Design and Fabrication of Tubular Cored Sandwich Panels under Three-Point Bending

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Abstract – The aim of this work is to design, fabrication and optimization of the tubular cored sandwich panels using finite element analysis. Square and Circular tubes are used as Cores in sandwich panels. Based on the analysis, panel structure parameters considered are Core-Gap, Face sheet thickness, Core shape, Core height, and Panel Dimensions. The Taguchi design of experiments is used to analyze the parameters by considering an orthogonal array of L_{36}. NX10 Unigraphics is used for modeling the problem and ANSYS for structural analysis in the transverse direction by three-point bending test (ASTM D790). Taguchi and Grey relational analysis are used for evaluating the optimum dimensions of the panel under three-point bending test.

Index Terms – Sandwich Panels, Taguchi Design, Grey relational analysis, Three-point bending.

1. INTRODUCTION

Sandwich panel is a structure made of three layers namely a low-density core and a thin skin-layer bonded to each side. Sandwich structures are utilized as a part of utilization where mechanical execution and weight-sparing are fundamental. From a decade ago broad research was carried on shape improvement during the time spent building plan which a noteworthy part in the determination of material, shape and dimensional advancement, cost, and efficiency. The shape and dimensional optimization are to determine the optimal shape and dimensions of a continuum medium to maximize or minimize a given criterion such as weight to volume ratio, minimization of deflection, stresses, etc. To save time and reduce costs, researchers are depending on the software like Ansys, Nastran etc.

Design of Experiments a major role as it increases the percentage of accuracy. The methodology provides a strong tool to design and analyze the experiment. Hence, Design of Experiments statistical techniques are useful in complex physical processes, such as the determination of material combination, geometrical dimensions, and Shapes, in many design processes. Taguchi method is adopted in the present study. In this method, the parameters identified for fabrication of tubular cored sandwich panels are core gap, core height, Face sheet thickness, core shape and panel dimensions. The effect of individual parameters under three-point bending is tested using Ansys workbench.

2. LITERATURE REVIEW

Steeve Chung Kim Yuen, et al [1] investigated the response of cladding sandwich panels with tubular cores to uniform blast load. Thin-walled circular tubes of 38 mm diameter made from aluminum 6063-T6 riveted laterally between the skin plates at varying spacing arrangements to provide four different types of panels. V. Diwakar Reddy, et al [2] investigated on optimization of process parameters of spot welded corrugated sandwich panel. The problem is modeled in ANSYS and the flexural modulus is evaluated in the transverse direction by the three-point bending test. A.Gopichand, et al [3] carried out his investigation of the effect of core shape in steel sandwich plates. During fabrication, adhesive bonding is made use of when bonding core to face sheets. For evaluating mechanical behavior, both numerical simulations based on FE techniques as well as Experimental testing were employed. L.St-Pierre, et al [4] carried out FE simulations on corrugated sandwich panels with top and bottom faces. The 3-Point test was simulated and done experimentally also. Experimental and analytical predictions are in good agreement with each other. Xue and Hutchinson [5] compared the performance of three different core geometries of metal sandwich plates to that of solid plates of the same material and same mass. These studies have indicated that advanced sandwich structures can potentially have significant advantages over monolithic plates in absorbing the blast energy, whether in air or underwater. Chung Kim Yuen and G.N. Nurick [6] used sacrificial claddings in the design of the structure for blast protection. The use of tubular structures as cores for sandwich panels subjected to blast loading and dynamic loading are studied. T.Y. Reddy, et al [7] investigated various phenomena associated with the large deformation compression of metal tubes between rigid plates are examined. K.Kantha Rao, et al[8]investigated on bending behavior of honeycomb sandwich structure made of aluminum alloy cores, through the four-point bending tests. The honeycomb sandwich panel failure modes are reported and discussed. G.A.O. Davies, et al [9] examined two types of sandwich panels with carbon Epoxy skins and an aluminum honeycomb core which were subjected to low-velocity impacts. These panels were tested for their compression after impact strength (CAI). Salih N. Akour, et al [10] investigated the effect of core material stiffness on a sandwich panel beyond the yield limit of the core material.

It is concluded from the literature survey that few studies have been carried out for the investigation on the usage of the tubular core as the core material in sandwich panels. Some of the information is really appreciated. However, there is no information regarding the effect of structural parameters to optimize the geometry of resin bonded tubular cored Aluminium sandwich panels. There is very less information regarding usage of Epoxy Resin for bonding both face sheets and core tubes.

3. DESIGN OF EXPERIMENTS

The panel consists of two rectangular plates (face sheets) and square and circular tubes as cores in between. The material used for both core tubes and face sheets is Aluminum 6061. The panels and the core tubes are joined by Fevitite named Epoxy resin. The process parameters and their levels are shown in the Table – 3.1.

