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RESEARCH PAPER

SELECTION OF OPTIMUM POURING CONDITIONS FOR IMPROVEMENT OF ALUMINUM ALLOY CASTINGS IN GHANA

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ABSTRACT

It has been discovered that the pouring conditions (temperature of the molten aluminum alloy and pouring speed) have effects on the mechanical properties of the cast aluminum alloy, either directly or indirectly. This paper develops a model to predict the effect of pouring conditions on the mechanical properties of the cast Aluminum alloy. In this work a 2^2 factorial design was applied to investigate the effects of temperature of the molten aluminum alloy and pouring speed on three mechanical properties, namely; the hardness, ultimate tensile strength, and elongation. The developed models were used to select optimum pouring conditions for the improvement of the Aluminum alloy in manufacturing companies in Ghana. The study revealed that increasing the pouring conditions causes the hardness to decrease as well as the ultimate tensile strength, and elongation. Also, the two – factor interaction effect of the pouring speed and temperature of the molten aluminum alloy on hardness is significant as the interaction effect decreases with increase in hardness but has insignificant effect on the elongation and the ultimate tensile strength. It is established that the optimal pouring conditions to improve the mechanical properties for the production of the Aluminum alloys are 2 cm/s for the pouring speed and 700°C for the temperature of the molten aluminum alloy producing a hardness of 61 HB, ultimate tensile strength of 115 N/mm² and 17 % elongation.

Keywords: Pouring conditions, 2^2 factorial design, hardness, ultimate tensile strength, elongation.

INTRODUCTION

The production of aluminum rods in some companies in Ghana often fails to meet the desired mechanical specifications of their clients which affects the productivity and growth of these companies. It has been discovered that hardness, percentage elongation, percentage reduction in diameter, durability, and other mechanical properties of cast materials are all affected by melting and pouring conditions (Pius, 2000).

In a paper presented by Ndaliman and Pius (2007) it was indicated that pouring temperatures and speeds have an effect on the mechanical properties of aluminum alloy castings. The findings revealed that, when the hardness and strength were 65.4 HB and 127 N/mm^2, the optimum pouring speed was in the range of 2.2 cm/s and 2.8 cm/s. Also, lowering the pouring temperatures (750°C to 700°C), close to the melting temperature (660°C) of the alloys, provided good quality castings and high mechanical properties (Ndaliman and Pius, 2007; Ager, 2014).

In an experiment conducted by Shailesh *et al*. (2014) to assess the effects of pouring temperature on grain refinement and consequential mechanical properties of 4600 Al alloy casting, it was revealed that a higher pouring temperature produces coarse grain structure and decrease in the mechanical properties.

The effect of pouring temperature on microstructural evolution, mechanical, and electrical properties of cast AA6063 proved that the ultimate tensile strength of as-cast samples increases with increasing pouring temperature, peaking at 106 MPa at 740°C (Adeosun *et al*., 2013). In an investigation of effect of processing factors on the characteristics of centrifugal casting, Mohapatra *et al*. (2020) established that grain refining increases the mechanical properties of a casting. The grain size of the cast metal and the temperature at which it is poured are inextricably linked. By enhancing the cooling effect, a lower pouring temperature results in smaller grain size and decreased dendritic arm spacing (DAS). On the other hand, using a higher pouring temperature increases the solidification time, allowing the nuclei to expand over a longer period of time, resulting in a coarse columnar grain structure.

2^2 factorial design is one of the most important model in the framework of experimental design theory (Antony, 2002). It has been deduced from literature that previous works done in the area of aluminum alloy castings under different pouring conditions by some researchers relied on one-factor-at-a-time (OFAT) experiments. However, OFAT experiments can prove to be ineffective and unreliable, leading to false optimal condition (Antony and Capon, 1998; Antony, 2002). This is because in the OFAT approach, typically, only two observations are used to estimate the effects of a factor (i.e., by keeping other factor levels constant). However, in many situations, the effects of a factor change when the conditions of other factor vary. The correct approach in dealing with several factors is to conduct a factorial experiment (Montgomery, 2017).

Unlike OFAT, factorial design allows the experimenter to analyze the importance of main and interaction effects among the factors considered for the experiment (Czitrom V., 1999; Antony, 2002; Montgomery, 2017). The factorial design approach provides a better optimization strategy than the OFAT approach (Antony, 2002). By using the factorial design approach, a mathematical model can be developed which represents the relationship between the response and a set of key factors and interactions which are most important to the process. By carefully studying this model, the setting of factors can be manipulated to achieve a pre-determined target performance for the response of interest (Antony, 2002).This research therefore seeks to develop a model to predict the effects of pouring temperature and pouring speed on the tensile properties of the cast aluminum alloy and to validate test results with the prediction model.

MATERIALS AND METHODS

Material

The sample engaged for this research is cast aluminum alloy. The type of the cast aluminum alloy used was an P1020 aluminum alloy with a chemical composition as shown in Table 1.

