Statistical Modelling and optimization to predict an improvised composition of asbestos cement corrugated roofing sheets

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Abstract - *Asbestos cement corrugated roofing sheets require improvements in terms of the replacement of the core asbestos fiber, that is carcinogenic, or in terms of reducing the cost. These two problems are addressed in this paper. The approach used is that of the data analysis, statistical modelling and optimization to predict the improvised composition by fiber replacement in terms of cost and the bending strength. This is a better approach than the trial and error approach as this is time saving and will give a better knowledge of the results theoretically before performing the experiments. Finally, the paper also compares the experimental validation of the predicted data.*

***Key Words*: Asbestos, Roofing sheets, Fibre replacement, Data analysis, Prediction, Validation, Bending Strength**

1. INTRODUCTION

The literature survey [1] shows that the asbestos cement corrugated sheets date back to centuries in offering an economical but effective roofing solutions for domestic and industrial purposes. The main raw materials that are used in the formation of these sheets are cement, fly ash, slag, asbestos fiber and cellulosic pulp. They are famously formed on a Hatschek machine developed by Ludwig Hatschek.

As typically, these sheets are used for their low cost, it would be great when the cost is reduced further but by not compromising on the quality. The second problem being the asbestos fiber, that is carcinogenic, needs to be replaced considering the ban in many countries. Therefore, to address these two problems, asbestos fiber is partially replaced by natural fibers such as cellulosic fibers (Jute).

To develop the required composition that can sustain the minimum bending strength, lab scale trials of various compositions are carried out on a trial and error basis. This is highly time consuming as the results can be obtained for every set only after a minimum period of 14 days required for curing. Therefore, the approach of modelling the experimental data, which is in turn used to predict the required composition by optimizing the cost and the flexural strength, is discussed in this paper.

2. STATISTICAL MODELLING

Model is a mathematical expression defining the set of data performed by the experiments. This is generally done by the multi variate regression analysis [2, 3].

Firstly, the variables for modelling are:

Dependent variables: Bending strength in MPa.
Y_P-Predicted Y
Y_E- Experimental Y
Independent variables:

Component	Variable name
1. Pulp	X1
2. Milled Asbestos Fibre	X2
3. Fly ash	X3
4. Portland Cement	X4
5. Fibre replacement	FR
6. Other material(slag+dry waste)	X5

Table-1: Naming of the variables

Initially, the following experiments were carried out at different percentages of replacement of the fiber and the final bending strengths are obtained. The data set is in the Table-2.

On applying the multi- variate linear regression on the above data set in Advanced Microsoft Excel- Data analysis tool, we get the following best fit:

Y_P = -605.5538 + 12.24798 * X2 + 12.32127 * X4 + 6.992564 * FR

To test the validation of the above model, the in sample error is calculated by considering the residuals after regression analysis. The in sample error thus obtained is negligible and is of the order 10^ (-11). Therefore, this best fit can be considered as the model to be used in optimization and prediction satisfactorily.

X1	X2	X3	X4	X5	FR	Y_E
1.9	7.23	34.19	42.99	13.5	0.2	13.23
1.9	6.93	34.19	43.21	13.5	0.3	12.97

1.9	6.78	31.13	46.4	13.5	0.3	15.27
1.9	6.63	30.33	45.35	15.5	0.3	15.20
1.9	7.83	34.19	42.59	13.35	0.15	15.30
1.9	6.83	34.2	43.08	13.5	0.5	12.51
2.4	6.58	34.2	42.83	13.5	0.5	12.47
2.65	6.33	32.78	44.25	13.5	0.5	13.23

Table 2: Data set of the initial experiments

3. OPTIMIZATION AND PREDICTION

To optimize and predict, the Solver tool of data analytics in Advanced Microsoft Excel software is used. The constraints imposed to optimize the data are:

- Firstly, the obtained statistic model:

  Y = -605.5538 + 12.24798 * X2 + 12.32127 * X4 + 6.992564 * FR

- Then, as the total composition sums up to 100% , the cement content is

  X4 = 100- (X1 + X2 + X3 + X5 + FR)

- As the bending strength has to be greater than or equal to control composition,

  Y >= CTRL MRT (Since our model gives Y= 15 when calculated for the control composition.)

