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An Experimental Study on Multi-Response Behavior of Aluminium Honeycomb Core Sandwich Structure under Flexure Test

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Abstract

In this study, aluminium honeycomb core sandwich structure were investigated to find the effect of various structural parameters like cell size, cell wall thickness and core height for the Flexural test. The effect of these structural parameters on the response characteristics like flexural stiffness, core shear modulus and Honeycomb core density can be determined individually by using statistical analysis based on the Taguchi's DOE. But this Conventional Taguchi method deals optimization problems with only single response at a time. Since the sandwich structure involved with many response parameters, Taguchi method alone cannot be useful to obtain optimal process parameters. In the present work, an attempt has been made to derive optimal combination of structural parameters in sandwich structure using grey relational analysis along with Taguchi method. Also by using analysis of variance the significant structural parameter were determined. Result shows that the most influencing structural parameters considering all the response characteristics were cell size followed by core height. The cell wall thickness has least effect compare to cell size and core height. The optimum combination of the input parameters has been found using Taguchi-grey relational analysis. Finally these findings were confirmed with the results of statistical analysis by plotting the main effect plots.

Keywords: Grey Relational, Taguchi, Sandwich structure, structural parameters and flexural test.

1. INTRODUCTION

Sandwich structures are light weight structure made of low density core placed between two face sheets. Generally the core is made of low density foam, or trusses. Honeycomb structures made of aluminum sheet are mostly used as low density core. A thin, dense and strong aluminum sheet was used as face sheet bonded to a thick light weight core to fabricate the entire honeycomb core sandwich structure as shown in Figure 1. Each component by itself is relatively weak and flexible but when working in combination they provide an extremely stiff, strong and lightweight structure [1& 2].

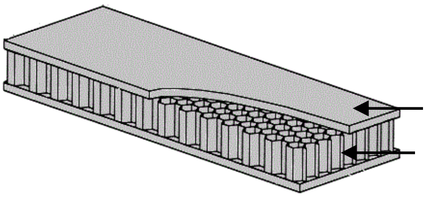

Figure 1 Hexagonal Honeycomb Core Sandwich Structure

Now-a-days there is an increasing attention towards the environmental consequences because of burning fossil fuels and the rise in oil prices. This leads our society to become more energy conscious and there is an increasing demand for light weight however strong and stiff structures in all walks of life from cheap doors to advanced aircraft structures. In order to meet the ever increasing demand of lighter vehicles and ships, the transportation industry is engaged in the design and manufacture of structures quite different from the traditional ones,and as a consequence a lack of experiences concerning the knowledge of many structural details has become apparent [3].

Composite structures are providing solutions to the current scenario and also find more applications in transport industry. A Sandwich structure is a type of composite structures most suitable for advanced aerospace structures, ship building, train structures and constructions etc., [4]. Honeycomb structure is selected as a core because of its high load absorbing capacity by distributing the load compared to other structures [5]. Honeycomb core Sandwich structures are loaded in two different ways such as in-plane loading and out-of plane loading. When loaded in out-of-plane direction it can withstand more loads compared to the in-plane loading because in out-of-plane loading it behaves like an 'I' beam. This leads to increase in moment of inertia and hence increases the flexural stiffness and impact strength. Advantages of sandwich structure are high stiffness, high impact strength and compression strength [1].

In this study, the flexural tests were carried out for the aluminium honeycomb sandwich structures with three different parameters (i.e. hexagonal cell size, foil thickness and height of honeycomb core) as shown in figure 2. Parametric studies can be conducted by three approaches namely numerical, analytical and experimental methods. Numerical method is very less expensive but requires computer and software's packages. Analytical method is simple and best because experimental method is more costly. The influence of each structural parameter on the flexural rigidity was analyzed. Also he suggested the designer to solve reverse problem by calculating the equivalent rigidities to find the geometric parameters. It is also proved that cell wall thickness has more influence compared to the core height of the sandwich structure [3]. To improve the bending strength and stiffness a parametric study was conducted on fibre reinforced corrugated core to investigate the effect of influencing parameters such as cell wall thickness, corrugation angle, fibre type in face sheet and core face sheet adhesion length [4]. Flexural test was conducted on Aluminium honeycomb core sandwich structure to investigate the structural behavior due to the influence of cell size, cell wall thickness and core height. By experimental observation the slope of the curve, i.e., the bending stiffness prior to plastic

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buckling is moderate due to the increase in core height. Therefore increase in the core height, the start of the plastic deformation can be delayed results in increase in flexural strength [5]. Static three point bend test was carried out in sandwich structure with different span length to identify the various failure modes. From the experimental results obtained in bending test the cell size has a strong influence in the energy absorption capability of sandwich structure [6].

