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Prediction Model for Compressive Strength Value of Aluminum Honeycomb Materials Joined with %1 MWCNT Reinforced Epoxy Adhesive

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In this study, aluminum(Al.) honeycomb composite structures were produced by joining core of different cell width and cell height to lower-upper layers by 1% multiwall carbon nanotube reinforced(mwcnt) epoxy adhesive. Compressive strength experiments of Al. honeycomb structures were carried out according to ASTM C365 standards using Instron 8081 model pulling device. Compressive strength values (F) are measured. Compressive experiments were performed three times and mean values were calculated. Experimental results shows that compressive force values decrease when cell height is increased while cell width is constant and values increase when height is decreased. When experimental result is analyzed for the same cell height, it is seen that compressive force values decrease while cell width increases and values increase when cell width decreases. Multiple regression prediction model of strength values of Al. composite structure was created using MINITAB14 programme. Logarithmic regression results of multiple regression prediction models were consistent with the results of the experiment with a coefficient of determination of 97.7%.

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1. Introduction

Composite sandwich structures consist of light core material compressed between two hard surfaces. There are two kinds of core structures: foam and honeycomb. Sandwich composite structures have a wide range of uses with regard to materials they contain and their characteristics. Composite surfaces are usually made of plastic reinforced with dense laminated fibers. In the field of aviation, the first sandwich structure was used during World War II in the wings and body of the first multi-purpose military aircraft Havilland Mosquito. The surfaces of this first structure were made of plywood and the core was made of balsa wood [1]. In course of time, interest on honeycomb structures has increased steadily and they have begun to be used in many areas such as construction, furniture, astronomy, navigation and trains [2, 3]. In order to learn the mechanical properties of honeycomb structures and lay down stated conditions, which will enable honeycombs to be used, experimental and numerical analysis model studies still continue in light of emerging technologies [4].

The experiments resulted in resistance to impact of honeycomb material, the resistance to compressive, bending resistance, adhesion properties, there are answers to issues such as the response to various conditions [5-8]. The assay was then used to generate results or predictive model is simulated by computer. These results contribute to the honeycomb material to go a step further.

At present, honeycomb structures are widely used owing to their some properties such as high "flexural stiffness/weight" ratio, durability and lightness [9]. In addition, they can be used as energy absorbers in accidents [10]. Honeycomb structures, which are one of the sandwich structures, have a very thin honeycomb core and can be made of aluminum, nomex and cupper [11]. Core structure consists of hexagon, triangle, zigzag and tetragon structures. Core is joined to lower-upper layers by using various adhesives to produce honeycomb structures [12].

Some parameters such as cell density, cell width, cell length, core material and upper-lower layers' coverage material and filling of cell spaces with a suitable material substantially affect the mechanical properties of honeycomb structures [13]. Some tests such as compressive, impact, bending and peel are performed to determine the mechanical properties of honeycomb structures [14,15]. Experiments showed that applying foam filling between honeycombs and decreasing cell width increase compressive forces, impact forces and bending forces [16, 17].

Adhesives used in creating honeycomb structures are important in providing rigidity [18]. Adhesive must be strong enough to maintain force transmission between upper-lower layers and core in case of an impact on honeycomb structure. Many alternative adhesives are used to join structures. One of recently used alternative adhesives is nano adhesives [19]. Some particles such as carbon nano tube, added to adhesive, effect the reaction of structures against impacts positively by increasing adherence property [20].

Model for regression analysis contains dependent (stated) and non-dependent (expository) variables [21]. In such a model; change in dependent variable is explained via non-dependent variables [22].

In this study, reactions of aluminum honeycomb structures, which are produced by using 1% mwcnt reinforced epoxy adhesives, against compressive were studied. Individual experimentation of each cell height and width is a limitation with regard to cost and time. Multiple regression models were formed to eliminate this limitation, define the relationships between experimental parameters and form

mathematical prediction model.

2. Materials and Methods

Core consisted of Al. 3000 series with four different cell width of 6,78-10,39-14,17-17,32 mm and two different cell height of 10-30 mm; upper-lower layers consisted of Al. 1000 series with 0,5 mm thickness. The list of experiment is presented in Table 1. In order to produce 1% mwcnt reinforced epoxy adhesive, mwcnt was dissolved in acetone, mixed for 30 minutes using ultrasonic mixer and put in a cooling bath. Then, it was incubated in 65 ^{o}C vacuuming oven for 24 hours to extract acetone. mwcnt added to epoxy adhesive was 50 nm in diameter, 10-30 μm in length and supplied from Times Nano Company. Before applying adhesive, surface roughness of upper and lower layers was achieved by using P100 sandpaper to enable core to attach more strongly. After this procedure, sanding dust of surfaces was removed using Sika Activator 205 (Sika Cleaner 205). Obtained adhesives were mixed with hardener in a ratio of 2:1, applied on the lower layer by using a lectern and core was placed on it. Then adhesive applied upper layer was placed on the core. Formed honeycomb composite structures were incubated under pressure in room temperature for 3 hours for first curing and in 15 bar pressure room temperature for 1 day for the last curing. Samples were pasted to 1x1 meter Al. layers in size of four cells and cut with a saw to obtain 100x100 mm size for compressive experiment. Compressive tests were performed using Instron 8081 pulling device according ASTM C365 standards. Produced samples and connection of the samples to test device is shown in Figure 1.

