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OPTIMAL COMPOSITION OF MIXED MATERIAL FOR THE THERMOFORMING PROCESS

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Abstract: *This research was analyzed the optimization of five parameters on thermoforming process namely; ratio of resin aluminum talcum (RAT), temperature and setting time by statistical method. The optimized ratio gave a contents of 50 grams resin, 24 grams aluminum, and 26 grams talcum, temperature between 70-90 degree Celsius and a setting time 7 hours. The results support the predicted value, where the optimal ratio is the maximum hardness is 86.5 Shore D. The RAT-composition material can save cost of 30% when comparing with other compositions on thermoforming process.*

Key words: *Resin aluminum talcum (RAT), hardness, thermoforming process, statistical analysis.*

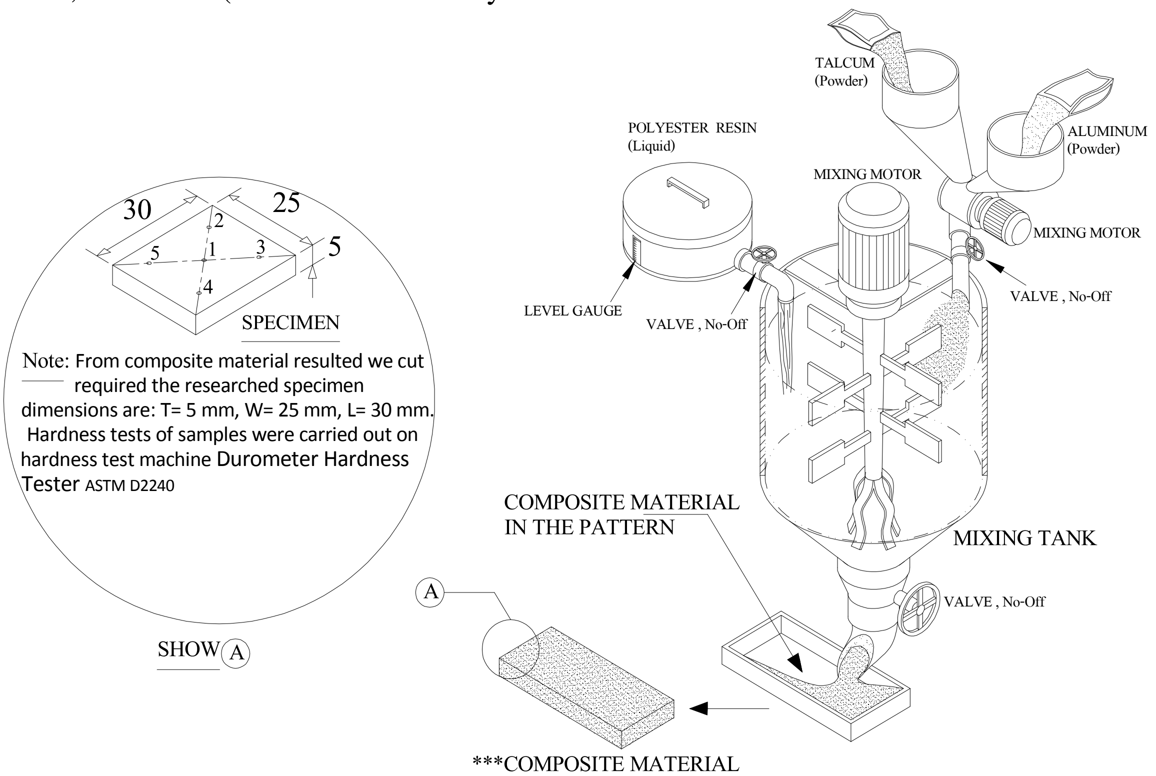
1. INTRODUCTION

Present manufacturing of plastics are being used to make everything from food packaging, electrical equipment, automotive body parts to human body parts. Each processing requires are experience manufacturing process that can a material for the part and mold based on specifications. Material composites suggest the feasibility to tailor the properties of a metal and polymer by adding a suitable reinforcement phase and to meet the demands in thermal management have been produced by powder metallurgy [1]. Composites are considered as one of the important examples of hierarchically organize structured materials. A part from textile composites, random fiber composites and multilevel composites also textiles, porous materials and biomaterials are being studied, both experimentally and by modeling [2]. Thermoforming molds for short term production or prototype can use molds made of non-metal such as wood, plastic, epoxy, on that inexpensive material, including mold making, it is quicker and easier. Cooling rate and temperature control and other attributes good of the thermoforming mold. To molds detail must also be able to evacuate all air trapped between the plastic part and molds surfaces. It can use of a making vacuum thermoforming mold providing vent holes at specific locations within the mold. [3].

In this case study used the Design Expert, a software application that shown the statistical techniques used for experiment design and interpretation in which many parameters can interfere. This software application offers the input parameters analysis possibility found in a process, a quick view for critical ones and interactions between them. This software also can make a numeric and graphic optimization, a process parameters deeper analysis and a process variable. Moreover, it allows a response surface shape graphical view under different model. [4][5] Response surface methodology (RSM) was employed to optimize the process. The experimental data were fitted to using multiple regression analysis and also examined using the appropriate statistical methods [6]. The essence of the material selection process is not to replace one material with another, but to select that material, which together with the associated processes provide a better solution. The main objective of this study was to material preparation and mixing materials process to achieve the desired properties for vacuum mold of thermoforming process.