Table 1: Chemical composition of P1020 Aluminum Alloy

Composition	Percentage %
Silicon	0.1
Iron	0.2
Aluminum	99.7

Selection of Pouring Parameters

In this study, casting experiments were planned using statistical two-level full factorial experimental design. Casting experiments were conducted considering two pouring parameters: Pouring Speed (cm/s) and Pouring Temperature (°C) and overall, 8 experiments were carried out. Table 2 shows the values of various parameters used for experiments:

Table 2: The Experimental matrix

Variables	Lower Level	Upper Level
Pouring Speed (cm/s)	2	8
Pouring Temperature (°C)	700	750

Experimental Method

Molten aluminum was transported from Volta Aluminium Company Limited (VALCO) and kept in a furnace at a temperature range of 680°C to 700°C. During the processing of alumina at VALCO, an inherent impurity was generated which makes it important for further treatment of the molten aluminum to meet the specification of the aluminium rod manufacturer, Western Rod and Wire Limited. A commercial degasser for aluminum alloys, ALU flux was used in the treatment to remove dissolved hydrogen from the metal. Subsequently, a cover flux was used to separate the molten metal from other non-metallic inclusions. The degasser was added to the molten metal to help remove the hydrogen at a temperature range of 730°C to 750°C for a time duration of 15 minutes. After degassing was done, the molten metal was skimmed to remove dross from the surface of the molten metal. After these processes, the molten aluminum was ready to be casted.

At the first run setting conditions (point 3), the molten metal of 750°C pouring temperature was filled into the mold at a constant pouring speed of 2 cm/s to avoid turbulence in the mold. The mold was left to cool for about an hour before the samples were taken from the molds. Three samples were produced by each mold. The casts were then tested for their mechanical properties using Tensile testing machine and Rockwell hardness test. The responses for Ultimate Tensile Strength (UTS), Elongation, and Hardness were measured and recorded. The process was repeated for the remaining set of conditions and the results were tabulated and presented in Table 3. The experiments were conducted at respective sets of the pouring speed and pouring temperature as indicated in Table 3. This implies that there are $2^2 = 4$ experimental conditions. The experiments were replicated twice, yielding a total of 8 experimental runs.

Table 3: Experimental Results

Runs	Points	Code		Uncoded		Mechanical Properties		
		PS	PT	PS (cm/s)	PT (°C)	Hardness (HB)	UTS (N/mm^2)	Elongation (%)
3	1	-	-	2	700	60	114	16
5	2	+	-	8	700	59	105	9
1	3	-	+	2	750	53	108	14
7	4	+	+	8	750	41	90	9
6	5	-	-	2	700	62	116	18
2	6	+	-	8	700	57	103	11
8	7	-	+	2	750	52	104	12
4	8	+	+	8	750	43	84	8

Since the experiments were replicated twice at the same setting conditions (i.e., point 1 and 5), the averages were computed for the 3 response and used to represent each setting condition as tabulated and presented in Table 4.

Table 4: Computed means for Hardness, Ultimate tensile strength and Elongation

Points	Code		Hardness (HB)			Ultimate tensile strength (N/mm2)			Elongation (%)		
	PS	PT	Run 1	Run 2	Mean	Run 1	Run2	Mean	Run 1	Run 2	Mean
1	-	-	60	62	H_1=61	114	116	U_1=115	16	18	E_1=17
2	+	-	59	57	H_2=58	105	103	U_2=104	9	11	E_2=10
3	-	+	53	52	H_3=52.5	108	104	U_3=112	14	12	E_3=13
4	+	+	41	43	H_4=42	90	84	U_4=87	9	8	E_4=8.5

Note:(-) represents the lower level of the variables, (+) represents the upper level of the variables, PS and PT represent the variables pouring speed and pouring temperature respectively.

The calculated averages were used to compute the main effects and the interaction effect for the responses.

RESULTS AND DISCUSSION

Computation of Effects and the Standard Error

There are two main effects, and one 2-factor interactions effect. The main effect of each of the process variables reflects the changes of the respective responses as the process variables change between low level and high level. The main effects and interaction equations are computed based on (Montgomery, 2017).

The main effect of pouring speed is:

$$E_S = \frac{1}{2}\{(A_2 + A_4) - (A_1 + A_3)\} \quad (1)$$

The main effect of pouring temperature is:

$$E_T = \frac{1}{2}\{(A_3 + A_4) - (A_1 + A_2)\}$$

(2)

The combined effect of two or more variables is referred to as interaction effect. The interaction effect of pouring speed and pouring temperature is defined as:

$$I_{ST} = \frac{1}{2}\{(A_1 + A_4) - (A_2 + A_3)\}$$

(3)

The mean of the runs is defined as:

$$E_m = \left[\sum_1^4 A_i/_4\right]$$

(4)

Where A_i are the responses (Hardness, Hi, Ultimate Tensile Strength, Ui, and Elongation, Ei)

When replicates are created under a given set of experimental conditions, the variation among the associated observations are used to estimate the standard deviation of a single observation and hence, the standard deviation of the results. In general, if *y* sets of experimental conditions are replicated and the n_i replicate runs made at the i^{th} set yield an estimated S_i^2 having $v_i = n\text{-}1$ degree (s) of freedom (Box, 1978). The estimate of run variance is

$$S^2 = \frac{v_1 s_1{}^2 + v_2 s_2{}^2 + v_3 s_3{}^2 + \cdots + v_y s_y{}^2}{v_1 + v_2 + v_3 + \cdots + v_y}$$

