

Response Surface Methodology Approach to Recycling Aluminium Chips AA6061 by Optimum Hot Extrusion Parameter

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Abstract: A method for recycling aluminium alloy chips by hot extrusion was studied as well as the possibility of using to recycle aluminium chips. As a result, according to an ANOVA analysis, preheat temperature is the most significant factor influencing the response variables investigated. Preheat temperature and the quadratic effect of factor preheat temperature provided a primary contribution to the responses investigated. Additionally, factor preheat time did not provide a significant contributing factor to the Ultimate Tensile Strength. This developed the Response Surface Methodology (RSM) model for ER12, which can now be used for analysis and predicting the Ultimate Tensile Strength for recycling aluminium chip using the hot extrusion process. The Miscellaneous Design and Response Surface Methodology enabled the determination of optimal operating conditions for obtaining hot extrusion production. The optimization of the analyzed responses demonstrated that the best results for hot extrusion process parameter. It reveals the empirical models developed were reasonably accurate, particularly for UTS at 550°C temperature and 3 hours preheating time. All the actual values for the confirmation run are within the 95% prediction interval.

Key-word: *Recycling Aluminium, Hot Extrusion, Response Surface Methodology, Optimization*

1. INTRODUCTION

The extrusion process capitalizes on the built-in advantages in aluminium and increases their use and applications. Repeating the experiment to achieve desired optimized extrusion process condition will be expensive and time-consuming. For improving recyclability of aluminium there are some areas should be focused for instance ram speed (V_r), preheat temperature (T) and preheat time (t) in the recycling of aluminium. Study for modelling of hot extrusion parameter process are not really established especially for optimization method. Extrusion ratio is another parameter that was considered which is influenced by using a higher or lower ratio for optimizing the extruded aluminium [1]. By using though the flat-face die, an ER of lower than 4 did not guarantee sufficient chip bonding. While at the higher extrusion ratio ($ER > 10$),

the extruded profiles were found to gain superior strength and ductility [2]. It is also stated that at high extrusion ratio, excessive strain, high compressive pressure and high shear forces can be imposed on the extruded profiles.

Moreover, a mathematical modeling technique was used to determine the optimum extrusion parameters with respect to various objectives and response criteria [3]. Furthermore, it helps us to obtain the surface contour that provides a good way of visualizing the parameter interaction. RSM uses statistical models, and therefore practitioners need to be aware that even the best statistical model is an approximation to reality. The idea behind the RSM is building an approximate functional relationship between the input variables and the output objective [4]. Among the objectives of the RSM not only to investigate the response over the entire space, but also to detect areas of interest in which the reaction reached optimum or near the optimum value.

1.1 Aims and Objectives

This study is to explore the effects of hot extrusion parameters and die performances (Extrusion ratio 12) in the solid-state recycling of aluminium AA6061 which specifically focused on the following objectives:

- i) To investigate the mechanical properties for both recycled and originally based of aluminium billet AA6061.
- ii) To develop a modeling and optimization on the effects of hot extrusion parameter over the mechanical properties responses by employing the Response surface methodology (RSM).

1.2 Scope of Works

The scope of this study is to investigate were:

- i) Ram Speed, Vr (1 mm/s constant), Preheat temperature, T (450°C, 500°C & 550°C) and the Preheat time, t (1, 2 & 3 hours).
- ii) Modelling and optimization of the extrusion quality characteristics through the use of 3 Level Factorial Design (2 factors, 3 levels), Miscellaneous Response surface methodology (RSM) optimization method.

