Corresponding Author Email: dr.sameer@uom.edu.iq

https://doi.org/10.18280/rcma.330207

Received: 27 February 2023
Accepted: 9 April 2023

Keywords:
glass-polyester, sandwich panel, graphite fillers, Taguchi's approach

ABSTRACT

The deflection and deformation behaviour of a 30% weight fraction glass-polyester sandwich panel was studied as a function of graphite filler quantity and impact velocity. Experiments based on Taguchi methods were carried out in order to collect data systematically. The panel is fastened on three sides and left free for the destructive test. By applying the impact force. The vibration data collector is used to measure the deflection (TVC 200). During the destructive test, the panel is additionally fastened to a solid base for stability. The steel hammer came crashing down from above. A Vernier calliper is used to measure the distortion. The tests were planned using Taguchi's L9 orthogonal array method. Examine the effects of impact force, height, and graphite filler content on low-velocity deflections and deformations using analysis of variance. The findings demonstrate that the mass is the primary parameter influencing the deflection, whereas the graphite filler is the primary parameter influencing the deformation. As a last step, a confirmation tests have been run to make sure the predicted experimental outcomes from those correlations were correct.

1. INTRODUCTION

Composites are man-made substances made up of two or more different materials, which when combined, exhibit superior qualities than those of the individual components. The two main parts of a composite are the fibers and the matrix. The fiber reinforcement provides the bulk of the material's strength, while the matrix acts to keep the fibers in place and distribute stress across them. It is common practice to use fillers and modifiers to lower production costs, improve a product's performance, or both [1, 2]. Sandwich composites are excellent for low-weight constructions that need strong in-plane and flexural stiffness [3]. Everyday occurrences like objects falling on a composite casing, cars colliding at low speeds, boulders striking a vehicle's composite bodywork, and ballistic strikes on military aircraft all result in collisions at low velocities. Biswas et al. [4] studied the effects of low-velocity impact on composite sandwich panels made with a honeycomb core sandwiched between glass fibre-reinforced face sheets. The dynamic response of the panel was studied by Chauhan et al. [5] by monitoring strain at a specific place on the panel when the panel was exposed to an impact force (both experimentally and numerically). Researchers [6] looked at how a compressive preload affected the low-velocity impact behaviour of a carbon fibre-reinforced composite plate. Modeling methodologies, with a focus on laminate delimitation and preload modeling, were developed for low-velocity impact simulation of plates under compressive preload using LS - DYNA. Researchers [7-9] use the Taguchi method to show how different amounts of aluminum and graphite filler affect the dynamic behavior of a glass-polyester sandwich panel subjected to low-velocity impact and the mechanical and tribological behaviour of a glass-polyester composite system, respectively. High-quality systems may be effectively designed using the Taguchi approach [10, 11]. Taguchi's method of experimentation offers a systematic framework for gathering, analyzing, and interpreting data in service of a given research question. Maximum insight may be gained with little effort via careful experimental design. The choice of design parameters in a Taguchi parameter design may maximize performance characteristics and lessen the system's susceptibility to the source of variation [12]. The effective use of experimental runs to the investigated variable combinations carries this out. An important part of any experimental design is identifying the variables that will be used to measure success. To determine the impact of several variables on the desired outcome, the Taguchi approach generates a standardized orthogonal array. Analysis of means and variance of the influencing variables is used to examine the experimental outcomes [13]. The primary goal of this research was to examine how the amount of graphite filler used in a composite sandwich panel affected its ability to flex and bend after being struck by a low-velocity item. To further the investigation [8], a set of experiments based on the Taguchi method was devised to systematically collect the necessary information. The Design of Experiments (DOE) method may be easily implemented to find the optimal processing path in the least amount of time. The goal is to narrow down the number of tests and costs to just those that are necessary, out of the infinite number of potential parameter combinations [14].

The literature review shows that the research [4-6] investigates the behaviour of a composite plate under dynamic load, while researchers [7-9] demonstrate the effect of filler on the behaviour of composite material using the Taguchi technique. In this research, the authors study the influence of filler on the dynamic response of composite plates using the Taguchi technique.