(5)

With only $n_i=2$ replicates at each of the *y* sets of conditions, the formula for the i^{th} variance reduces to:

$$S_i{}^2 = d_i{}^2/_2$$

(6)

With $v_i=1$, where d_i is the difference between the duplicate observations for the i^{th} set of conditions. Thus, equation 5 becomes:

$$S_i{}^2 = \Sigma\left(d_i{}^2/_2\right)/y$$

(7)

If a total of *N* runs is made when conducting a replicated factorial design, the variance of an effect is given as:

$$V\,(effect) = \frac{4}{N}s^2$$

(8)

And the standard error of the effect is given as:

$$S_e = \sqrt{V\,(effect)}$$

(9)

Hence, the two main effects (pouring speed, S, and pouring temperature, T) and the 2-factor effect, (ST), being a measure of the interactions of the two variables, pouring speed, and pouring temperature were estimated using the mean of the runs. Table 5 summarizes the findings.

Table 5: Coefficient of Analysis for the three responses

Response	Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF	Status
Hardness	Constant		53.250	0.395	134.71	0.000		
	S	-7.000	-3.500	0.395	-8.85	0.001	1.00	Real
	T	-12.500	-6.250	0.395	-15.81	0.000	1.00	Real
	ST	-4.000	-2.000	0.395	-5.06	0.007	1.00	Real
Ultimate Tensile Strength	Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF	Status
	Constant		102.75	1.06	96.87	0.000		
	S	-15.50	-7.75	1.06	-7.31	0.002	1.00	Real
	T	-12.50	-6.25	1.06	-5.89	0.004	1.00	Real
	ST	-3.50	-1.75	1.06	-1.65	0.174	1.00	Chance
Percentage Elongation	Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF	Status
	Constant		12.125	0.451	26.90	0.000		
	S	-5.750	-2.875	0.451	-6.38	0.003	1.00	Real
	T	-2.750	-1.375	0.451	-3.05	0.038	1.00	Real
	ST	1.250	0.625	0.451	1.39	0.238	1.00	Chance

As presented in Table 5., the first column shows the three responses of interest in this study. The second column depicts the terms under the study and the interaction between them. The corresponding effects of the terms and their interaction on the responses (hardness, ultimate tensile strength, and elongation) are presented in the third column. The third and fourth columns present the coefficients and standard error coefficients of the parameters of the predicted model for the study. The coefficients are half of the effects, respectively. The coefficients are used to compute for the prediction model. The P-values help you to determine the significance of the results. If the P-value is less than the significance level (P-value < 0.05), the effect is considered statistically real (significant) otherwise the effect is a chance (not significant). The study used confidence level of 95 % (P = 0.05). From Table 5, the main effects of pouring speed and pouring temperature on each of the three responses (hardness, ultimate tensile strength, and elongation) are significant since their corresponding P – values are less than the significance level of 5 %. The interaction effect of pouring speed and pouring temperature on hardness is real (significant). However, the interaction effect of pouring speed and pouring temperature on ultimate tensile strength and percentage elongation is not significant (chance).

Identification of Significant Effects

The focus is to identify factors that have huge impacts on the responses by performing a factorial design and gather the response data to fit a model. The response data gathered is utilized to create graphs to determine the effects. The utilization of the outcomes from fitting a mathematical model, and also the engagement of the two graphical methods to aid in determining which factors are vital for optimizing the hardness, ultimate tensile strength and the elongation during the casting process. The main effects (pouring speed and pouring temperature) and the interaction plots were generated for hardness, ultimate tensile strength and elongation, and are presented in Figs. 1 and 2 respectively.

