PRINT ISSN 1119-8362
Electronic ISSN 2659-1502

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 28 (2) 431-439 February 2024

Optimization of Selected Squeeze Casting Parameters on the Mechanical Behaviour of Aluminium Alloy

***[1]OJARIGHO, EV; [2]AKPOBI, JA; [2]EVOKE, E**

**[1]Department of Mechanical Engineering, Benson Idahosa University, Benin City, Edo State, Nigeria*
[2]Department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria

**Corresponding Author Email: eojarigho@biu.ng*
Co-Authors Email: john.akpobi@uniben.edu; voke.ebojoh@uniben.edu

ABSTRACT: Aluminum alloy have versatile applications and can be produced via a cost-effective squeeze casting technique. Existing literature has revealed that squeeze casting enhances the mechanical properties of cast products and has the advantage of producing products almost without porosity. However, squeeze casting is faced with some challenges including extrusion segregations, centerline segregation, and oxide inclusion, porosity, blistering, under fill, sticking, hot tearing, case debonding, and shrinkages. In view of minimizing these defects, casting should be done applying optimal parameters that will yield the desired result. The present study focused on the optimization of squeeze parameters of squeeze pressure, pressure duration, pouring temperature, initial die temperature in the production of the aluminium alloy (Al-12%Si). Evaluated responses are yield strength and ultimate tensile strength. The results showed that the process parameters had statistical significance on all properties at 95 % confidence level. Combined interactions of these parameters also presented significant effects on the property responses. Optimum setting for process factors as regards yield strength and ultimate tensile strength were evaluated 150MPa, 15seconds, 700°C and150°C for squeeze pressure, pressure duration, pouring temperature and initial die temperature respectively. The results obtained for the three responses which are yield strength and ultimate tensile strength, were 302.86MPa and 347.72MPa respectively.

DOI: https://dx.doi.org/10.4314/jasem.v28i2.15

Open Access Policy: All articles published by **JASEM** are open-access articles under **PKP** powered by **AJOL**. The articles are made immediately available worldwide after publication. No special permission is required to reuse all or part of the article published by **JASEM**, including plates, figures and tables.

Copyright Policy: © 2024 by the Authors. This article is an open-access article distributed under the terms and conditions of the **Creative Commons Attribution 4.0 International (CC-BY- 4.0)** license. Any part of the article may be reused without permission provided that the original article is cited.

Cite this paper as: OJARIGHO, E. V; AKPOBI, J. A; EVOKE, E. (2024). Optimization of Selected Squeeze Casting Parameters on the Mechanical Behaviour of Aluminium Alloy. *J. Appl. Sci. Environ. Manage.* 28 (2) 431-439

Dates: Received: 11 December 2023; Revised: 23 January 2024; Accepted: 17 February 2024 Published: 28 February 2024

Keywords: Squeeze Casting Parameters; Taguchi Method; Optimization; Mechanical Properties

Lately, huge attention has been focused on aluminium and its alloys due to their great technological value and wide range of industrial usage as well as their various advantages such as high castabilty, excellent corrosion resistance, attractive tensile strength, lower density, high thermal conductivity, good formability, high specific rigidity (Smillie, 2006; Schwam,2002). Because of the aforementioned reasons, aluminium alloys are widely used in most foundries. In addition to this, they offer important opportunities for applications in different areas particularly in aerospace industry and mechanical automotive Manjunath *et al*., (2018). Casting process is desired because it is very versatile, flexible, and economical and happens to be the shortest and quickest way to transform raw materials into finished products Manjunath *et al*., (2015). Squeeze casting combines the desirable merits of both conventional casting and forging processes to produce near net-shape casting components. Hence squeeze casting is also known as squeeze forming, liquid metal forging, liquid pressing, pressurized crystallization and extrusion casting Rolland *et al*., (1996). The process falls in the category of permanent mould casting method which has the merit of

