Application of Box Behnken Design to Optimize the Parameters for Kenaf-Epoxy as Noise Absorber

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Abstract. This journal discusses the application of Box Behnken design to plot the experiments to find the Noise Absorption Coefficient (NAC) for Kenaf/Epoxy sandwich sample with an overall objective of optimizing the density, thickness, pressure and frequency. Response Surface Methodology (RSM) has been embraced to express the yield parameters (reactions) that are chosen by the input procedure parameters. RSM likewise evaluates the connection between the variable input parameters and the comparing yield parameters. The proposed Box-Behnken configuration requires 24 trial of run for information securing and displaying the reaction surface. Software’s were utilized to plan the examination and randomize the runs. Regression model was created and its capability was checked to foresee the yield esteems at about all conditions. Facilitate the model was approved by performing tests, taking 24 sets of inputs. The yield parameters estimated through tests (actual) are in great match with the anticipated esteems utilizing the model, Utilizing Design Expert software, 2D and 3D plots were produced for the RSM evolved. This research resulted in ascertaining the optimised set of noise absorber parameters for Kenaf/Epoxy sandwich sample, to get the optimum NAC. This work gains significance in the sense with minimum number of experiments, reliable model has been generated, validated and further, the process has been optimised and mathematical equation generated.

1. Introduction
Noise pollution is one of the foremost fears influencing anthropological life expectancy. As a solution, to moderate the engendering of noise pollution and its unfavourable impacts is to utilize a sound ingestion medium. To protect the environment, the natural fibre is mix with the polymer to fabricate as a noise absorber.

For the structure of polymer and nonwoven textures utilized for sound protection, numerous parameters impact the capacity of the texture to be a decent solid safeguard, much of the time the impact of these parameters is examined by changing every parameter independently [1,2,3]. This, in any case, does not give adequate data since it examines these parameters separately neglecting the intuitive impacts of these parameters and sometimes even prompts conflicting conclusions as detailed in available writing [4,5].

To overwhelm this issue of deluding elucidations, it is important to contemplate the individual and intuitive impacts of various parameters all the while. Reaction surface philosophy, which fuses outline of examinations, is extremely helpful in researching the impacts of various factors at the same time [6,7]. The benefit of such a technique is, to the point that the impact of different parameters can be known quantitatively and subjectively together with their collaboration impacts. This strategy likewise...
takes into consideration the expectation of the improved region including synchronous impacts of different parameters. Box-Behnken factorial outline is an instrument that can be utilized to examine the concurrent impact of various parameters time [8,9,10,11]. There are few distributed investigations accessible today about the association impacts of parameters on sound protection properties by utilizing such a factorial plan technique.

Hence, this work is intended to analyse the consequence of the controlled parameters and its effects to attain concentrated NAC. The parameters studied are density of the composition, thickness of the sandwich composition, the pressure applied during compressing process and the frequency applied during the test by suing the impedance tube test. A Box-Behnken factorial outline with three factors, each changed at three levels (-1, 0, +1), was chosen for the experiment. The sound absorption coefficient of the samples was measured according to the ISO 10534-2, ASTM E 1050 and ASTM E2611 standard acoustic testing instrument consisting of a horizontal impedance tube, two microphones and a digital frequency analyser [12,13]. At the point when a sound wave is episode on a material, it can be reflected, retained and transferred by the material. Every one of the three occurrences are conceivable relying on the kind of material. Engrossing the episode sound wave is a successful method to control noise proliferation.

In this study the optimization approach provided by the Box–Behnken Design (BBD), which is a response surface methodology (RSM) is proposed [14]. For applying the approach, Design-Expert software (Version 11.0, Stat-Ease Inc., Minneapolis, USA), was used. On the basis of the BBD, the process parameters (density of the mixture, the thickness of the sandwich sample, the pressure applied to the sandwich sample and frequency exposed to the sample) in the fabrication process could be optimized with a minimum number of experimental runs. As a pool of factual and scientific methods for creating, enhancing, and streamlining procedures, RSM is particularly connected in circumstances where a few info factors possibly impact an execution measure or quality normal for the item or process [15,16].

