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Statistical Analysis to Identify the Significant Parameters that Affect the Torque and Thrust of Grain Refined and Modified Al-Si Alloys (LM-25, LM-6 and LM-30) Using ANOVA

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Abstract:
Background*: The world's most common and extensively used metal is undisputably Aluminium. Aluminium has applications in almost all the sectors of engineering ranging from automobiles to electronics. Since pure aluminium is ductile and malleable, it becomes necessary to alloy it to enhance the mechanical properties. It is already established that Al alloyed with Si enhances these properties. Al-Si alloys are classified into hypoeutectic LM-25 (7wt% Si), eutectic LM-6 (12wt%Si) and hypereutectic LM-30 (17wt% Si). These three alloy compositions have their own specific properties which can be further improved with the addition of grain refiners and modifiers.*
Experimental Methods and Analysis*:In this study the Al-Si alloys Lm-25, LM-6 and LM-30 are treated with 0.2wt%Al-5Ti-1B, 1wt%Al-3B grain refiners and 0.3wt% Al-10Sr modifier. The torque and thrust values of the untreated and treated samples are noted. Statistical analysis of torque and thrust is carried out using ANOVA to predict the percentage contribution of the independent variables on dependent variable.*
Results and Conclusion*: It is seen that Force in X direction is the maximum influencing parameter with F ratio of 6.02 for thrust. It is seen that Force in X direction, Al, Si and hardness are the maximum influencing parameters with F ratio of 8.59, 11.87, 14.84 and 7.83 respectively for torque.*
Key Word*: Al-Si alloys,Torque, Thrust, Grain Refiner, Modifier, ANOVA.*

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I. Introduction

Aluminium-Silicon alloys are the most extensively used alloys in all engineering applications. Good casting characteristics, strength to weight ratio, corrosion resistance and electrical and thermal conductivity are few characteristics attributed to these alloys. Based on the application the right type of alloy is used. It is a established fact that addition of grain refiners and modifiers enhances the mechanical properties of these alloys.

II. Experimental Methods

Al-Si alloys with different percentage of grain refiners / modifier (0.2wt.% Al-5Ti-1B and 1wt % Al-3B / 0.3 wt.% Al-10Sr) were prepared by melting commercially available pure aluminium namely LM-25, LM-6 and LM-30 in an induction furnace. The melt was degassed by adding commercially available degasser tablet hexachloroethane. A total of twelve samples are obtained as in Table no 1. The lathe machine having 112-1800 rpm of spindle speed and 1 H.P motor was used and values in X, Y & Z directions in KN v/s samples of untreated and treated LM-25, LM-6 and LM-30 alloy samples are observed by giving a constant feed and speed N= 770rpm, depth of cut was 2 mm with 5° rake angle. The Vickers hardness values were noted for all the twelve samples.

III. Result

Study of microstructure

A filtering electron microscope furnished with Energy Dispersive X-Ray Spectroscopy (EDS) (Model-FEI Quanta-200, NE Dawson Creek Drive, Hillsboro, USA) was used to obtain the SEM micrographs of the samples.

The micrographs of the untreated sample and the samples treated with 0.2 wt % Al-5Ti-1B, 1 wt % Al-3B, 0.3wt % Al-10Sr are shown in Fig.1 to Fig.3. Nuclei or seed will begin to form in many parts of the melt simultaneously when a liquid metal or alloy is cooled. Heterogeneous nucleation provides a method for control of the grain size of the solidified casting. By creating numerous sites for heterogeneous nucleation a fine grainsize can be obtained

Table no 1: Prepared Sample Designation

Grain refiners	0.2% Al-5Ti-1B	1% Al-3B	0.3% Al-10Sr
Untreated Alloy	Samples	Samples	Samples
Untreated LM-25	LM-25+0.2% Al-5Ti-1B	LM-25+1% Al-3B	LM-25+0.3% Al-10Sr
Untreated LM-6	LM-6+0.2% Al-5Ti-1B	LM-6+1% Al-3B	LM-6+0.3% Al-10Sr
Untreated LM-30	LM-30+0.2% Al-5Ti-1B	LM-30+1% Al-3B	LM-30+0.3% Al-10Sr