**Corresponding Author Email: eojarigho@biu.ng*

producing good surface finish, close dimensional tolerance and the absence of sand inclusions on the cast surfaces of the products (Chadwick, 1991). Furthermore, among the available casting methods, squeeze casting possesses the following characteristics; minimum material loss due to non-use of feeders or risers, component parts made have low shrinkage and porosity, cast products possessed better mechanical properties as compared with the ones fabricated using the other conventional procedures and improved fluidity due to pressure application Dong *et al*.,(1999). According to Vijian and Arunachalam (2007), a way of minimizing these defects is by the setting of optimum processing factors such as the intensity of applied pressure, the die temperature and the melt temperature. Diverse investigations have been embarked on in optimizing the process parameters of aluminum alloy. Manjunath *et al*., (2014) investigated the relationship between squeeze pressure, pouring temperature, die temperature and process variables of LM20 alloy utilizing Taguchi technique. Shi-bo Bin et al., (2013) analyzed the effects of forming pressure, die temperature, pouring temperature and filling velocity on tensile strength, hardness and percentage elongation of squeeze cast AlSi9Cu3 alloys using Taguchi method. Souissi *et al*., (2014) applied Taguchi technique in the optimization of squeeze casting process parameters of 2017 A wrought aluminium alloy. Process variables were squeeze pressure, melt temperature and die temperature. Properties studied are hardness and ultimate tensile strength. The findings revealed squeeze pressure be the most important variable. Squeeze pressure 90MPa, die temperature 200°C melt and temperature 700°C respectively are recommended to obtain higher mechanical properties in squeeze casting of 2017 A Al alloy. Vijian *et al*.,(2007a) viewed surface roughness as an important response with respect to influencing process variables such as squeeze pressure, die temperature and die insert material (copper, cast iron and stainless steel) using Taguchi technique for LM6 alloy. From the above literatures, compelling outcomes have been presented revealing the influence of the process variables. Hence, accurate control of these process variables is essential to achieve higher mechanical properties and to reduce trial by error technique by foundry men in the manufacturing industries. The present study was aimed at accessing the contributions of the process variables of squeeze pressure, pressure duration, pouring temperature and initial die temperature on the aluminium alloy, with the view to optimize the parameters for optimal performance using the Taguchi method for the design of experiment.

MATERIALS AND METHODS

Moulds (dies) were fabricated as revealed in Fig. 1. Meanwhile, the properties of the alloy are portrayed in Table 1. Melting of the aluminium alloy scrab was carried out using a graphite crucible furnace. Squeeze casting procedures was carried out employing the various parameters of the experimental runs (Table 2).

Table 1. Chemical composition of aluminum alloy (wt. %).

Elements	Al	Si	Mg	Cu	Ni
Contents (%)	85.00	12.20	1.00	0. 0.90	0

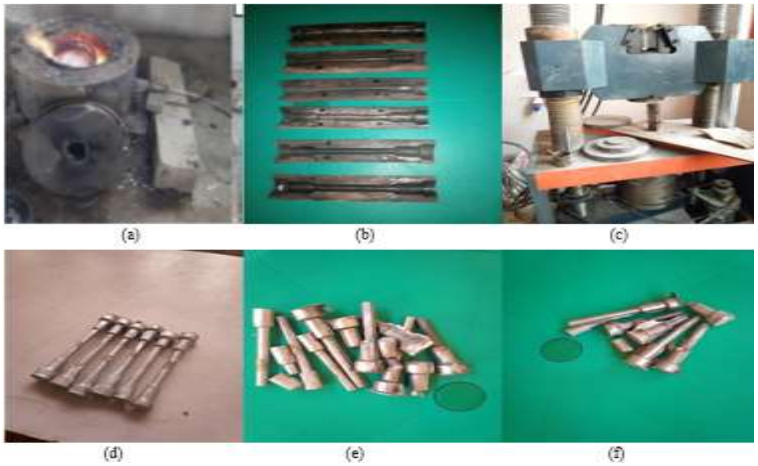


Fig 1. Overview of the experimental process (a) crucible furnace (b) casting mould (c) squeeze casting process (d) cast samples for analysis (e) samples from tensile testing (f) samples from impact testing.

Material preparation: In accordance with ASTM E 8/E8M-21 [15i] procedure, machined tensile specimen (dog-boned shape) of dimensions; 120 mm specimen length, gauge length 60 mm, and gauge diameter 10 mm were tested for tensile strength employing a universal testing machine (Instron 3369 Series). To ensure the reproducibility of test samples, three repetitive tests were carried out for the yield and the ultimate tensile strength and the average results were recorded. Load of 10 kN was applied.

Mix design

Taguchi method of design of experiment: Four factors are considered, namely; squeeze pressure (A), pressure duration (B), pourig temperature (C), Initial die temperature (D). As displayed in Table 2, Taguchi method of the design of experiment and the experimental runs are tabulated. Taguchi analysis was used to determine the optimum parameters which will yield the best results for the properties under investigation. Twenty-seven (27) mix proportions (L27) were initially determined as presented in an orthogonal array (Table 2) with the view of limiting number of experiments. Taguchi method is implemented to determine the control factors and minimize noise factor. According to Ramon *et a*l., (1987); Surajit and Susanta (2010) respectively, the Signal-Noise ratio for multi responses were calculated following the procedures. The higher the signal-to-noise ratio (S/N), the minimal the noise.

Analysis of variance (ANOVA): ANOVA was conducted on the obtained results to determine the significance of the experimental factors at 95 % confidence level and 5 % significance. The p value was used as test of statistical significance for models as well as the terms in the models. Generally, any model term that has a p value that is less than 0.05 is considered to have a significant effect on the model. If the p value is greater than 0.05, that model terms is considered to have an insignificant effect on the model Montgomery (2005).This test was conducted on the response values of yield strength and ultimate tensile strength. The input properties which are the dependent variables are represented with A for squeeze pressure, B for pressure duration, C for pouring temperature and D for initial die temperature. The analysis of result at a confidence level of 95 % was obtained with the aid of Minitab 19 software. More so, the same software was used in analyzing for the Pareto chart and normal plot for standardized effects on each property. Results were interpreted and discussed in relation to each response.