Table-3.1: Process Parameters

S.No	Parameter	Level-1	Level-2	Level-3
1	Face Sheet Thickness (FS)	20Gauge	18Gauge	-----
2	Core Shape(CS)	Circular(CR)	Square (SQ)	-----
3	Core Height (CH)	10mm	20mm	-----
4	Core-Gap (CG)	30mm	10mm	20mm
5	Panel Dimension (PD) (LxW)	R1 (Rectangular Panel of 350mmx250mm)	R2 (Rectangular Panel of 250mmx350mm)	SQ (Square panel of 350 mm x350mm)

From this table the first parameter considered is the thickness of the sheet which is 20Gauge and 18Gauge.The second parameter considered is the core shape which is Square (SQ) and Circular (CR) tubes. Core-Gap is also considered as one of the parameters for the analysis. Three spacing were considered, i.e. 10, 20 and 30mm. The other important parameters to minimize the volume fraction is the core height such as 10mm and 20mm.The Panel Dimension is considered as Rectangular (R1) 350 mm x 250 mm, Rectangular (R2) 250 mm x350 mm and Square (Sq) 350 mm x 350 mm.

By Taguchi method, L36 are designed. These are mixed levels as they are obtained from the input parameters which have three factors with two levels and two factors with three factors.

4. MODELING AND ANALYSIS

The method of fabrication of panels consists of two Aluminum 6061 sheets and in between Aluminum 6061 tubular cores are inserted and these panels are joined by means of Epoxy resin. The geometry specification of the Tubular cored sandwich panel is shown in Figure 4.1.

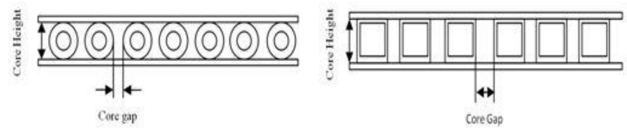

Figure -4.1: Nomenclature of the Tubular cored sandwich panel

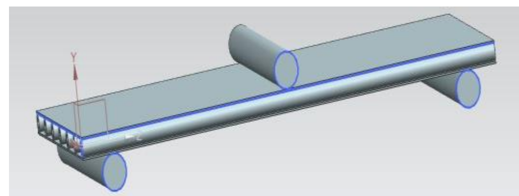

Figure-4.2: Three-point bending setup

Table-4.1: Factors and Response Table

S.NO	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Response1	Response2	Response3
	Face sheet thickness	Core Shape	Core Height	Core Gap	Panel Dimension	Von Mises Stress(MPa)	Maximum Shear Stress(MPa)	Deformation(mm)
1	20	CR	20	30	R1	900.19	518.43	28.221
2	20	CR	20	10	R2	140.86	78.749	0.4475
3	20	CR	20	20	Sq	537.1	310.6	11.785
4	20	CR	20	30	R1	900.19	518.43	28.221
5	20	CR	20	10	R2	140.86	78.749	0.4475
6	20	CR	20	20	Sq	537.1	310.6	11.785
7	20	CR	10	30	R1	802.34	457.36	19.62
8	20	CR	10	10	R2	269.29	143.29	1.0633
9	20	CR	10	20	Sq	434.76	249.57	7.5626
10	20	SQ	20	30	R1	520.05	296.61	8.9885
11	20	SQ	20	10	R2	72.243	40.65	0.3003
12	20	SQ	20	20	Sq	199.05	113.48	2.0908
13	20	SQ	10	30	R2	437.4	237.78	1.134
14	20	SQ	10	10	Sq	197.58	105.53	1.7114
15	20	SQ	10	20	R1	413.93	237.95	5.929
16	20	SQ	10	30	R2	401.17	223	1.1337
17	20	SQ	10	10	Sq	213.82	118.02	1.9013
18	20	SQ	10	20	R1	405.6	231.9	5.9297
19	18	CR	10	30	R2	371.12	212.55	1.427
20	18	CR	10	10	Sq	221	126.38	2.4622
21	18	CR	10	20	R1	398.83	226.72	6.4376
22	18	CR	10	30	R2	378.93	211.68	1.4429
23	18	CR	10	10	Sq	197.12	110.79	2.1602
24	18	CR	10	20	R1	395.66	227.21	6.5215
25	18	CR	20	30	Sq	453.13	258.87	11.839
26	18	CR	20	10	R1	331.03	188.45	4.7349
27	18	CR	20	20	R2	128.41	70.913	0.40303
28	18	SQ	10	30	Sq	318.97	183.23	5.5697
29	18	SQ	10	10	R1	190.13	106.47	1.7251
30	18	SQ	10	20	R2	313.01	169.96	0.87445
31	18	SQ	20	30	Sq	278.8	160.13	4.1226
32	18	SQ	20	10	R1	132.03	75.163	1.2227
33	18	SQ	20	20	R2	135.4	75.014	0.29462
34	18	SQ	20	30	Sq	298.57	168.51	4.1376
35	18	SQ	20	10	R1	130.47	73.869	1.2075
36	18	SQ	20	20	R2	147.66	84.173	0.29508

5. TAGUCHI ANALYSIS

Response table for S/N Ratios (Smaller is better) for Von-Mises stress, Maximum Shear Stress, and Directional deformation. Analyzing the experimental data to determine the effect of each variable on the output, the S/N ratio is plotted as follows.