2. MATERIALS AND SPECIMEN PREPARATION

In this study, (360×10^{-3}) kg woven roving glass fiber with E-glass in the ((8-14) $\times10^{-6}$) m size range was employed. The matrix system used was an unsaturated polyester resin, namely the commercially available TOPAZ -1110 TP medium reactive based on Phthalic Anhydride and a room temperature hardener (Methyl Ethyl Kenton Peroxide (MEKP)). Graphite granules served as the filler (no. 7782-42-5 Merck index 10, 4410 Swiss). Injecting fillers into a polymer matrix may save production costs, increase modulus, reduce mold shrinkage, regulate viscosity, and provide a smooth surface.

All the composite honeycomb sandwich panel samples were made using the dry hand layup process described in the study [8], with a weight fraction of 30% and a graphite filler percentage of 5%, 7.5%, and 10%, respectively. Figure 1 depicts the process flow for making a composite and detailing its properties. The 54 composite honeycomb sandwich panels present with (80 mm x 40 mm x 40 mm) dimensions were manufactured.

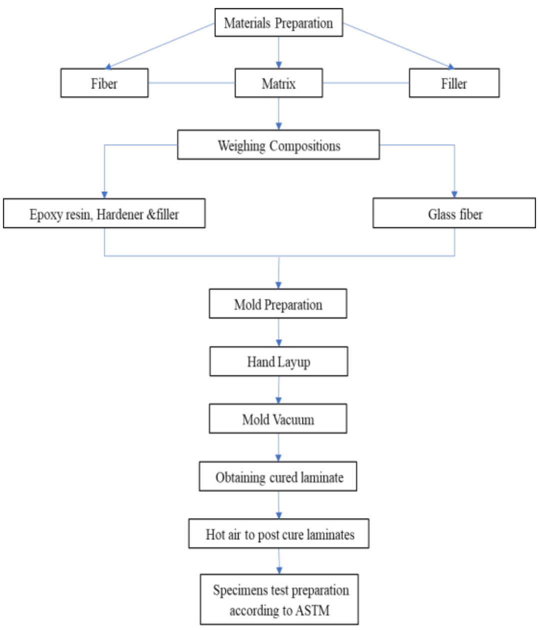


Figure 1. Process flow chart

Finally, a band knife cutting machine was used to form ASTM-compliant cuts in the slag and coconut shell-reinforced composite plates.

3. EXPERIMENTAL DESIGN

Tensile testing reveals the material's mechanical characteristics. Table 1 shows the results of tensile tests performed on materials following ASTM-D 638 [15].

1. As shown in Figure 2, the composite honeycomb sandwich panel (80 mm x 40 mm x 40 mm) was mounted on three sides and left free on the fourth for a non-destructive test (deflection behavior). The accelerometer is fixed in place in the middle of the bottom sheet. Steel balls of (45), (65), and (85) g are dropped from (90), (105), and (120) cm above the panel's center using a metal hose secured by an appropriate framework. The vibration data collector (TVC 200) receives a digital readout of the strain.
2. The impact load withstands (deformation resistance) of the honeycomb sandwich panel was shown using a destructive test. The honeycomb sandwich panel was subjected to low-velocity impact testing by dropping steel impactors of 12, 15, and 18 kg from towers of 1.5, 2, and 2.5 meters in height. The panel is secured to a sturdy base, and the released impactor item is placed in its center. A digital Vernier calliper was used to determine the deformation of the panel in length.

In order to find the sweet spot for deflection and deformation, three factors were investigated. Each with three levels (graphite content, mass, and height). The values for these parameters are shown in Table 2. Taguchi's method of experimentation offers a systematic framework for gathering, analysing, and interpreting data in service of a given research question. Maximum insight may be gained with little effort via careful experimental design. To model and analyse the impact of control elements on performance outcomes, Taguchi design of experiment is a strong analytic tool. The process of deciding which variables to use as controls is the most crucial part of an experiment's design. By selecting the right Taguchi orthogonal array with control parameters and levels [16, 17], the optimal level combination may be produced. Three of these characteristics have been investigated here, and their effects are summarized in Table 3 using an L9 (33) orthogonal design.