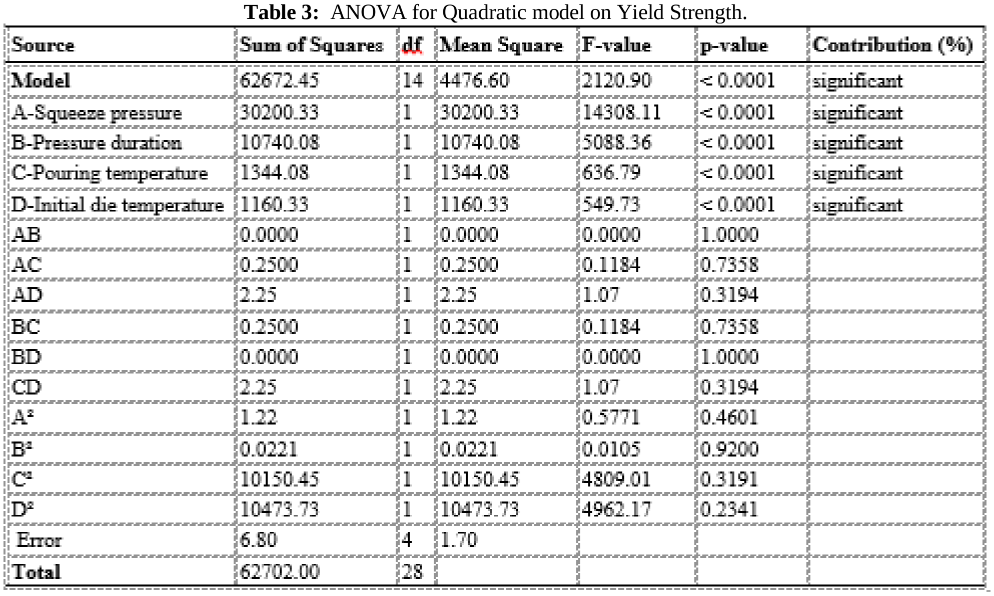
Table 2: Orthogonal array of the experimental runs

Experimental runs	**Factors level**				**Input Variables**				**YS (MPa)**	**UTS (MPa)**
	(A)	**(B)**	**(C)**	**(D)**	**A (MPa)**	**B (seconds)**	**C (˚C)**	**D (˚C)**		
1	1	1	1	1	50	15	600	150	281.00	342.00
2	1	2	2	2	50	30	700	200	221.00	282.00
3	1	2	2	2	50	30	700	200	220.00	262.00
4	1	2	2	2	50	30	700	200	222.00	282.00
5	1	3	3	3	50	45	800	250	321.00	362.00
6	1	3	3	3	50	45	800	250	381.00	422.00
7	1	3	3	3	50	45	800	250	301.00	352.00
8	2	1	2	3	100	15	700	250	300.00	342.00
9	2	1	2	3	100	15	700	250	302.00	322.00
10	2	1	2	3	100	15	700	250	223.00	242.00
11	2	2	3	1	100	30	800	150	319.00	372.00
12	2	2	3	1	100	30	800	150	303.00	352.00
13	2	2	3	1	100	30	800	150	299.00	352.00
14	2	3	1	2	100	45	600	200	280.00	322.00
15	2	3	1	2	100	45	600	200	241.00	292.00
16	2	3	1	2	100	45	600	200	281.00	332.00
17	3	1	3	2	150	15	800	200	201.00	262.00
18	3	1	3	2	150	15	800	200	220.00	272.00
19	3	1	3	2	150	15	800	200	301.00	341.00
20	3	2	1	3	150	30	600	250	219.00	270.00
21	3	2	1	3	150	30	600	250	221.00	271.00
22	3	2	1	3	150	30	600	250	242.00	274.00
23	3	3	2	1	150	45	700	150	323.00	340.00
24	3	3	2	1	150	45	700	150	303.00	343.00
25	3	3	2	1	150	45	700	150	302.00	342.00
26	1	1	1	1	50	15	600	150	300.00	344.00
27	1	2	2	2	50	30	700	200	243.00	282.00

RESULTS AND DISCUSSION

Yield strength: *Analysis of variance on yield strength:* Table 3 shows the table of analysis of variance for yield strength. The model is significant with p value less than 0.05. In the same manner, the effects of squeeze pressure (A), pressure duration (B), pouring temperature (C), and initial die temperature (D) on the yield strength response were considered significant as the p -values are less than 0.05. Cross interactions A*C and A*D are statistically significant while interactions A*A, B*B, C*C and D*D are insignificant owing to p value > 0.05. The model for yield strength (YS) is presented in Eq. (1). From the equation, A, B, C and D stands for squeeze pressure, pressure duration, pouring temperature and initial die temperature respectively. From the model, parameters with positive coefficient indicate factors with resultant positive (synergetic) effect on the response while the ones with negative coefficient depict resultant negative (antagonistic) influence. As observed, factors A, B, C and D had synergetic effect on the response, similar trend was observed with interaction AC and AD. On the hand Interactions AA, BB, CC and DD portrayed negative effect on the response.