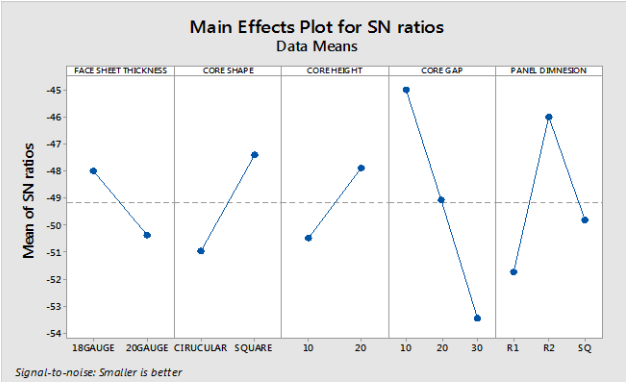

Figure-5.1: Graph of Main Effects of S/N ratios effects of Von-Mises stress

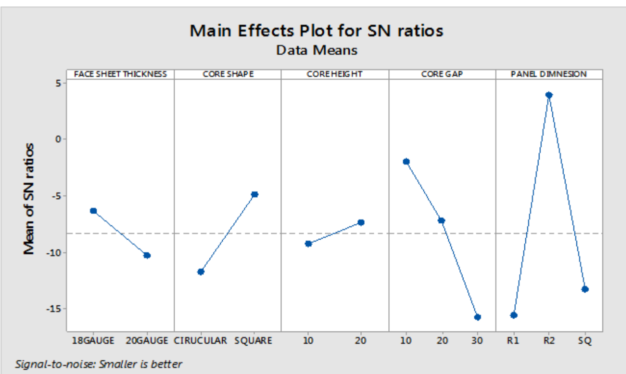

Figure-5.2: Graph of Main Effects of S/N ratios effects of Directional Deformation

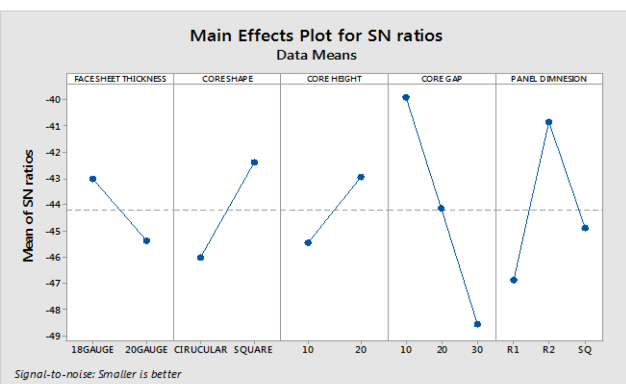

Figure-5.3: Graph of Main Effects of S/N ratios effects of Maximum Shear Stress

A. Analysis of Von-Mises Stress, Directional Deformation and Maximum shear stress:

From the response, Table5.1 represents S/N ratios for Von Mises Stress and the results show that Core gap is most influencing and followed by Panel dimension, Core shape, Core height and Face sheet thickness. The deformation induced to be minimum in three-point bending of the panel, smaller is better is considered for analysis and S/N ratios and mean effective plots are obtained and are shown in Table5.2 The results show that the first three influence parameters are Panel Dimension, core Gap and shape of Core and the least influence is the Core Height. The response Table-5.3 shows S/N ratios and means for Maximum Shear Stress. The results show that Core-Gap is most influencing and least influenced by Face sheet thickness.

