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Taguchi analysis in investigation of feed force, cutting force and thrust force while machining aluminium metal matrix composite

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Metal matrix composite finds several applications in automotive and aerospace sectors because of its excellent mechanical properties and ease of machinability characteristics Taguchi analysis is used to investigate the cutting force, feed force and the thrust force while machining aluminium metal matrix composite. The analysis of variance (ANOVA) is used to investigate the experimental results and the parameters influencing the cutting force, feed force and thrust force in turning of aluminium metal matrix composite. Taguchi analysis is used and the response table for the feed force, cutting force and Thrust force is calculated and it is found the forces are highly influence by the steam pressure.

Keywords: Feed force, Cutting force, Thrust force, Metal matrix composite, ANOVA, Taguchi technique.

Introduction

Cutting force is the maximum force in machining operations and it is tangential to the rotating direction. The dynamometers are embedded between the tool and turret head and it is mounted on the tool turret head with an adapter. The measurement of cutting force is helpful in analysis of chip formation, identification of wear processes, understanding materials behavior, identification of optimum process parameters and machine abnormalities. Ultrasonic assisted turning aluminium metal matrix composite is demonstrated and it is concluded that the reduction in cutting force will improve the surface finish of the turning process [1]. The machinability studies of the aluminium metal matrix composites are investigated for its usage in several engineering industries due to its increase mechanical properties [2]. Response surface methodology is used to assess the cutting forces in turning aluminium metal matrix composite. Desirability function analysis is employed to determine the optimal machining parameters that influence better surface finish and tool wear [3]. The machining of metal matrix composite with HSS and copper is conducted to evaluate the tool wear, surface roughness and thrust force. Stir casting process is used to fabricate the metal matrix composite and the turning operation is performed using a CBN tool insert. The responses are assessed and ranked for the individual response and combination of all responses [4]. The investigation of cutting forces for metal matrix composite is done using a novel technique TOPSIS. The composite are prepared with 90% weight proportion of aluminium and 10% of silicon carbide. L27 orthogonal array is used to conduct the experiments and the optimal machining levels are determined [5]. The machining of metal matrix composite using uncoated tungsten carbide inserts is discussed. It is found that when the cutting speed is 600 m/min, the surface roughness brings very low values and it is found to be optimal. Also it is reported that during the high cutting speed, built up edges are generated on the cutting tool [6]. The comparative study of cutting forces in metal matrix composites is done and it is reported that the composite containing silicon carbide alone will experience high cutting force when compared to others [7]. Several Optimization techniques such as Grey relation analysis are demonstrated to determine the optimum machining characteristics of the composite laminate [8-10]. The steam is used as a coolant in turning metal matrix composite [11]. Today's technological advancement has paved the simplest method to the use of eco-friendly resources giving more importance to the plants origin thereby ecological balance is obtained. An Eco-friendly resource leads to better properties than the individual components. The composite is manufactured under the mixture of reinforcement phase and matrix phase. Metal matrix composites are inexpensive and lighter in weight, little density, extraordinary toughness, and bio-degradable. So the usages of Aluminium metal matrix composites

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are increasing in the day today life in several engineering applications. Several researchers used RSM, Taguchi Technique and TGRA analysis for multi objective optimization to determine the optimal parameters [12-14].

Experimental Work

The silicon carbide is used as the reinforcing element with volume concentration of 15% along with the aluminium alloy 6061, which is used as the metal matrix in fabrication the Al-SiC metal matrix composite and the mean diameter of the silicon carbide particles are 25 μm. Silicon carbide is preferred as the reinforcing material because of its high hardness and wear resistance. The specimens are prepared in the cylindrical form of 40 mm diameter and 100 mm in length. Stir casting process is employed for the fabrication process with poring temperature of 650-700 degree Celsius. The specimens are treated in chemical solutions maintained at 500 degree Celsius for 3 to 4 hours and then water quenched to room temperature. The hardness of the sample is tested and on an average it is found to 90-95 BHN. The metal matrix composite is then turned in a turning machine in an automatic lathe with cubic boron nitride inserts. Steam is used as the cooling agent and steam generator is used to generate steam and the steam is supplied to the work–tool

Table 1. Experimental work.