2. MATERIAL AND METHOD

In this work, the objective is find the operating conditions of maximum hardness (HD) on thermoforming process which occur the optimization parameters (e.g. ratio of RAT, temperature and setting time). First step of material mixing, is fill the resin into the mixing tank rotating. Another step, add the talcum powder 325-1,250 mesh (or about the density 0.60 g/cm^3) and aluminum powder 100-300 mesh (or about the density 1.60 g/cm^3). After that, rotate the three materials about three minutes. The most important thing the ingredients of both materials over the polyester resin in a mixing tank rotate all the ingredients for another seven minutes. After all the ingredients are mixed together, pour the ingredients into the pattern leave to solidify in normal temperature. Finally, cut the specimen to the hardness test as shown in the Figure 1.



ig 1. Schematic of mixed process and specimen.

Thus, this study selected an optimized output product from hardness measurement. The specimen dimension were prepared 25x30x5 mm. Hardness tester was used the Durometer-ASTM D2240 and measuring method by Shore D type as shown in Figure 2. The RAT-composite material can be formed on vacuum mold by casting process as shown in Figure 3.

Fig 2. Durometer-ASTM D2240.

Fig 3. Vacuum mold for plastic plate.

3. EXPERIMENTAL

In this research, this research was found the optimized condition of thermoforming parameters by response surface methodology (RSM). These parameter were ratio of resin aluminum talcum (RAT), temperature and setting time which called independent variables.

The response variable of experiment was maximum hardness (HD). In RSM, the choice of parameters is generally achieved by designing experiments and numerical analysis is repeated as many times as are set out in planning experiments. RSM should be noted that an optimal solution depends on the precision accuracy of response surface approximation.

Then, based on these results, response surface is constructed. Experiment planning purpose is to establish values of independent variables so their variation in space can be taken advantage. When using RSM, the first phase of establishing the conditions for optimization initial, then the RSM is establishing among independent variables, response and maximum desirability function (D-value).

To achieve experimental data agent of the hardness of RAT-composite material, they applied the factorial design. Following introduction of the minimum values of independent variables that will give maximum number of 46 experiments (virtual experiments, numerical simulation).

After completion of the 46 experiments and numerical analysis, we determined the values of the dependent variable (thermoforming parameters) as shown in Table 1. Data corresponding response variable (hardness: HD), last column on the right in Table 1 was entered manually from the computer keyboard.

Table 1.
Thermoforming data for statistical analysis by RSM.