Table-5.1: Response Table for S/N Ratios for Von Mises Stress

Level	Face sheet thickness	Core Shape	Core Height	Core-Gap	Panel Dimension
1	-47.98	-50.97	-50.49	-44.97	-51.76
2	-50.38	-47.39	-47.87	-49.09	-45.98
3	-	-	-	-53.48	-49.81
Delta	2.4	3.59	2.62	8.51	5.78
Rank	5	3	4	1	2

Table-5.2: Response Table for S/N Ratios for Directional Deformation

Level	Face sheet thickness	Core Shape	Core Height	Core-Gap	Panel Dimension
1	-6.303	-11.763	-9.234	-1.935	-15.696
2	-10.345	-4.885	-7.414	-7.179	4.042
3	-	-	-	-15.859	-13.319
Delta	4.043	6.878	1.82	13.924	19.738
Rank	4	3	5	2	1

Table-5.3: Response Table for S/N Ratios for Maximum Shear Stress

Level	Face sheet thickness	Core Shape	Core Height	Core-Gap	Panel Dimension
1	-43.01	-46.02	-45.46	-39.9	-46.87
2	-45.39	-42.38	-42.95	-44.13	-40.83
3	-	-		-48.57	-44.9
Delta	2.38	3.64	2.51	8.67	6.04
Rank	5	3	4	1	2

6. GREY RELATIONAL ANALYSIS

In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcoming in statistical regression. Grey relation analysis is an effective means of analyzing the relationship between sequences with fewer data and can analyze many factors that can overcome the disadvantages of statistical method.

A. Data Pre-Processing:

In the grey relational analysis, when the range of the sequence is large or the standard value is enormous, the function of factors is neglected. However, if the factors, goals, and directions are different, the gray relational might produce incorrect results. Therefore, one has to pre-process the data which are related to a group of sequences which is called 'grey relational generation'.

Data pre-processing is a process of transferring the original sequence to a comparable sequence. For this purpose, the experimental results are normalized in the range between zero and one. The normalization can be done from three different approaches.

If the target value of the original sequence is infinite, then it has a characteristic of "the larger the better". The original sequence can be normalized as follows.

$$x_i^*(k)=\frac{x_i^0(K)-\min x_i^0(K)}{\max x_i^0(K)-\min x_i^0(K)} \quad \text{..... (1)}$$

If the expectancy is the smaller the better, then the original sequence should be normalized as follows.

$$x_i^*(k)=\frac{\max x_i^0(K)-x_i^0(K)}{\max x_i^0(K)-\min x_i^0(K)} \quad \text{..... (2)}$$

Where $x_i^*(k)$ is the value of the grey relational generation (data pre-processing), $\max x_i^0(k)$ is the largest value of $x_i^0(k)$, $\min x_i^0(k)$ being the smallest value of $x_i^0(K)$ and x^n is the desired value.

Based upon the normalized values of output responses deviation sequences are calculated. Based on these values grey relational coefficients are calculated by using formula (3)

$$\zeta_i(k)=\frac{\Delta_{\min}+\zeta.\Delta_{\max}}{\Delta_{0i}(k)+\zeta.\Delta_{\max}} \quad \text{..... (3)}$$

Where $\Delta_{0i}(k)$ are the deviation sequence of the reference sequence $x_0^*(k)$ and the comparability sequence , they are

$$\Delta_{0i}(k)=\| x_0^*(k).x_i^*(k)\|$$

$$\Delta_{\max}=\max_{\forall j\varepsilon i}\min_{\forall k}\| x_0^*(k)-x_i^*(k)\| \quad \text{..... (4)}$$

ζ is distinguishing or identification coefficient $\zeta\varepsilon$ to [0,1]. ζ =0.5 is generally used.

After obtaining the grey relational coefficient, we normally take the average of the grey relational coefficient as the grey relational grade. The grey relational grade is defined as follows.

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\zeta(k) \quad \text{..... (5)}$$

In the grey relational analysis, the grey relational grade is used to show the relationship between the sequences. If the two sequences are identical, then the value of the grey relational grade is equal to 1. The grey relational grade also indicates the degree of influence that the comparability sequence is more important than the other comparability sequences to the reference, and then the grey relational grade for comparability sequence will be higher than other grey relational grades.

Deviation sequence of each performance characteristic and the results for the grey relational coefficients and average grey grade according to formulas (2), (3), (4) and (5) are given in *Table 6.1 and 6.2*

Table-6.1: Deviation sequence of each performance Characteristic

Exp No	DEVIATION SEQUENCE		
	$\Delta_{0i}(1)$	$\Delta_{0i}(2)$	$\Delta_{0i}(3)$
1	1.0000	1.0000	1.0000
2	0.0829	0.0055	0.0797
3	0.5615	0.4115	0.5650
4	1.0000	1.0000	1.0000
5	0.0829	0.0055	0.0797
6	0.5615	0.4115	0.5650
7	0.8818	0.6920	0.8722
8	0.2380	0.0275	0.2148
9	0.4379	0.2603	0.4373
10	0.5409	0.3113	0.5357
11	0.0000	0.0002	0.0000
12	0.1532	0.0643	0.1524
13	0.4410	0.0301	0.4126
14	0.1514	0.0507	0.1358
15	0.4127	0.2018	0.4130
16	0.3973	0.0300	0.3817
17	0.1710	0.0575	0.1619
18	0.4026	0.2018	0.4003
19	0.3610	0.0405	0.3598
20	0.1797	0.0776	0.1794
21	0.3945	0.2200	0.3894
22	0.3704	0.0411	0.3580
23	0.1508	0.0668	0.1468
24	0.3906	0.2230	0.3905
25	0.4600	0.4134	0.4567
26	0.3126	0.1590	0.3093
27	0.0678	0.0039	0.0633
28	0.2980	0.1889	0.2984
29	0.1424	0.0512	0.1378
30	0.2908	0.0208	0.2706
31	0.2495	0.1371	0.2501
32	0.0722	0.0332	0.0722
33	0.0763	0.0000	0.0719
34	0.2734	0.1376	0.2676
35	0.0703	0.0327	0.0695
36	0.0911	0.0000	0.0911