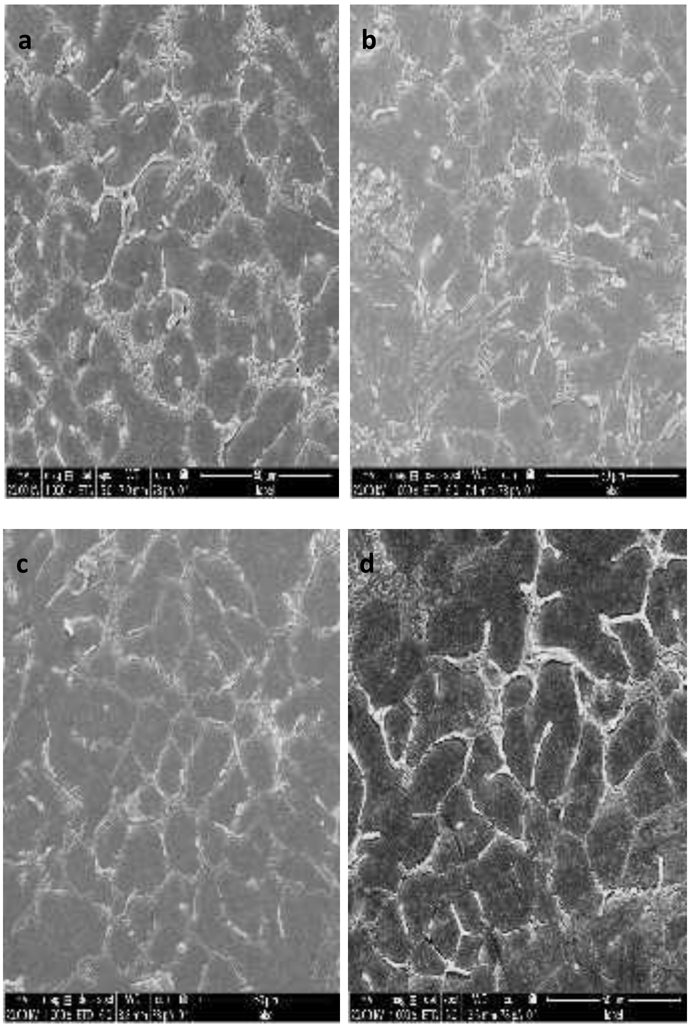

Fig.1 : LM-25 samples (a) Untreated alloy, (b) Al-5Ti-1B, (c) Al-3B & (d) Al-10Sr

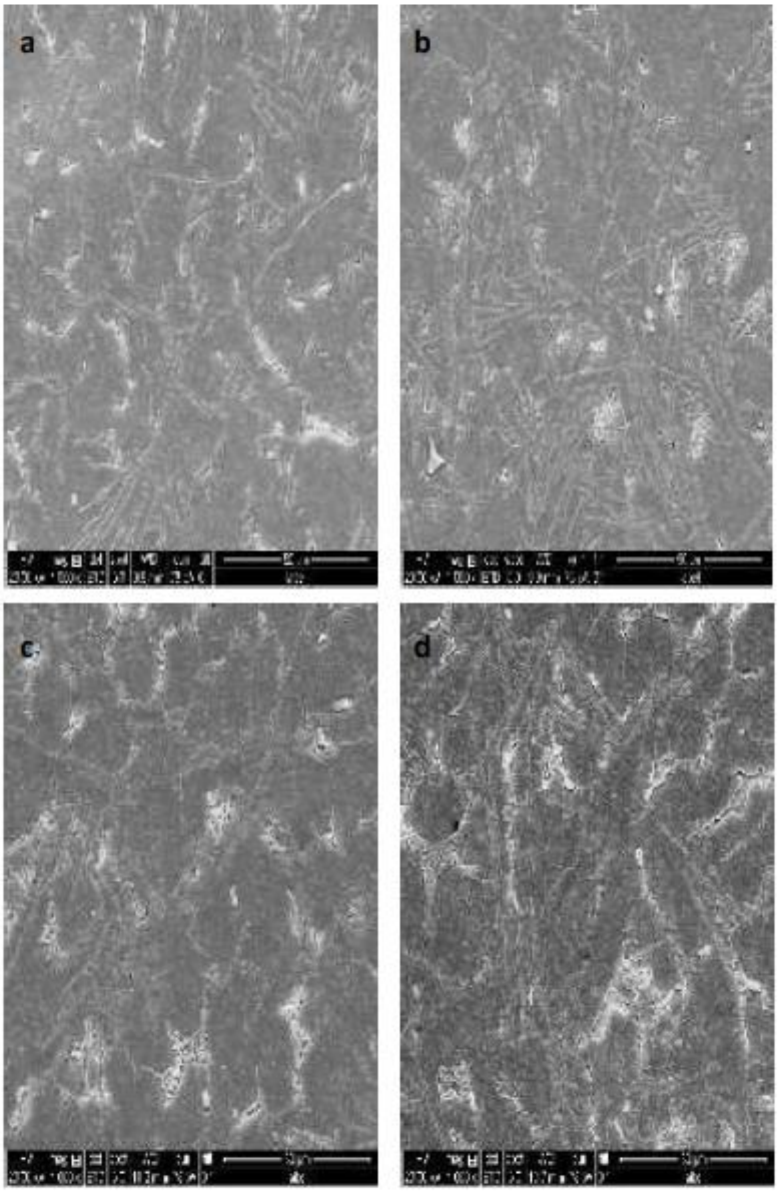

Fig. 2: LM-6 samples: (a) Untreated alloy, (b) Al-5Ti-1B, (c) Al-3B & (d) Al-10Sr