Table 3: ANOVA for Quadratic model on Yield Strength.



Source	Sum of Squares	df	Mean Square	F-value	p-value	Contribution (%)
Model	62672.45	14	4476.60	2120.90	< 0.0001	significant
A-Squeeze pressure	30200.33	1	30200.33	14308.11	< 0.0001	significant
B-Pressure duration	10740.08	1	10740.08	5088.36	< 0.0001	significant
C-Pouring temperature	1344.08	1	1344.08	636.79	< 0.0001	significant
D-Initial die temperature	1160.33	1	1160.33	549.73	< 0.0001	significant
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.2500	1	0.2500	0.1184	0.7358	
AD	2.25	1	2.25	1.07	0.3194	
BC	0.2500	1	0.2500	0.1184	0.7358	
BD	0.0000	1	0.0000	0.0000	1.0000	
CD	2.25	1	2.25	1.07	0.3194	
A^2	1.22	1	1.22	0.5771	0.4601	
B^2	0.0221	1	0.0221	0.0105	0.9200	
C^2	10150.45	1	10150.45	4809.01	0.3191	
D^2	10473.73	1	10473.73	4962.17	0.2341	
Error	6.80	4	1.70			
Total	62702.00	28				

$$\mathbf{YS} = (-2491.97500 + 0.943000A + 2.12667B + 5.67400C + 6.30767D - 2.78401\mathrm{E} - 15AB \;\&+ 0.000050AC + 0.000300\,AD - 0.000167BC - 3.94553\mathrm{E} - 18BD - 0.000150CD - 0.000173A^2 - 0.000259B^2 - 0.003956C^2 - 0.016073D^2) \qquad (1)$$

Pareto chart and normal plot: Fig. 2a presents the parameters that are significant, and these are factors A, B, C and D and interactions C*C, and D*D. With respect to the normal plot (Figure 2b), factors on the positive side of the line had resultant positive contributions on the response, while the ones on the negative side had resultant negative contributions. On account of that, factors A, B, and C, which are squeeze pressure, pressure duration, and pouring temperature respectively, reflect the resultant positive contributions on the response. Therefore, squeeze pressure, pressure duration, and pouring temperature have resultant positive contributions on yield strength. Conversely, interactions D, C*C, and D*D had resultant negative contributions on yield strength. B*B The observation is reflected in the model for yield strength in Equation (1) as terms with positive coefficients. Factor D and interactions CC and DD have resultant negative contributions hence they are confirmed as the negative terms of the model. Therefore, the normal plot corroborated the model in identifying the positive terms and the negative terms.

Main effects of fitted means: The main effect plot (fitted means) of the process parameters on yield strength as represented by the mean values of the response is presented in Figure 2c. The figure shows the main effect plots for yield strength representing the fitted lines for the mean values of yield strength. It is revealed that squeeze pressure from 50 to 150MPa had a positive effect on the response, which is, as the pressure increased between 50 to 150MPa the mean tensile strength increased. The profile based on the line of fit for squeeze pressure as it affects yield strength is linear. Likewise, as the speed duration increased from 15 to 45 seconds, the strength was enhanced at the mean level thereby depicting a positively linear profile. As for pouring temperature, between 600 and 700˚C, there was strength enhancement, while between 700 and 800˚C, mean yield strength reduced. The profile for pouring temperature is inverted parabolic profile with point of inflexion at 700˚C yielding a value of 271.88MPa. Similar to pouring temperature, 150 to 200˚C initial die temperature yields strength improvement, meanwhile between 200 and 250, there is decrease in the value. Initial die temperature is realized to depict an inverted parabolic profile with point of inflexion at 200˚C equivalent to 271.95MPa.