2. METHODOLOGY

2.1 Experimental Design with Miscellaneous RSM

The experimental design of the research work consisted of two phases. During the first phase, experimentation is performed in the full factorial design whereby three main parameters (i.e. preheat time and preheat temperature) were being chosen whereas experiments incorporating miscellaneous RSM were conducted in the second phase. For the second phase, the experimental runs were designed based on the Miscellaneous RSM. The total number experiments for full factorial design is 9 (2 factors and 3 levels) whereby for RSM with three center point is 11 (Rahim S. N. *et. al*, 2017). Table 2.1 shows the experimental design with RSM. Linear and quadratic models are directly generated from the Design Expert software after ANOVA analysis. In the optimization process, a technique called Desirability Function (DF) was applied to generate the contour plot of the feasible region with respect to the responses and parameter constraints.

Table 2.1 : Experimental design with Miscellaneous RSM

Run No	Std. Run	Block	Ram Speed, (Vr) (mm/s)	Preheat Temp. (T)(°C)	Preheat Time, (t)(h)	Ultimate Tensile Strength (UTS)(MPa)
1	10	1	1	550	2	
2	9	1	1	400	1	
3	7	1	1	550	1	
4	6	1	1	500	2	
5	1	1	1	500	2	
6	4	1	1	400	3	
7	3	1	1	500	2	
8	8	1	1	500	1	
9	5	1	1	550	3	
10	12	1	1	400	2	
11	2	1	1	500	3	

3. RESULTS AND DISCUSSION

3.1 Modelling and Optimization by using RSM (ER12)

A predictive model for mechanical properties and physical properties of extrusion for ER 12 have been developed and presented in this chapter. RSM was used to identify the factors that influenced the main responses such as Ultimate Tensile Strength (UTS), elongation to failure (%) and hardness (HV). Additionally, these relationships were quantified using empirical modelling. Table 2.2 shows the Design of Experiments matrix and results in the hot extrusion process.

Table 2.2 : Experimental result of response surface methodology (RSM)

Run No	Ram Speed (mm/s)	Preheat Temp. (° C)	Preheat Time (h)	Ultimate Tensile Strength (Mpa)
1	1	500	2	159.93
2	1	450	1	169.58
3	1	500	1	146.06
4	1	550	2	185.45
5	1	450	2	171.46
6	1	550	3	189.20
7	1	500	2	150.58
8	1	450	3	175.72
9	1	500	3	163.50
10	1	550	1	169.74
11	1	500	2	160.25

The corresponding data on the three response variables were evaluated and recorded as shown on the right hand column of Table 2.3. The 11 experiments were conducted in the average value of the ultimate tensile test (UTS), elongation (%) and hardness (HV). Analysis of variance (ANOVA) was performed for this purpose. The Model F-value of 19.75, which implies the model is significant. There is only a 0.26% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicates model terms are significant. In this case, A, B and A² are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), the model reduction may improve that model. The "Lack of Fit F-value" of 0.27 implies that the Lack of Fit is not significantly relative to the pure error. There is an 84.58% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good where it makes the model to fit. The values of R² and adjusted R² are over 90%. This means that regression model provides an excellent explanation of the relationship between the independent variables (factors) and the response (UTS). The associated p-value for the model is lower than 0.05 (i.e. $\alpha = 0.05$, or 95% confidence) which indicates that the model is considered to be statistically significant (Montgomery et al., 2008). The lack-of-fit term is non-significant as it is desired. Furthermore, factor A (temperature) and factor B (preheat time), and second order term of factor A (temperature) have a significant effect. These significant effects, in descending order, are factor A (temperature) and the quadratic effect of factor A (temperature). This situation demands that appropriate second order or quadratic terms should be included in the model with which the variability of the predictive equation could be better explained. The result proves that the preheat temperature enhances the UTS [2][6][7]. Other model terms are said to be non-significant.