Table 1. Experimental list

Experimental Number	D (mm)	h (mm)
1	6,78	10
2	6,78	30
3	10,39	10
4	10,39	30
5	14,17	10
6	14,17	30
7	17,32	10
8	17,32	30

Figure 1. The produced samples and connecting it to samples of the test device

3. Experimental results

Force values were measured after compressive experiments. Compressive experiments were performed three times and mean values were calculated. Results are shown in Table 2.

Table 2. Test results obtained the strength values

Experimental Number	D (mm)	h (mm)	F (kgf)
1	6,78	10	1949,09
2	10,39	10	1232,71
3	14,17	10	766,33
4	17,32	10	499,21
5	6,78	30	1434,99
6	10,39	30	923,24
7	14,17	30	442,86
8	17,32	30	369,09

Table 2 shows that compressive force values decrease when cell height is increased while cell width is constant and values increase when height is decreased. When Table 2 is analyzed for the same cell height, it is seen that compressive force values decrease while cell width increases and values increase when cell width decreases. Figure 2 shows the change in the shape of the sample after experiment, both in the device and separate from the device.

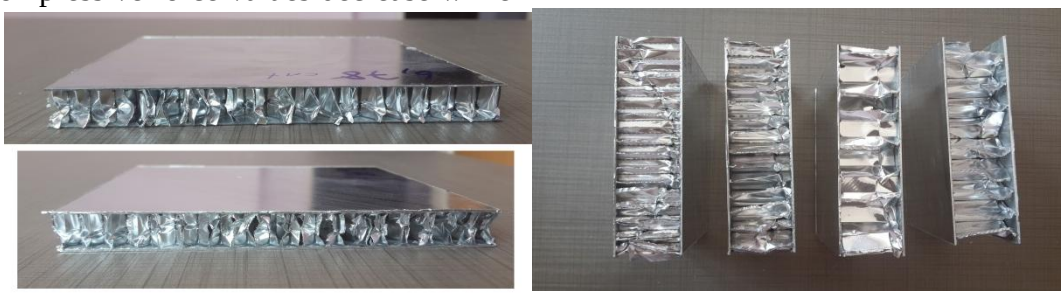

Figure 2. Experimental results the changes occurring in the samples

4. Regression equations

Findings achieved by multiple regression equations:

- Coefficient of determination (R^2) non-dependent variables' declaration ratio for dependent variables is the ratio of the amount of declared to the amount of non-declared in the model. When coefficient of variables in the regression results approaches to 1, most of the change in dependent variable can be explained by non-dependent variable.
- "Coef" expresses the coefficients of the values. Regression coefficient expresses the amount of effect created by one unit change in non-dependent variable on dependent variable,
- "Coef SE" expresses standard error in coefficients,
- Results of "T" test statistics for constant and regression coefficient,
- "P" tests the significance of regression analysis. P<0,05 means that non-dependent variable has effect on dependent value in regression equation,
- "Sum of squares" expresses summation of squares,
- "Mean square" expresses mean of squares
- "df" expresses degree of freedom,
- "Sig." expresses reliability [21].

4.1. First degree regression equation of F

1st degree regression equation for F values is

given in equation (3). 1st degree regression equation coefficients are presented in Table 3.

$$F = 2740 – 121*D – 16*h \quad (3)$$

Table 3. First degree from the regression equation coefficients for F

Predictor	Coef	SE Coef	T	P
Constant	2740,1	201,7	13,59	0,000
D	-120,73	13,4	-9,01	0,000
h	-15,965	5,309	-3,01	0,030

Coefficient of determination in 1st degree regression equation for F is 94.7%. Since it is close to 1, there is a strong relationship between variables. 94.7% of change in dependent variable can be explained by non-dependent variables. Cell width is the most effective non-dependent variable affecting F dependent variable in 1st degree regression equation ($p<0,5$). ANOVA table on MINITAB 14 programme concludes that 1st degree regression equation is confidential. Table 4 shows ANOVA.

