# OPTIMIZATION PARAMETERS OF COMPOSITE MATERIALS FOR THERMOFORMING MOLD USING THE DESIGN OF EXPERIMENT

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**Abstract**

This research aimed to evaluate composite material design using precise engineering experiment principles called the design of experiment, employing the $2^k$ full factorial test method to determine optimal mixes of natural and synthetic materials. Natural materials included ash powder, pineapple fiber powder, and sugar cane leaf fiber powder, while synthetic materials included aluminum, resin, cobalt, and resin hardener. The study utilized technical processes and experimental design methods to analyze and identify suitable composite materials. The statistical analysis demonstrated the precision of the experimental design by determining the optimum values of thermoforming molds, explicitly analyzing the Shore D hardness level compared to ASTM D2240 standards. The findings revealed that natural materials could effectively replace synthetic materials in the plastic molding industry. All factors expected to influence the Shore D value in the composite material were tested, yielding a hardness value not lower than or close to 80.00 Shore D. The optimal composition as the optimization parameters were identified as 70% resin, 0.01% cobalt, 2.0% hardener, and 20% aluminum powder, with a setting time of 18 hours and a temperature of 70°C. The response optimization method indicated a Shore D value of 80.6725, with experimental results closely aligning with these findings.

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The analysis showed an R-squared coefficient of 83.72%, confirming that adjusting factor levels according to the experimental design can significantly enhance the performance of composite materials in the thermoforming molding industry.

**Keywords**: optimization parameters, composite materials, thermoforming mold, design of experiment

## Introduction

Currently, there is a study of the usage of composite materials as a proportion of composite materials for reinforcement in the production process or different forming techniques depending on conditions and factors, such as forming using the stir mixing method. The advantage of this technique is that it lowers costs. Extrusion is widely used in the automotive, aerospace, and engineering industries, including the trend of environmental products (Eco products) or eco-friendly products. The development of composite materials can be used to reduce the cost of creating molds for the production of various packaging; for example, Integrated fiber material Does not mix with powder materials, which is a group of powder materials suitable for reducing material content or reducing costs (Liu et al., 2019), natural material from sugarcane in the form of powdered bagasse ash particles mixed with aluminum and then tested for mechanical properties suitable for the automotive and aerospace industries. Although there has been some development in mold-making materials or studies using the finite element method (Yashpal et al., 2020) and materials to create the workpiece However, it has not been used in the mold industry or has only been researched to study the possibility of creating molds (Sonsiri, 2021c). The experiment results above were used to compare in a reference test according to ISO 868: 2003 or ASTM D2240 standards.

From the above, the researcher has an idea to find the most suitable natural composite material for thermoforming molds by designing an experiment and adjusting parameters using a Minitab response optimizer. The best parameters for use in the plastic molding industry will be emphasized by technical processes and methods, designing experiments to analyze and find the appropriate proportions in the testing of composite material proportions and find the most suitable value of the mold. Lastly, the consequence of the experiment is used to solve the problem of finding mixed materials.

## Methodology

This research studies techniques for finding suitable parameters for the plastic molding industry that start by setting the values of the variables used in the test. The parameters are then adjusted by considering the main and interaction effects and confirming the estimated effects to find the optimization value. It obtains the most appropriate level of composite material, is then tested to compare with the Shore D standard, and then made into a real piece (Noguera, 2020). The researcher plans the research method step-by-step, as shown in Figure 1.