Table 2.3 : ANOVA table for UTS (before modified second order)

Source	Sum of squares	Degree of freedom	Mean square	f-Value	Prob > f	
Model	1672.72	5	334.54	19.75	0.0026	significant
A-Temp	127.24	1	127.24	7.51	0.0408	
B-Time	308.74	1	308.74	18.23	0.0079	
AB	44.36	1	44.36	2.62	0.1666	
A ²	1160.25	1	1160.25	68.49	0.0004	
B ²	13.1	1	13.1	0.77	0.4194	
Residual	84.7	5	16.94			
Lack of Fit	24.35	3	8.12	0.27	0.8458	not significant
Pure Error	60.34	2	30.17			
Cor. Total	1757.42	10				
Standard deviation = 4.12			R ² = 0.9518			
Mean = 167.41			R ² adjusted = 0.9036			
Coefficient of variation = 2.46			Predicted R ² = 0.7899			
Predicted residual error of sum of square (PRESS) = 369.31			Adequate precision = 14.371			

The fit summary recommended that the quadratic model is statistically significant in the analysis of UTS. The results of the quadratic model for UTS in the form of ANOVA are given in Table 2.3. To fit the quadratic model for UTS appropriate, the non-significant terms are eliminated from the backward elimination process. The ANOVA table for the reduced quadratic model for UTS is shown in Table 2.4. The reduced model results indicate that the model is significant (R² and adjusted R² are 91.91% and 88.44%, respectively), while lack of fit is non-significant (p-value is less than 0.05). The predicted R² is 78.66%. Figure 2.1 displays the normal probability plot of the residuals for UTS. Residuals fall in a straight line, which means that the errors are normally distributed. Furthermore, each observed value is compared with the predicted value calculated from the model in Figure 2.2. It can be seen that the regression model fits fairly well with the observed values [8]. After eliminating the non-significant terms, the final response equation for UTS is given as follows with the statistical significance of Eq. 2.1.

(In actual factors)

$$UTS = 2175.101 - 8.226T + 7.173t + 0.0083T^2 \dots(2.1)$$

Table 2.4 : ANOVA table for UTS (after modified of second order)

Source	Sum of squares	Degree of freedom	Mean square	f-Value	Prob > f	
Model	1615.26	3	538.42	26.51	0.0003	significant
A-Temp	127.24	1	127.24	6.27	0.0408	
B-Time	308.74	1	308.74	15.2	0.0059	
A ²	1179.28	1	1179.28	58.07	0.0001	
Residual	142.16	7	20.31			
Lack of Fit	81.81	5	16.36	0.54	0.7487	not significant
Pure Error	60.34	2	30.17			
Cor. Total	1757.42	10				
Standard deviation = 4.51			R ² = 0.9191			
Mean = 167.41			R ² adjusted = 0.8844			
Coefficient of variation = 2.69			Predicted R ² = 0.7866			
Predicted residual error of sum of square (PRESS) = 375.08			Adequate precision = 14.626			