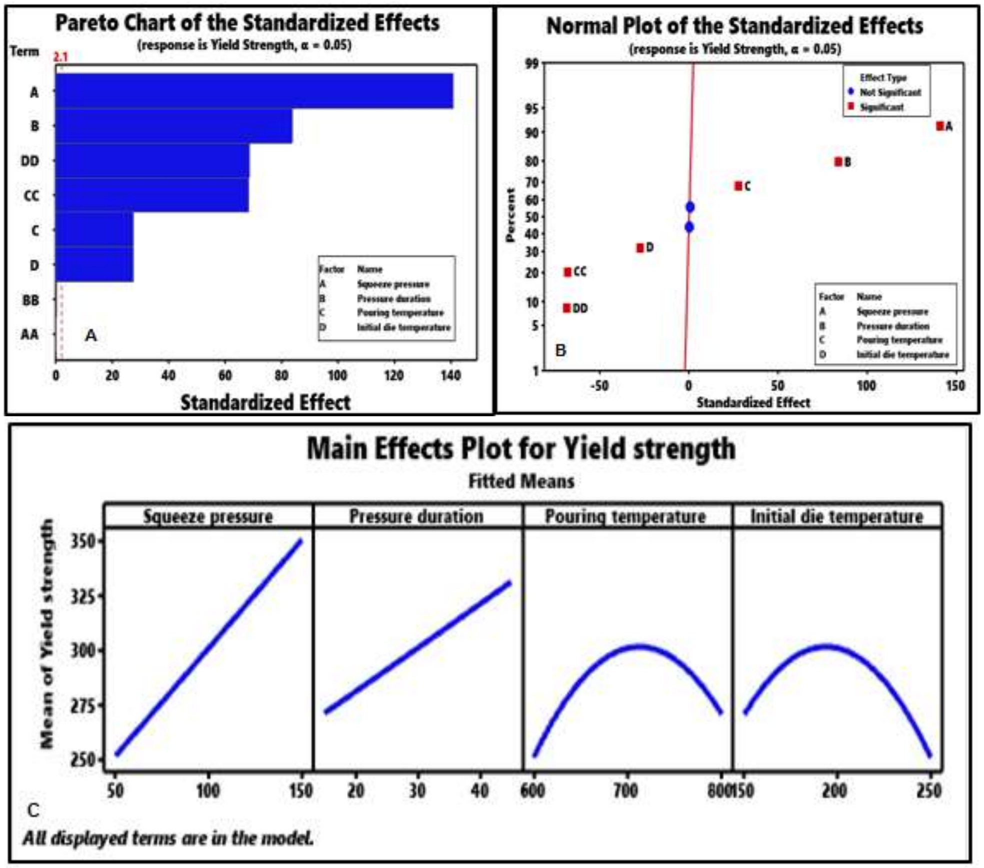


Fig. 2. Analysis for ultimate tensile strength as regards (a) Pareto chart (b) Normal plot (c) Main effect plot for fitted means

Ultimate tensile strength: Analysis of variance of Ultimate tensile strength: Results of the ANOVA presented in Table 4shows that the model is significant with p value less than 0.05. Similarly, the input factors A, B, C and D had significant influence on the Ultimate tensile strength response, hence are statistically significant. In addition, the interactions B*C, C*D, C*C and D*D depicted significant contributions to the enhancement of the Ultimate tensile strength while A*B, A*C, A*D, B*D,A*A and B*B are insignificant. The model for Ultimate tensile strength (UTS) is as presented in Eq. (2). From the equation, A, B, C and D stands for squeeze pressure, pressure duration, pouring temperature and initial die temperature respectively. Parameters with positive coefficient in the model are the positive terms of the model depicting synergetic effect of the parameter on the response. However, parameters with negative sign had antagonistic influence on the response and are negative terms of the model. It is worthy to mention that factors A, B, and interactions CD and BB exhibited synergetic effect on the response, whilst interactions AC, AD,AA,CC and DD displayed an antagonistic effect on Ultimate tensile strength.

$$UTS = (-2309.45000 + 1.36600A + 3.85333B + 5.99133C + 3.70200D - 2.81501 \times 10^{-15}AB - 0.000050AC - 0.001000AD - 0.003500BC + 1.03569 \times 10^{17}BD + 0.000800CD - 0.000763A^2 + 0.008185B^2 - 0.004328C^2 - 0.010713D^2) \qquad (2)$$

Pareto chart and normal plot: As presented in Fig. 3a, factors A, B, and D are significant, likewise, interactions A*A, B*B and A*B are also significant. On the other hand, the interactions C, A*A and D are insignificant. It was found that ANOVA result was confirmed by the Pareto charts, thus revealing the order of significance of the process parameters. The normal plot is as shown in Fig. 3b, while the main effect plot for fitted means are displayed in Fig. 3c respectively. From the displayed result, factor A has the highest significance, that is, the squeeze pressure has the highest significant effect on the ultimate tensile strength. Strength. Factor B (pressure duration) is the second while 3rd, 4th, and 5th in terms of contribution to ultimate tensile strength are interaction CC, DD and BB respectively.