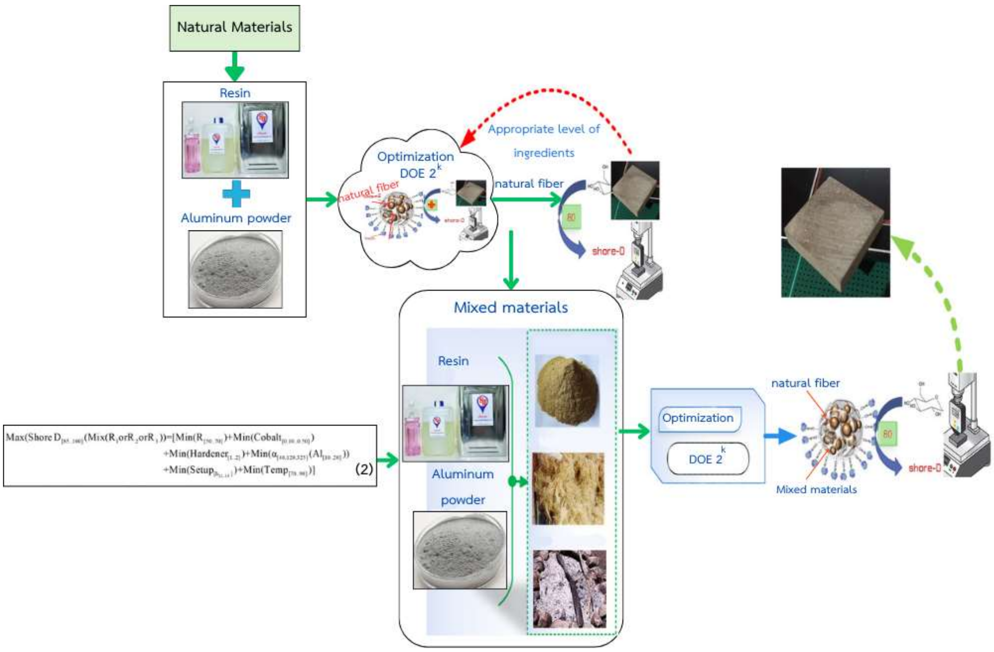


**Figure 1** Research procedures.

According to Figure 1, the optimization parameter of composite materials for thermoforming mold using the design of the experiment has the research methodology as follows:

The first step is the experimental design of variables for entering variables (Sreela-or et al., 2022). This results in material values that will lead to an experimental design that has variables in each factor from all factors and then set to 2 levels, low and high (Sonsiri, 2010a; Inchan, 2018) that are the weight of resin 50 and 70 grams, a cobalt accelerator 0.1 and 0.5 percents, a hardener 1 and 2 percents, the weight of aluminum powder 10 and 20 grams, temperature change 70 and 90°C, setting time 12 and 18 hours, and talcum powder weight 20 and 30 grams.

1.1 Determining the input factors for the $2^k$ full factorial experiment (Badr, Al-Qahtani, Mahmoud, 2020) because each factor can be controlled (Suwanchana & Tangjitsichaloen, 2021), or is a factor that must be entered as a value, an input of the weight value of the material (Wimol, 2018). The test of interaction factors hypothesis is in determining the proportion of the main composite material between resin and aluminum that is an input factor, calibrating the Shore D as an output, standard of experimental variable level values shown in Equation 1 as follows:

$$\mathrm{Max}(\mathrm{Shore\,D}\,(\mathrm{Mix}[\alpha,\beta,\mu])) \tag{1}$$

where Max Shore D = The finding of the hardness equation for thermoforming mold composite materials.

σ = The mixing time was 5 minutes.

$\beta$ = Stirring speed at 250 Rpm.

$\mu$ = Mixing set 400 mm.

Table 1 shows the parameters and levels of the first experimental design. The researcher emphasized studying and determining the variable conditions in the materials used in the experiment. As shown in Equation 2, there are 2 levels, low and high, in 6 factors.

$$\begin{aligned}\mathrm{Max}(\mathrm{Shore\,D}_{[85..100]}(\mathrm{Mix}(\mathrm{R}_1)) = {} & [\mathrm{Min}(\mathrm{R}_{[50..70]}) + \mathrm{Min}(\mathrm{Cobalt}_{[0.10..0.50]}) \\ & + \mathrm{Min}(\mathrm{Hardener}_{[1..2]}) + \mathrm{Min}(\alpha_{[40,120,325]}(\mathrm{Al}_{[10..20]})) \\ & + \mathrm{Min}(\mathrm{Setup}_{[h_{12..18}]}) + \mathrm{Min}(\mathrm{Temp}_{[70..90]})]\end{aligned} \tag{2}$$

Equation 2 shows the components of the experiment design in this research. Table 1 explains it in detail.