Objective of this work is to create a model for the forecast of noise absorber sample by controlling three parameters which is the density of the mixture, the thickness of the sample and the pressure applied to the sandwich sample by mixing between the Kenaf fibre and the Epoxy. Based on the experimental data, further the model was validated with various values (frequency) and surface plots were generated to describe the tendency of NAC, under specific combination of process parameters. Ultimately it was useful in determining the influence of process parameters and the output parameters, further enables in determining the optimum set of parameters in terms of NAC.

2. Experiment Details
Work material: Woven Kenaf Fibre and cut into 30 mm diameter, Epoxy.
Compressed and Heated Machine used: compressed machine used to get sandwich sample from 10mm till 50mm. Epoxy was lay-up between woven kenaf fibre, compressed, heated and leave the sample to cool down to room temperature for 24 hours to get sandwich sample.
Cutter Machine: Sample was cutted in circle shape with dimension 30mm due to the dimension of Impedance Tube.
Impedance Tube: (Larson Davis Model CAL200 serial Number: 12525) was used to do provide the random frequency to the sample and to identify the absorption coefficient of every sample.

3. Methodology
It can be seen from the literatures [16,17] that developments and current practices in the area of process improvement recommend employing RSM for expressing the output parameters (responses), in terms of input variables.

3.1. Response Surface Methodology (RSM)
RSM uses various methods such as assortments of statistical and mathematical methods which can be applied for engineering problems. In this procedure, the fundamental goal is to improve the reaction surface that is affected by different process parameters [14,15]. RSM likewise evaluates the connection between the controllable info parameters and the acquired reaction surfaces. The outline methodology of RSM is as per the following:

- Outlining of a progression of trials for sufficient and reliable estimation of the response of interest.
- Developing a numerical model of the second order response surface with the best fittings.
- Finding the ideal arrangement of experimental parameters that deliver the maximum value of response.
- Representing the immediate and intuitive impacts of process parameters through two and three dimensional plots.

3.2. Design of Experiments for RSM

RSM plans enable us to gauge cooperation and impacts, and consequently give us a thought of the (local) profile of the reaction surface under study. Box-Behnken outlines and focal composite compositions are effective plans for fitting second order polynomials to reaction surfaces, since they utilize moderately modest number of perceptions to assess the parameters. Rotatability is a sensible reason for the determination of a reaction surface plan. The reason for RSM is enhancement and the area of ideal is unidentified before running the trial, it bodes well to utilize a plan that gives measure up to accuracy of estimation every way. For such purposes, Central Composite Design (CCD) - spherical or face centered and Box–Behnken design are the commonly used experimental design models for three level three factor experiments.

3.2.1 Box–Behnken design of Experiments for RSM

Box and Behnken suggested three level plans for fitting reaction surfaces. These plans are shaped by consolidating 2k factorials with inadequate block outlines. Figure 1 outlines the three variable Box–Behnken illustration. It can be seen that the Box-Behnken configuration is a round outline with all focuses lying on a sphere of radius $\sqrt{2}$. Additionally the configuration does not have any point at the vertices of the cubic region made by the upper and lower limits for every factor.

| Run | $x_1$ | $x_2$ | $x_3$ |
|-----|-------|-------|-------|
| 1   | -1    | -1    | 0     |
| 2   | -1    | 1     | 0     |
| 3   | 1     | -1    | 0     |
| 4   | 1     | 1     | 0     |
| 5   | -1    | 0     | -1    |
| 6   | -1    | 0     | 1     |
| 7   | 1     | 0     | -1    |
| 8   | 1     | 0     | 1     |
| 9   | 0     | -1    | -1    |
| 10  | 0     | -1    | 1     |
| 11  | 0     | 1     | -1    |
| 12  | 0     | 1     | 1     |
| 13  | 0     | 0     | 0     |
| 14  | 0     | 0     | 0     |
| 15  | 0     | 0     | 0     |

**Figure 1.** Three factor Box-Behnken design

This could be invaluable when the focuses on the sides of the solid shape speak to factor level blends that are difficult to test because of physical process requirements or restrictively costly. Its "missing corners" might be very useful when the researcher ought to maintain a strategic distance from consolidated factor extremes. This property hinders potential losses of information in those cases.