TABLE-6.2: Grey relational coefficient (ξ_i) of each performance characteristic and Grey relational grade (ɣ).

EXP NO	GREY RELATION COEFFCIENTS			GREY RELATIONAL GRADE (γ_i)
	VON-MISES STRESS (ξ_1)	DIRECTIONAL DEFORMATION (ξ_2)	MAX SHEAR STRESS (ξ_3)	
1	0.3333	0.3333	0.3333	0.3333
2	0.8578	0.9892	0.8625	0.9031
3	0.4711	0.5486	0.4695	0.4964
4	0.3333	0.3333	0.3333	0.3333
5	0.8578	0.9892	0.8625	0.9031
6	0.4711	0.5486	0.4695	0.4964
7	0.3618	0.4195	0.3644	0.3819
8	0.6775	0.9478	0.6995	0.7749
9	0.5331	0.6577	0.5335	0.5748
10	0.4804	0.6163	0.4828	0.5265
11	1.0000	0.9996	1.0000	0.9999
12	0.7655	0.8860	0.7664	0.8060
13	0.5313	0.9433	0.5479	0.6742
14	0.7676	0.9079	0.7864	0.8206
15	0.5478	0.7125	0.5477	0.6027
16	0.5572	0.9433	0.5671	0.6892
17	0.7452	0.8968	0.7554	0.7991
18	0.5539	0.7125	0.5554	0.6073
19	0.5807	0.9250	0.5815	0.6958
20	0.7357	0.8656	0.7359	0.7791
21	0.5590	0.6945	0.5621	0.6052
22	0.5744	0.9240	0.5828	0.6937
23	0.7683	0.8821	0.7730	0.8078
24	0.5614	0.6916	0.5615	0.6048
25	0.5208	0.5474	0.5226	0.5303
26	0.6153	0.7587	0.6178	0.6639
27	0.8805	0.9923	0.8876	0.9201
28	0.6266	0.7258	0.6262	0.6595
29	0.7783	0.9071	0.7840	0.8231
30	0.6323	0.9601	0.6488	0.7471
31	0.6671	0.7848	0.6666	0.7062
32	0.8738	0.9377	0.8738	0.8951
33	0.8676	1.0000	0.8742	0.9140
34	0.6465	0.7842	0.6514	0.6940
35	0.8767	0.9386	0.8779	0.8977
36	0.8459	1.0000	0.8459	0.8973

The higher grey relational grade will give the optimal condition. By using the grey relational grade value at each level the mean grey relational grade value is calculated for different factors. All these values of mean grey relational grades and the total mean of the grey relational grade are summarized in Table 6.3. *A* response graph of the grey relational analysis is obtained to find optimum levels of input parameters in *Figure 6.1*.

Table-6.3: Response table for Grey relational grade value

LEVELS	FACE SHEET THICKNESS	CORE SHAPE	CORE HEIGHT	CORE GAP	PANEL DIMENSION
1	0.5776	0.6388	**0.7176**	0.5765	0.6062
2	**0.7519**	**0.7644**	0.6856	**0.8390**	**0.8177**
3				0.6893	0.6808
DELTA	0.1743	0.1256	0.032	0.2625	0.2115
RANK	3	4	5	1	2