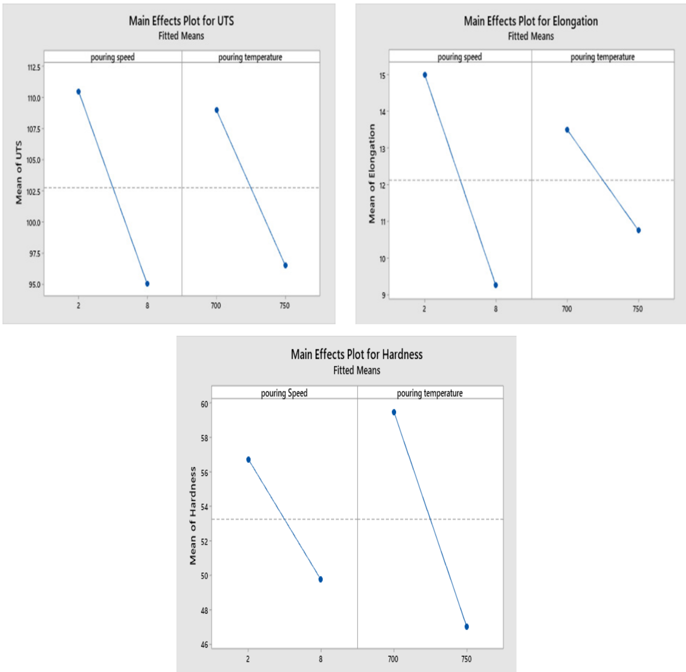


Fig. 1: Main effects plots

Fig. 1 depicts the plot of main effects of pouring speed and temperature on hardness, Ultimate Tensile Strength (UTS) and elongation. The main effect plot displays the degree of an effect at low and high levels. The hardness as exhibited on the plot is high (56.75 HB) when the pouring speed is 2 cm/s, and low (49.75 HB) when the pouring speed is 8 cm/s. Likewise the hardness is high (59.5 HB) when the pouring temperature is 700°C, and low (47 HB) when the pouring temperature is high at 750°C. This implies that the hardness decreases when pouring speed, and pouring temperature increase. Similarly, the Ultimate Tensile Strength as shown on the plots is high (110.5 N/mm^2) at a low speed of 2 cm/s, and low (95 N/mm^2) at a speed of 8 cm/s. The Ultimate Tensile Strength has a high value of (109 N/mm^2) at low pouring temperature of 700°C and low value of (96.5 N/mm^2) at temperature of 750°C. This implies that the Ultimate Tensile Strength decreases with increasing pouring speed, and temperature.

The elongation as shown on the plots is high (15 %) at a low speed of 2 cm/s and low (9.25 %) at high speed of 8 cm/s. The elongation has a high value of (13 %) at low pouring temperature of 700°C and low value of (10.75 %) at temperature of 750°C. This implies that the elongation decreases with increasing pouring speed and temperature.

Fig. 2 shows the plot of interaction effects of pouring speed and temperature on hardness, Ultimate Tensile Strength, and elongation. The plot evaluates two-way interactions. The plot also examines the lines to understand how interactions influence the dependent variable.

The dotted lines show low levels and the solid lines depicts high levels of the independent variables. The combined effect of pouring speed and pouring temperature on hardness, ultimate tensile strength, and elongation is significant since the lines of interaction are not parallel.

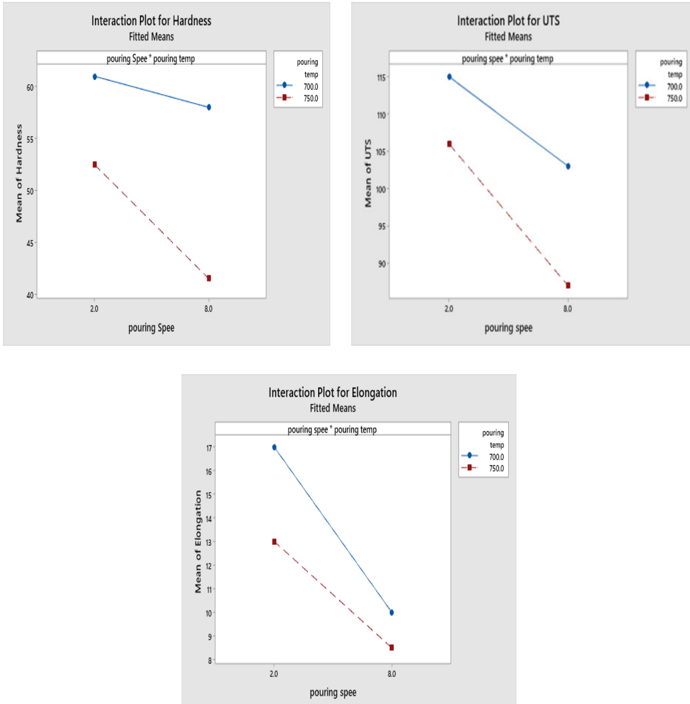


Fig. 2: Interaction plots

Fig. 3 depicts a Pareto chart of the standardized effects of pouring speed, temperature and the interaction of both factors on hardness, Ultimate Tensile Strength (UTS), and elongation at a confidence level of 95 %. The Pareto chart is another important tool used to verify the significance of the effects. It uses the standard rules of the normal plot of standardized effects. The effect tends to be significant when it extends across the reference line of 2.78. The effect becomes insignificant when it does not cross the reference line. For the hardness, the pouring speed is significant with an exact standardized effect of 15.811, and the pouring temperature is also significant with an absolute standardized effect of 8.854, since both cross the reference line of 2.78. The pouring speed-temperature interaction is significant with an absolute standardized effect of 5.0596 since it has extended over the reference line 2.78. For Ultimate Tensile Strength (UTS), the pouring speed is significant with an absolute standardized effect of 7.31, and the pouring temperature is significant with an absolute standard effect of 5.89, since both has crossed the reference line of 2.78. The interaction between the pouring speed and temperature is insignificant with an absolute standardized effect of 1.65, since it does not cross the reference line of 2.78. For elongation, the pouring speed is significant with an absolute standardized effect of 6.38, and the pouring temperature is significant with an absolute standard effect of 3.10, since both crosses the reference line of 2.776. The pouring speed – temperature interaction is insignificant with an absolute standardized effect of 1.39 since it does not cross the reference line of 2.776.