Run	Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Nozzle Diameter (mm)	Steam Pressure (bar)	Feed force (N)	Cutting Force (N)	Thrust Force (N)
1	100	0.2	0.5	2	5	129.653	171.254	75.365
2	100	0.1	1	2	10	124.253	172.579	33.652
3	50	0.1	1	3	10	144.598	169.357	58.239
4	100	0.2	0.5	3	5	78.658	185.692	61.834
5	100	0.2	0.5	3	10	87.324	147.285	47.698
6	50	0.2	0.5	2	10	142.365	306.168	57.216
7	50	0.1	1	3	5	120.361	152.587	77.254
8	50	0.1	0.5	3	5	108.365	197.354	39.245
9	100	0.1	1	3	10	147.258	231.606	43.029
10	100	0.1	0.5	2	10	143.158	312.257	33.692
11	100	0.1	1	2	5	91.221	209.258	47.258
12	100	0.2	0.5	2	10	126.327	207.474	60.296
13	100	0.2	1	2	10	113.697	201.272	33.478
14	50	0.1	0.5	3	10	147.324	239.09	43.021
15	50	0.1	1	2	10	115.24	214.254	47.268
16	50	0.1	0.5	2	5	87.658	312.314	30.358
17	50	0.2	1	2	5	94.211	221.312	70.265
18	50	0.2	1	3	10	113.988	319.248	50.398
19	100	0.1	0.5	3	10	111.816	230.027	43.301
20	100	0.1	0.5	3	5	93.625	197.357	49.027
21	50	0.1	0.5	2	10	134.022	351.197	36.215
22	100	0.2	1	3	10	114.074	307.327	30.258
23	100	0.2	1	3	5	110.368	346.982	51.0362
24	100	0.1	1	3	5	119.701	268.364	66.327
25	100	0.1	0.5	2	5	98.234	257.368	37.024
26	50	0.2	1	2	10	111.035	282.171	57.63
27	100	0.2	1	2	5	116.234	217.357	64.267
28	50	0.1	1	2	5	63.756	127.264	53.641
29	50	0.2	0.5	3	5	105.324	173.652	55.0312
30	50	0.2	0.5	3	10	114.326	223.274	47.038
31	50	0.2	1	3	5	121.237	323.652	60.267
32	50	0.2	0.5	2	5	110.563	247.257	55.697

interface in the turning process through a nozzle with a steam supply pressure. Steam is used as a cutting fluid in the turning process of aluminium metal matrix composite Steam generation circuit is used in manufacturing process where direct or indirect cooling is needed in a turning process. The steam generation circuit which is used to produce steam can be installed anywhere and it can be utilized with varying the steam pressure. The steam carries away the heat from the cutting zone and it gives efficient way for a cooling method and it depends largely on the steam jet pressure. A pressure regulator is attached to the steam generation circuit and the steam, which is used as the cutting fluid is supplied through the nozzle by varying the steam jet pressure using this pressure regulator.

The cutting force and thrust force is measured using tool dynamometer. Thrust force is a axial force, the force in the feed direction. Cutting force is the resistance of the material against the intrusion of the cutting tool. The cutting force and thrust force are together and provides the resultant force during the machining process. Taguchi analysis is used to investigate the cutting force, feed force and the thrust force while machining aluminium metal matrix composite. The cutting speed, feed, depth of cut, nozzle diameter and steam pressure are considered as the input parameters with two levels for each. L32 orthogonal array is selected and 32 experiments are conducted and for the each combination of experiments as designed by the design of expert software, the response are measured and recorded as shown in Table 1. The cutting fluid is supplied at higher pressure and as a result capillaries are formed and it reduces the friction between the tool and the work interfaces.