NO.	Resin (A) (%)	Al (B) (%)	Talcum (C) (%)	Temp. (D) (℃)	Setting time (E) (Hour)	HD (Shore D)
1	60	19	21	90	8.5	84.79
2	50	24	26	90	8.5	86.86
3	60	24	16	90	7	85.55
4	55	19	26	70	10	84.76
5	70	14	16	90	8.5	83.99
6	55	24	21	90	7	86.44
7	70	14	16	70	10	83.71
8	60	14	26	80	7	84.64
9	55	24	21	90	10	86.63
10	60	19	21	70	10	84.68
11	60	24	16	70	7	85.27
12	60	14	26	70	8.5	83.92
13	50	24	26	70	7	85.96
14	65	14	21	70	7	83.89
15	55	19	26	90	7	85.75
16	50	24	26	90	10	86.11
17	50	24	26	80	8.5	86.65
18	70	14	16	80	10	83.79
19	70	14	16	70	7	83.65
20	60	24	16	70	10	86.61
21	60	24	16	90	10	86.31
22	50	24	26	90	7	86.62
23	60	14	26	70	7	83.81
24	60	24	16	80	8.5	85.46
25	50	24	26	70	10	86.08
26	60	14	26	90	7	84.33
27	60	24	16	80	7	85.53
28	55	19	26	90	10	85.35
29	60	14	26	70	10	84.7
30	60	14	26	90	10	83.68
31	70	14	16	90	7	83.26
32	70	14	16	90	10	84.02
33	60	19	21	80	7	85.59
34	55	19	26	80	10	84.68
35	65	14	21	80	8.5	83.97
36	55	19	26	70	7	84.48
37	70	14	16	70	8.5	83.84
38	50	24	26	70	8.5	86.42
39	60	24	16	70	8.5	85.57
40	70	14	16	80	7	83.8
41	50	24	26	80	7	86.61
42	55	19	26	80	10	84.87
43	55	19	26	90	7	84.89
44	60	14	26	70	7	84.63
45	60	19	21	80	7	84.66
46	55	24	21	90	10	86.45

4. OPTIMIZATION MODEL AND RESULT

To decide on model best analyze the mathematical relationship among dependent variable and response variable were used the F-test of statistical, coefficient of determination (R^2) and adjusted factor of determination (R^2adj). The result of analysis of variance (ANOVA) was exhibited in Table 2, that mathematical models are compared for maximum hardness. Every source was examined probability ("Prob> F") in order to see. If it exhibited < 0.05, a value which represents maximum admissible level of statistical significance. As can be seen (see Table 2), in addition Linear x Linear model is the highest R^2adj, P-value < 0.05 and lack of fit > 0.05. Based on the mixed model between linear of mix order with linear of process, chosen best model for thermoforming process.

Table 2.

Comparison the optimization model for thermoforming process

Mix Order	Process Order	Mix P-value	Lack of Fit	Adjusted R-Squared	Predicted R-Squared
Linear	***Linear***	***< 0.0001***	***0.9126***	***0.8874***	***0.8561***
Linear	2FI	< 0.0001	0.9058	0.8849	0.8294
Linear	Quadratic	< 0.0001	0.855	0.87	0.7612
Linear	Cubic	< 0.0001	0.8453	0.8664	0.6651
Quadratic	Linear	0.4502	0.9195	0.8879	0.7834
Quadratic	2FI	0.5306	0.9071	0.8823	0.6342

Subsequent creating the type of mathematical model for approximating the dependent variables, inspected whether each term of significance in model. The most concerted criterion in order to cut-off the term of significance was based on partial F-test. In Table 3 the result of ANOVA was indicated the adequately mixed model between linear of mix order with linear of process for thermoforming process. The term "sample F-test is smaller than 0.0001 (see Table 3). Therefore only a 0.01% probability that average model lie outside the confidence interval (see Table 3). The value of Prob> F-test is less than 0.05 and indicates that model terms are significant. In this work, all the terms BE, and CE are significant terms of the model (see Table 3). Moreover, the value of Prob> F-test of lack of fit is more than 0.05 (see Table 3) this model appropriate.