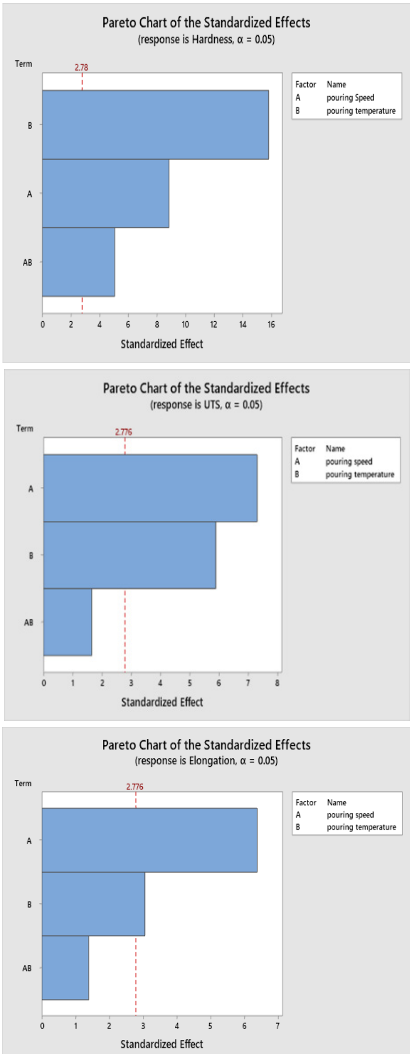


Fig. 3: Pareto chart of standardized effects

Fig. 4 represents the normal plot of the standardized effect on hardness, Ultimate Tensile Strength (UTS), and elongation. The normal plot denotes the statistical significance and positional movement of the main and interaction effect coupled with their percentage on the variable at 95 % confidence level and also at a 5 % significance level. For the hardness, the effect of pouring speed is significant and has a percentage of 50% with standardized effect of – 8.854. The effect of pouring temperature is significant and yield a percentage of 20.5 % with a standardized effect of – 15. 811. Both the pouring speed and temperature have main effects of negative values which means that the hardness decreases with increase in the two effects. The interaction effect between pouring speed and temperature is significant with at percentage level of 79.4 % and produces a standardized effect of – 5.049.

For Ultimate Tensile Strength (UTS), the effect of pouring speed is significant with a percentage of 20.6 % and standardized effect of – 7.31. The effect of pouring temperature also is significant at a percentage of 50 % and a standardized effect of – 5.89. Both the pouring speed and temperature have main effects of negative values which means that the Ultimate Tensile Strength (UTS) decreases with increase in the two effects. However, pouring speed – temperature interaction is statistically insignificant at a percentage of 79.4 % and standardized effect of – 1.65. The direction of the interaction effect is negative which means that as this effect increases, the Ultimate Tensile Strength (UTS) decreases.

Similarly, for the elongation, the effect of pouring speed is significant with a percentage of 20.6 % and standardized effect of – 6.38. The pouring temperature also produce an effect which is significant at a percentage of 50 % and a standardized effect of – 53.06. Both the pouring speed and temperature have main effects of negative values which means that the elongation decreases with increase in the two effects. However, the interaction effect between the pouring speed and temperature is insignificant at a percentage of 79.4 % and standardized effect of 1.39. The direction of the interaction effect is positive implying that as this effect increases, the elongation increases.

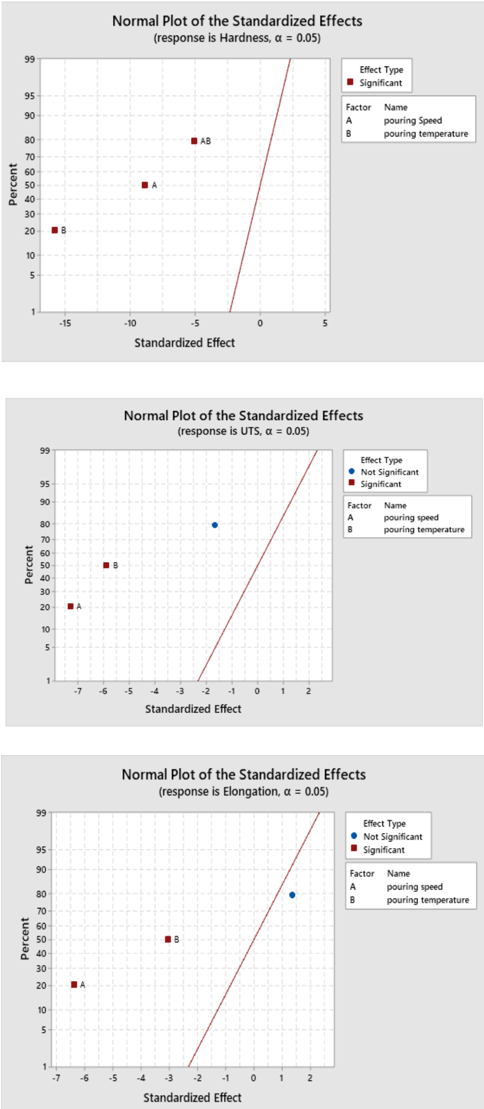


Fig. 4: Normal plot of standardized effects

Generation and Evaluation of Prediction Model

A full 2^2 model is made up of two main effects, and a 2-way interaction. The residuals from a 2^2 design can easily be achieved by fitting a regression model to the data.

For the experiment, the model is defined as:

$$A = \beta_0 + \beta_1 S + \beta_2 T + \beta_{12} ST \pm e \tag{10}$$

Where A is the response (Hardness, Ultimate Tensile Strength and Elongation);

And β_1, β_2, β_{12} are related to the main effects and the interaction effect.