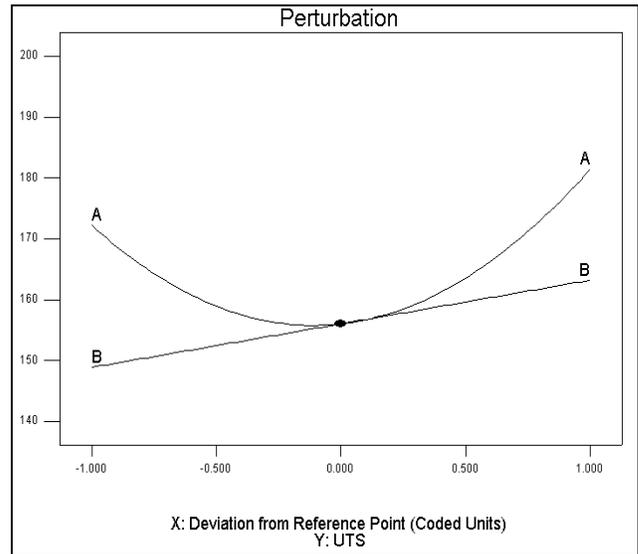


Figure 2.3 : Perturbation plot for UTS

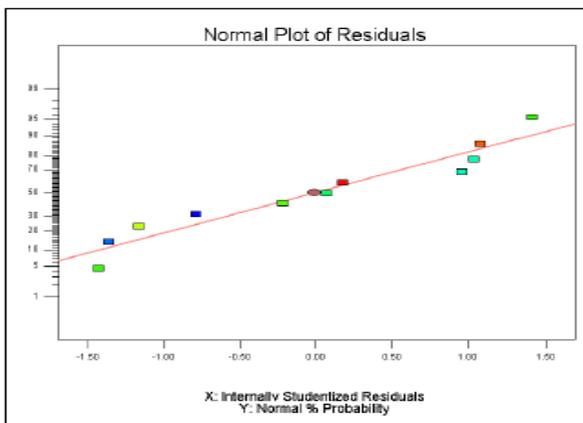


Figure 2.1 : Normal probability plot residuals for UTS

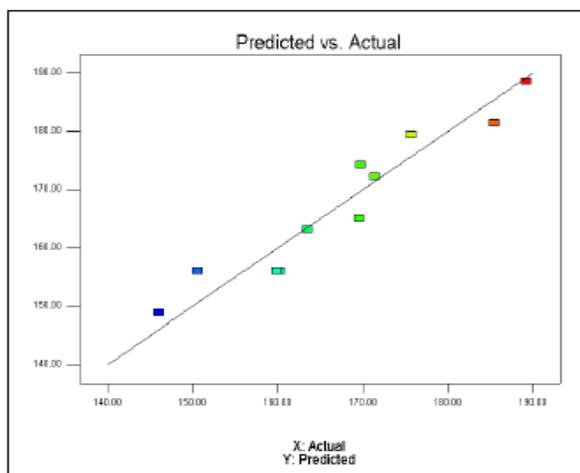


Figure 2.2 : Plot of actual vs. Predicted the response of UTS

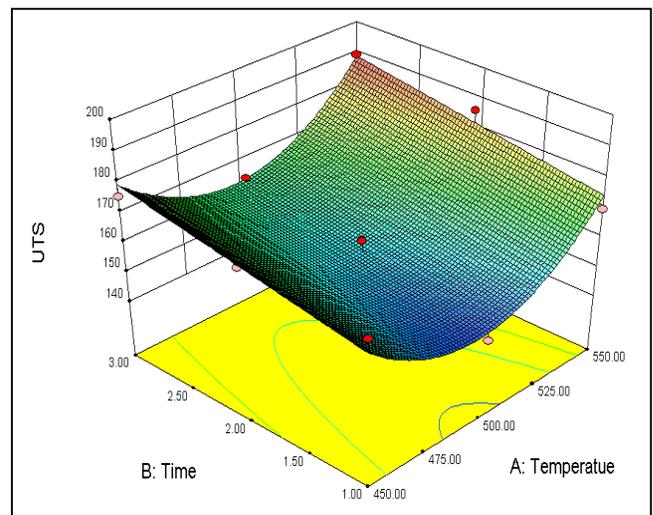


Figure 2.4 : Effect of temperature and preheat time on UTS

Determination of optimal extrusion parameters by using optimization techniques is a continuous engineering task with the main aim to reduce production cost and achieve the desired product extrusion, the forming conditions play an important role in the efficient use of a machine tool. Since the cost of the extrusion process is sensitive to the quality [10]. In the forming process such as forward forming conditions maximum values have to be determined before a part is put into production. Preheating time has a minor influence on UTS while increase of extrusion temperature causes its increment. These results occur probably due to solid solution strengthening effect [11].

4. CONCLUSION

The effect of the invention prior to the heating temperature and heating time using hot extrusion process in extrusion ratio of 12 are :-

- i. According to an ANOVA analysis, results showed that preheat temperature is the most significant factor influencing the response variables investigated.
- ii. Factor A (preheat temperature) and the quadratic effect of factor A (preheat temperature) provided a primary contribution to the responses investigated. When the temperature increased, ultimate tensile strength increased too.
- iii. This empirical model can be used for analysis and predicting the UTS for recycling aluminium chip using the hot extrusion process. 3D surface counter plots are useful in determining the optimum condition.
- iv. Response surface optimization showed that the optimal combination of extrusion parameters is (550°C, 3 hours) for temperature and preheat time respectively.