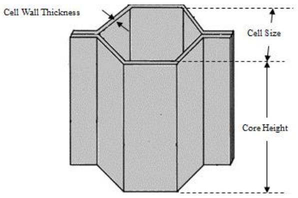


Figure 2 Unit cell of Hexagonal honeycomb core

A correct use of these structures in different applications needs a better knowledge of their mechanical behaviour. Thus, even if the concept of the honeycomb core sandwich construction is not very new, there is always need for new research activities to help the designers of sandwich structures with new reliable data. Very limited research was carried out in optimization of sandwich structure; there is also a need for multi response optimization because of several responses (flexural stiffness, core shear modulus) involved while conducting the flexural test. The aim of the present work is to apply the Taguchi grey relational analysis on structural parameters of sandwich structure to optimize the multi response behaviour.

2. EXPERIMENTS AND MATERIALS

2.1 Materials and Specimens

Due to its inherent properties and importance in aerospace sector Aluminum alloy 6061 has been used as material. The specimen for flexural test were prepared as per ASTM Standard C 393 and the specimen dimensions were 200 x 50 mm in length, breadth and varied height (20, 25, 30) mm as shown in Figure 3.

Figure 3 Honeycomb Core sandwich structure

2.3 Honeycomb Core Density

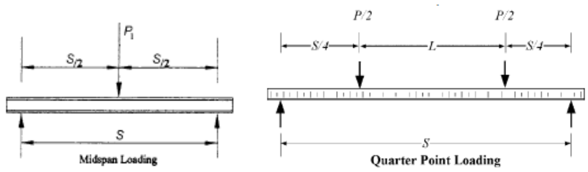
To calculate the Honeycomb core density, ASTM standard C271 was used and it was denoted by “d” and expressed in kg/m3, as given by Equation 1.

$$d = \frac{1\ 000\ 000\ W}{lwt} \qquad (1)$$

Where, W = final mass (g), l = final length (mm), w = final width (mm), and t = final thickness (mm).

2.4 Flexural Test

Flexure tests on flat sandwich constructions were conducted to determine the sandwich flexural stiffness and core shear modulus. ASTM Standard D 7250 was used to find the flexural stiffness and core shear modulus and the formulas are given in the following equation 2, 3 & 4. Both three point and four point bending test as shown in figure 4 was conducted on the samples listed in table 1.



a) Three Point Bend Test **b) Four Point Bend Test**

Figure 4 Flexural test configurations

$$\text{Flexural Stiffness (N/mm2)}\ D = \frac{P_1 S_1^3 (1 - 11S_2^2/8S_1^2)}{48\Delta_1 (1 - 2P_1 S_1 \Delta_2 / P_2 S_2 \Delta_1)}$$

$$\text{Transverse Shear Rigidity (N)}\ U = \frac{P_1 S_1 (8S_1^2/11S_2^2 - 1)}{4\Delta_1((16P_1 S_1^3 \Delta_2 / 11 P_2 S_2^3 \Delta_1) - 1)}$$

$$\text{Core Shear Modulus (MPa)}\ G = \frac{U(d - 2t)}{(d - t)^2 b} \qquad (2, 3 \& 4)$$

Where, Δ = beam mid-span deflection (mm), U = transverse shear rigidity (N), P = total applied force (N), d = sandwich thickness (mm), b = sandwich width (mm), t = facing thickness (mm), S = support span length (mm), L = load span length (mm)

3. EXPERIMENTAL METHODOLOGY

3.1 Taguchi’s design of experiment

Taguchi’s Design of Experiment is a systematic and effective approach to find the contribution of structural parameters. This method utilizes the orthogonal array of combinations to reduce the number of experiments. Flexural stiffness and core shear modulus highly depends on the material properties and structural parameters and hence there is a need to find the contribution. To identify the most influencing structure parameters three different parameter has chosen such as cell size, cell wall thickness and core height [7]. Three variations of the parameters or factors are representative of their high medium and low levels respectively assuming that the factor effects are linear when it changes from one level to the other one. Three factors at three levels results in nine combinations and hence experimental trials are listed in Table 1.

