# Experimental Investigation of Damping Properties of Composite Corrugated Core Sandwich Panel

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***Abstract:*** Corrugated sandwich construction has been recognized as of promising concept for structural design of light transportation systems such as aircraft high speed trains and fast ships. Corrugated sandwich panel can be used as a light weight structure which may reduce effect of vibration if its damping behavior is analyzed. The aim of the present study is experimental investigation of damping properties of composite sandwich panel. Damping properties are determined by using logarithmic decrement method. Also the effect of various parameters on damping properties are analyzed for the optimization of these parameters. The experimental results of natural frequencies and damping ratio are obtained.

***Keywords-*** Corrugated sandwich panel, Logarithmic Decrement, Natural Frequency, Damping ratio.

## I. Introduction

For design and construction of light weight transportation systems such as satellites, aircraft, high-speed trains and fast ferries, structural weight saving is one of the major considerations. To meet this requirement, sandwich construction is frequently used instead of increasing material thickness. This type of construction consists of thin two facing layers separated by a core material. One of the advantages of sandwich structures is that they can have a relatively high fraction of open space, hence a much lower density as compared to the parent material. In nature, cellular materials have evolved to make biological parts more structurally efficient by eliminating unstressed material and providing pathways for the growth of other organic materials. The human bone is a typical example of a natural structural cellular material, which satisfies both these purposes. Corrugated core sandwich panel belongs to the more general category of manmade metallic periodic cellular structures along with other structures such as the prismatic core structure and lattice truss structure. This dissertation work is undertaken with the objective of investigating the damping properties of Sandwich panel using corrugated perforated sheets as core material under vibrations. Specifically, the aims of the work are as follows:

- To fabricate corrugated sandwich panel.
- To analyze the damping characteristics of sandwich panels & study effect of parameters on damping properties.
- To determine the damping ratio of corrugated sandwich panels experimentally

## II. Literature Review

Siddhesh Sawant and Ashok Mache (2018) have investigated damping properties of natural fiber reinforced composite in their studies. Their study gives information about procedure to find damping properties of material in the form of cantilever beam like structure. Setup for experimentation and experimental equipment are also shown in the paper. The mathematical procedure as well as Ansys analysis is used in this paper for determination of damping ratio as well as natural frequency. H. Abramovich, D. Govich and A.Grunwald (2015) showed procedure to find damping ratio of material. They studied half power bandwidth method, logarithmic decrement method and Hysteresis loop method. Out of these methods detail study of logarithmic decrement method is given. Choi J et al. (2013) showed the fabrication of CWML and comparison between numerical model and result of experiment, and prediction for bone replacement in their research work “Mechanical Behaviour and numerical analysis of corrugated wire mesh laminates”.

## III. Selection of Parameters

The most important stage during the experimentation is to select the critical parameters affecting the damping ratio of corrugated sandwich panels. In corrugated sandwich structure several parameters are involved in its configuration such as material of the wire mesh, angle of corrugation, type of wire mesh, number of corrugated layers, number of corrugations and corrugation parameters such as the corrugation height and the base angle which can be altered to provide a wide range of stiffness and strength to the laminate structure. These parameters are contributing in the damping properties of corrugated sandwich panel, among which some parameters are critical whose effect on damping properties of structure cannot be predicted directly. Hence in order to analyze damping properties of corrugated sandwich panel the effect of these parameters on the damping ratio of corrugated sandwich panel needs to be evaluated. The parameters are selected in this study are corrugation angle, type of wire mesh and number of layers. It is recommended that further numerical and experimental testing be conducted to study the influence of the corrugation angle on the damping ratio of the sandwich structure. With variations in the value of corrugation angle damping properties of sandwich structure changes. The levels of corrugation angles (θ) taken were 45°, 50°, 55°. The corrugated sandwich panel structure consists of multiple layers of corrugated wire meshes arranged over each other in the manner depending on the structure of laminates. All the layers are made with the same corrugated material, i.e., that the mesh material and geometry are the same and the corrugation angle θ, the base length $L_B$, and corrugation height $H_c$ are also the same for the all the layers for that particular sample. In order to get moderate damping ratio it is need to be analyze damping ratio for various layers. Hence three level of no of corrugated layers are selected as 1, 2 and 3.