Results and Discussion

The analysis of variance (ANOVA) is used to investigate the experimental results and the parameters influencing the cutting force, feed force and thrust force in turning of aluminium metal matrix composite. (ANOVA) is used to determine whether there are any statistically significant differences between the means of two or more independent parameters. In this work ANOVA analysis is used to predict the contributions of the each process parameter in the analysis of forces during the machining of AMMC. Significance level of α=0.05 with a confidence level of 95% is used for the analysis. With this, the sources with p-value less than 0.05 are considered to be highly significant and other parameters are summarily considered as insignificant. The examination of the ANOVA table shows that the steam pressure contributes maximum and it influences the cutting force, feed force and thrust force to a major extent, whereas the other parameters are in significant and their contribution are considered to be very less. The analysis of variance for the feed force is shown in Table 2, the analysis of variance for the cutting force and thrust force are given in Table 3 and Table 4 respectively.

Table 2. Analysis of Variance for Feed force.

Source	Degree of freedom	Sequential sum of squares	Adjusted sum of squares	Adjusted mean of squares	F value	P value
Cutting speed	1	25.87	25.87	25.87	0.69	0.419
Feed	1	117.07	117.07	117.07	3.11	0.097
Depth of cut	1	0.19	0.19	0.19	0.01	0.944
Nozzle diameter	1	42.14	42.14	42.14	1.12	0.306
Steam pressure	1	3647.35	3647.35	3647.35	96.85	0.000
Cutting speed × Feed	1	62.32	62.32	62.32	1.65	0.217
Cutting speed × Depth of cut	1	557.21	557.21	557.21	14.80	0.001
Cutting speed × Nozzle diameter	1	1208.18	1208.18	1208.18	32.08	0.000
Cutting speed × Steam pressure	1	206.10	206.10	206.10	5.47	0.033
Feed × Depth of cut	1	0.11	0.11	0.11	0.00	0.957
Feed × Nozzle diameter	1	1715.40	1715.40	1715.40	45.55	0.000
Feed × Steam pressure	1	1622.51	1622.51	1622.51	43.08	0.000
Depth of cut × Nozzle diameter	1	2576.83	2576.83	2576.83	6842	0.000
Depth of cut × Steam pressure	1	70.59	70.59	70.59	1.87	0.190
Nozzle diameter × Steam pressure	1	285.00	285.00	285.00	7.57	0.014
Error	16	602.57	602.57	37.66		
Total	31	12739.43				
S = 6.13685 R-Sq = 95.27% R-Sq(adj) = 90.84%						

Table 3. Analysis of Variance for Cutting Force.

Source	Degree of freedom	Sequential sum of squares	Adjusted sum of squares	Adjusted mean of squares	F value	P value
Cutting speed	1	1209.0	1209.0	1209.0	3.59	0.076
Feed	1	1787.2	1787.2	1787.2	5.30	0.035
Depth of cut	1	1.0	1.0	1.0	0.00	0.958
Nozzle diameter	1	299.5	299.5	299.5	0.89	0.360
Steam pressure	1	2917.8	2917.8	2917.8	8.66	0.010
Cutting speed × Feed	1	5710.9	5710.9	5710.9	16.94	0.001
Cutting speed × Depth of cut	1	7396.1	7396.1	7396.1	21.94	0.000
Cutting speed × Nozzle diameter	1	5763.9	5763.9	5763.9	17.10	0.001
Cutting speed × Steam pressure	1	4830.8	4830.8	4830.8	14.33	0.002
Feed × Depth of cut	1	38431.0	38431.0	38431.0	114.01	0.000
Feed × Nozzle diameter	1	6149.3	6149.3	6149.3	18.24	0.001
Feed × Steam pressure	1	261.3	261.3	261.3	0.78	0.392
Depth of cut × Nozzle diameter	1	34139.8	34139.8	34139.8	101.28	0.000
Depth of cut × Steam pressure	1	1852.7	1852.7	1852.7	5.50	0.032
Nozzle diameter × Steam pressure	1	2151.9	2151.9	2151.9	6.38	0.022
Error	16	5393.6	5393.6	337.1		
Total	31	118297.5				
S = 18.3602 R-Sq = 95.44% R-Sq(adj) = 91.17%						

Table 4. Analysis of Variance for Thrust Force.