**Table 1** The full factors and levels of the first experimental design.

| Factors | Levels | | Unit |
|---|---|---|---|
| | Low | High | |
| Resin | 50 | 70 | Grams |
| Cobalt | 0.1 | 0.5 | % |
| Resin hardener | 1 | 2 | % |
| Aluminum powder | 10 | 20 | Grams |
| Setting time | 12 | 18 | Hours |
| Temperature | 70 | 90 | °C |

Furthermore, the following topic below illustrates the parameters, including their details for the second experiment under the $2^k$ full factorial design.

1.2 The second experiment variables: The variables were determined with the additional proportion of natural materials mixed with pineapple leaf powder, wood ash powder, and sugarcane leaf powder. Then, put the values as an input of the level values, and conduct the experimental variables and equations as the following details:

$\lambda$ = Sieve number under the standard ASTM E11-17.

Al = Aluminum powder (grams) where the weight value is divided into 2 levels;
Weight of aluminum powder, low level 20%.
Weigh of aluminum powder, high level 30%.

P = Pineapple leaf powder (grams) where its value is divided into 2 levels;
Weight of pineapple leaf powder, low level 20%.
Weight of pineapple leaf powder, high level 30%.

W = Wood ash powder (grams) with weight values divided into 2 levels;
Weight of wood ash powder, low level 20%.
Weight of wood ash powder, high level 30%.

C = Sugar cane leaf fiber powder (grams) where its value is divided into 2 levels;
Weight of sugarcane leaf powder, low level 20%.
Weight of sugarcane leaf powder, high level 30%.

$Setup_h$= Setup time (hours), which is divided into 2 levels;
Low setting time: 12 hours.
High setting time: 18 hours.

Temp = temperature change (°C) with the change period divided into 2 levels;
Temperature change: low 70°C
Temperature change, high 90°C

**Table 2** Factors and levels of the second experimental design.

| Factors | Levels | | Unit |
|---|---|---|---|
| | Low | High | |
| Wood ash powder | 20 | 30 | Grams |
| Pineapple leaf powder | 20 | 30 | Grams |
| Sugarcane leaf powder | 20 | 30 | Grams |
| Setting time | 12 | 18 | Hours |
| Temperature | 70 | 90 | °C |

Table 2 shows the components of parameters and their levels, and can conclude the experimental design shows the relationship of parameters as the outcome. The two-level fractional factorial is defined as low and high (Sonsiri et al., 2021c), according to the variables used in each experiment, to ensure precision in the parameters and level of experimental design. The first experiment design has 32 trials, and the second has 16. From the first and second experiments put the addition of the proportion of the composite material in the fineness of the composite filler, an input aluminum, and the sieve number in the experimental variable levels at 2 levels, sieve No. 40 and sieve No. 120 of Sieve Designation. It is determined under the standard values of the U.S. Alternative sieve per 1 square inch of length of the experiment according to the criteria of the most appropriate level factor.

## Discussion

From the experiment, the results were analyzed to study the parameters that influence the hardness according to the Shore D standard under the conditions of full factorial design. For the specimens tested in this study, the researcher made a 25x25 mm block as a model for testing the specimen. and mix according to the experimental design and use a 5-axis CNC machine to prepare the workpiece smoothly. Each experiment had 5 replicates and was put into the oven simultaneously according to the experimental plan. Before measuring the Shore D hardness. In each experiment at the significance level of 0.05 ($\alpha$ = .05) and to find the suitable factor level using the optimum technique (Srivabut, 2022) in a statistical package of Minitab.

1. The results of the first two-level factorial experiment, which involved 32 experiments, determined the proportion of the main composite material between resin and aluminum. The hardness values are shown in Shore D in Table 3.

Table 3 shows the results of the experiment to determine the proportion of main composite materials. The analysis of 32 experiments was run with the statistical package Minitab. The following step is to do the residual plots for Shore D. When considering the residual plots for the Shore D graph; it can be seen that the distribution of residual values appears to be arranged along a straight line, indicating that the residual values are normally distributed. Then, the independence of the residuals was checked using a scatter plot.