## IV. METHODOLOGY

Design of experiment is one of the most accurate methods used to analyze what factor influence which feature. With increment in product quality, these techniques are much essential for improving quality of product by analytical approach. This technique acquires existing cause and effect relationship within the system scientifically and thus system is adopted. DOE is defined as the selection of parameters and specification of features that would help the creation of products or process with a predefined, expected performance. It is predefined plan of set of experiments, in which parameters required are changed over defined range through which optimized parameters are established for highest quality. It enhances the potential by creating a physical and informational structure. These experiments require least number of trials and thus ensures the best economy which is the great advantage of DOE technique. Orthogonal arrays are involved by experimental design of Taguchi method to arrange the parameters affecting the process & the levels in which they should be varied. With minimum no of experimentation it evaluates contribution of each factor that affects the process & their minimum values for their response which saves efforts, time & resources. Hence the work undertaken to achieve above objectives are selection of parameters, sandwich panel fabrication using Taguchi's Design of Experiments, Experimentation and Confirmation Experiments. Under vibrational analysis, using L9 orthogonal array experiments were conducted on the samples. In order to validate the results, analysis of variance (ANNOVA) was performed and confirmation tests were carried out. In the present study objective is to find moderate damping ratio. It should neither be more nor be less, so nominal the better approach is used.

Nominal the better

This case considered when specified value of response is most desirable, means no smaller or larger value is desired. Hence response is needed to be kept as close as target value. So nominal is the better response. S/N ratio can be given as,

$$n = 10 \log_{10} [\text{Square of means / Variance}] \qquad [1]$$

Table 1 Orthogonal array with detailed values

| Expt No | Parameters | | |
|---|---|---|---|
| | **Corrugation Angle** | **Types Of Wire Mesh** | **No Of Layers** |
| 1 | 45 | Round | 1 |
| 2 | 45 | Diamond | 2 |
| 3 | 45 | Rectangle | 3 |
| 4 | 50 | Round | 2 |
| 5 | 50 | Diamond | 3 |
| 6 | 50 | Rectangle | 1 |
| 7 | 55 | Round | 3 |
| 8 | 55 | Diamond | 1 |

## V. FABRICATION

In the current study aluminum composite sheet is used as face sheet for sandwich panel. The wire mesh used are round, rectangular and diamond shaped made of 6061 aluminum alloy, commonly used as core material for lightweight sandwich constructions in mechanical, automotive, marine and aerospace engineering which is satisfying the requirements. The fabrication of corrugated sandwich is bit slower task yet simple. The first step in the fabrication of corrugated sandwich panel is to create the corrugations, which is done by subjecting the plain mesh to a die and punching process. Single layers of the corrugated mesh are then cut to size and arranged in their desired sequence of lamination. The final and major step in the fabrication process is the bonding of the different layers of the corrugated aluminum sheets to each other using techniques such as welding, adhesive bonding, brazing or soldering which involve high temperature processing. There are various adhesives material but by considering all conditions, we have selected epoxy adhesives.

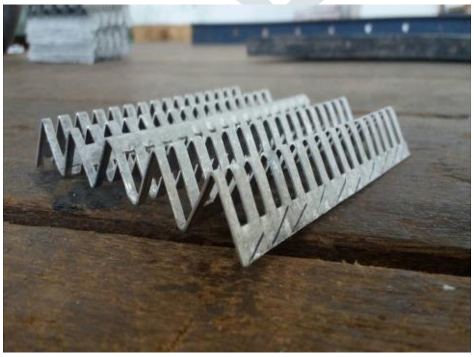

Figure 1. Test Samples

## VI. EXPERIMENTATION & MATHEMATICAL ANALYSIS

Experiments are conducted as per the combination given by Taguchi's orthogonal array and results are recorded for desired response using NI LABVIEW. Figure 2 shows the experimental setup for the research work. The sandwich panel is clamped in cantilever beam with the vice. At free end of beam tapping is given with hand. After tapping a signal is recorded by unidirectional piezoelectric accelerometer. With the help of four channeled FFT analyzer amplitude Vs time response graph is obtained for all nine panels one of which is shown in Figure 3. This response is used to calculate Damping ratio by Logarithmic decrement method using equations 2 and 3. Figure 4 shows the variation of nine panels with respect to the damping ratio obtained using logarithmic decrement method.