Source	Degree of freedom	Sequential sum of squares	Adjusted sum of squares	Adjusted mean of squares	F value	P value
Cutting speed	1	117.20	117.20	117.20	8.80	0.009
Feed	1	605.72	605.72	605.72	45.48	0.000
Depth of cut	1	162.94	162.94	162.94	12.23	0.003
Nozzle diameter	1	27.53	27.53	27.53	2.07	0.170
Steam pressure	1	918.78	918.78	918.78	68.98	0.000
Cutting speed × Feed	1	0.21	0.21	0.21	0.02	0.901
Cutting speed × Depth of cut	1	703.81	703.81	703.81	52.84	0.000
Cutting speed × Nozzle diameter	1	6.78	6.78	6.78	0.51	0.486
Cutting speed × Steam pressure	1	210.13	210.13	210.13	15.78	0.001
Feed × Depth of cut	1	773.83	773.83	773.83	58.10	0.000
Feed × Nozzle diameter	1	913.66	913.66	913.66	68.60	0.000
Feed × Steam pressure	1	72.10	72.10	72.10	5.41	0.033
Depth of cut × Nozzle diameter	1	26.31	26.31	26.31	1.98	0.179
Depth of cut × Steam pressure	1	320.42	320.42	320.42	24.06	0.000
Nozzle diameter × Steam pressure	1	15.98	15.98	15.98	1.20	0.290
Error	16	213.10	213.10	13.32		
Total	31	5088.50				
S = 3.64950 R-Sq = 95.81% R-Sq(adj) = 91.89%						

The Thrust force, feed force and cutting force are highly influenced by the steam pressure in the analysis of the machining of Aluminium metal matrix composite. Steam is cheap, pollution-free and eco-friendly, and then is a good and economical coolant and lubricant. Steam generator and steam feeding system were developed to generate and feed steam. The steam pressure gives a jet t flow which directly influences lubricating and cooling effect of the turning process.

Taguchi Analysis

The Taguchi analysis is carried out and the signal to noise ratios are determined for these forces. Smaller the

Table 5. Response table for Feed force.

Level	Cutting speed	Feed	Depth of cut	Nozzle diameter	Steam Pressure
1	-41.02	-41.06	-40.96	-40.86	-40.13
2	-40.93	-40.89	-40.99	-41.08	-41.82
Delta	0.10	0.17	0.02	0.22	1.69
Rank	4	3	5	2	1

Table 6. Response table for Cutting Force.

Level	Cutting speed	Feed	Depth of cut	Nozzle diameter	Steam Pressure
1	-47.30	-46.84	-47.16	-47.26	-46.75
2	-46.96	-47.42	-47.10	-47.01	-47.51
Delta	0.34	0.57	0.07	0.25	0.76
Rank	3	2	5	4	1

Table 7. Response table for Thrust Force.