Table 3.

Combined model mixture process fit summary for composite material for thermoforming mold.

Source	Sum of Squares	df	Mean Square	F-value	p-value Prob > F
Model	46.06149	8	5.757687	45.33735	< 0.0001
Linear Mixture	43.96803	2	21.98401	173.1072	< 0.0001
AD	0.014218	1	0.014218	0.111954	0.7398
AE	0.304805	1	0.304805	2.400103	0.1298
BD	0.35384	1	0.35384	2.786216	0.1035
BE	0.597716	1	0.597716	4.70655	0.0365
CD	0.017231	1	0.017231	0.135682	0.7147
CE	1.045565	1	1.045565	8.233019	0.0068
Residual	4.698872	37	0.126997		
Lack of Fit	3.526172	32	0.110193	0.469826	0.9126
Pure Error	1.1727	5	0.23454		
Total	50.76037	45			

The optimization result of regression equation for a maximum hardness (HD) mathematical model of thermoforming process:

$$
\begin{aligned}
HD = {} & 80.09806(A) + 75.55762(B) \\
& + 101.9705(C) - 0.044102(AD) \\
& + 0.40693(AE) + 0.17168(BD) \\
& + 1.47947(BE) + 0.017029(CD) \\
& - 2.27917(CE)
\end{aligned}
$$

In Figure 4, a response surface is graphically propose and corresponds to regression equation for hardness mathematical model.

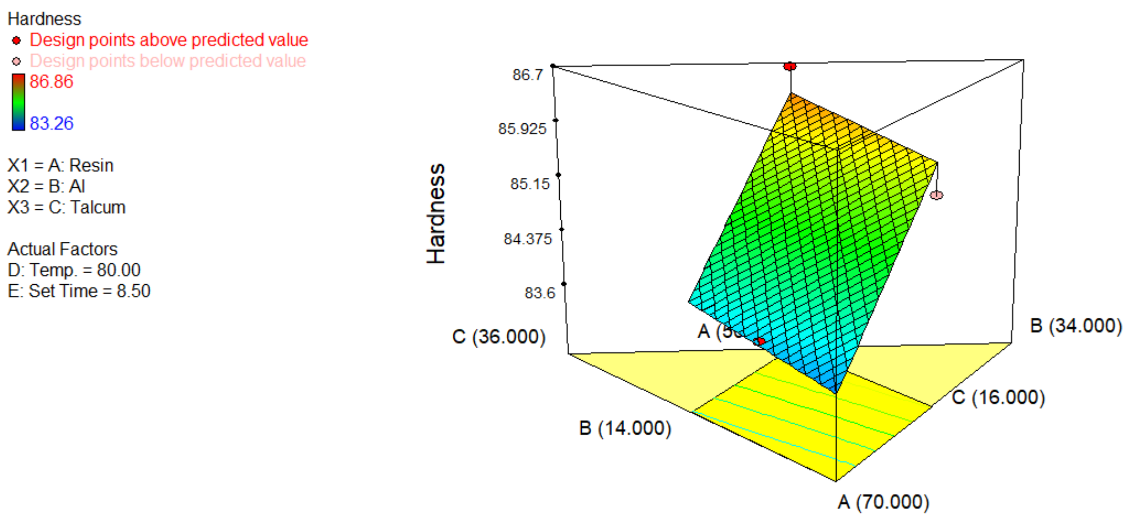


Fig 4 The response surface of hardness mathematical model.

In the satisfactory analysis of the experiment, in order to obtain maximize hardness shown in Table 4, After these figures were imported to the response surface metrology, the satisfactory dimension of the experiment is presented as in Figure 5.

Table 4.