Table 4. First degree from the regression ANOVA results

Source	DF	Sum of squares	Mean square	F	P
Regression	2	2032860	1016430	45,08	0,001
Residual Error	5	112733	22547		
Total	7	2145593			

4.2. Logarithmic regression equation for F

Logarithmic regression equation for F values is given in equation (4). Logarithmic regression equation coefficients are shown in Table 5.

$$F =5135-3166*Log(D)-669*Log(h) \quad (4)$$

Table 5. Logarithmic regression equation coefficients for F

Predictor	Coef	SE Coef	T	P
Constant	5134,7	303,8	16,9	0,000
Log(D)	-3165,5	227,6	-13,91	0,000
Log(h)	-669,2	146,6	-4,57	0,006

Coefficient of determination in logarithmic regression equation for F is 97,7%. Since it is close to 1, there is a strong relationship between variables. 94.7% of change in dependent variable can be explained by non-dependent variables. Cell width is the most effective non-dependent variable affecting F dependent variable in logarithmic regression equation ($p<0,5$). ANOVA table on MINITAB 14 programme concludes that logarithmic regression equation is confidential. Table 6 shows ANOVA.

Table 6. Logarithmic regression ANOVA results

Source	DF	Sum of squares	Mean square	F	P
Regression	2	2096675	1048337	107,15	0,000
Residual Error	5	48918	9784		
Total	7	2145593			

4.3. Comparing the results of regression equations for F

Calculations made after mathematical expressions obtained from 1st degree and logarithmic regression equations for F are presented in Table 7. Figure 3 shows graph of the results. Analysis of Table 7 and Figure 3 indicates that logarithmic regression equation is closer to results of the experiment.

Table 7. Experimental F, I st degree regression and logarithmic regression results

Experimental Number	Experimental F (kgf)	I. degree F (kgf)	LogarithmicF (kgf)
1	1949,09	1759,62	1834,33
2	1232,71	1322,81	1247,40
3	766,33	865,43	820,76
4	499,21	484,28	544,76
5	1434,99	1439,62	1515,13
6	923,24	1002,81	928,20
7	442,86	545,43	501,57
8	369,09	164,28	225,56

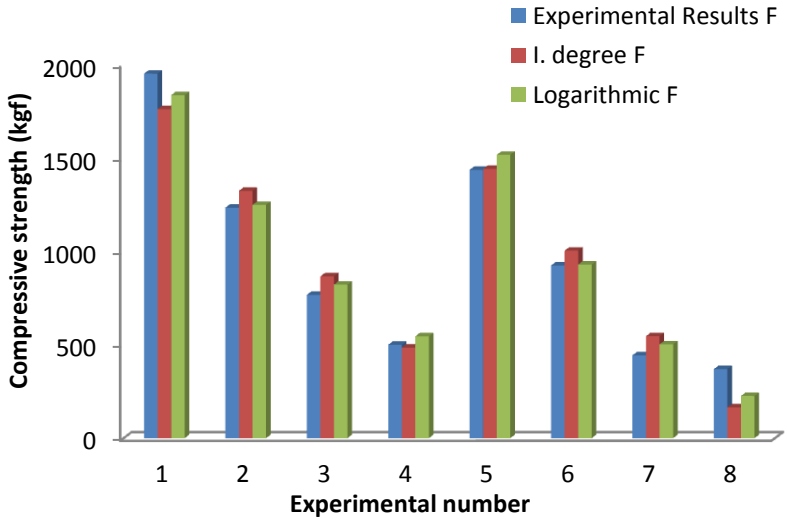

Figure 3. The experimental F, the first degree of regression and logarithmic regression results comparison

5. Conclusions

In this study, reactions of hexagon honeycomb composites to compressive were shown using multiple regression models. Results obtained by experiments and multiple regression models are below.

- It was concluded that increasing cell height, while cell width is constant, decreases force values.
- For same cell heights, increase in cell width decreases force values.
- Coefficient of determination in 1st degree regression equation for F is 94.7%. Cell width is the most effective non-dependent variable affecting F dependent variable in 1st degree equation ($p<0,5$).
- Coefficient of determination in logarithmic regression equation for F is 97.7%. Cell width is the most effective non-dependent variable affecting F dependent variable in logarithmic regression equation ($p<0,5$).

- When 1st degree and logarithmic regression equations for F are considered, it is seen that logarithmic regression equation results are closer to experimental results with its coefficient of determination of 97,7%.
- It is advised to develop the system by changing honeycomb structure (different cell width, different cell height, different honeycomb material, filled honeycombs, empty layered core, different adhesive) and using different prediction models (artificial neural network, fuzzy logic).

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