**Table 3** Results of the experiment to determine the proportion of main composite materials from the statistical package (Minitab).

| RunOrder | Resin | Cobalt | Hardener | Al | Time | Temp | ShoreD |
|---|---|---|---|---|---|---|---|
| 1 | 50 | 0.1 | 1 | 10 | 12 | 70 | 87.58 |
| 2 | 70 | 0.1 | 1 | 10 | 12 | 90 | 83.92 |
| 3 | 50 | 0.5 | 1 | 10 | 12 | 90 | 85.54 |
| 4 | 70 | 0.5 | 1 | 10 | 12 | 70 | 88.24 |
| 5 | 50 | 0.1 | 2 | 10 | 12 | 90 | 87.64 |
| * | * | * | * | * | * | * | * |
| * | * | * | * | * | * | * | * |
| * | * | * | * | * | * | * | * |
| * | * | * | * | * | * | * | * |
| 28 | 70 | 0.5 | 1 | 20 | 18 | 70 | 86.70 |
| 29 | 50 | 0.1 | 2 | 20 | 18 | 90 | 84.38 |
| 30 | 70 | 0.1 | 2 | 20 | 18 | 70 | 80.80 |
| 31 | 50 | 0.5 | 2 | 20 | 18 | 70 | 85.92 |
| 32 | 70 | 0.5 | 2 | 20 | 18 | 90 | 86.34 |

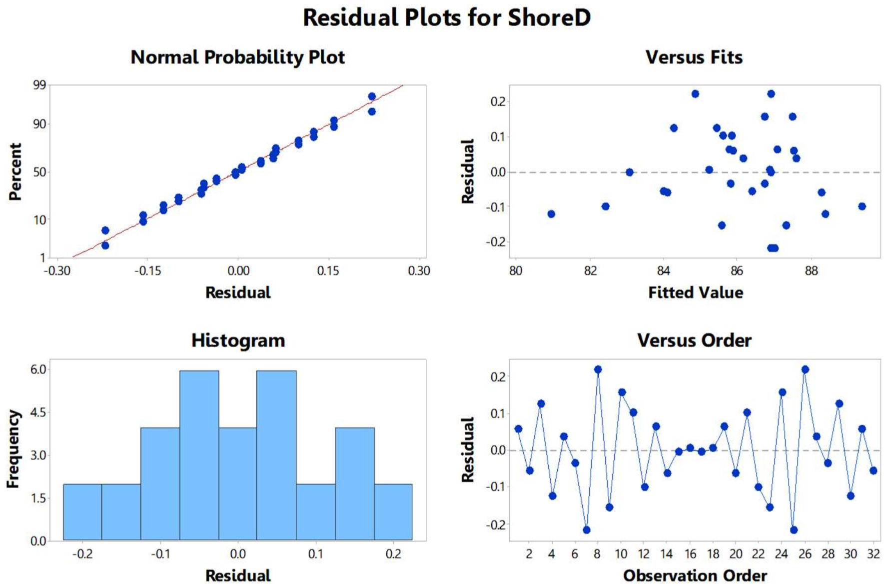


**Figure 2** Residual plots for shore D.

According to Figure 2, it can be concluded that the residual value is in the specified assumptions. It is considered that the data obtained from the experiment are accurate and appropriate for analysis of the experimental results. The residuals had no definite pattern, or the exact pattern could not be estimated. It is evenly distributed and shows that the residues complement each other. Finally, the stability of the residual variance was examined. However, the distribution chart of the residues showed that they were evenly distributed in the positive and negative directions. Therefore, the residuals are stable in variance.

2. The analysis of experimental results, by analyzing the proportion of the main composite material between resin and aluminum, shows that factors influence the hardness value and the Shore D standard under the conditions of the analysis results, as shown in Table 4.