Level	Cutting speed	Feed	Depth of cut	Nozzle diameter	Steam Pressure
1	-34.17	-33.01	-33.42	-33.55	-34.68
2	-33.41	-34.57	-34.16	-34.02	-32.89
Delta	0.75	1.56	0.74	0.47	1.79
Rank	3	2	4	5	1

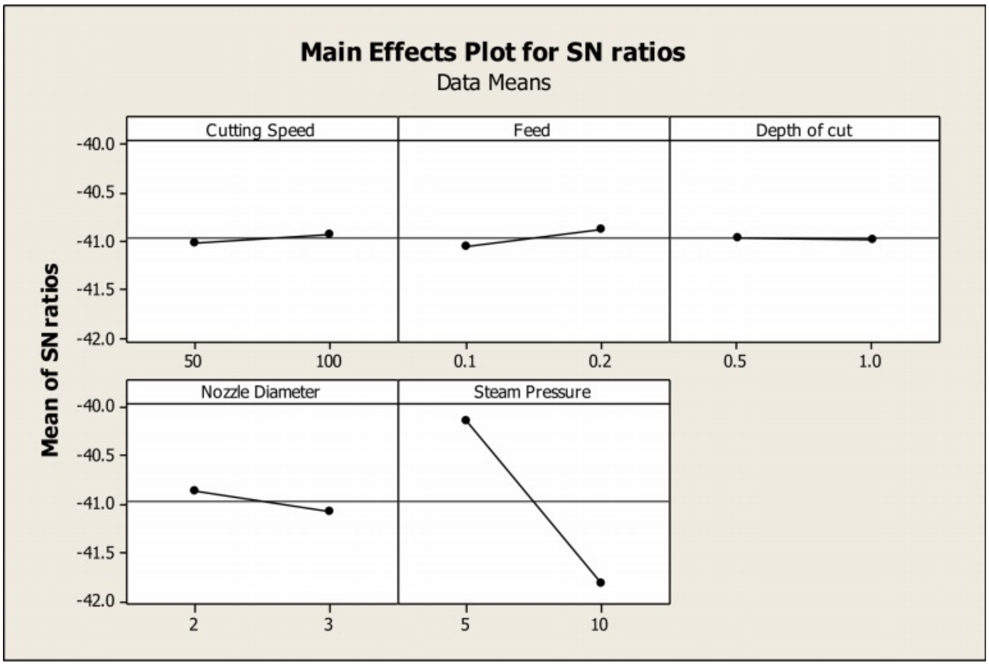

Fig. 1. Main effects plots for SN ratios for Feed force.