Box-Behnken design needs less treatment blends than a CCD, in issues including 3 or factors. The Box-Behnken configuration is rotatable (or about so) however it contains zone of poor forecast quality
like the CCD. In this research, the Box-Behnken type response surface design were used to plan and carry out the investigations.

3.3. Mathematical Modelling
The process of fabrication of the sample needs to have various input variables. They are the density, thickness, pressure of the sample and the applied frequency to the sample which also represent the NAC for the second order response surface. A relapse model can likewise be utilized for this reason.

3.4. Analysis of Variance (ANOVA)
Analysis of variance (ANOVA), is a statistical decision making tool utilized for distinguishing any distinctions in normal exhibitions of tried parameters [18]. It employs sum of squares and F statistics to discover relative significance of the investigated processing parameters, dimension flaws and uncontrolled parameters. ANOVA was utilized to check the amRESH of the model for the reactions in the experimentation.

4. Experiment Details

4.1 Selection of Parameter
Fabrication parameters for the study as given in Table 3. The parameters were fixed based on the available literatures.

4.2 Design of Experiment
RSM layout enables us to evaluate relations and impacts, and consequently give us the possibility of the (local) shape of the reaction surface under study. Box-Behnken configuration is having the most efficient proficiency for a RSM problem including three variables and three levels. Likewise the quantity of runs required is less contrasted with a central composite plan.

The proposed Box-Behnken configuration requires 24 trial run for displaying a response surface. The procedure parameters for the trial runs are chosen in view of the standard outline as per in Figure 1. Software’s was utilized to outline the investigation and randomize the runs. Randomization guarantees that the conditions in a single run neither rely upon the states of the past runs nor forecast the conditions in the ensuing runs. Randomization is basic for reaching inferences from the analysis, in precise, unambiguous and accurate way.

5. Results and Discussions
Noise Absorption experiments were conducted in Impedance Tube: (Larson Davis Model CAL200 serial Number: 12525) for the set of input parameters under the 24 conditions given by Box – Behnken design. NAC were measured by the ACUPRA Measurement System Software Version 4.20b during the experiment and the values were recorded.

5.1. Experimental Results
The NAC values evaluated as output parameters (responses) for the 24 runs are depicted in Table 3.

The mathematical modelling and analysing the problems in which a process response is influenced by several input variables and the research-objective is to optimize this response. In order to adopt RSM, determination of supporting parameters, their levels and legitimate test configuration are fundamental. RSM comprises of a congregate of procedures utilized as a part of setting up observational investigation of the connection between a reaction and a few other factors. The standpoint of utilizing RSM is to comprehend and assess the impact of various parameters and their associations with each other in drawing out the response(s).

Hence, it is measured as an suitable method to optimize a procedure with one or more feedback [19]. The connection between the variables and the outcome measures are communicated by numerous
relapse conditions, which can be utilized to evaluate the normal estimations of the execution level for any factor levels [20,21].

Second order RSM representing the relationship between the output and the parameters, which is the NAC and the input process parameters, the Density, Thickness, Compression Pressure and the applied of the frequency.