**Table 4** Results of the analysis of experimental data from the factorial experiment, including Analysis of Variance.

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Model | 27 | 98.6499 | 3.6537 | 34.00 | 0.002 |
| Linear | 6 | 6.9308 | 1.1551 | 10.75 | 0.019 |
| R1 | 1 | 0.3612 | 0.3612 | 3.36 | 0.141 |
| Cobalt | 1 | 1.5665 | 1.5665 | 14.58 | 0.019 |
| Hardener | 1 | 0.0060 | 0.0060 | 0.06 | 0.824 |
| Al | 1 | 3.1250 | 3.1250 | 29.08 | 0.006 |
| Time | 1 | 0.2521 | 0.2521 | 2.35 | 0.200 |
| Temp | 1 | 1.6200 | 1.6200 | 15.07 | 0.018 |
| 2-Way Interactions | 15 | 50.6094 | 3.3740 | 31.39 | 0.002 |
| R1*Cobalt | 1 | 2.8800 | 2.8800 | 26.80 | 0.007 |
| R1*Hardener | 1 | 0.8450 | 0.8450 | 7.86 | 0.049 |
| R1*Al | 1 | 6.6613 | 6.6613 | 61.98 | 0.001 |
| R1*Time | 1 | 11.7128 | 11.7128 | 108.98 | 0.000 |
| R1*Temp | 1 | 0.3785 | 0.3785 | 3.52 | 0.134 |
| Cobalt*Hardener | 1 | 0.7442 | 0.7442 | 6.92 | 0.058 |
| Cobalt*Al | 1 | 0.0840 | 0.0840 | 0.78 | 0.426 |
| Cobalt*Time | 1 | 4.8672 | 4.8672 | 45.29 | 0.003 |
| Cobalt*Temp | 1 | 2.1840 | 2.1840 | 20.32 | 0.011 |
| Hardener*Al | 1 | 4.6513 | 4.6513 | 43.28 | 0.003 |
| Hardener*Time | 1 | 1.2168 | 1.2168 | 11.32 | 0.028 |
| Hardener*Temp | 1 | 4.1760 | 4.1760 | 38.86 | 0.003 |
| Al*Time | 1 | 0.2665 | 0.2665 | 2.48 | 0.190 |
| Al*Temp | 1 | 0.2178 | 0.2178 | 2.03 | 0.228 |
| Time*Temp | 1 | 9.7240 | 9.7240 | 90.48 | 0.001 |
| 3-Way Interactions | 6 | 41.1097 | 6.8516 | 63.75 | 0.001 |
| R1*Cobalt*Temp | 1 | 10.2152 | 10.2152 | 95.05 | 0.001 |
| R1*Hardener*Temp | 1 | 1.4112 | 1.4112 | 13.13 | 0.022 |
| R1*Al*Time | 1 | 3.2258 | 3.2258 | 30.01 | 0.005 |
| R1*Time*Temp | 1 | 25.2050 | 25.2050 | 234.52 | 0.000 |
| Cobalt*Hardener*Time | 1 | 0.7080 | 0.7080 | 6.59 | 0.062 |
| Hardener*Al*Temp | 1 | 0.3444 | 0.3444 | 3.20 | 0.148 |
| Error | 4 | 0.4299 | 0.1075 | | |
| Total | 31 | 99.0798 | | | |

| Model Summary = | S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|---|
| | 0.327834 | 99.57% | 96.64% | 72.23% |

Table 4 shows the analysis results of the proportions of the main composite materials between resin and aluminum. The two-level factorial experiment of set 1 included 32 experiments, with the results appearing in the hardness value (Shore D) Analysis of Variance box. It was found at the significance level of $\alpha$ = .05 that the factors influencing the hardness value as the Shore D standard can be determined from the P-value that is less than the significance level of .05. When considering the main factors as the main effect is including Cobalt, Al, Temp. Two-Way interactions are R1*Cobalt, R1*Al, R1 * Time, Cobalt*Time, Cobalt*Temp, Hardener*Al, Hardener*Temp Time*Temp respectively. Three-way interactions are R1 * Cobalt*Temp, R1 * Al*Time, and R1 * Time*Temp, and the common factor is the interaction effect in the decision coefficient. R-sq is 99.57% and R-sq (adj) is 96.64%. This means that the variance of the response variable is distributed around the mean, which can be explained in this linear model by up to R-sq (adj) 96.64%. It is in good condition, so the results are used for experimentation in the second experiment under the appropriate conditions.

3. Response Optimizer

The results were analyzed to find appropriate factor levels. The response optimizer function in the statistical package Minitab, which sees the most suitable factor values, was used. The results will be used to mix the proper proportions for a hardness value with a Minimum Shore D value of not less than 80 within the target, which will significantly affect the hardness value test for testing in Equation 2. It will be in proportion to natural materials in the future.