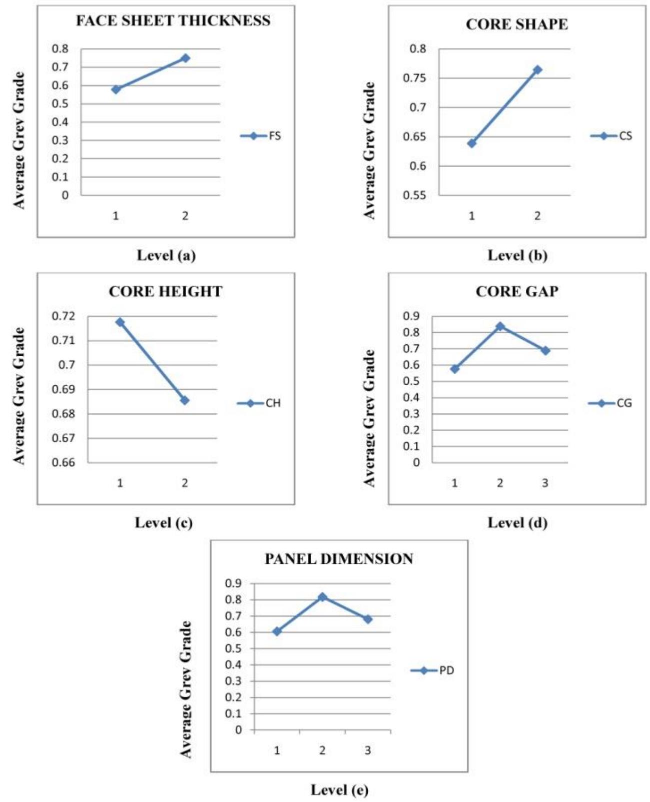

Figure-6.1: Graphs of levels of controllable factors and average grey relational grades
(a) Face sheet thickness (b) Core-shape (c) Core height (d) Core-Gap (e) Panel Dimension

In Table 6.3 shows the Face sheet thickness at level 2, Core shape at level 2, Core-Gap at level 2, Core height at level 1, Panel Dimension at level 2 largest values of the grey relational grade for factors Core-Gap, Core shape, Panel Dimension, Core Height, and face sheet thickness. Therefore the Core-Gap at level 2, Core shape at level 2, Panel Dimension at level 2, Core height at level 1, Face sheet thickness at level 2 are the conditions for the optimal design parameter combination of the tubular cored sandwich panel to minimize Von-Mises Stress, Shear Stress, and Directional deformation. The influence of each parameter can be clearly presented by means of the grey relational grade graph. It shows the change in responses. The response graph for Tubular cored sandwich panel parameter is presented in Figure 6.1. In this figure, the greatest values of average grey relational grade gives the optimum level of parameters.

According to the ranking and response tables of Taguchi and Grey relational analysis, the Core-Gap, Panel Dimension are the most influencing factors for all the three parameters. The selected levels of fabrication, based on the analysis are shown in Table-6.4

Table-6.4 Optimized Values of Design Parameters

S.NO	Design Parameter	Optimized Values
1	Face Sheet Thickness(FS)	18Gauge
2	Core-Gap(CG)	10mm
3	Core Shape(CS)	Square Shaped tube
4	Core Height(CH)	20mm
5	Panel Dimension(PD)	R2- 250mmx350mm

B. FEA results for optimum parameter combination**:**

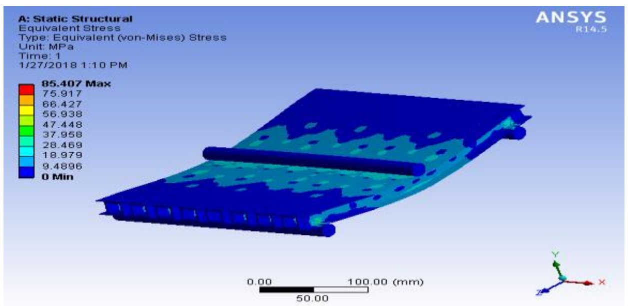

Figure-6.2: FEA result for Von Mises stress

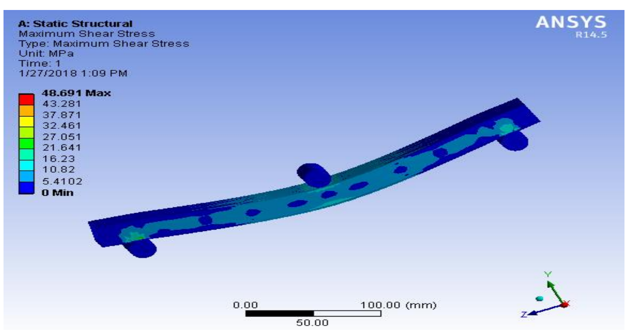

Figure-6.3: FEA result for Maximum Shear stress

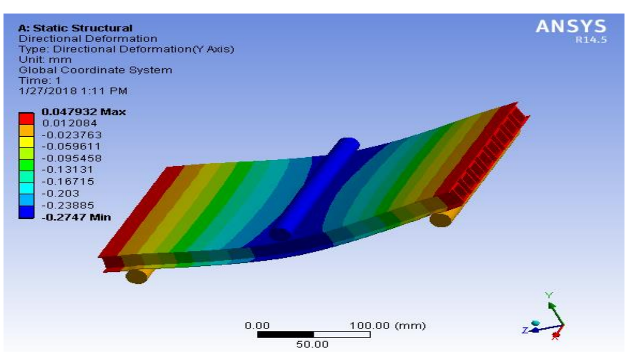

Figure-6.4: FEA result for Directional deformation

7. FABRICATION AND TESTING OF PANEL

The panel consists of two rectangular thin sheets and square tubular core. Epoxy resin is used to bond both face sheets and tubular cores. Based on the optimum parameters the panel is fabricated as shown in Figure-7.1.The fabricated panel is tested under three-point bending as shown in Figure-7.2.