3.2 Selection of Quality Characteristics Level

To determine the quality characteristics, the response in each trial has to be transformed into signal to noise ratio (S/N Ratio). Since the flexural stiffness and core shear modulus has to be maximized, maximum the better type of quality characteristics were selected. Hence the S/N Ratio for these responses has been calculated form the following Equation 5 and 6.

$$\text{S/N ratio} = -10\ \text{X}\ \log \frac{1}{x}\Sigma\left(\frac{1}{Y_{nj}^2}\right) \qquad (5)$$

Since the aim of the honeycomb sandwich structure was to reduce the mass of the structure with increase in flexural properties. In order to achieve the Honeycomb core density is to be minimized, so minimum the better type of quality characteristics were chosen and hence S/N ratio have been computed from the following Equation

$$\text{S/N ratio} = -\ 10\ \text{X}\ \log \frac{1}{x}\Sigma Y_{nj}^2 \qquad (6)$$

Where x is the number of experimental replication Ynj is the response of the nth trial jth dependent level.

Table 1 Taguchi's L9 Orthogonal Array with Factor Response

Trial #	Factors			Response		
	Cell Size (mm)	Cell Wall Thickness (mm)	Core thickness (mm)	Honeycomb core Density (kg/m3)	Flexural Stiffness (D) N/mm2	Core shear modulus (G) N/mm2
	1≈4 , 2≈6, 3≈8	1≈0.3,2≈0.5,3≈0.7	1 ≈ 20, 2 ≈ 25, 3 ≈ 30			
1	1	1	1	469.3	637496	573.75
2	1	2	2	696.0	1596747	1175.21
3	1	3	3	844.1	1883823	1172.16
4	2	1	2	368.7	493775	363.42
5	2	2	3	507.1	680720	423.56
6	2	3	1	642.1	762677	686.41
7	3	1	3	308.9	437747	272.38
8	3	2	1	421.0	568421	511.58
9	3	3	2	528.7	347134	255.49

4. GREY RELATIONAL OPTIMIZATION

4.1 Compute normalized S/N ratio

To determine the interrelation between the response parameter, grey relational optimization can be used as an effective technique. Calculate the S/N ratio of the individual responses by using the appropriate equations depending on the quality characteristics. To distribute the responses evenly, normalize the S/N ratio to scale it into acceptable range for further analysis by following Equations 7 and 8. Flexural stiffness and core shear modulus has been assumed as larger the better quality whereas core density has been considered as smaller the better quality characteristics. this study includes both the quality characteristics, the distinguishing value for co-efficient has been taken as 0.5 [7].

For larger the better,
$$Z_{nj} = \frac{(Y_{nj} - \text{Min } Y_{nj})}{(\text{Max } Y_{nj} - \text{Min } Y_{nj})} \quad (7)$$

For smaller the better
$$Z_{nj} = \frac{(\text{Max } Y_{nj} - Y_{nj})}{(\text{Max } Y_{nj} - \text{Min } Y_{nj})} \quad (8)$$

Where, Znj is the normalized value of nth trial for jth dependent response.

4.2 Compute the grey co-efficient with grade and rank

The grey co-efficient for the normalized S/N ratios can be computed as per the following Equation 9 and 10 as shown in Table 4

$$GC_{nj} = (\Psi_{Min} + \delta \Psi_{Max}) \quad (9)$$

Where, GC is the grey co-efficient for Nth trial of jth response, δ is the quality loss function and Ψ is the distinctive co-efficient which has value from 0 to 1. Grey relational grade can be computed by the following equation.

$$G_n = \left(\frac{1}{Q}\right) \Sigma GC_{nj} \quad (10)$$

By ranking the grey relational grade value from maximum to minimum, the optimum structural parameters can be identified by taking the higher value as better the multi performance characteristics as shown in table 2. Therefore, the parameters of trial number 4 have the optimum structural parameters for the efficient multi-performance characteristics such as flexural stiffness, core shear modulus and Honeycomb core density.

Table 2 Grey relational Coefficients (grey relational grade)

Trial number	Grey relational coefficient			Grey relational grade	rank
	Honeycomb core Density	Flexural Stiffnes	Core Shear Modulus		
1	0.545828	0.438358	0.515541	0.499909	6
2	0.382238	0.836465	1.000000	0.739568	2
3	0.333333	1.000000	0.996606	0.776646	1
4	0.739600	0.387098	0.393984	0.506894	4
5	0.503474	0.453790	0.427812	0.461692	8
6	0.407198	0.483270	0.586598	0.492356	7
7	1.000000	0.366872	0.342924	0.569932	3
8	0.618814	0.413761	0.478464	0.503680	5
9	0.483281	0.333333	0.333333	0.383316	9

5. RESULTS AND DISCUSSION

The main effects plot for the response such as honeycomb core density; flexural stiffness and core shear modulus with respect to the structural parameters (cell size, cell wall thickness and core height) were generated using MINITAB Software as shown in Figure 5, 6 and 7. In the main effects plot, the deviation from horizontal line indicates the process parameter has more influence on response variables. Table 3 and Figure 8 show the response table and graph of the average grey relational grade for each level of the parameters.