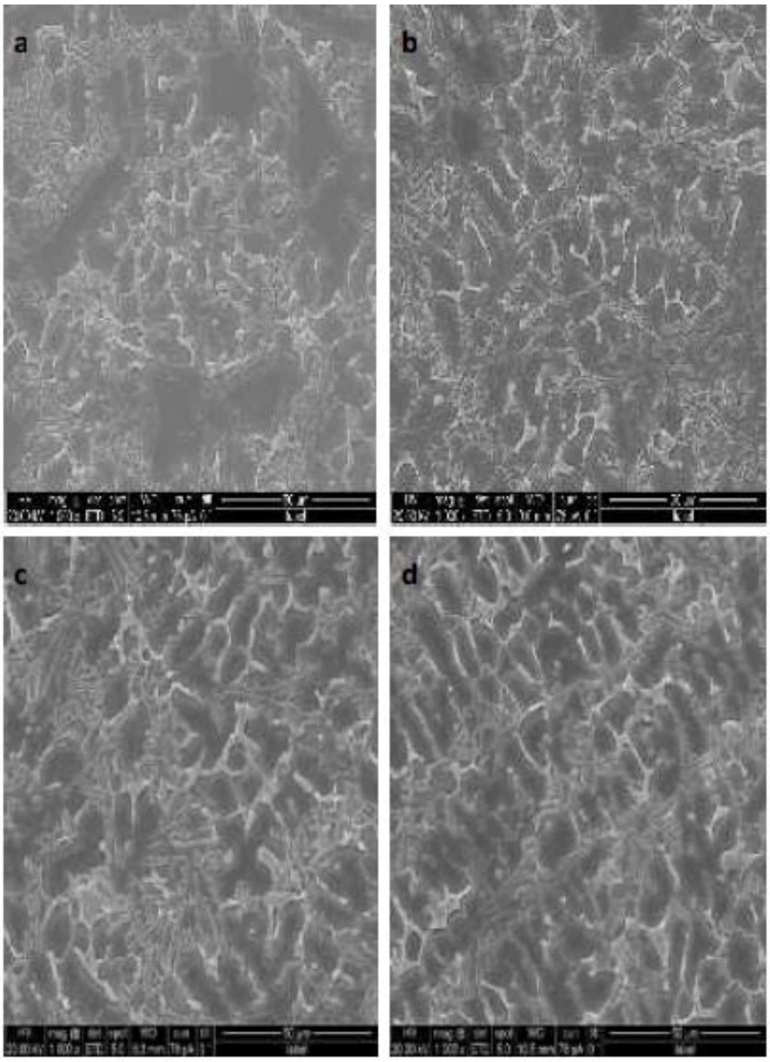

Fig. 3: LM-30 samples: (a) Untreated alloy, (b) Al-5Ti-1B, (c) Al-3B & (d) Al-10Sr

Torque

The drilling test was done by giving the spindle speed of 500rpm and depth of cut as 5mm. Fig..4 to Fig.6 show the observation of the torque response and it can be seen that the difference in torque is very low.