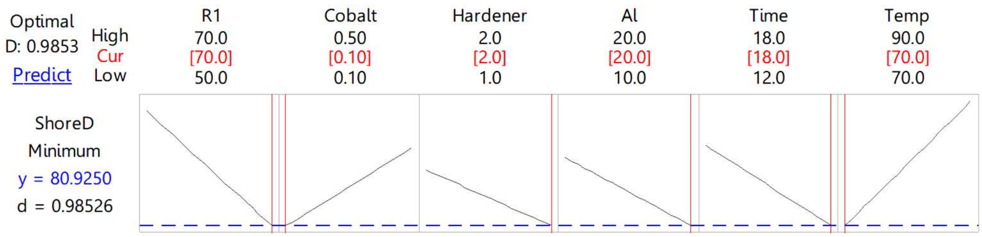


**Figure 3** An analysis of the composite material level of the specified optimum value.

According to the analysis results in Figure 3, the suitable level of factor values for the main factors expressed in the hardness value as the Shore D standard with the factors used in the second composite material experiment showed R1=70, Cobalt=0.01, Hardener=2.0, Al=20, Time=18, and Temp. =70, respectively.

4. Experimental steps to confirm results

The experiment results determined the proportion of the main composite material between resin and aluminum to confirm the results with the appropriate factor-level analysis values. The second experimental variable involved the addition of mixed materials with natural materials, such as pineapple leaf powder (Gorrepotu et al., 2023), wood ash powder, and sugarcane leaf powder. The experimental results show the hardness value Shore D in Table 5 below.

**Table 5** Results of experiments on mixing natural materials with the main composite material between resin and aluminum from Minitab.

| RunOrder | Al | Ashes | Pineapple | Sugar | ShoreD |
|---|---|---|---|---|---|
| 1 | 10 | 20 | 30 | 20 | 78.80 |
| 2 | 10 | 30 | 30 | 20 | 63.12 |
| 3 | 20 | 20 | 30 | 30 | 81.82 |
| 4 | 20 | 30 | 30 | 30 | 79.80 |
| 5 | 20 | 20 | 30 | 20 | 80.52 |
| 6 | 10 | 20 | 20 | 20 | 78.86 |
| 7 | 20 | 30 | 20 | 20 | 80.42 |
| 8 | 20 | 20 | 20 | 30 | 78.54 |
| 9 | 10 | 20 | 20 | 30 | 76.42 |
| 10 | 10 | 30 | 20 | 20 | 80.06 |
| 11 | 20 | 30 | 30 | 20 | 79.26 |
| 12 | 10 | 30 | 30 | 30 | 79.20 |
| 13 | 10 | 20 | 30 | 30 | 77.02 |
| 14 | 20 | 20 | 20 | 20 | 81.08 |
| 15 | 10 | 30 | 20 | 30 | 79.44 |
| 16 | 20 | 30 | 20 | 30 | 81.10 |

Table 5 shows the experiment results; they were used to test the proportion of natural materials mixed between resin and aluminum from Table 5 before analyzing the data distribution. The Normal Plot for the Standardized Effects data includes all 16 experiments showing the hardness value: Shore D. The data distribution is close to linear and accepts the hypothesis at the significance level of .05, as shown in Figure 4.