The significance of the process parameters was tested by ANOVA. Using grey relational grade value, ANOVA was formulated for identifying the significant factors. The results of ANOVA are presented in Table 7. It is observed from the table that the significant factor is cell wall thickness. The cell size (51.8%) influences more on the multi-performance characteristics of aluminium honeycomb core sandwich structure followed by core height (36.3.3%) and cell wall thickness (2.03%).

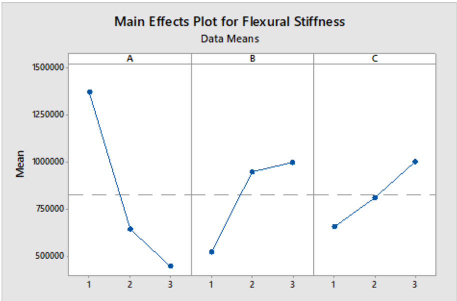


Figure 5 Main Effect Plot for flexural stiffness

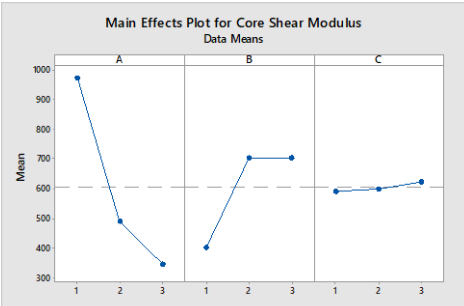


Figure 6 Main Effect Plot for core shear modulus

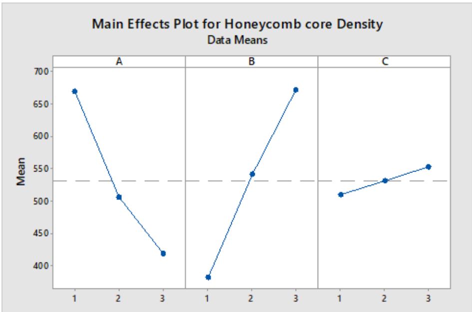


Figure 7 Main Effect Plot for honeycomb core density

Table 3 Response Table of the average grey relational grade

Input factors	Average grey relational grade by factor level			Max - Min
	Level 1	Level 2	Level 3	
Cell Size	0.4204	0.5500	0.7006	0.2802
Foil Thickness	0.39744	0.5680	0.6055	0.2080
Core Height	0.5268	0.5757	0.5891	0.0622

Total mean grey relational grade = 0.5482

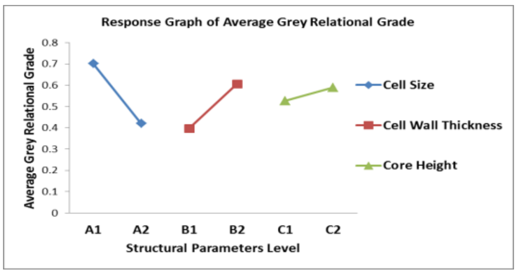


Figure 8 Response Graph for structural parameters

Table 4 Results of Analysis of Variance

Parameter	DoF	Sum of Squares	Mean Squares	F-Test	% Contri.
Cell Size	2	0.06899	0.0344	1.53	51.8
Cell Wall Thickness	2	0.00270	0.0013	0.06	2.03
Core Height	2	0.01630	0.0081	0.36	36.30
Error	2	0.04490	0.0224		
Total	8	0.13300			

6. CONCLUSIONS

In this finding, Taguchi's design of experiment with orthogonal array and grey relational analysis was used to optimise the multiple response characteristics of flexural test for aluminium honeycomb core sandwich structure. In this perspective a parametric study was conducted to determine the effect of various geometric parameters, such as cell wall thickness, cell size and core height, on the bending resistance of the honeycomb core. The multi response characteristics like flexural stiffness and core shear modulus with respect to honeycomb density by varying the structural parameters were analysed. ANOVA results also confirmed that cell size had more influence on multi-response characteristics of aluminium honeycomb sandwich structure followed by core height and least effect due to cell wall thickness.

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