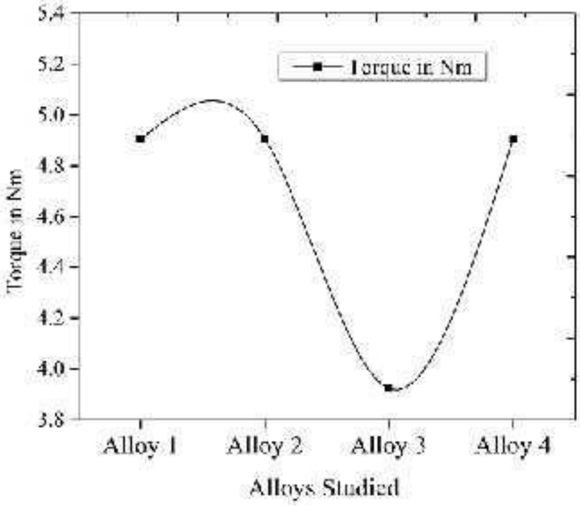

Fig. 4 Torque of LM-25 for all grain refiners

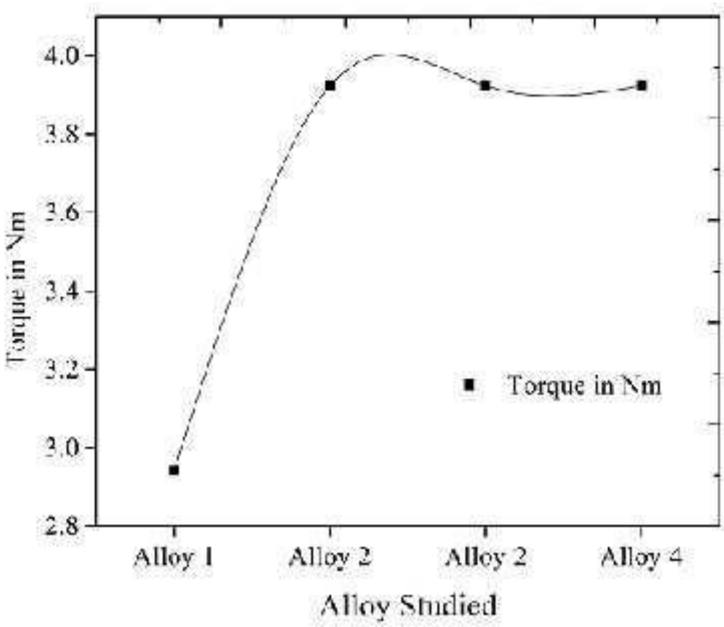

Fig. 5 Torque of LM-6 for all grain refiners

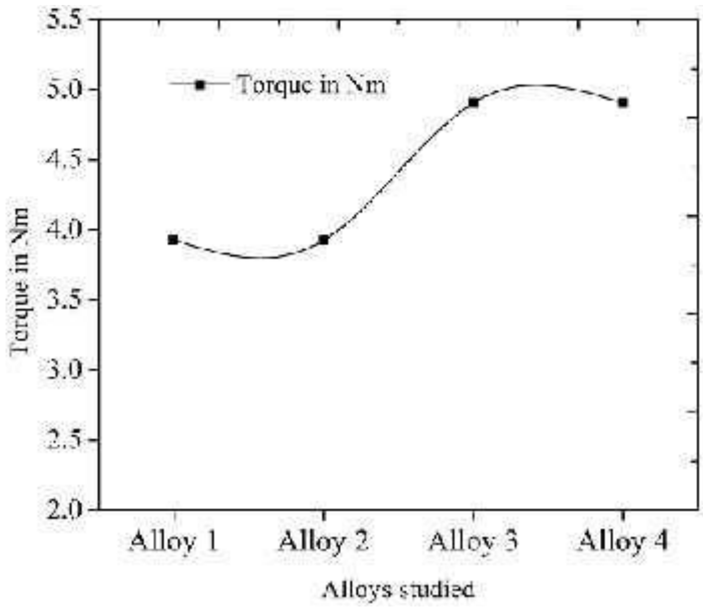

Fig. 6 Torque of LM-30 for all grain refiners

Statistical analysis of Torque

In the present study, statistical analysis of torque of untreated and treated samples of LM-25, LM-6 and LM-30 was carried out to predict the percentage contribution of the independent variables on dependent variable. The process parameters selected for performing ANOVA for torque are Force X, Force Y, Force Z, Al, Si, Mix (Grain refiner) and hardness. From Table no 2 it is observed that Force in X direction, Al, Si and hardness are the maximum influencing parameters with F ratio of 8.59, 11.87, 14.84 and 7.83 respectively towards the outputparameter with high statistical significance.

Table no 2 ANOVA analysis of Torque

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-value**	**Remarks**
Regression	7	0.040747	0.040747	0.005821	3.93	0.102	Insignificant
Force X	1	0.001952	0.012710	0.012710	8.59	0.043	Significant
Force Y	1	0.004798	0.000272	0.000272	0.18	0.690	Insignificant
Force Z	1	0.000677	0.004350	0.004350	2.94	0.162	Insignificant
Al	1	0.000429	0.017563	0.017563	11.87	0.026	Significant
Si	1	0.020856	0.021959	0.021959	14.84	0.018	Significant
Mix	1	0.000442	0.006799	0.006799	4.59	0.099	Insignificant
Hardness	1	0.011593	0.011593	0.011593	7.83	0.049	Significant
Error	4	0.005920	0.005920	0.001480			
Total	11	0.046667					

Fig.7 shows the percentage contribution of the process parameters. The percentage contribution of Force in X direction is 4.18%, Al is 1%, Si is 44.69% and hardness is 24.84% respectively, compared to other process parameters such as Mix (grain refiner), force in Y and Z direction

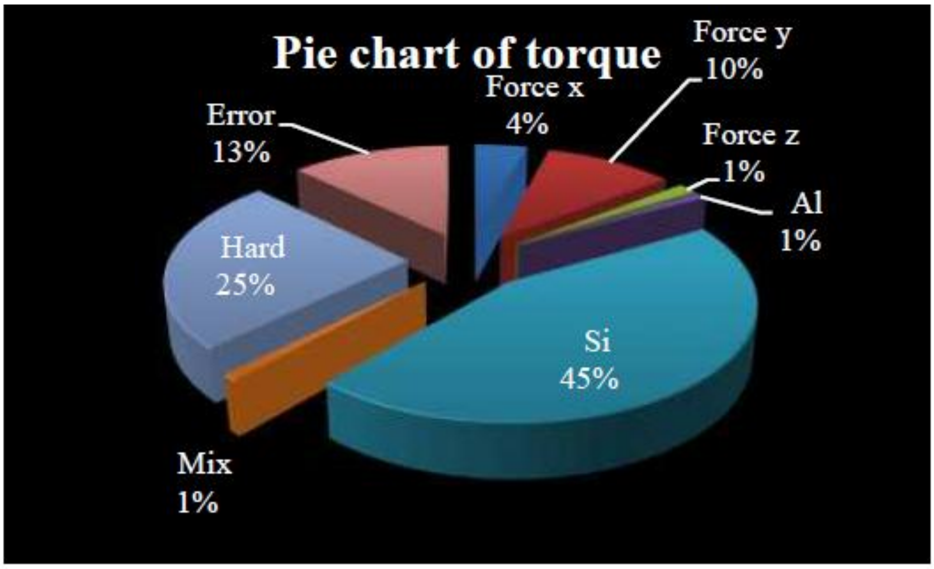

Fig. 7 Pie chart of Torque and percentage contribution

Fig. 8 clearly depicts that the residual plots are equally distributed on either side of the reference points.