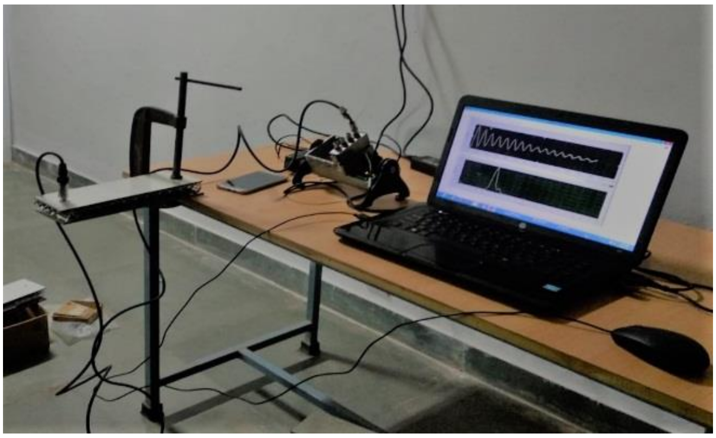

Figure 2. Experimental setup

Logarithmic Decrement (δ):

The rate of decay of amplitude is measured by the parameter known as logarithmic decrement. It is proportional to the amount of damping present in system. Larger the damping greater will the rate of decay until some limit. It is defined as the natural logarithm of the ratio of any two successive amplitude on the same side of mean position.

$$\delta = \frac{1}{n}\ln\left\{\frac{x_1}{x_n+1}\right\} \quad \text{..........} \quad (2)$$

$$\xi = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} \quad \text{..........} \quad (3)$$

Table 2 Damping ratio as a response

| Sr. No | Corrugation Angle | Types Of Wire Mesh | No Of Layers | Damping Ratio | Mean |
|---|---|---|---|---|---|
| 1 | 45 | Round | 1 | 0.01065 | 0.01065 |
| 2 | 45 | Diamond | 2 | 0.01780 | 0.01780 |
| 3 | 45 | Rectangle | 3 | 0.00850 | 0.00850 |
| 4 | 50 | Round | 2 | 0.00730 | 0.00730 |
| 5 | 50 | Diamond | 3 | 0.00994 | 0.00994 |
| 6 | 50 | Rectangle | 1 | 0.00641 | 0.00641 |
| 7 | 55 | Round | 3 | 0.00488 | 0.00488 |
| 8 | 55 | Diamond | 1 | 0.00740 | 0.00740 |
| 9 | 55 | Rectangle | 2 | 0.00840 | 0.00840 |

