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Research Article / Araştırma Makalesi

EXPERIMENTAL DESIGN FOR BENDING STRENGTH ALUMINUM HONEYCOMB STRUCTURE

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ABSTRACT

In this study, a Taguchi model was formed for the three point bending test behaviors of aluminum honeycomb composite structures. Effect of the three independent variables (cell width, cell height and adhesive) on the dependent variable (bending forces) was determined using mix design L16(4*1 2*2) orthogonal series. As a result of the experiments, bending force values were measured. As a result of Taguchi analysis according to 'better than most' solution approach, bending force value was concluded to be optimum with the use of 58.59 S/N ratio A1 B2 C1 level namely, primary 6.78 mm for cell width and secondary 30 mm for cell height and primary epoxy adhesive. Order of importance according to S/N answer table for force factor was ordered as cell width, cell height and adhesive. 95% was significant for the force values of the factor and levels selected in ANOVA results.
Keywords: Epoxy, MWCNT, aluminum honeycomb, three point bending test, Taguchi..

ALÜMİNYUM HONEYCOMB YAPILARDA EĞİLME MUKAVEMETİ İÇİN DENEYSEL TASARIM

ÖZ

Bu çalışmada alüminyum honeycomb kompozit yapıların eğilme davranışlarına yönelik bir Taguchi modeli oluşturulmuştur. Üç bağımsız değişkenin (hücre genişliği, hücre yüksekliği ve yapıştırıcı), bağımlı değişkene(eğilme kuvvetleri) etkisi karışık dizayn L16(4*1 2*2) ortogonal dizi kullanılarak belirlenmiştir. Deneyler sonucu eğilme kuvvet değerleri ölçülmüştür. Yapılan en yüksek en iyi çözüm yaklaşımına göre Taguchi analizi sonucu 58,59 S/N oranı 1 2 1 seviyesi yani hücre genişliği için birinci seviye 6,78 mm, hücre yüksekliği için ikinci seviye 30 mm ve birinci seviye epoksi yapıştırıcı kullanılması ile eğilme kuvvet değerinin optimum olacağı sonucuna varılmıştır. Kuvvet faktörü için S/N cevap tablosuna göre önem sırası hücre genişliği, hücre yüksekliği ve yapıştırıcı olarak sıralanmıştır. ANOVA sonuçlarında seçilen faktör ve seviyelerinin kuvvet değerleri için %95 anlamlı olduğu sonucu elde edilmiştir.
Anahtar Sözcükler: Epoksi, MWCNT, alüminyum honeycomb, üç nokta eğilme deneyi, Taguchi.

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1. INTRODUCTION

"Light design" philosophy is essential in the industrial sectors such as automotive, aviation, ship, construction[1]. Thus, new materials and technologies have been accepted in recent years. One of these materials is sandwich honeycomb structures[2]. Honeycomb structures can be manufactured from a wide range of materials including phenolic impregnated resin, nomex, aramid paper, glass fiber, carbon fiber, ceramic, kraft paper, thermoplastic, aluminum, steel, and titanium[3]. Although polymer foams have been applied for years, today there is a significant and growing interest in sandwich structures with aluminum foam core and honeycomb core layers in the science and industry world[4].

Honeycomb sandwiches, especially thanks to the lightness, high "bending rigidity/weight" ratio, durability properties they comprise compared to the classic materials; have common areas of usage such as aviation and space industry, maritime, high-speed train, automotive, industrial building jacketing, package industry, insulation and fire protection, furniture industry, wall panels in architectural projects, decorative profiles in interior decoration, yacht, boat, ship, caravan decoration, energy- absorbing buffer design to be used for reducing loss of life and property in accidents in the back of the big vehicles, viaduct, road barriers for reducing the accident risks likely to occur in hairpin bends in road transport[5,6].

For the development of a material having many areas of usage, it is necessary to know the advantages and disadvantages and to develop it accordingly. Unexpected results against any external effect that may appear especially in production, mounting and usage stage may come out in the engineering constructions. To prevent it, it is requested to know how the material will behave before such types of effects[7].

The common point of today's studies is that there is a need for adequate and additional information about mechanical behaviors of honeycomb sandwich panels[8]. Although honeycomb structures are not a very new issue, these behaviors are required to be known. These behaviors can be predicted with the test such as tension, impact, bending, compression and peeling[9].

Factors such as cell width, cell height, cell thickness, the material used, adhesive affect the mechanical properties of the honeycomb materials[10.11]. In recent days, nano adhesive is increasingly used in different sectoral applications[12]. In the researches made, the biggest property of the nano adhesives is to exhibit a good coupling between the surfaces[13].

Fundamental philosophy of Taguchi method is to provide the quality in the designing stage. The primary objective of Taguchi method is to perform product and process designing which is efficient in terms of time and cost with the adjustment of controllable factors and is also insensitive to the effects of the uncontrollable factors.