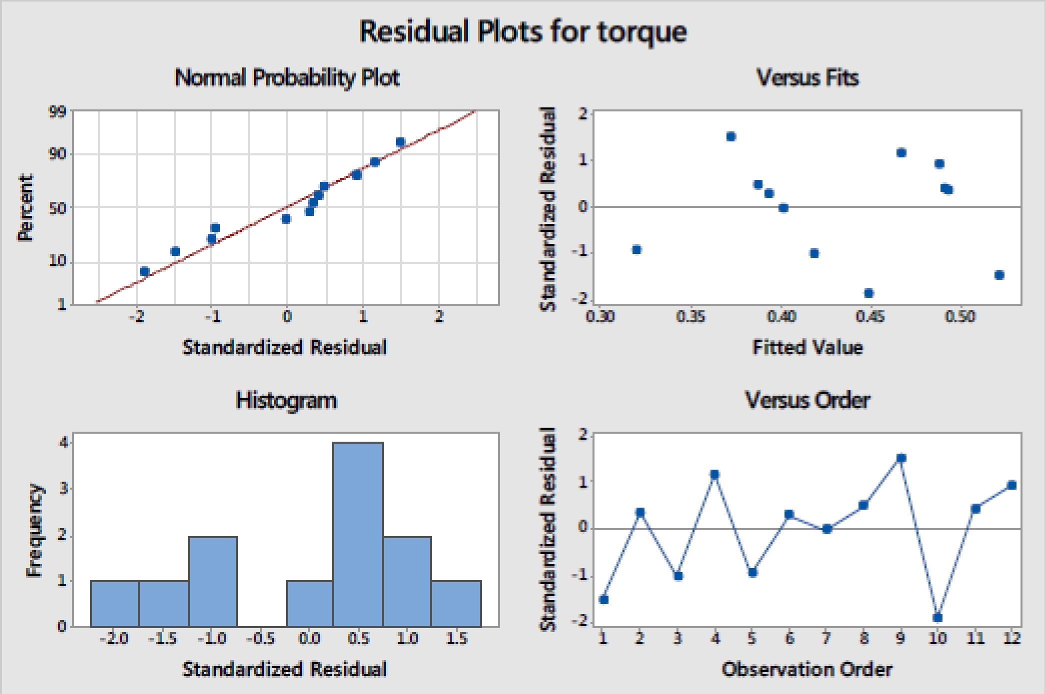

Fig. 8 Residual and observation plots of torque

Multiple linear regression model of torque : The general regression equation for torque is

Torque = 6.59 – 0.001571Force X + 0.000242 Force Y – 0.01638 Force Z – 0.0410 Al -0.070Si - 0.1615 Mix – 0.02171 Hardness ... (Eq.1)

Table 3 and 4 shows the coefficient of determination of 87.32% with a T-value is more forforce in X direction, Al, Si and hardness. It indicates that these process parameters are more influencing than other parameters. Table 5 shows the measured and the predicted values ofthe torque.

Table 3 Model summary of Torque

SS	**R^2**	**R^2 (adj)**
0.0384692	87.32%	85.12%

Table 4 Regression coefficients of Torque

Terms	**Coefficients**	**T-value**	**P-value**
Constant	6.59	4.84	0.008
Force X	0.001571	2.93	0.043
Force Y	-0.000242	-0.43	0.690
Force Z	0.01638	1.71	0.162
Al	-0.0410	-3.45	0.026
Si	-0.0700	-3.85	0.018
Mix	-0.1615	-2.14	0.099
Hard	-0.02171	-2.80	0.049

Table 5 Measured and predicted values of Torque

Sl. No.	Measured thrust	Predicted thrust	Error
1	16	13.3115	2.68853
2	23	24.3542	-1.35421
3	31	26.9498	4.05016
4	16	21.3845	-5.38448
5	14	17.3224	-3.32244
6	20	16.8938	3.10622
7	12	12.9770	-0.97700
8	14	12.8068	1.19323
9	23	21.7578	1.24222
10	20	20.1704	-0.17041

A graph of experimental values against predicted values is drawn for all LM-25, LM-6 and LM-30 as depicted in Fig. 9. Fig. 10 shows the error between the variables from the predicted equation. It clearly shows that the error is less than 5% and the predicted points are very close to the measured values. Hence the predicted equation is good predictive capability with the acceptable accuracy