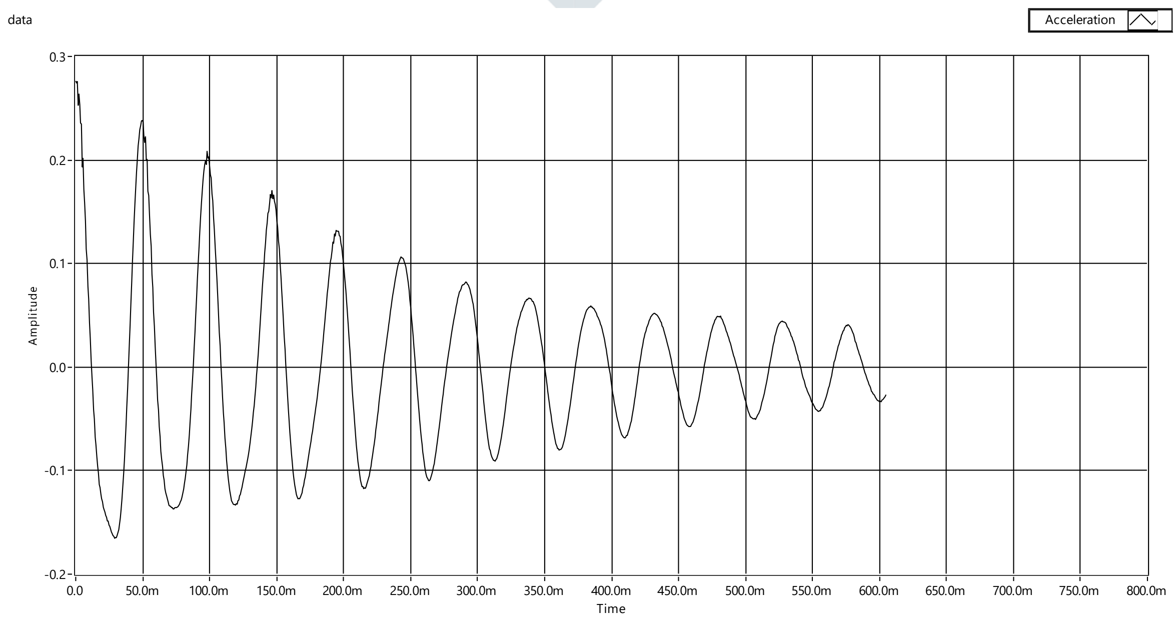


Figure 3 Graph of Amplitude Vs Time

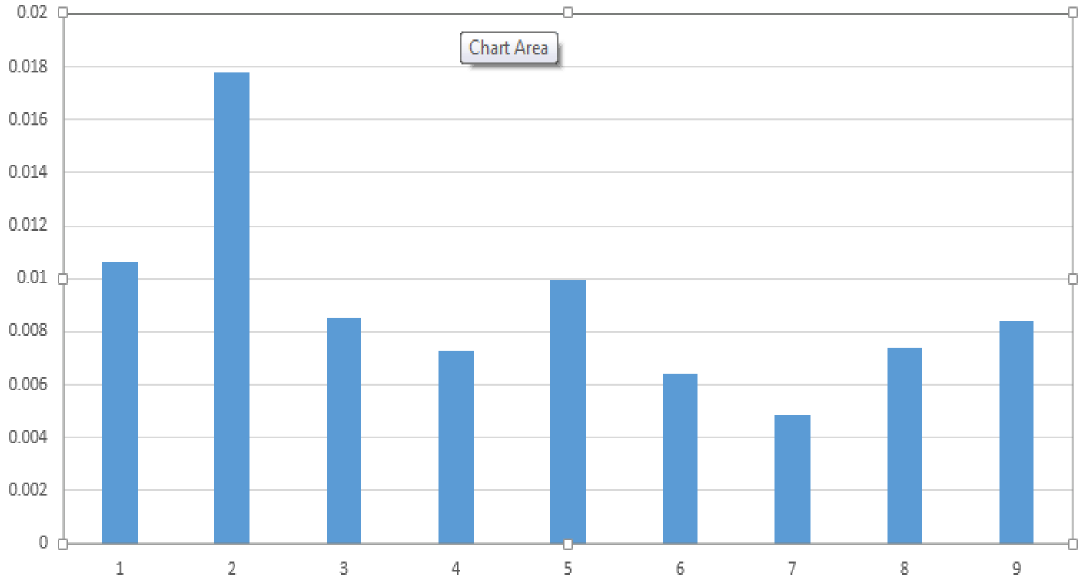


Figure 4 Panels and damping ratio variation

## VII. Result and Discussion

Table 2 shows the calculated values of damping ratio using logarithmic decrement method as well as values of mean obtained using MINITAB 17. Mean help us to show variation of all panel parameter which we have selected. The table 3 indicates the mean for nine experimental run factor level set for each trial. Delta values given in the table gives the variations in mean within the levels, more the variation more is the delta value and hence more is the contribution of that factor in the response. The rank for each control factor given in table gives the order in which every factor is contributing in a particular response and it is decided on the value of delta. Fig 5 depicts the main effects plot for means which gives the optimum value of levels for each selected parameter. 50 degree corrugation angle, Rectangle perforated sheets and 2 layers shows moderate damping ratio. Fig 6 shows the percentage contribution for damping ratio for different parameters which is validated using Analysis of Variance (ANNOVA) as shown in Table 4. ANOVA is a statistically based, objective decision making tool for detecting any differences in the average performance of groups of items tested [Philip J. Ross]. ANOVA helps in testing the significance of all main factors and their interactions by comparing the mean square of deviations of individual factor against the experimental errors at specific confidence levels.