In this study, three-point bending tests were performed according to the test parameters of aluminum honeycomb materials produced with different cell sizes and with different adhesives, said parameters being formed with Taguchi experimental design. The parameters acting on the bending forces obtained as a result of the experiment, order of importance, the point in which bending force was optimum were analyzed with Taguchi method and the results were examined.

2. MATERIALS AND METHODS

Three-point bending tests were performed using Taguchi experimental design method in order to determine bending force values for four different cell widths (6.78-10.39-14.17-17.32mm), two different cell heights (10-30mm) and two different adhesives (pure epoxy-with 1%mwcnt reinforcement) of aluminum honeycomb composite structures. Factor and levels used in the experiments for Taguchi L16 experimental design were given in Table 1, L16 experimental design list formed was given in Table 2.

Honeycomb material was formed of aluminum 3000 series core with 0.05mm wall thickness and aluminum 1000 series bottom-top layer with 0.5mm thickness. Mega Glue 3012 pure epoxy as the primary adhesive and epoxy with 1% mwcnt reinforcement as the secondary adhesive were used. Diameter and length of cnt added into epoxy were 56 nm and 10-30 µm, respectively, wherein it was supplied from Times Nano Company. Honeycombs adhered at a height of 10 and 30 mm and in the form of 1X1 m layers were cut and provided with the test measurements of 50mm width and 210mm length. The samples produced and the connection of the same to the test machine were shown in Figure 1.

Table 1. Control factors and levels

Factors	**Unit**	**1^{st} Level**	**2^{st} Level**	**3^{st} Level**	**4^{st} Level**
Cell width	mm	6,78	10,39	14,17	17,32
Cell height	mm	10	30		
Adhesive	-	Pure epoxy	%1 mwcnt		

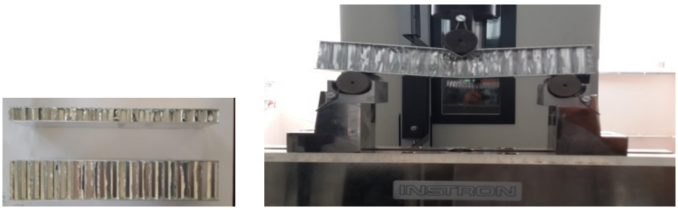

Figure 1. Connecting to the produced samples and testing of samples device.

Three-point bending tests were performed for 10 samples at a speed of 6 mm/min and for 10 mm and 30 mm samples with Instron 8081 tensile testing device for 30 mm collapse according to ASTM E1556-08 standard in Selçuk University, Laboratory of Mechanical Engineering. Samples as an example to the deformation occurring as a result of the three-point bending test were shown in Figure 2.

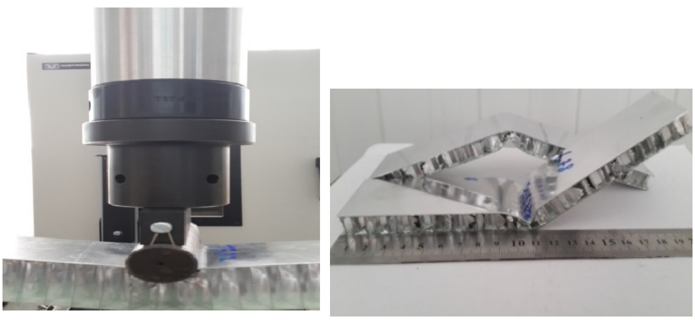

Figure 2. The shape changes occurring in the sample result of three points bending test.

3. EXPERIMENTAL RESULTS AND TAGUCHI METHOD

Experiments were performed as three repetitions and mean values of the forces measured were calculated. Mean results of the bending force values obtained in the measurements were given in Table 2. While test conditions were determined, Taguchi mix design L16 (4*1 2*2) experimental design method was used. Taguchi and ANOVA analyses were performed utilizing

MINITAB14 program. While performing analysis, three independent variables (four levels of cell width, two levels of cell height and two levels of adhesive) and interactivity of the same with each other were defined.

The criterion used in the measurement and evaluation of the quality characteristics is S/N ratio in Taguchi experimental design method. S(Signal) is the actual value given by the system and desired to be measured. N(Noise), however, shows the percentage of undesirable factors within the measured value. "n" and "y_i" in the equations are the repetition number and measured value of the variable, respectively[14].

$$10\log\left[\frac{\overline{y}^2}{s^2}\right] \quad \text{Nominal the best condition (1)}$$

$$-10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad \text{The biggest best condition (2)}$$

$$-10\log\left[\frac{1}{n}\sum_{i=1}^{n}y_i^2\right] \quad \text{The smallest best condition (3)}$$

The objective in the three cases is to maximize S/N ratio. Maximization of these ratios increases the signal and decreases the variance. As the bending force was desired to be maximum, 'better than most' approach was used in the analysis to calculate S/N ratio. S/N ratio calculated for the results was given in Table 2. Graph of the factor levels based on S/N ratio according to the 'better than most' solution was given in Figure 3.