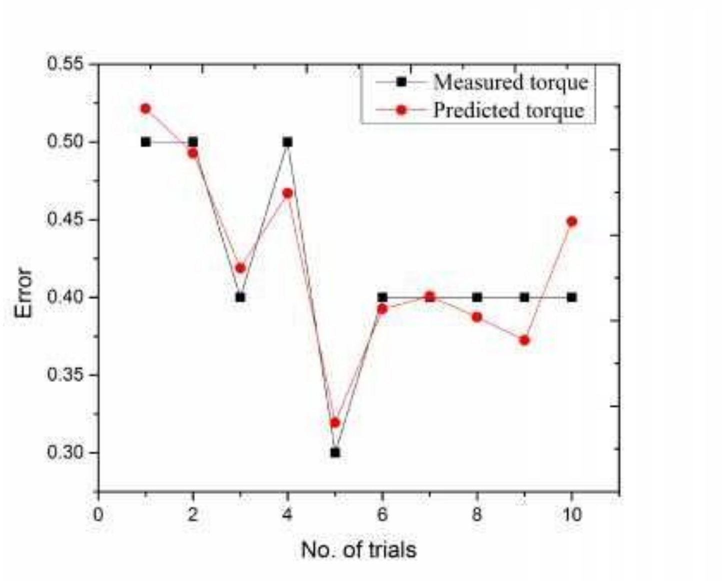

Fig.9 Measured and predicted values of torque

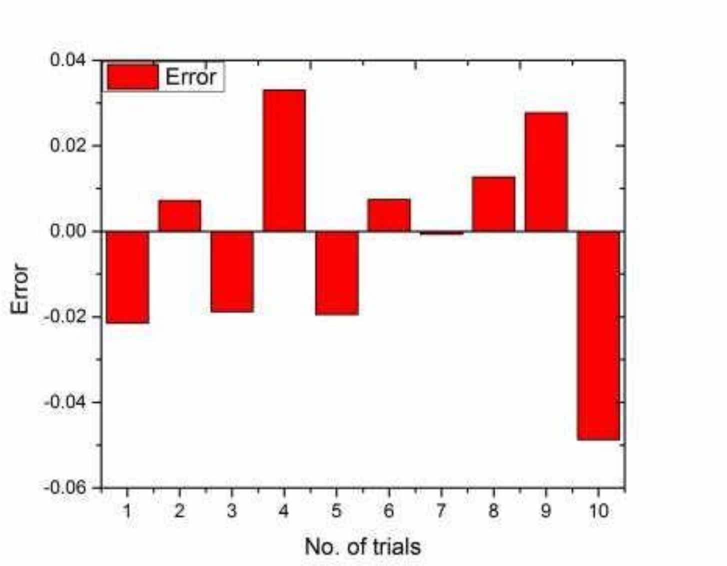

Fig. 10 Error graph of torque

Thrust

The lathe machine used for this test was high precision heavy duty machine having spindle RPM range of 112- 1800rpm and 1 H.P motor. The experiment was conducted by giving constant feed, speed (N=770rpm), depth ofcut (2mm). The drill tool dynamometer readings are shown in Fig. 11 to Fig 13.

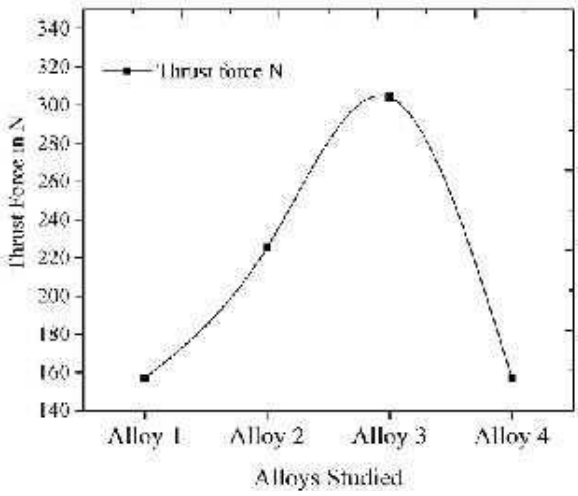

Fig. 11 Thrust of LM-25 for all grain refiners

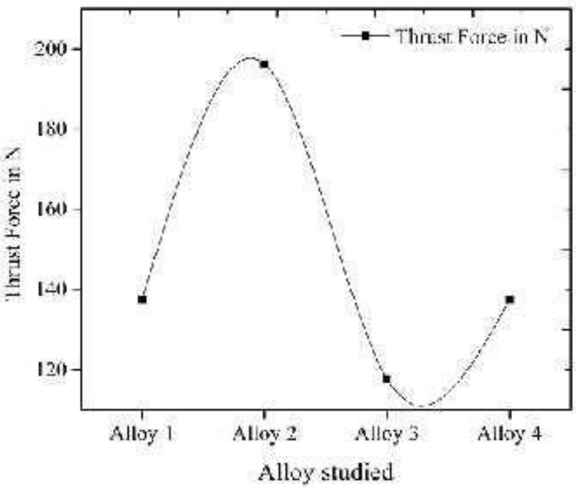

Fig. 12 Thrust of LM-6 for all grain refiners

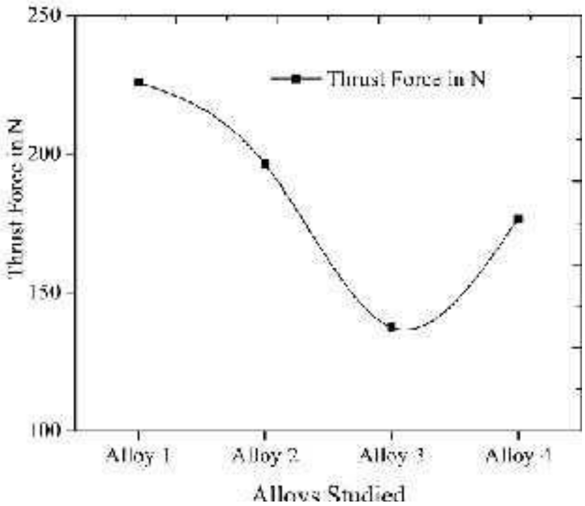

Fig. 13 Thrust of LM-30 for all grain refiners

Statistical analysis of Thrust

The process parameters selected for performing ANOVA for thrust are Force X, Force Y, Force Z, Al, Si, mix and hardness. Table 6 depicts the ANOVA analysis of thrust for the LM-25, LM-6 and LM-30 respectively. It is seen that Force in X direction is the maximum influencing parameter with F ratio of 6.02 towards the output parameter