Table 3. Response table for damping ratio

| Column | Factors | Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| 1 | Corrugation Angle | 0.012317 | 0.007883 | 0.006893 | 0.005423 | 1 |
| 2 | Types of wire mesh | 0.011713 | 0.007770 | 0.007610 | 0.004103 | 2 |
| 3 | No of Layers | 0.008153 | 0.11167 | 0.007773 | 0.003393 | 3 |

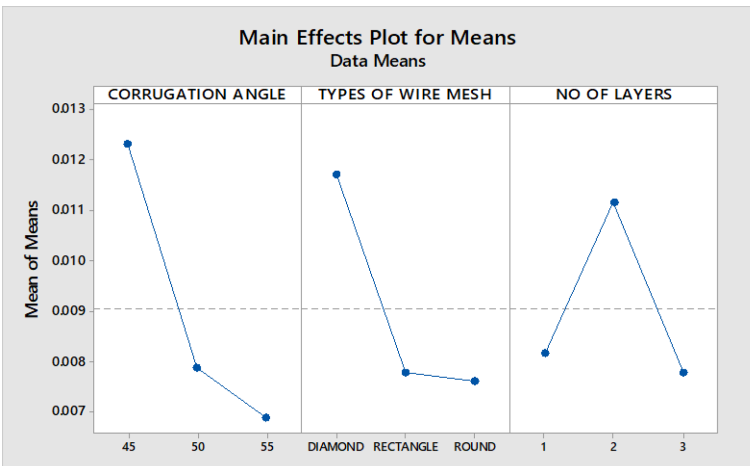


Figure 5 Main effect plot

Table 4. ANOVA TABLE

| Sn. | Factor | SS | DOF | MSS | F | % contribution |
|---|---|---|---|---|---|---|
| 01 | CORRUGATION ANGLE | 0.000050047 | 2 | 2.50235E-05 | 6.601918325 | 45.18% |
| 02 | TYPES OF WIRE MESH | 3.24128E-05 | 2 | 1.62064E-05 | 4.275709332 | 29.26% |
| 03 | NO OF LAYERS | 2.07393E-05 | 2 | 1.03696E-05 | 2.735805306 | 18.72% |
| 04 | Error | 0.000007581 | 2 | 3.79034E-06 | | 6.84% |
| 05 | Total | 0.00011078 | 8 | | | 100 |

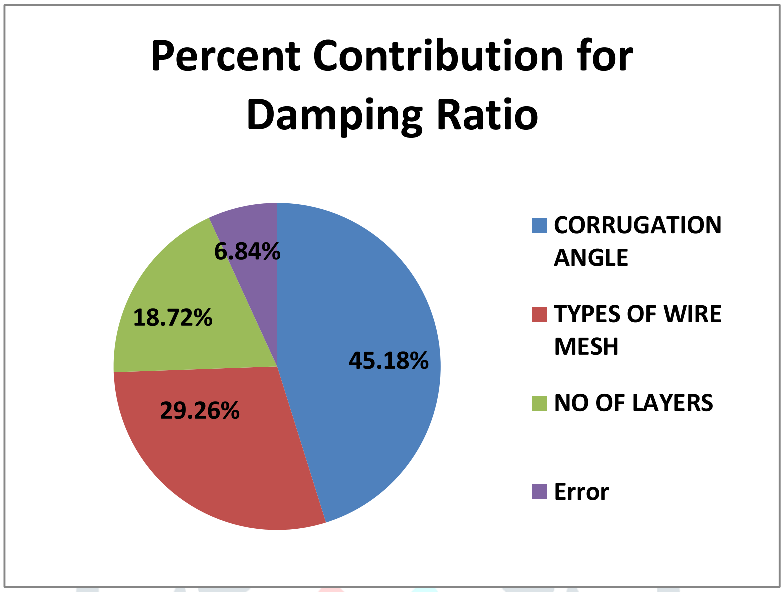


Figure 6 Percent contribution

## VIII CONFIRMATION EXPERIMENT

The Optimum combination of the levels for corrugated sandwich panel parameters to get moderate damping ratio is determined. To perform a confirmation experiment, specimens of corrugated sandwich panel are prepared with optimum levels of parameters obtained from the Taguchi analysis. The configuration of sample to be tested along with observed result is as given in Table 4.