Table 4. ANOVA on Ultimate tensile strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	Significance
Model	55133.88	14	3938.13	288.73	< 0.0001	significant
A-Squeeze pressure	28714.08	1	28714.08	2105.25	< 0.0001	significant
B-Pressure duration	9690.08	1	9690.08	710.45	< 0.0001	significant
C-Pouring temperature	340.33	1	340.33	22.96	0.0025	significant
D-Initial die temperature	456.33	1	456.33	33.46	< 0.0001	significant
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.2500	1	0.2500	0.0183	0.8942	
AD	25.00	1	25.00	1.83	0.1972	
BC	110.25	1	110.25	8.08	0.0130	significant
BD	0.0000	1	0.0000	0.0000	1.0000	
CD	64.00	1	64.00	4.69	0.0480	significant
A^2	23.62	1	23.62	1.73	0.2093	
B^2	22.00	1	22.00	1.61	0.2248	
C^2	12152.09	1	12152.09	890.96	< 0.0001	significant
D^2	4653.06	1	4653.06	341.15	< 0.0001	significant
Residual	190.95	14	13.64			
Lack of Fit	185.75	10	18.57	14.29	0.0103	insignificant
Error	5.20	4	1.30			
Cor Total	55324.83	28				

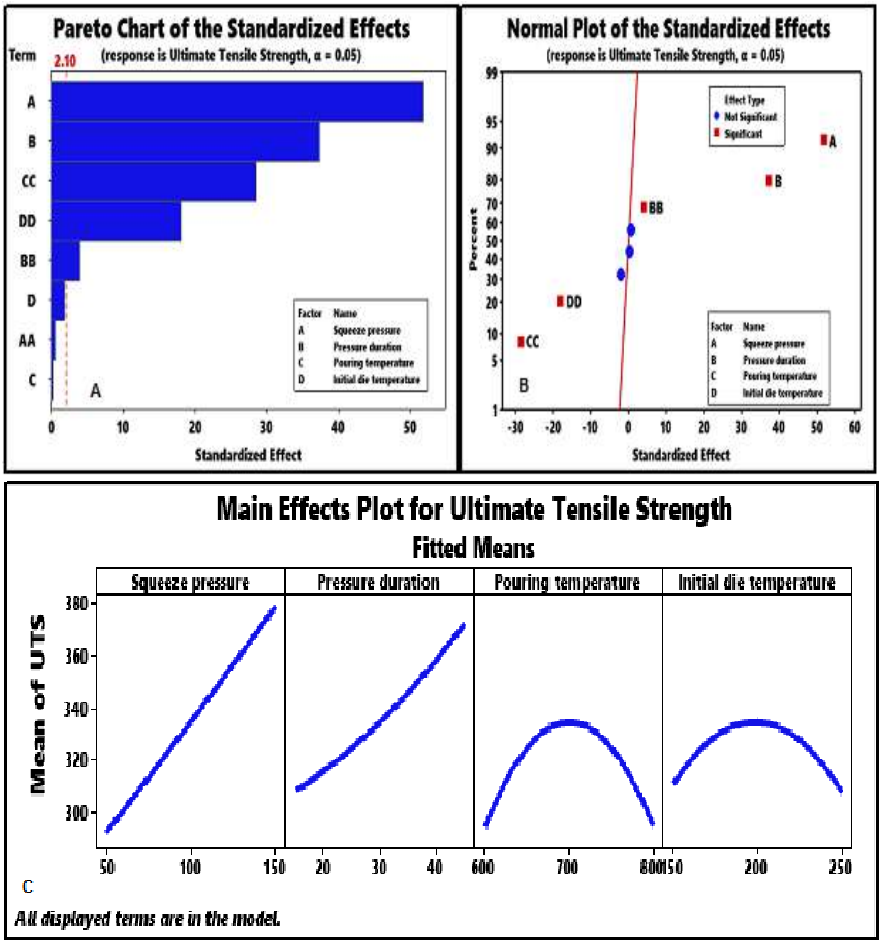


Fig. 3. Analysis for ultimate tensile strength as regards (a) Pareto chart (b) Normal plot (c) Main effect plot for fitted means.

Main effect of fitted and data means: The main effect plot (fitted means) of the process parameters for ultimate tensile strength is showcased in fig. 3c . 50 – 150MPa squeeze pressure amounted to progressive enhancement of response depicting a positive linear interaction profile. 15 to 45 seconds pressure duration ensued enhancement in strength with a slow rise between 30 and 40 seconds, thereby depicting a convex interaction profile. As in the case of pouring temperature, 600 – 700˚C yielded strength improvement while 600 to 800˚C led to strength decrease. Hence, exhibiting an inverted parabolic profile with point of inflection at 700˚C corresponding to 318.79MPa. Initial die temperature also depicted an inverted parabolic profile in that 150 to 200˚C provoked strength enhancement, meanwhile 200 – 250 triggered decrease. The point of inflexion exists at 200˚C corresponding to 309.95MPa.

Single objective optimization by signal-to-noise ratio: Taguchi design has been proved to be an effective optimization tool in experimental procedures Peasant *et al., (*2011). Signal-to-noise ratio (S/N) is a measure of soundness employed to indicate the process parameters that has the lowest noise on the measured response. The method uses a loss function to assess the variation between experimental results and desired outcome. There exist three approaches to evaluating signal-to-noise ratio (S/N), which are the lower the better, the larger the better, and the nominal is best. The choice of any of the approach settings depends on the kind of goal target; whether to maximize or minimize. The S/N ratio was evaluated using Eq. (3) for the 'larger the better'option which goal is to maximize the responses.

$$\mathrm{S/N} = \left[-10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y^2}\right)\right] \qquad (3)$$

Where n represents number of observations while Y stands for measured value.