The estimated coefficients are half of the effects, respectively, as presented in equation 11.

$$\beta_0 = mean\,;\, \beta_1 = \frac{E_S}{2}\,;\, \beta_2 = \frac{E_T}{2}\,;\, \beta_{12} = \frac{I_{ST}}{2} \tag{11}$$

And e is the experimental error.

For real world, substitute S and T as follows:

$$S = \frac{S - \frac{1}{2}(S_L - S)}{\frac{1}{2}(S_H - S_L)}\,;\; T = \frac{T - \frac{1}{2}(T_L - T_H)}{\frac{1}{2}(T_H - T_L)} \tag{12}$$

The significant effects and interactions are used to develop the empirical model for the response with the use of equations 9 and 10 and Table 5. Thus, using the corresponding coefficients in Table 5, the coded model for the responses (Hardness, Ultimate Tensile Strength and Elongation) are given as equations 13,14, and 15 respectively;

For hardness, the coded model is defined as:

$$H = 53.250 - 3.500S - 6.250T - 2.000ST \tag{13}$$

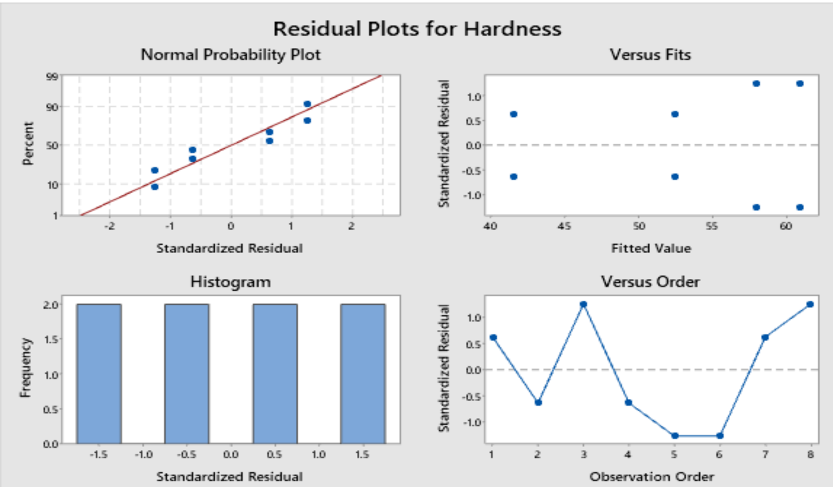
The coded model for Ultimate Tensile Strength (UTS) is defined as:

$$UTS = 102.75 - 7.75S - 6.250T - 1.75ST \quad (14)$$

Similarly, for elongation, the coded model is defined as:

$$E = 12.12 - 2.875\, S - 1.375\, T + 0.625\, ST \quad (15)$$

The models were evaluated by generating plots to visualize the effects, evaluate the fit of the reduced model, and also do a residual analysis. A good standard by which to evaluate the model is to look at p-values. The fitted values are the results predicted by the model and the residuals are the actual values minus the predicted values. The results obtained are presented in Fig. 5



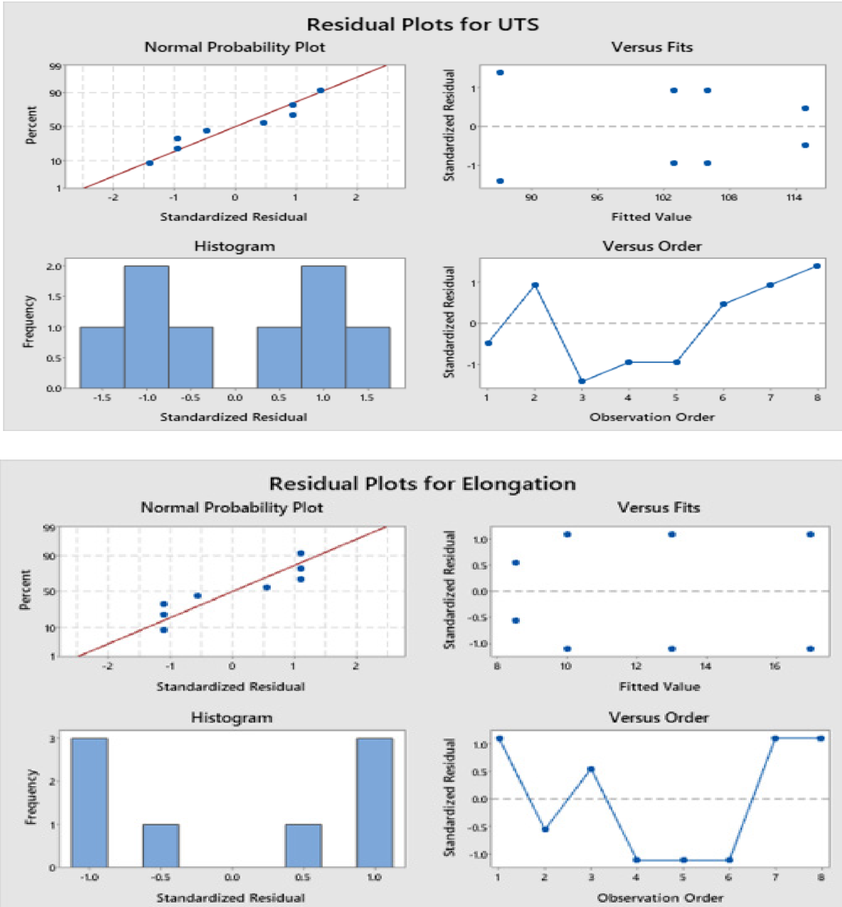


Fig. 5: Residual plots for hardness, ultimate tensile strength, and elongation.