5.1.1 Point Prediction
Two-sided Confidence = 95% Population = 99%

| Response | Predicted Mean | Predicted Median | Observed | Std Dev | SE Mean | 95% CI low for Mean | 95% CI high for Mean | 95% TI low for 99% Pop | 95% TI high for 99% Pop |
|----------|---------------|------------------|----------|---------|---------|---------------------|----------------------|-----------------------|------------------------|
| NAC      | 0.594541      | 0.594541         | 0.204235 | 0.041689| 0.0507284| -0.198484           | 0.681798             | -0.198484             | 1.387568               |

5.1.2 Final Equation in Terms of Actual Factors

\[
NAC = 0.205153 + (-0.270833 \times \text{DENSITY}) + (0.002308 \times \text{THICKNESS}) + (0.010292 \times \text{PRESSURE}) + (0.000160 \times \text{FREQUENCY})
\]

The calculation with regards to the genuine actual factors can be used to make predictions about the reaction for given levels of each factor. Here, the levels should be resolved in the first units for each factor. This condition ought not to be used to choose the relative impact of each factor in light of the fact that the coefficients are scaled to suit the units of each factor and the intercept isn't at the point of the design space.

5.2. Analysis of Results
The evaluation of difference (ANOVA) strategy was utilized to check the suitability of the created models at 95% certainty level [10,18]. The criteria followed in this method is that if the figured estimation of the F-proportion of the relapse design is more than the standard esteem indicated value (F-table) for 95% certainty level, and afterward the model is viewed as satisfactory within its limitations [10,18]. From Table 2, it can be said that every one of the models fulfil the suitability conditions in a linear form.

5.2.1 ANOVA for Response Surface Model
ANOVA outcomes for the response surface linear models are depicted in Table 2. The results were attained by means of Design Expert software.

|                                | Std. Dev. | R²       | Adjusted R² | C.V. % | Predicted R² | Adeq Precision |
|--------------------------------|-----------|----------|-------------|--------|--------------|----------------|
| Mean                           | 0.2042    | 0.7058   | 0.6439      | 34.35  | 0.5306       | 9.5526         |

In all the responses, ‘Predicted R-squared’ values of 0.5306 is in reasonable agreement with the ‘Adjusted R-Squared’ values of 0.6439 which is less than 0.2. While the ‘Adequate Precision’ indicates the signal to noise (S-N) ratio. Normally the ratio greater than 4 is desirable. For this model the ratio of 9.5526 indicates an adequate signal for the model to be used effectively and to be used to navigate the design space.

5.2.2 Surface plots
2-D and 3-D plots can be drawn for different combination of parameters which exhibit the trend of variation of response within the selected range of input parameters and also influence of each parameter over the other parameters. Few such typical plots are shown (Figure 2 to 8).

**Figure 2.** Perturbation  
**Figure 3.** All factors  
**Figure 4.** Interaction  
**Figure 5.** Interaction all factors  
**Figure 6.** Predicted vs actual  
**Figure 7.** 3D graph
The pattern of the contour plots in Figure 5 is almost alike when the pressure and frequency kept constant, pattern of the contour lines is showing the reverse trend. It is observed that the region showing optimum conditions for achieving high percentage of the NAC when the thicker of the sample and less on the sample’s density as per Figure 3, 4, 5 and 7.  

5.2.3 Validation of the Models

In addition to verification through ANOVA technique, the Models were validated by conducting experiments with new set of parameters and the multiple response values were measured and compared with the predicted values using the Models [10,18]. Details of the experiments conducted, predicted and measured values of the output variables are given in Table 3.