- Based on the analysis of the experimental data of the above 8 samples, it can be concluded that the fibre can be replaced to about 4 parts to one part of the replacing fibre. Therefore,

  X2 = 7.83-4* FR

- For proper handling and minimum reinforcement to maintain the quality, let the minimum quantity of asbestos fibre be 6%. Therefore,

  X2>= 6

The target set in the solver tool is for the cost saving variable, which has to be optimized to the maximum value with the above constraints. The predicted composition thus obtained is:

Table 3: Predicted composition

X1	X2	X3	X4	X5	FR	Cost saving (INR/Ton)	Y_P
1.9	6.2	30.66	47.33	13.49	0.4	231	15

4. EXPERIMENTAL VALIDATION

The above obtained composition is tried in the lab scale by preparing plate templates in an FSU press and later checked for bending strengths after a 14 days of stretch wrap curing.

The experimental procedure followed to prepare the plates is:

- Firstly, the milled asbestos and pulp fibres are opened in one litre of water.
- Then, the dry powders are mixed in a ball mill for 5 minutes.
- The two mixtures are then mixed finally in a double blade planetary mixer at 600 RPM
- This slurry is poured into the mould of an FSU press and dewatered by vacuum suction for 110 seconds.
- Pressure of 34000 psi is then applied for 75 seconds.
- The plate thus formed with dimensions of 8”X3”X 0.275” is then placed in a humidity chamber at 25^{0}C and 98% humidity for 24 hrs and later stretch wrapped with a polythene sheet for 14 days at room temperature.
- After curing, the plates are immersed in water for 24 hours at 25^{0}C to obtain saturation.
- Later, these plates are subjected to 3 point loading with a span of 152cm and the bending strength is obtained.
- 4 specimens for each of the predicted composition are prepared and the average bending strength is calculated to reduce the error.

5. RESULTS AND DISCUSSIONS

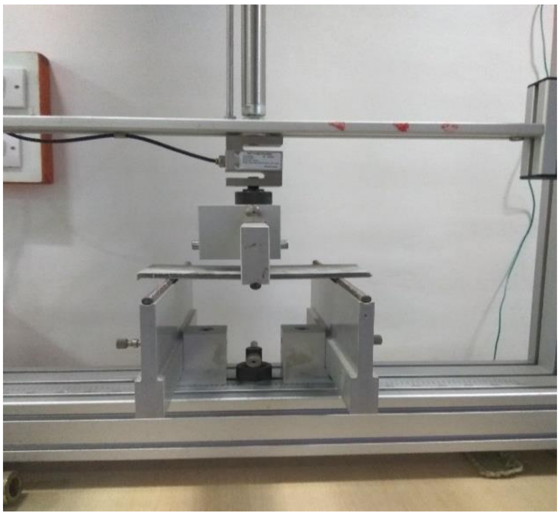

Fig-1: Testing of bending strength

Property	Control Composition	Predicted Composition
MRT (MPa)	14	14
MRA (MPa)	15.06	16.24
DENSITY (g/cc)	1.35	1.3
Water Absorption (%)	31.2	32.1

Table 4: Experimental validation- Results

As it can be observed, the bending strength predicted was 15MPa w.r.t. the bending strength of the control composition. We get a bending strength of 15Mpa when the control composition is used in the model. Therefore, it can be concluded that this model gives a prediction that the bending strength that will be obtained will be similar to that of the bending strength of the control composition. And it can be observed that the same trend has followed in the experimental validation as both the compositions have given equal bending strength of 14MPa.

6. CONCLUSIONS

[1] The effort of the rigorous experimental program can be reduced if a model is developed every time to predict the bending strength of a different composition.

[2] The model developed in this research along with the constraints proves to be beneficial as the overall cost is further reduced compared to our trial and error compositions but keeping up the strength.

[3] Future scope of this paper includes identifying the compositions with the desired physical and chemical properties by a similar modelling and optimization.

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