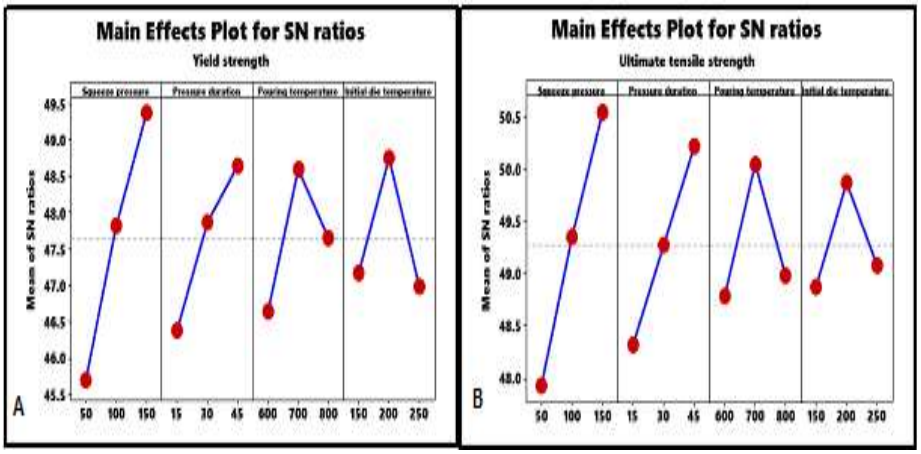


Fig. 5: Main Effects Plot for SN ratio for (a) Yield strength **(**b) Ultimate tensile strength

As indicated in Fig. 5a, for yield strength, the value of signal-to-noise ratio for factor squeeze pressure is maximum at 150MPa. It is also noted that there is higher difference in SN between 50 and 100MPa (+2.123dB) than between 100 and 150MPa (+1.5467dB). This indicates that squeeze pressure has higher influence on yield strength when value is increased from 50 to 100MPa than when increased from 100 – 150MPa.

Yield strength: The variations in the mean signal to noise ratio for the yield strength for all factors are as presented in Table 6. Optimum yield strength is attainable at conditions of 150MPa, 45 seconds, 700˚C and 200˚C values for squeeze pressure, pressure duration, pouring temperature and initial die temperature.

Table 6: Mean signal to noise ratio (dB) for yield strength

Levels	Squeeze pressure	Pressure duration	Pouring temperature	Initial die temperature
Level 1	45.6983	46.3814	46.6484	47.1654
Level 2	47.8213	47.8611	48.5919	48.7457
Level 3	49.3680	48.6451	47.6473	46.9764
Delta	3.6697	2.2637	1.9435	1.9817
Rank	1	2	4	3

Table 6 presents the delta value for each factor, of which higher delta values shows higher significance of the factors indicated by the ranks. By ranking, the order of significance is squeeze pressure, pressure duration, initial die temperature and pouring temperature in that order.

Table 7: Mean signal to noise ratio (dB) for ultimate tensile strength

Levels	Squeeze pressure	Pressure duration	Pouring temperature	Initial die temperature
Level 1	47.9276	48.3231	48.7886	48.8731
Level 2	49.3481	49.2742	50.0500	49.8700
Level 3	50.5429	50.2213	48.9801	49.0754
Delta	2.6153	1.8982	1.2614	0.9969
Rank	1	2	3	4

Table 8: Mean signal to noise ratio (dB) for multi-objective characteristics

Levels	Squeeze pressure	Pressure duration	Pouring temperature	Initial die temperature
Level 1	17.9188	22.8110	21.3920	23.7056
Level 2	22.9894	22.3322	23.1368	22.7098
Level 3	23.8754	19.6404	20.2557	18.3682
Delta	5.9566	3.1706	2.8811	5.3374
Rank	1	3	4	2

Ultimate tensile strength: The variations in the mean signal to noise ratio for the ultimate tensile strength for all factors are as presented in Table 7.Optimum ultimate tensile strength is attained at conditions of 150MPa squeeze pressure, 45 seconds pressure duration, 700˚C pouring temperature and 200˚C, initial die temperature. The variations in the mean signal to noise ratio for the ultimate tensile strength for all factors and corresponding delta value is presented in Table 7. Higher delta values show higher significance of the factors indicated by the ranks. By ranking, the order of significance is squeeze pressure, pressure duration, pouring temperature and initial die temperature in that order.

Signal to noise ratio for the combined characteristics: The variations in the mean signal to noise ratio for the combined characteristics of all factors are as presented in Table 8. Optimum condition for the for the multi-objective optimization is 150MPa for pressure, 15 seconds for the pressure duration, 700˚C for molding temperature and 150˚C for initial die temperature. Going by the corresponding delta value (Table 9), the order of significance of the factors are squeeze pressure, pouring temperature, pressure duration and initial die temperature.