Table 3. Predicted vs. Experimental values for validation data

| Run | Factor 1 | Factor 2 | Factor 3 | Factor 4 | PREDICTED | EXPERIMENTAL |
|-----|----------|----------|----------|----------|------------|--------------|
|     | A:DENSITY | B:THICKNESS | C:PRESSURE | D:FREQUENCY | NAC (%) | NAC (%) |
|     | g/cm³ | mm | tonne | Hz | | |
| 1   | 0.45 | 50 | 3 | 5000 | 0.9800 | 0.7820 |
| 2   | 0.65 | 30 | 3 | 125 | 0.1493 | 0.1790 |
| 3   | 0.45 | 50 | 1 | 2562.5 | 0.6201 | 0.7850 |
| 4   | 0.45 | 10 | 5 | 2562.5 | 0.5690 | 0.6860 |
| 5   | 0.25 | 50 | 3 | 2562.5 | 0.6949 | 0.8540 |
| 6   | 0.65 | 30 | 3 | 5000 | 0.9315 | 0.7500 |
| 7   | 0.45 | 50 | 3 | 125 | 0.2496 | 0.2870 |
| 8   | 0.45 | 50 | 5 | 2562.5 | 0.6613 | 0.8800 |
| 9   | 0.25 | 30 | 1 | 2562.5 | 0.6281 | 0.7970 |
| 10  | 0.45 | 10 | 1 | 2562.5 | 0.5278 | 0.9300 |
| 11  | 0.25 | 10 | 3 | 2562.5 | 0.6025 | 0.5310 |
| 12  | 0.65 | 10 | 3 | 2562.5 | 0.4942 | 0.4600 |
| 13  | 0.65 | 30 | 1 | 2562.5 | 0.5198 | 0.6550 |
| 14  | 0.45 | 30 | 1 | 125 | 0.1829 | 0.1660 |
Based on Figure 6, it shows the graphical illustration of projected values with the utilization of the Model coupled with the corresponding computed values of all the responses which finally gives a better picture and clearer understanding.

In the Figure 6, Ideal line is plotted taking the predicted value same as the measured value and is considered as a reference line. Measured values of each response are plotted and their closeness to the Ideal line depicts the accuracy (fitness) of the model. The model evolved for each response is considered precise, where all the measured values are lined up or closer with the Ideal line. In many cases, projected and the experimental values follow close match and the degree of deviation is negligible.

**5.2.4 Optimization**

| Run | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Response 1 |
|-----|----------|----------|----------|----------|------------|
| SAMPLE | DENSITY (g/cm$^3$) | THICKNESS (mm) | PRESSURE (TONNE) | FREQUENCY (Hz) | NAC (%) |
| 1 | MINIMISE | MAXIMISE | MINIMISE | MAXIMISE | MAXIMISE |

Multi-objective optimisation was aimed at to achieve better quality coupled with higher productivity. Accordingly optimisation criteria for each response were selected as given in Table 4. Best solution satisfying the above criteria was obtained using the ‘Design Expert’ software, which is given below and it has the overall desirability of 1.0.

**Table 5. Best solution**

| Run | Factor 1 | Factor 2 | Factor 3 | Factor 4 | Response 1 | Desirability |
|-----|----------|----------|----------|----------|------------|--------------|
| SAMPLE | DENSITY (g/cm$^3$) | THICKNESS (mm) | PRESSURE (TONNE) | FREQUENCY (Hz) | NAC (%) |
| 8/100 | 0.45 | 30 | 1 | 5000 | 0.965 | 1.0 |
Contour plot given in Figure 10, shows the variation of Desirability with change in Density and Thickness.

6. Conclusion
In a nut shell, it can be said that Box Behnken design was positively accepted, achieved the objectives and the tests were outlined picking the information factors for the designated levels. With least number of examinations which is 24 samples as per Table 3, data was gathered to develop the models. Response Surface Models evolved for responses depicts effects of each input parameter and its interface with other parameters, showing the trend of response as per equation in para 5.1.2. Verification of the Fitness of each model using ANOVA technique, shows that all the models can be utilised with assurance level of 0.95, for directing the design space. Further validation of the models done with the additional test data collected demonstrates that the models have high dependability for adoption within the chosen range of parameters. Set of improved input parameters could be distinguished when considering density, thickness, weight and recurrence according to Table 3. Surface plots produced demonstrate the pattern of various reactions by changing the 2 input parameters keeping the third parameter consistent. With diminished number of exploratory runs, genuinely persuading, coherent and satisfactory outcomes have been gotten, which can be taken after for getting answer for the shop-floor prerequisites. This has brought about sparing of extensive measure of time and cash.

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