Figure 2. The honeycomb sandwich panel

Table 1. Mechanical characteristics and the amount of graphite filling

Graphite %	Modulus of elasticity (Gpa)	Yield stress (Mpa)	Tesile strength (Mpa)
5%	2.950	80	151
7.5%	3.610	89	169
10%	3.090	77	158

Table 2. Factors and their levels

a- Nondestructive test				
Factor and Unit	**Symbol**	**Factor levels**		
		Level 1	**Level 2**	**Level 3**
Graphite (%)	AA	5 %	7.5 %	10 %
Mass (g)	BB	45	65	85
Height (cm)	CC	90	105	120
b- Destructive test				
Factor and Unit	**Symbol**	**Factor levels**		

		Level 1	Level 2	Level 3
Graphite (%)	AA	5 %	7.5 %	10 %
Mass (kg)	BB	12	15	18
Height (m)	CC	1.5	2	2.5

Table 3. Standard Taguchi's orthogonal array L9

No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4. RESULTS AND DISCUSSION

Elastic modulus, yield stress, and ultimate tensile strength are only some of the mechanical qualities that have been measured. As can be seen in Table 1, the composite's mechanical characteristics tend to improve as the filler percentage rises. Given that the filler collaborates with the fiber and resin to provide increased strength and durability. The filler and the fiber, as well as the filler and the resin, are all compatible with one another.

4.1 S/N ratio

The signal-to-noise (S/N) ratio is another fundamental component of the Taguchi technique. The S/N ratio is derived from experimental findings. Various signal-to-noise (S/N) ratios may be used to achieve the required quality level. The S/N ratio "smaller is better" has been employed in calculations since both non-destructive testing (deflection) and destructive testing (deformation) are objectives of the current study. To calculate it, use the logarithmic formula [17].

$$S/N = -10\ log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (1)$$

The number of observations is denoted by n, the signal-to-noise ratio by S/N, and the quantity of interest, y_i, by i. The experimental results for deflection and deformation are shown with the predicted S/N ratios for all 9 observations in Table 4.

4.2 Analysis of means

Each control parameter's influence is determined by averaging the S/N ratios at the same setting [16]. The optimal combination of the process parameters may be selected based on the findings of the mean analysis. A signal-to-noise ratio was used to construct the analysis. Table 4 summarizes the average S/N ratio values that were obtained for each parameter across all levels in response to the average impacts of deflection and deformation. For the graphite parameter impact, level-1 is the mean of the first three S/N ratio calculations shown in Table 5-a (level-1 equals an average of -14.582, -16.40495, and -16.5202). Based on the experimental layout (orthogonal array) given in Table 3, the first three rows of the L9 array correspond to the graphite parameter's level-1. Both of the other parameters and the other two levels have undergone the same process. The optimal level is the one with the maximum signal-to-noise ratio. As a result, the reaction of deflection is determined by the level combination of the three factors A2B1C1, which is comparable to (7.5% graphite), (45 g) (mass), and (90 cm) (height). Furthermore, the optimal combination level for the deformation is the same as the deflection, A2B1C1, where A2 is 7.5% graphite, B1 is 12 Kg, and C1 is 1.5 m. Table 5 shows that the parameters' relative importance varies depending on the kind of analysis being performed, with the mass parameter being more important for calculating bending moments than any of the others, while the graphite parameter is more important for calculating bending moments. This is determined by the parameter rank, which is the maximum minus minimum value of the three levels for each parameter.

Table 4. Nondestructive test and destructive test

a. Nondestructive test

Exp. No.	Combinations A: Graphite (%)	B: Mass (g)	C: Height (cm)	Deflection (δ µm)	S/N ratio (dB)
1	0.05	45	90	5.3592	-14.582
2	0.05	65	105	6.6107	-16.40495
3	0.05	85	120	6.699	-16.5202
4	0.075	45	105	4.7673	-13.56545
5	0.075	65	120	5.9432	-15.48041
6	0.075	85	90	6.12974	-15.74884
7	0.1	45	120	6.50386	-16.26342
8	0.1	65	90	6.422766	-16.15444
9	0.1	85	105	6.703766	-16.52638

b. Destructive test

Exp. No.	Combinations A: Graphite (%)	B: Mass (Kg)	C: Height (m)	Deflection (Δ mm)	S/N ratio (dB)
1	0.05	12	1.5	9.7	-19.73543
2	0.05	15	2	12	-21.58362
3	0.05	18	2.5	14.1	-22.98438
4	0.075	12	2	6.3	-15.98681
5	0.075	15	2.5	7.5	-17.50123
6	0.075	18	1.5	6.8	-16.65018
7	0.1	12	2.5	11	-20.82785
8	0.1	15	1.5	9.4	-19.46256
9	0.1	18	2	11.3	-21.06157