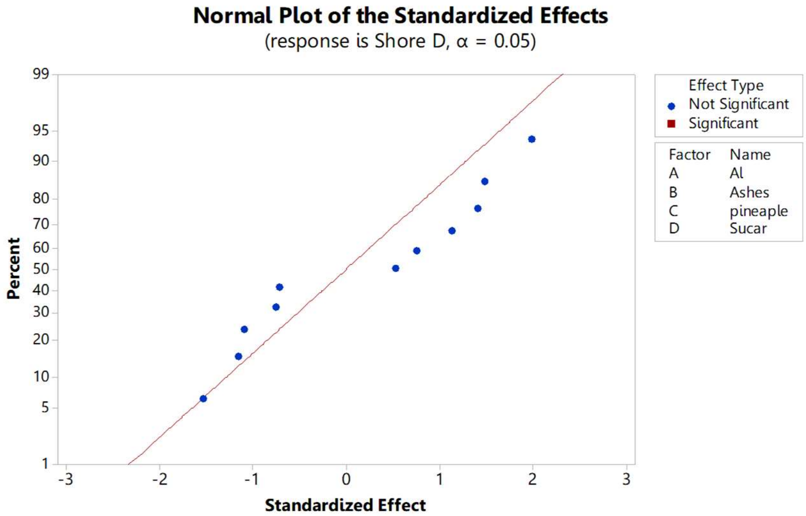


**Figure 4** Normal plot of the standardized effects.

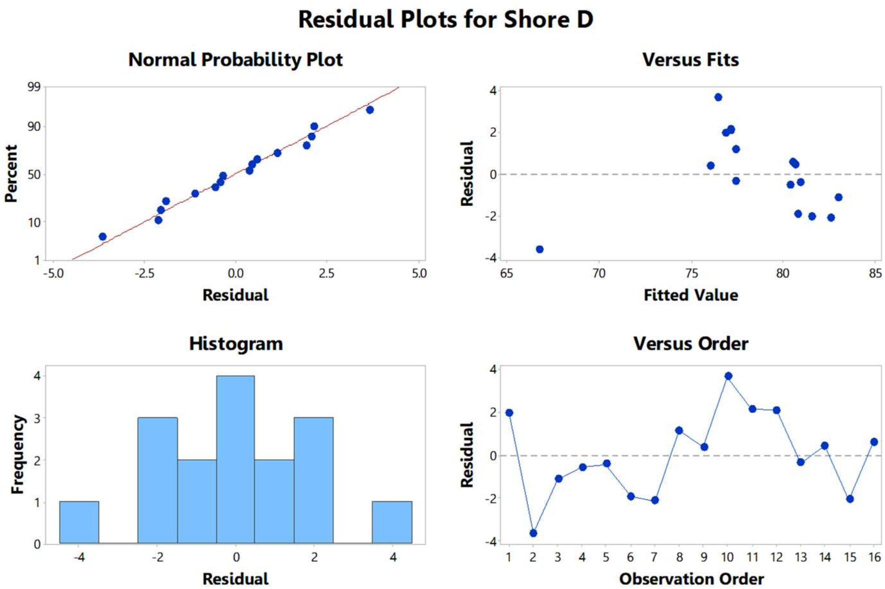


**Figure 5** Residual plots for shore D.

Figure 4 shows the normal plot of the standardized effects, it explains the value of the factors used in the experiment, and the response optimizer is 80.9250 of Shore D. The normal plot of the standardized effects in Figure 5 shows that although no factors are statistically significant, the standardized effects in the normal plot lie in an acceptable range close to the normal line. After testing with the main composite materials of resin and aluminum, the results are close to those of the response optimizer. Moreover, factors in the model had an effect but were not found to be significant, so variables can be controlled. Therefore, no effect values occur while the distribution is within the acceptable range, and it can be seen that the residual plots in the normal probability plot have a clustered distribution within an acceptable range and the histogram is a normal distribution. It can be concluded that the experiment confirms the results with reliable information, and are permissible.

## Conclusion

This experiment design research has aimed to study the rate of material mixing and experiment design using engineering experiment design principles with the $2^k$ full factorial test method. It has also determined the value of natural composite materials between resin and aluminum powder by comparing ash powder, pineapple fiber powder, and sugarcane leaf fiber powder. Moreover, this study went on to find the rates of composite materials using natural materials in proper proportions with application processes by analyzing and comparing statistically for the most suitable value of thermoforming under Shore D values.

The most suitable proportion of composite materials with the processes of the $2^k$ full factorial experiment is as follows: a hardness value not lower than or close to 80.00 Shor D under the 70 percent resin composite material (R1 ), 0.01 percent cobalt (Cobalt), 2.0 percent hardener, 20 percent aluminum powder, setting time 18 hours), and temperature 70 degrees Celsius. Consequently, the analysis of the response optimizer shows the Shore D value of 80.9250 when mixing natural materials with the main composite material between resin and aluminum. Lastly, it matches the decision coefficient R-sq equal to 83.72%, and it concludes that it can be adjusted the proper levels of factors in this experiment, and the value of Shor D will not be lower than the hardness values mentioned in the objectives.

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