Figure-7.1: Fabricated Panel

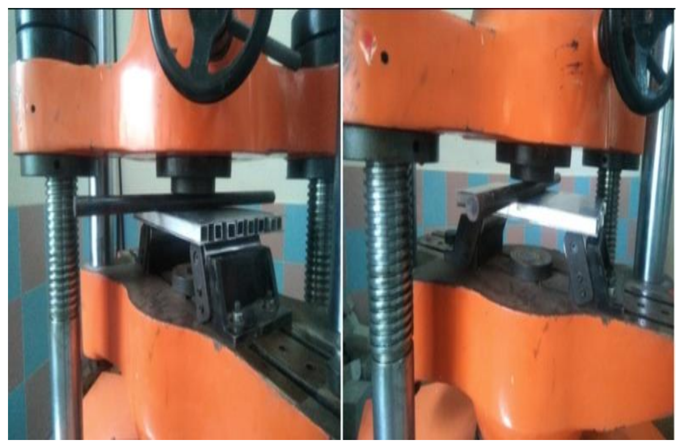

Figure-7.2: Experimental Set up to 3 Point Bending

Figure-7.3: Tested sandwich Panel

01.	**Gauge Length**	270 mm	04.	**Area**	0 mm^2
02.	**Width**	250mm	05.	**Sensor Type**	ENCODER
03.	**Thickness**	22 mm	06.	**Punch Top Radius**	13mm

C. RESULTS

01. Maximum Load 20.5 KN

A. The solution for delamination of Sandwich Panel

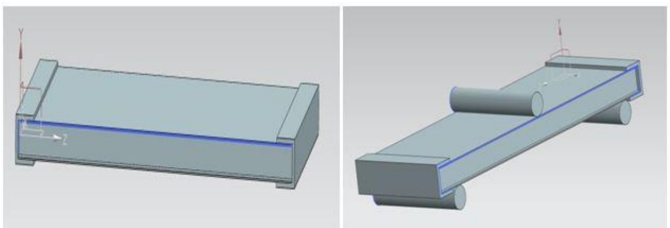

Figure-7.4: Clamping of C-channel at edges

1. The sandwich panel is delaminated at edges under three-point bending test. the delaminated sandwich panel was shown in figure-7.3.
2. The edges of the sandwich panel can be clamped with a c channel in order to limit delamination of the panel at the edges. The 3D model of the sandwich panel with C channel clamped at edges is shown in figure-7.4.

8. EXPERIMENTAL RESULTS OF THREE POINT BENDING OF FABRICATED PANEL

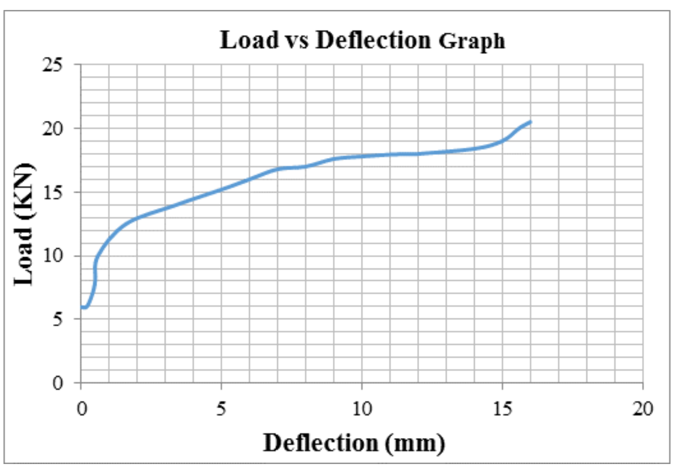

Figure-8.1: Load vs. Deflection Graph

The fabricated tubular cored sandwich Panel, tested under three-point bending (supporting span of 270mm) as shown in Figure 8.1 gives typical flexural load Vs deflection curve. Different key features are clearly identified: the initial linear-elastic behavior followed by an elastoplastic phase until a peak value is reached at load 20.5 KN after which the failure of the component happened.