Identifications of the goals for proper variables for maximum hardness

Resin (A) (%)	Al (B) (%)	Talcum (C) (%)	Temp. (D) (°C)	Setting time (E) (Hour)	HD (Shore D)	Desirability
50	24	26	90	7	84.79	0.922

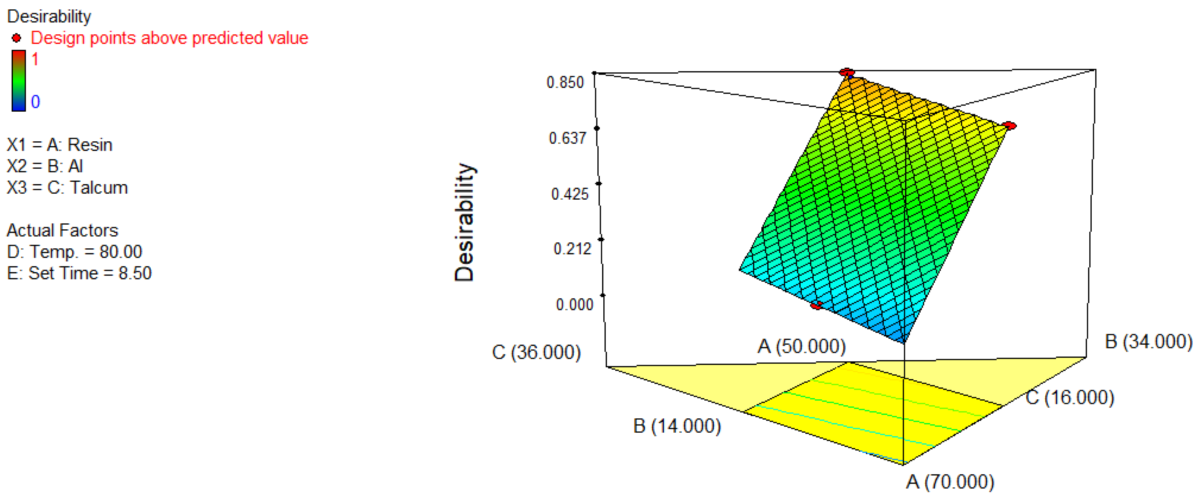


Fig 5 The response surface of Desirability.

5. CONCLUSION

Subsequent hardness measurement on the RAT-composite material affair to the explained mixed condition, the data generated by RSM was used in this inquisition as shown in Table 1. The result of ANOVA as shown in Table 2 were used to analyze the effect the maximum hardness from parameter of RAT-composition thermoforming process. Therefore, all main effects and some interaction effects were statistically significant at the 0.05 level (p-values < 0.05). A coefficient of determination value of R^2 was observed. Thus, the optimized model was indicated the reliability of response variable about 67.29%. Annotation that the coefficient of determination (R^2) procures the ratio of the total variation in the response variable and it is explained by using the procedure parameters that comprise in the model.

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Compoziția optimă a materialului mixt pentru procesul de termoformare

Rezumat: Această cercetare a fost realizată pentru a proiecta și analiza experimentul pentru a găsi compoziția optimă a matritelor mixte pentru termoformare pentru plăcile din plastic folosind procedeul de vid. Experimentele au folosit metoda de proiectare a procesului de amestecare combinată, care a fost utilizată pentru a determina raportul optim al Talcului de aluminiu rezistent (RAT), temperatura şi timpul de setare, fiind 46 de experimente pentru acest design. Raportul optimizat a dat un conținut de 50 grame de rășină, 24 de grame de aluminiu și 26 de grame de talc, o temperatură între 70-90 grade Celsius şi un timp de fixare de 7 ore. Rezultatele susțin valoarea estimată, unde raportul optim este puterea maximă de duritate. Rezistența maximă la duritate este 86,5 Shore D. Materialul amestecat poate economisi 30% din costul când se compară între RAT şi metal sunt utilizate pentru formarea termoformării în procesul de vacuum din placă din material plastic.

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