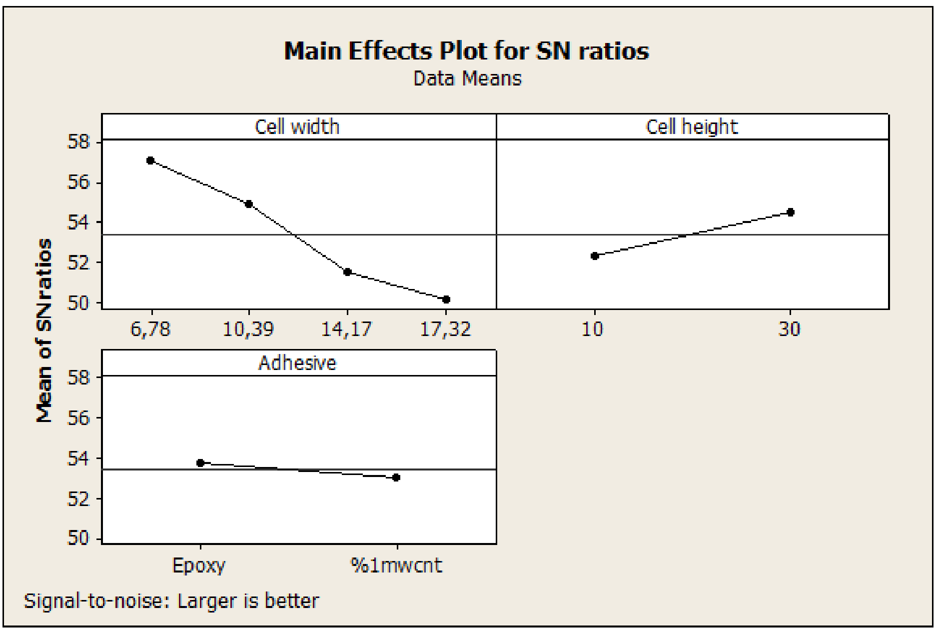

Figure 3. The best solution for the greatest force for bending the S/N ratio by the factor levels.

Table 2. Taguchi L16 orthogonal array design of experiments, experimental results and S / N ratio.

Experimental Number	Cell width	Cell height	Adhesive	Bending force(N)	S/N rates
1	1	1	1	678,81	56,39
2	1	1	2	538,07	55,65
3	1	2	1	887,85	58,59
4	1	2	2	819,43	57,86
5	2	1	1	498,08	54,15
6	2	1	2	457,15	53,42
7	2	2	1	652,71	56,36
8	2	2	2	639,43	55,62
9	3	1	1	350,16	50,75
10	3	1	2	346,37	50,01
11	3	2	1	406,16	52,95
12	3	2	2	401,50	52,22
13	4	1	1	319,19	49,40
14	4	1	2	259,35	48,67
15	4	2	1	364,01	51,61
16	4	2	2	353,67	50,87

Table 3. The S/N answer table for the force factors.

Level	Cell width	Cell height	Adhesive
1	57,12	52,3	53,78
2	54,89	54,51	53,04
3	51,48		
4	50,14		
Delta	6,98	2,21	0,74
Rank	1	2	3

When Figure 3 was examined, bending forces were at optimum level in A1 B2 C1 level in the third test where primary 6.78mm for cell width; secondary 30mm for cell height and epoxy adhesive values for primary adhesive were present. In Table 2, bending forces are shown to have reached optimum point in the highest S/N ratio A1 B2 C1 level with 58.59. The rank values determined with delta values in S/N answer table for force factor in Table 3 show that cell width, cell height and adhesive were ranked as the first, second and third parameters to have the most effect on the forces. ANOVA results were given Table 4. According to ANOVA results, significance level should be at $p<0.01$ or $p<0.05$[14]. According to the results in Table 4, cell width, cell height and adhesive were concluded to have more effect on the bending forces, respectively. The parameters selected according to the ANOVA results are reliable with a significance level of 95% on the bending force.

Table 4. ANOVA results.

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Cell width	3	121,578	121,578	40,526	106,550	0,000
Cell height	1	19,482	19,482	19,482	51,220	0,000
Adhesive	1	2,166	2,166	2,166	5,690	0,038
Residual Error	10	3,803	3,803	0,380		
Total	15	147,029				

4. CONCLUSIONS

In this study, aluminum honeycomb composite structures adhered with different adhesives were formed with different cell sizes and three-point bending tests were performed according to Taguchi L16 (4*1 2*2) mix design. Experiments were performed as three repetitions and mean of the measurements for bending force was calculated. Taguchi analysis and ANOVA analysis were performed. Taguchi results S/N ratios were calculated. In the 'better than most' solution in Taguchi experimental design, optimum result for bending forces was obtained in the third experiment with 58.59 S/N ratio. Bending force values are maximized in A1 B2 C1 level where 6.78 mm cell width; 30 mm cell height and epoxy adhesive were used.

Satisfactory results to be used in the future academic and industrial studies were obtained. It is recommended to make differences by making changes such as different cell shapes, different cell heights, different materials, different adhesive types in the future studies.

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