Table 8.1: UTM test results of Tubular Cored sandwich Panel

A. UNIVERSAL TESTING MACHINE - CAPACITY: 600 KN - MODEL:

UTK-60 (PC) SR.NO. 2008/947

B. TEST PARAMETERS

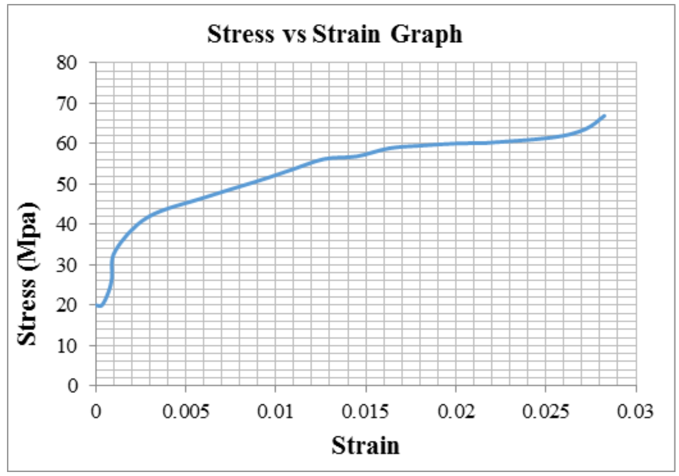

Figure-8.2: stress vs. Strain Graph

9. CONCLUSIONS

The parameters identified for the fabrication of the Tubular Cored sandwich panel are Thickness of the sheet, Core height, Core shape, Core-Gap, Panel size. These parameters are analyzed by Design of experiments using Taguchi; in order to optimize the geometry of the panel.

1. The Analysis of Taguchi for L36 orthogonal array shows that, for the Von-Mises stress of three-point bending test, Core-Gap is most influence parameter while the Face sheet thickness is the least influence parameter. The remaining parameters have a moderate effect.
2. For Directional deformation, Panel Dimension is highly influenced while Core Height is least influence. The remaining parameters have a moderate effect.
3. For Maximum shear, the high influenced parameter is Core-Gap and least influence parameter is Face Sheet Thickness.
4. From the S/N ratio plots, the optimal geometry of the panel is Square tube Core shape (S), 18 Gauge face sheets, 10mm core gap, 20mm core height and R2 panel shape. The panels are fabricated based on this result.
5. The above results are confirmed by conducting experiments by three points bending on UTM with a span length of 270mm for the R2 panel. The results show that

the initial linear-elastic behavior followed by an elastoplastic phase until a peak value is reached at load 20.5 KN after which the failure of the component happened by delamination. The proof graph shows the acceptable linear behavior between stress and strain relations.

REFERENCES

[1] Steeve Chung Kim Yuena, Gerald N. Nurickb and Misha C. du Plessi (2014), "Response of sandwich panels with tubular cores to blast load" Applied Mechanics and Materials Vol 566 (2014) pp 581-585.

[2] G.Nirupama, V.Diwakar Reddy and G.Krishnaiah (2014) "Design and Fabrication of Spot Welded Corrugated Panel Under Three-Point Bending by FEM" 12th Global Congress on manufacturing and management, GCMM 2014, Procedia Engineering 97 (2014) 1282 – 1292.

[3] Satya Kiran O. N. V, Dr. A. Gopichand, Mahesh Krishna B, P S N Raju, "Impact and strength analysis of all-steel sandwich structures for different core shapes" International Journal of Engineering Trends and Technology (IJETT), V32(2),106-112 February 2016.

[4] L. St-Pierre, N. A. Fleck, V. S. Deshpande, "Sandwich Beams with Corrugated and Y-frame Cores: Does the Back Face

[5] Contribute to the Bending Response", Journal of Applied Mechanics, 2012, 79, pp. 011002-1 - 011002-13.

[6] Z. Xue and J.W. Hutchinson, A comparative study of impulse-resistant metal Sandwich plates, Int J Impact Eng**,** Vol. 30(10), (2004), p. 1283-1305.

[7] L. Valdevit, Z. Wei, C. Mercer, F.W. Zok, A.G. Evans, "Structural performance of near-optimal sandwich panels with corrugated cores", International Journal of Solids and Structures,2006,43(16), pp. 4888–4905.

[8] Jukka Saynajakangas and Teroi Taulavuori, Outokumpu Stainless Oy, Finland " A review in design and manufacturing of stainless steel sandwich panels" stainless steel world October 2004.

[9] K.Kantha Rao, K. Jayathirtha Rao, A.G.Sarwade, B.Madhava Varma, "Bending Behavior of Aluminum Honey Comb Sandwich Panels", International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, 2002.

[10] Salih N. Akour, Hussein Z. Maaitah, "Effect of Core Material Stiffness on Sandwich Panel Behavior Beyond the Yield Limit", Proceedings of the World Congress on Engineering, 2010.

[11] G.A.O. Davies, D. Hitchings, T. Besant, A. Clarke, C. Morgan, "Compression after impact strength of composite sandwich panels", Composites Science and Technology 69 (2009), pp 2231–2240.