Table 4 Optimum conditions of parameters for response

| Response | Control factors | | | Observed Results |
|---|---|---|---|---|
| | Corrugation angle | Types of wire mesh | Number of corrugated layers | |
| **Damping Ratio** | 50 | Rectangle | 1 | 0.00641 |

After the optimal combination of process parameters and their levels are obtained the estimated result against experimental value can be compared using following statistical equation. Table 6 shows that comparison between the observed and estimated mean value is very close to each other.

Estimated damping ratio at optimum condition is computed by

$$\hat{\mu} = \overline{A2} + \overline{B3} + \overline{C1} - 2\overline{T}$$

Table 5 Estimated damping ratio at optimum condition

| Grand Average | Corrugation Angle | Laminate Structure | Number of Corrugated Layers | Estimated damping ratio |
|---|---|---|---|---|
| $\overline{T}$ | $\overline{A2}$ | $\overline{B3}$ | $\overline{C1}$ | |
| 0.00903 | 0.00788 | 0.00777 | 0.00815 | 0.00574 |

Table 6 Comparison of Experimental and Estimated results

| SR NO | Response | Estimated Value | Observed Value |
|---|---|---|---|
| 1 | Damping Ratio | 0.00574 | 0.00641 |

The estimated results are only a point estimate based on the averages of the results obtained from the experiments. While performing the confirmation experiment it is better to have a range of value than having an exact value of predicted results within which the observed values should fall with some confidence. This range is called as confidence interval (C.I.) [Philip J. Ross]. It has a maximum and minimum value between which the observed value should fall. It can be calculated by statistical way by using following expression:

$$C.I. = \pm\sqrt{(F(1, n_2) \times V_e)/N_e}$$

Where F (1, $n_2$) is the F value from F table at a required confidence level at DOF 1 and error DOF $n_2$.
$N_e$ = Effective number of replications

Using these equations confidence interval for all responses is calculated which is shown in Table 7. The F value is taken for 95% of confidence.

Table 7 Comparison between Experimental Results and Predicted Results

| **Sr. No.** | **Response** | **Predicted Results** | **Confidence Interval (C. I.)** | | **Observed Results** |
|---|---|---|---|---|---|
| | | | **Lower** | **Upper** | |
| **1** | **Damping Ratio** | 0.00574 | 0.002636 | 0.0141 | 0.00641 |

So from the table 7 it is clear that the observed results are falling within the confidence interval of predicted results hence the confirmation experiment has validated the results

## IX CONCLUSION

The objective of this project is to investigate damping properties of composite sandwich panel. Statistically design experiments based on Taguchi method have been perform using L9 orthogonal arrays to analyze damping ratio. After performing experimental test on corrugated sandwich panel samples and analyzing the results using mean approach, Taguchi's Methodology and analysis of variance (ANOVA), the influences of corrugation angle, types of wire mesh and the no of corrugated layers on these responses were establish. Mean and ANOVA both have given similar results which are verified by confirmation experiments. Design of corrugated sandwich panel with optimum levels of control factors results in nominal values of damping ratio. The most dominating factor in corrugated sandwich panel is corrugation angle which affects its damping properties greatly as compare to other factors. The corrugation angle of 45˚ results in lower damping ratio while corrugation angle of 55˚ results in higher damping ratio. The corrugation angle of 50˚ gives nominal value of damping ratio. The other factor type of wire mesh also showed effective contribution in work. The round shape wire mesh gives lower damping ratio and diamond shaped wire mesh gives higher damping ratio while rectangular wire mesh gives nominal damping ratio. The 3rd factor i.e. no of layer also have influence on damping ratio. Two layered structure gives higher damping ratio and three layer gives lower damping ratio while single layer gives moderate damping ratio.

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