5. Limitation and recommendation

From this study, a comprehensive knowledge about recycling aluminium alloy regarding the sustainability has been issued. Further research should focus on combination with other hot extrusion machine parameters to get better results (extrusion speed, extrusion ratio, type of die, porthole, and ECAP) and also combination of reinforcing agents (alumina, magnesium, aluminium pure).

REFERENCES

- [1] Misiolek, W. Z., Haase, M., Ben Khalifa, N., Tekkaya, a. E., & Kleiner, M. (2012). *High quality extrudates from aluminum chips by new billet compaction and deformation routes*. CIRP Annals - Manufacturing Technology, 61(1), 239–242. <https://doi.org/10.1016/j.cirp>.
- [2] Chiba, R., & Yoshimura, M. (2015). *Solid-state recycling of aluminium alloy swarf into c-channel by hot extrusion*. Journal of Manufacturing Processes, 17, 1–8. <https://doi.org/10.1016/j.jmapro.2014.10.002>
- [3] Rahim, S. N. A., Lajis, M. a., & Ariffin, S. (2015). *A Review on Recycling Aluminum Chips by Hot Extrusion Process*. Procedia CIRP, 26, 761–766. <https://doi.org/10.1016/j.procir.2015.01.01>
- [4] Kamaruzaman, A. F., Zain, A. M., & Yusof, N. M. (2016). *Optimization of Machining Parameters for Minimization of Roundness Error in Deep Hole Drilling using Minimum Quantity Lubricant, 1024*.
- [5] Rahim, S. N. A., & Lajis, M. A. (2017). *Effects on Mechanical Properties of Solid State Recycled Aluminium 6061 by Extrusion Material Processing, 730, 317–320*. <https://doi.org/10.4028/www.scientific.net/KEM.730.317>
- [6] Schikorra, M., Donati, L., Tomesani, L., & Tekkaya, a. E. (2008). *Microstructure analysis of aluminum extrusion: Prediction of microstructure on AA6060 alloy*. Journal of Materials Processing Technology, 201(1–3), 156–162. <https://doi.org/10.1016/j.jmatprotec.2007.11.160>
- [7] Chanda, T., Zhou, J., & Duszczyc, J. (2001). *A comparative study on iso-speed extrusion and isothermal extrusion of 6061 Al alloy using 3D FEM simulation*. Journal of Material Processing Technology, 114, 145–153.
- [8] A. Ahmad, M. A. Lajis, N.K. Yusuf, S. Shamsudin, Z.W. Zhong (2017), Parametric Optimisation of Heat Treated Recycling Aluminium (AA6061) by Response Surface Methodology, AIP Conference Proceedings 1885, 020046 (2017); doi: 10.1063/1.5002240,
- [9] Rahim S.N., Abdullah Faris N.A., M.A. Haron, Lajis M.A., Z.Shayfull (2019), *Optimum parameters by miscellaneous response surface of solid-state recycling of AA6061 chips*, AIP Conference Proceedings 2129.020010.
- [10] Rasyid, M. F. A., Akil, M. S. S. H. M., & Ishak, Z. A. M. (2016). *Optimization of Processing Conditions Via Response Surface Methodology (RSM) of Nonwoven Flax Fibre Reinforced Acrodur Biocomposites*. Procedia Chemistry, 19,

469–476. <https://doi.org/10.1016/j.proche.2016.03.040>

- [11] Lela, B., Krolo, J., & Jozi, S. (2016). *Mathematical modeling of solid-state recycling of aluminum chips.* <https://doi.org/10.1007/s00170-016-8569-5>