Table 5. Mean S/N ratio for each factor level of

a. Nondestructive test

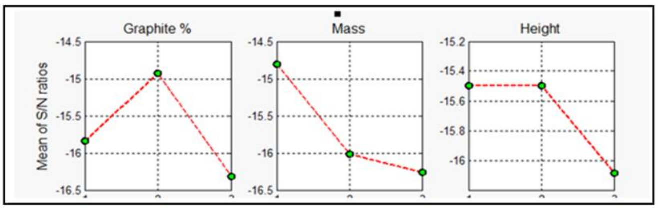
Factor	Symbol	Average of levels for S/N ratio: Level 1	Level 2	Level 3	Max-Min	Rank
Graphite (%)	A	-15.83572	**-14.93157**	-16.31475	1.38318	**2**
Mass (g)	B	**-14.80362**	-16.01327	-16.26514	1.46151	**1**
Height (cm)	C	**-15.49509**	-15.49893	-16.08801	0.58908	**3**

b. Destructive test

Factor	Symbol	Average of levels for S/N ratio: Level 1	Level 2	Level 3	Max-Min	Rank
Graphite (%)	A	-21.43448	**-16.71274**	-20.45066	4.72174	**1**
Mass (Kg)	B	**-18.85003**	-19.51580	-20.23204	1.38201	**3**
Height (m)	C	**-18.61606**	-19.54400	-20.43782	1.82176	**2**

The underlined value represents the optimum level (A2B1C1)

Using the information supplied in Table 5, the primary impact of the S/N ratio is shown visually in Figure 3. For both destructive and non-destructive testing, the figures depict the correlation between the S/N ratio and parameter values. Graph 2 shows that the S/N values consistently decrease as the mass increases. As a result, the smaller mass will result in the smallest bending moment. The graph also reveals that the greatest mean S/N value is found at graphite level 2. In the case of mass, the largest S/N mean is found at level 1. Levels 1 and 2 seem to have the same impact and are closer to a straight-line connection when the height parameter is included. This indicates that the deflection is not significantly affected by whether using level -1 or level -2. However, Figure 3 demonstrates that the mass and height parameters are related to deformation, suggesting that these two factors share the same impact. To rephrase, more deformation occurs as height or mass increases. In addition, the best level is the one that produces the greatest S/N ratio on the graph. Therefore, the parameters and their values of A2B1C1 are the best possible combination.



a- Non destructive test.

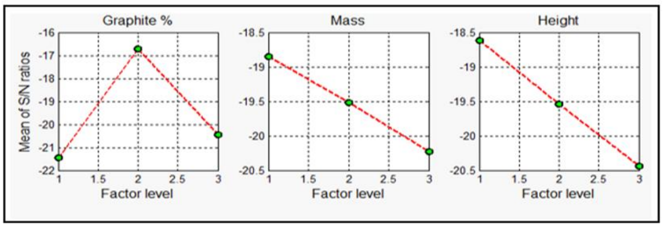


Figure 3. Representation of S/N ratio versus levels of each parameter for the destructive test

4.3 Analysis of variance (ANOVA)

Table 6. ANOVA

Source	Sum of Squares SS	Degree of Freedom d.f.	Mean Squares MS	F value (MS/error)	Contribution (%)
a.	**Deflection δ (nondestructive test)**				
Graphite (%)	2.96014	2	1.48007	3.25	35.9543
Mass (g)	3.66271	2	1.83135	4.02	44.4878
Height (cm)	0.69858	2	0.34929	0.77	8.48506
Error	0.91162	2	0.45581		11.0726
Total	8.23305	8			100
b.	**Deformation Δ (destructive test)**				
Source	**Sum of Squares SS**	**Degree of Freedom def.**	**Mean Squares MS**	**F value (MS/error)**	**Contribution (%)**
Graphite (%)	37.2347	2	18.6174	336.65	82.3951
Mass (Kg)	2.8662	2	1.4331	25.91	6.3425
Height (m)	4.9788	2	2.4894	45.01	11.0178
Error	0.1106	2	0.053		0.2447
Total	45.1904	8			100 %