Conclusion: Taguchi technique was employed in analyzing the squeeze casting parameters and optimizing the mechanical performance of the aluminium alloy (Al-85%, Mg-8%, Si- 12%, Mg- 1%, Cu- 0.90%, Ni- 0.90%). The normal plot and ANOVA analysis showed that the four parameters; squeeze pressure, pressure duration, pouring temperature, Initial die temperature had significant effect on yield strength and ultimate tensile strength, as p value is < 0.05 in each case.

REFERENCES

ASTM E 8/E8M-21, Standard Test Methods for Tension Testing of Metallic Materials, ASTM Int., West Conshohocken, PA, 2021, 2021.

Dong, JX; Karnezis, PA; Durrant G; Cantor B (1999).The effect of Si and Fe additions on the microstructure and mechanical properties of a direct squeeze cast Al-7Si-0.3Mg alloy. *Metallurg. Mat. Transact* S. Suzuki. Product quality by vertical filling casting machine. Light Metal Age.

Hajjari, E; Divandari, M (2008): An Investigation on The Microstructure and Tensile Properties of Direct Squeeze Cast and Gravity Die Cast 2024 Wrought Al Alloy. *Mat. Design*, 29: 1685-1689.

Manjunath P; Prasad K.; Mahesh B (2014). Optimization of squeeze cast process parameters using Taguchi and grey relational analysis. *Dept. Mech. Eng. Nat. Inst. Technol*. Karnataka, Surathkal-575025, India.

Manjunath, P; Krishna P; Parappagoudar M (2015). Modelling in Squeeze Casting Process-Present State and Future Perspectives. *Adv. Auto. Eng.* 4: 111. DOI:10.4172/2167-7670.1000111

Manjunath, PGC; Arun, K.S; Mahesh, BP (2018). A systematic approach to model and optimize wear behaviour of castings produced by squeeze casting process. *J. Manuf. Processes*. 32: 199–212.

Montgomery, DC (2005). Design and Analysis of experiments.6th ed., New York: John Wiley Sons, Inc.

Peasant, SV; Subramanian R; Radhika, N; Anandavel B (2011). Dry sliding wear and friction studies on AlSi10Mg-fly ash-graphite hybrid metal matrix composites using Taguchi method. *Tribology* 5 (2) 72–81.

Raji, A; Khan R H (2005).Effects of pouring temperature and squeeze pressure on Al-8% Si alloy squeeze cast parts. *AU JT* 9(4): 229-237.

Ramon, V; Leon, Anne CS; Raghu, NK (1987). Performance measures independent of adjustment: an explanation and extension of Taguchi's signal-to-noise-ratios, *Technometrics* 29 (3): 253–265.

Rolland, T; Schmidt R; Arnberg L; Thorpe W (1996). Macrosegregation in indirectly squeeze cast Al-0.9 wt% Si. *Mat. Sci. Eng. A*, 212: 235-241.

Schwam, D; Wallace, JF; Chang, Q; Zhu Y, (2002). Cast Optimization of the squeeze casting process for aluminum alloy parts. *Case Western Reserve University*.

Senthil, P; Amirthagadeswaran, KS (2013b).Experimental study and squeeze cast process optimization for high quality AC2A aluminium alloy castings. *Arabian J. Sci. Eng.* 39(3): 2215–2225. DOI: 10.1007/s13369-013-0752-5, 2013.

Shi-bo Bin; Shu-ming Xing, Long-mei Tian; Ning Zhao; Lan, LI (2013): Influence of technical parameters on strength and ductility of AlSi9Cu3 alloys in squeeze casting. *Transact. Nonferrous Met. Soc.* China. 23, 977-982

Smillie, M (2006).Casting and analysis of squeeze cast Aluminum Silicon eutectic alloy. Ph.D. thesis, Dept. Mechanical Engineering, University of Canterbury, Christ Church, New Zealand.

Souissi N., Souissi S, Christophe L.,Ben Amar M., Chedly B and Foued E, (2014). Optimization of Squeeze Casting Parameters for 2017 A Wrought Al Alloy Using Taguchi Method. *Metal Open Acc. J*. 4: 141-154. DOI: 10.3390/met4020141

Surajit Pal; Susanta KG (2010). Multi-response optimization using multiple regression–based weighted signal-to-noise ratio (MRWSN), Qual. Eng. 22 (4):336–350.

Vijian, P.; Arunachalam, V.P. and Charles, S. (2007a). Study of surface roughness in squeeze casting LM6 aluminium alloy using Taguchi method *Indian J. Eng. Mat. Sci. 5:* 7-11.

Vijian, P; Arunachalam VP (2007).Optimization of squeeze casting process parameters using Taguchi analysis. *Int. J. Adv. Manu. Techno*. 33, 1122-1127.