Table 6 ANOVA analysis of Thrust

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F-Value**	**P-value**	**Remarks**
Regression	7	228.836	228.836	32.691	1.48	0.369	Insignificant
Force X	1	117.718	132.495	132.495	6.02	0.050	Significant
Force Y	1	0.887	3.543	3.543	0.16	0.709	Insignificant
Force Z	1	1.470	8.624	8.624	0.39	0.565	Insignificant
Al	1	36.511	64.444	64.444	2.93	0.162	Insignificant
Si	1	53.334	40.231	40.231	1.83	0.248	Insignificant
Mix	1	4.168	18.887	18.887	0.86	0.407	Insignificant
Hardness	1	14.747	14.747	14.747	0.67	0.459	Insignificant
Error	4	88.081	88.081	22.020			
Total	11	316.917					

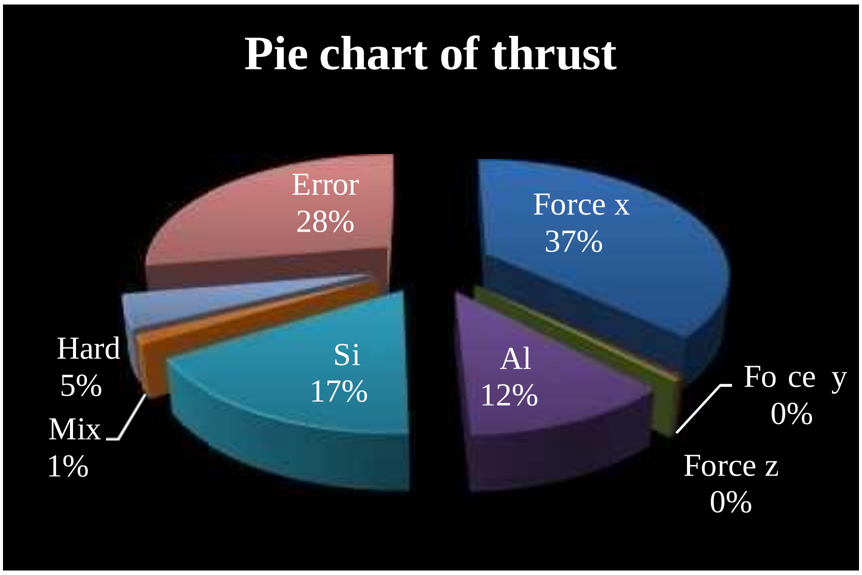

Fig. 14 Pie of thrust and percentage contribution

Fig. 14 shows the percentage contribution of the process parameters and in the present study Force in X direction is a significant parameter with a percentage contribution of 37% on thrust of the LM-25, LM-6 and LM-30 respectively. Fig. 15 clearly depicts that the residual plots are equally distributed on either side of the reference points.