The purpose of the ANOVA statistical approach is to investigate the effect of various design elements on the overall variation of the outcomes [18]. Deflection and distortion ANOVA findings are shown in Table 6. Mass, as can be shown in Table 6-a, is the most important factor, accounting for 44.48% of the total variation in the process. Therefore, it is the most important factor in determining deflection (by 35.95%). Height has less of an impact than width and depth. It is also evident from the relative contributions of the three factors that the mass parameter is the most important one, followed by the graphite% and the height parameter. Table 6–b reveals that the graphite parameter contributes 82.39% to the deformation, making it the most important one. The height parameter comes in second, followed by the mass. The findings of the analysis of variance and the results of the analysis of mean are identical.

4.4 Confirmation test

Confirmation tests are performed as the last stage of experimental design. Predicting and verifying inference derived during the analysis state and improvements in observed values by using the optimum level of process parameters [17, 19, 20] are the goals of this exercise. The optimal values of deflection and deformation are used in the confirmation experiment. Consequently, the formula for the deflection is graphite (7.5%, 45 g, 90 cm) while the formula for the deformation is graphite (7.5%, 12 Kg, 1.5 m). This equation [17] may be used to determine the ideal S/N ratio for a given set of process parameters.

$$\eta_{opt} = \eta_m + \sum_{i=1}^{k} (\eta_i - \eta_m) \tag{2}$$

where:
η_{opt}: predicted S⁄N ratio.
η_m: Total mean of S⁄N ratios.
η_i: mean S⁄N ratio at optimum levels.
k: number of main design parameters that affect the quality characteristics.

In order to compare the anticipated S/N ratio with the observed value, an experiment was performed using the combination A2B1C1, for both, deflection and deformation. Based on the variables listed in the last column of Table 4, a deflection value of (_m=-15.69401 dB) for the overall mean S/N ratio were obtained. the value for distortion of (_m=-19.53263 dB). The cumulative mean of the S/N ratio have been utilized in conjunction with the highlighted variables in Table 5 to get the optimal anticipated value of S/N. The confirmation test findings are summarized in Table 7.

Table 7. Confirmation results

a.	**Nondestructive test**	
Optimum Process Parameters Graphite (7.5%), Mass (45g), Height (90cm)		
	Experiment	**Prediction**
Levels	$A_2B_1C_1$	$A_2B_1C_1$
Deflection (µm)	4.565	4.921
S/N (dB)	-13.188	-13.84226
b.	**Destructive test**	

Optimum Process Parameters Graphite (7.5%), Mass (12Kg), Height (1.5m)		
	Experiment	**Prediction**
Levels	$A_2B_1C_1$	$A_2B_1C_1$
Deformation (mm)	5.323	5.6963
S/N (dB)	-14.523	-15.11357

5. CONCLUSIONS

Following are some inferences that may be made:

1. According to the mean effect analysis, the mass is the most important factor in determining the deflection, whereas the graphite content is the most important factor in determining the deformation.
2. Level 2 for graphite, 1 for mass, and 1 for height is the optimal combination for the two responses (bend and twist). Which is the reason why it has been given the letter code A2B1C.
3. Similar conclusions hold when analysing variance. The mass contributes the most to deflection (44.48 percent), followed by graphite (35.95 percent). The graphite contributes the most (82.39%) to the deformation, followed by the height (11.01%). Therefore, the mass is the most important quantity when assessing the deflection, whereas the graphite is the most important parameter when studying the deformation.

ACKNOWLEDGMENT

This study has been carried out in the laboratory of the University of Technology-Iraq.

REFERENCES

[1] Alpaydin, N.K., Türkmen, H.S. (2009). The dynamic response of the sandwich panel subjected to the impact load. RAST 2009 - Proceedings of 4th International Conference on Recent Advances Space Technologies, Istanbul, Turkey, pp. 176-180. https://doi.org/10.1109/RAST.2009.5158191

[2] Alwan, H.L. (2014). Application of Taguchi approach to study the effect of filler type on tribological behavior of polymer composite under dry conditions. Engineering and Technology Journals, 32(8): 1916-1930.