Fig. 5 depicts residual plots for the responses (Hardness, Ultimate Tensile Strength and Elongation). Included in the plots are normal probability plot, histogram, versus fits and versus order. The graphs that constitute the residual plot are used to examine the goodness-of-fit in regression and Analysis of Variance (ANOVA). Examining the residual plots helps one to predict whether the ordinary least squares assumptions are met. If the assumptions are satisfied, then ordinary least squares regression will produce unbiased coefficient estimates with the minimum variance. From the normal probability plot, it can be deduced that the data is normally distributed and hence, the model is significant and thus fits the data well. The histogram depicts closeness of the data values which shows that there are no outliers that might have occurred as a result of external factors which influence data collection during experiments. Residual versus Order plot is used to verify the assumptions that the residuals are independent from one another. Ideally, the residuals on the plot should fall randomly around the center line. In Fig. 5, the residuals appear to be randomly scattered around the center line with no recognizable pattern in the points.

In testing the model, the R-squared analysis was used. The higher the R-squared value, the better the model fits the data. More so, the predicted R-squared determine how well the model predicts the response for new observations. Models that have larger predicted R-squared values have better predictive ability. For the data used in this study, the R-squared value and the predicted R-squared value obtained for hardness were 98.88 % and 95.53 % respectively. The R-squared is 95.78 % for ultimate tensile strength and the R-squared predicted is 83.13 %. For elongation, the R-squared is 92.85 % and the R-squared predicted is 71.39 %. These values indicate that, the model provides a good fit to the data. The predicted models were validated to determine if the experimental results fall within the predicted values for the three responses (Hardness, Ultimate Tensile Strength and Elongation). The experimental errors were determined using the equation:

$$e = \pm \frac{2S_p}{N}\, t_{\alpha/2};v$$

(16)

Where N is the number of runs of the experiment, t is the distribution, α is the confidence level, v is the $n - 1$ degree of freedom, and S_p is the pool variance, defined as:

$$S_p = \sqrt{\frac{1}{2}\frac{\sum d_i}{n}}$$

(17)

Where d_i is the difference between the duplicate observations for the set of conditions, and n is the number of experimental sets of condition (4). For 2 replicates at each of the sets of conditions, N is 8 and v is 1. Substituting the values into equation 17, the pool variance is 1.264, 3.00, and 1.06 for the three responses (Hardness, Ultimate Tensile Strength and Elongation) respectively. Applying 95 % confidence level, $t_{\alpha/2};v$ is 2.776 for each of for the responses (Hardness, Ultimate Tensile Strength and Elongation). Substituting the values into equation 16, the experimental errors were calculated to be ± 1.25, ± 2.94, and ± 1.04 for the three responses (Hardness, Ultimate Tensile Strength and Elongation) respectively. The results obtained for both the experimental and predicted models are tabulated and presented in Table 6.

Table 6: Comparison of Experimental values with Predicted values for Hardness, Ultimate Tensile Strength, and Elongation.

Experimental Hardness (HB)	Predicted Hardness (HB)	Accuracy Y/N	Experimental UTS (N/mm²)	Predicted UTS (N/mm²)	Accuracy Y/N	Experimental Elongation (%)	Predicted Elongation (%)	Accuracy Y/N
60	60.97±1.25	Y	114	114.97±2.94	Y	16	16.93 ± 1.04	Y
59	57.95±1.25	Y	105	102.91 ± 2.94	Y	9	9.96 ± 1.04	Y
53	52.47±1.25	Y	108	105.98 ± 2.94	Y	14	12.97 ± 1.04	Y
41	41.34±1.25	Y	90	86.93 ± 2.94	N	9	8.46 ± 1.04	Y
62	60.97±1.25	Y	116	114.97 ± 2.94	Y	18	16.93 ± 1.04	N
57	57.95±1.25	Y	101	102.91 ± 2.94	Y	11	9.96 ± 1.04	Y
52	52.47±1.25	Y	104	105.98 ± 2.94	Y	12	12.97 ± 1.04	Y
43	41.34±1.25	N	87	86.925 ± 2.94	Y	8	8.46 ± 1.04	Y

From the results obtained and presented in Table 6, if the experimental value of the response falls within the range of the predicted values, then it is accurate, which is denoted by 'Y', otherwise it is denoted by 'N'. From the results, it can be concluded that 87.5 % of the experimental values fall within the predicted values, hence, the predicted model can be used to estimate the hardness, ultimate tensile strength, and percentage elongation if the experimental conditions are known.