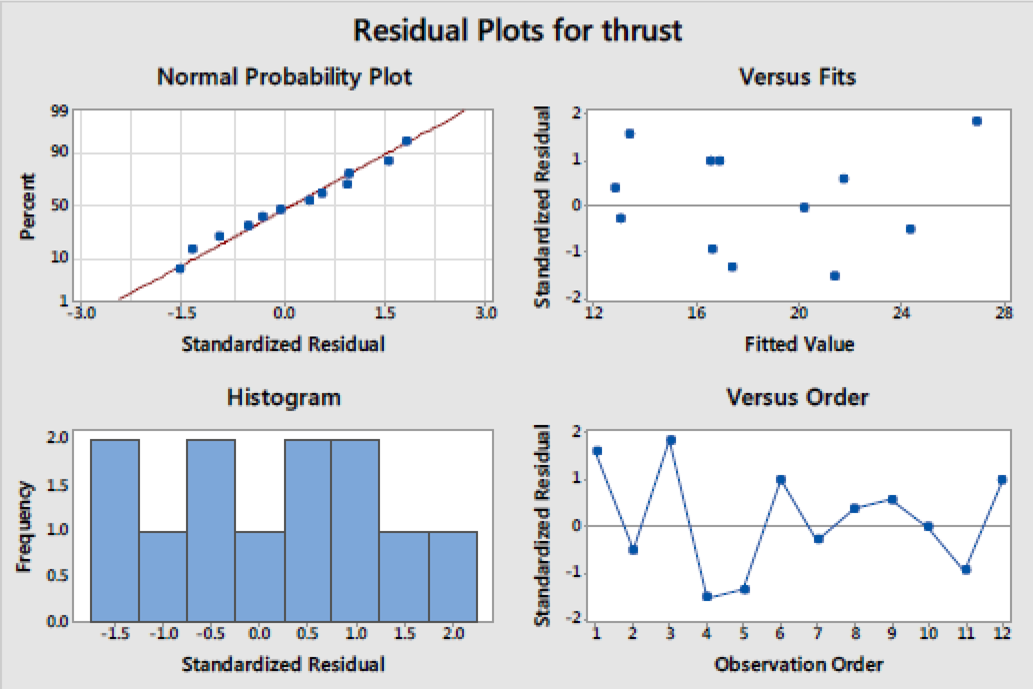

Fig. 15 Residual and observation plots of thrust

Multiple linear regression model of thrust is

Thrust = 205 – 0.1604Force X + 0.0276 Force Y – 0.73 Force Z – 2.48 Al -3.00 Si + 8.51 Mix + 0.774 Hardness ... (Eq. 2)

The general regression equation for thrust is as shown in the Equation 2. It shows the influence of independent variables on the dependent variables of thrust. Table 7 and Table 8 shows the coefficient of determination of 72.21% with a T-value is more for force in X direction. It indicates that this process parameter is more influencing on other parameters. Table 9 shows the measured and the predicted values of the thrust.

Table 7 Model summary of thrust

SS	R^2	R^2 (adj)
4.69256	72.21%	69.57%

Table 8 Regression coefficients of thrust

Terms	Coefficients	T-value	P-value
Constant	205	1.23	0.285
Force X	-0.1604	-2.45	0.070
Force Y	0.0276	0.40	0.709
Force Z	-0.73	-0.63	0.565
Al	-2.48	-1.71	0.162
Si	-3.00	-1.35	0.248
Mix	8.51	0.93	0.407
Hard	0.774	0.82	0.459

Table 9 Measured and predicted values of Thrust

Sl. No.	Measured thrust	Predicted thrust	Error
1	16	13.3115	2.68853
2	23	24.3542	-1.35421
3	31	26.9498	4.05016
4	16	21.3845	-5.38448
5	14	17.3224	-3.32244
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A graph of experimental values against predicted values is drawn for all LM-25, LM-6 and LM-30 as depicted in Fig. 16 and Fig. 17 shows the error between the variables from the predicted equation. It can be seen that the error is less than 5% and the predicted points are very close to the measured values. Hence the predicted equation has good predictive capability with acceptable accuracy.

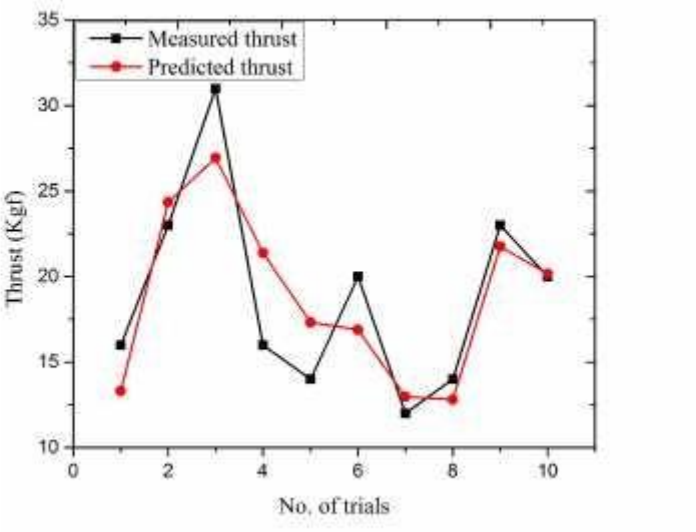

Fig. 16 Measured and predicted values of thrust

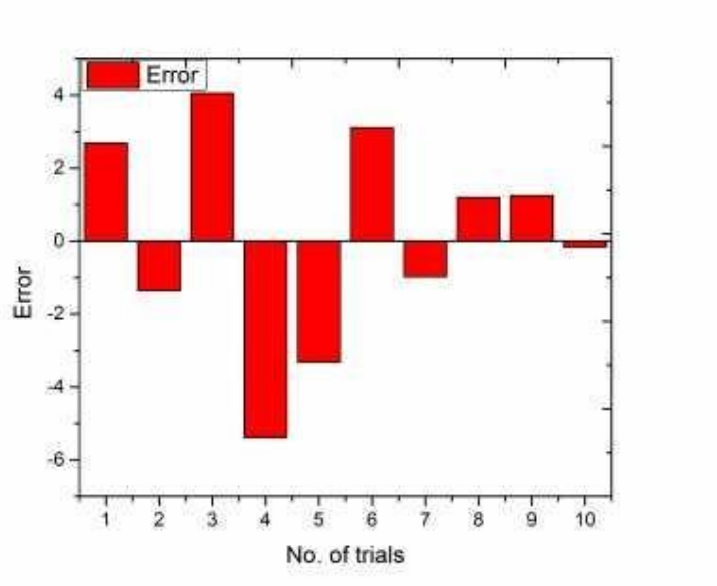

Fig. 17 Error graph of thrust

IV. Conclusion

For thrust force in X direction is the maximum influencing parameter. Whereas for torque, Si followed by force in X direction, Al and hardness are the maximum influencing parameters.

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