[3] Basavarajappa, S., Chandramohan, G. (2005). Wear studies on metal matrix composites: A taguchi approach. Journal of Materials Science and Technology, 21(6): 845-850.

[4] Biswas, S., Patnaik, A., Kumar, P. (2011). Silicon carbide filled polymer composite for erosive environment application: A comparative analysis of experimental and FE simulation results. Silicon Carbide - Materials, Processing and Applications in Electronic Devices. https://doi.org/10.5772/21547

[5] Chauhan, S.R., Kumar, A., Singh, I., Kumar, P. (2010). Effect of fly ash content on friction and dry sliding wear behavior of glass fiber reinforced polymer composites - A Taguchi approach. Journal of Minerals and Materials Characterization and Engineering, 9(4): 365-387. https://doi.org/10.4236/jmmce.2010.94027

[6] Long, A.C. (Ed.). (2014). Composites forming technologies. Elsevier.

[7] Daniel, M.I., Abot, L.J. (2000). Fabrication, testing and analysis of composite sandwich beams. Composites Science and Technology, 60(12-13): 2455-2463. https://doi.org/10.1016/S0266-3538(00)00039-7

[8] Erickson, M.D., Kallmeyer, A.R., Kellogg, K.G. (2005). Effect of temperature on the low-velocity impact behavior of composite sandwich panels. Journal of Sandwich Structures & Materials, 7(3): 245-264. https://doi.org/10.1177/1099636205048636

[9] Eweed, K.M., Sabri, S.Z. (2015). Effect of graphite content on the dynamic behavior of sandwich panel under low velocity impact. Journal of Engineering and Sustainable Development, 19(1): 1-13. https://www.iasj.net/iasj/download/f211afe134a3e95e

[10] Heimbs, S., Heller, S., Middendorf, P. (2008). Simulation of low velocity impact on composite plates with compressive preload. LS-DYNA Anwenderforum, Bamberg, pp. 11-24.

[11] Kiran, G., Suman, K., Rao, N., Rao, R. (2011). A study on the influence of hot press forming process parameters on mechanical properties of green composites using Taguchi experimental design. International Journal of Engineering, Science and Technology, 3(4): 253-263. https://doi.org/10.4314/ijest.v3i4.68557

[12] Mahapatra, S.S., Patnaik, A. (2009). Study on mechanical and erosion wear behavior of hybrid composites using Taguchi experimental design. Materials and Design, 30(8): 2791-2801. https://doi.org/10.1016/j.matdes.2009.01.037

[13] Mahel mohammed, F., Mershed, K.A., Zuhair Sabri, S. (2013). Aluminum filler content effect on the dynamic behavior of sandwich panel subjected to impact load. Engineering and Technology Journals, 31(14): 2716-2726.

[14] Hodgkinson, J.M. (1990). Advanced Composites Bulletin. Mechanical Testing of Advanced Composites, 11: 13.

[15] Mohammadi, I., Haghighi-Yazdi, M., Safarabadi, M., Yousefi, A. (2023). Crashworthiness analysis of a composite guardrail under impact loading. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 146442072311524. https://doi.org/10.1177/14644207231152432

[16] Roy Ranjit, K. (1990). A primer on Taguchi method. VNR Publication, New York, 7-10.

[17] Shaker, D.H., Mohammed, F.M., Smait, D.A. (2021). Acoustic isolation behavior of composite materials reinforced by natural filler using robust design. Solid State Technology, 64(2): 1658-1666.

[18] Taguchi, G. (2011). Taguchi on robust technology development. Taguchi on Robust Technology Development, 115(3): 336-337 https://doi.org/10.1115/1.800288

[19] Vasiliev, V.V., Morozov, E.V. (2018). Mechanics of a composite layer. In Advanced Mechanics of Composite Materials and Structures, 75-189. https://doi.org/10.1016/B978-0-08-102209-2.00002-5

[20] Yeh, M.K., Chiu, Y.W. (2013). Bending strength analysis of centrally-debonded composite sandwich beam using taguchi method. Proceedings of the 13th East Asia-Pacific Conference on Structural Engineering and Construction, EASEC 2013, Sapporo, Japan, pp. 1-5.