Optimization of the Model

The optimization plots for hardness, Ultimate Tensile Strength (UTS), and elongation were generated and the results are illustrated in Fig. 6. Within the selected range of 700°C to 750°C for pouring temperature and 2 cm/s to 8 cm/s for pouring speed, the optimum values for the mechanical properties occurred at 700°Cand 2 cm/s. This is also shown in Table 5.

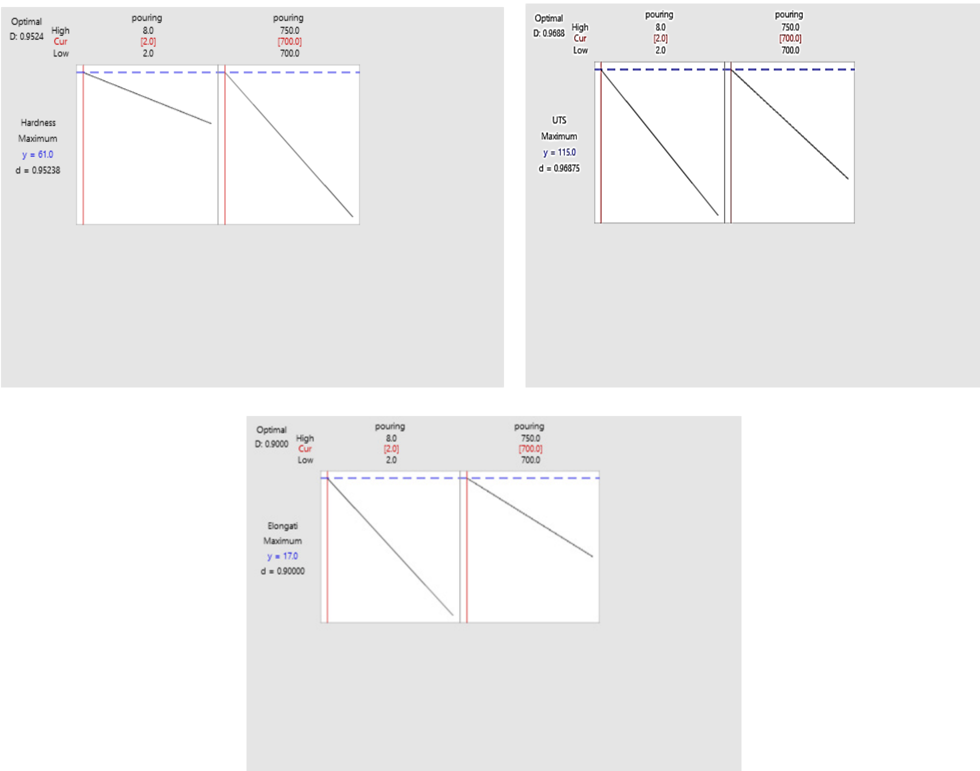


Fig. 6: Optimization plots hardness, ultimate tensile strength, and elongation.

From the plot, it can be seen that the optimal conditions for hardness are indicated in bracket with the values of 2 cm/s for the pouring speed and 700°C for the pouring temperature producing a maximum of 61 HB hardness. Similarly, for Ultimate Tensile Strength (UTS), the optimal conditions are 2 cm/s for the pouring speed and 700°C for the pouring temperature producing a maximum of 115 N/mm^2 Ultimate Tensile Strength (UTS). For elongation, the optimal conditions are 2 cm/s for the pouring speed and 700°C for the pouring temperature producing a maximum of 17 % elongation. The optimum pouring conditions attained in this study strengthens the findings of a previous work by Ndaliman and Pius (2007) Their findings revealed an optimum pouring speed range of 2.2 cm/s to 2.8 cm/s and pouring temperature of 700°C, close to the melting temperature (660°C) of the aluminium alloy. These optimum conditions provided good quality castings and high mechanical properties (Ndaliman and Pius, 2007; Ager, 2014).

CONCLUSION

The study is to investigate the effects of pouring speed and temperature on tensile properties (hardness, UTS and elongation) of aluminum alloy during casting operation. It is concluded that, the effects of pouring speed and temperature on tensile properties (hardness, UTS and elongation) of cast aluminum alloy can be modeled and optimized. The predicted model obtained for the hardness, UTS and elongation are H = 143.7 + 18.17S – 0.1167T – 0.02667ST, UTS = 212.3 + 14.35S – 0.1333T – 0.0233ST, and E = 87.0 – 0.700 S – 0.0967 T – 0.00833ST, respectively. Where H = Hardness (HB); UTS = Ultimate Tensile Strength (N/mm^2); E=Elongation (%); S = pouring speed in centimeter per seconds (cm/s) and T= pouring temperature in degree Celsius (°C).

The optimal conditions for hardness are 2 cm/s for the pouring speed and 700°C for the pouring temperature producing a maximum of 61 HB hardness. Similarly, for Ultimate Tensile Strength (UTS), the optimal conditions are 2 cm/s for the pouring speed and 700°C for the pouring temperature producing a maximum of 115 N/mm^2 Ultimate Tensile Strength (UTS). For elongation, the optimal conditions are 2 cm/s for the pouring speed and 700°C for the pouring temperature producing a maximum of 17 % elongation. These optimum conditions when considered will help to improve the quality of aluminum alloy castings by manufacturing companies in Ghana.

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