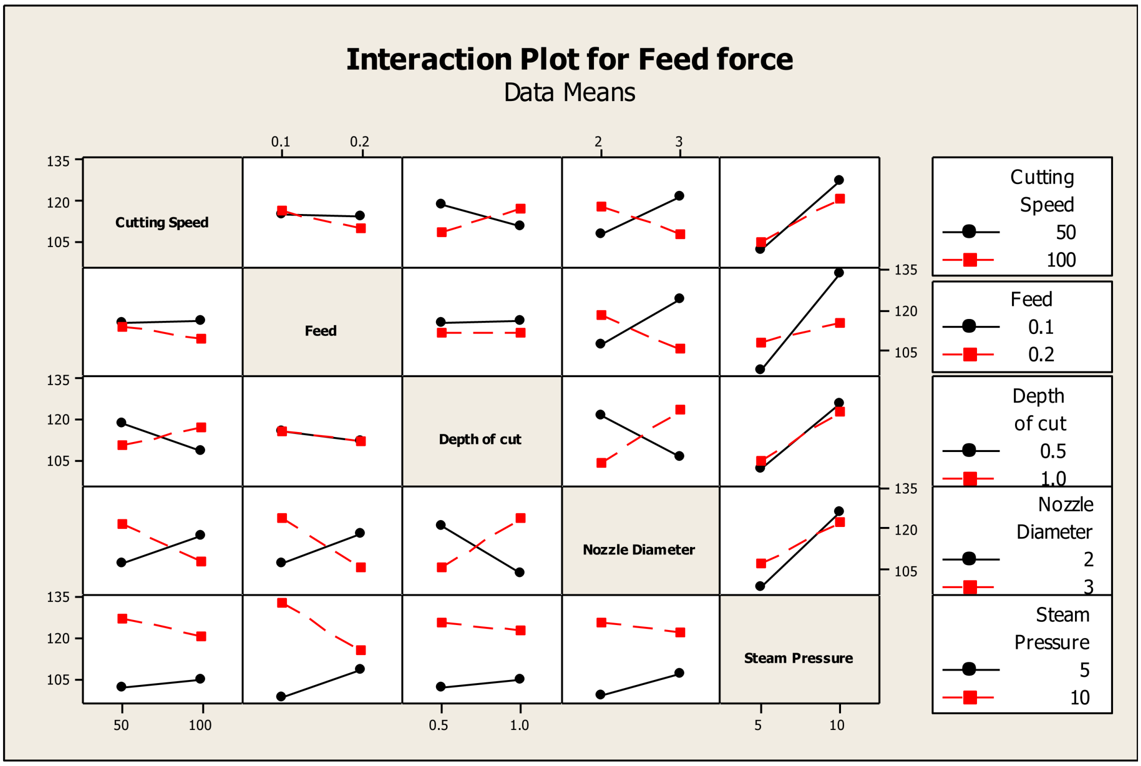

Fig. 2. Interaction plot for Feed force.

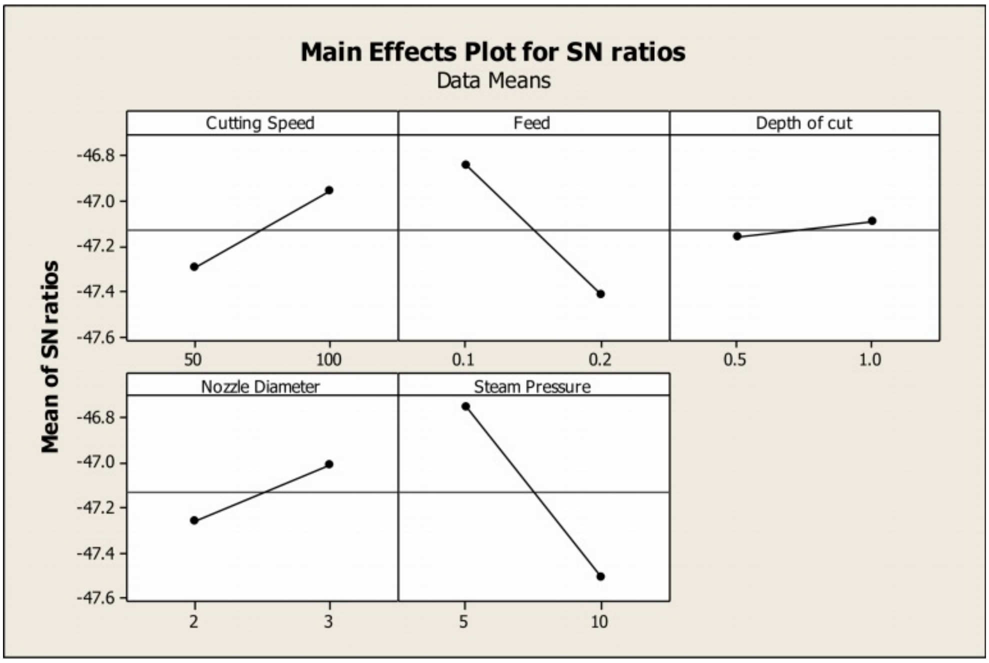

Fig. 3. Main effects plot for cutting force.

better in Taguchi analysis is taken into consideration since less amount of cutting force will provide lesser amount of tool wear. The response table for the feed force is presented in Table 5 and it is found that the steam pressure contributes to a major extent and it is followed by nozzle diameter, feed cutting speed and depth of cut. Similarly the response table for the cutting force is calculated as shown in Table 6 and it is found that the steam pressure contributes maximum and it is followed by feed rate, cutting speed and depth of cut. Similarly the response table for the thrust process is also determined using the signal to noise

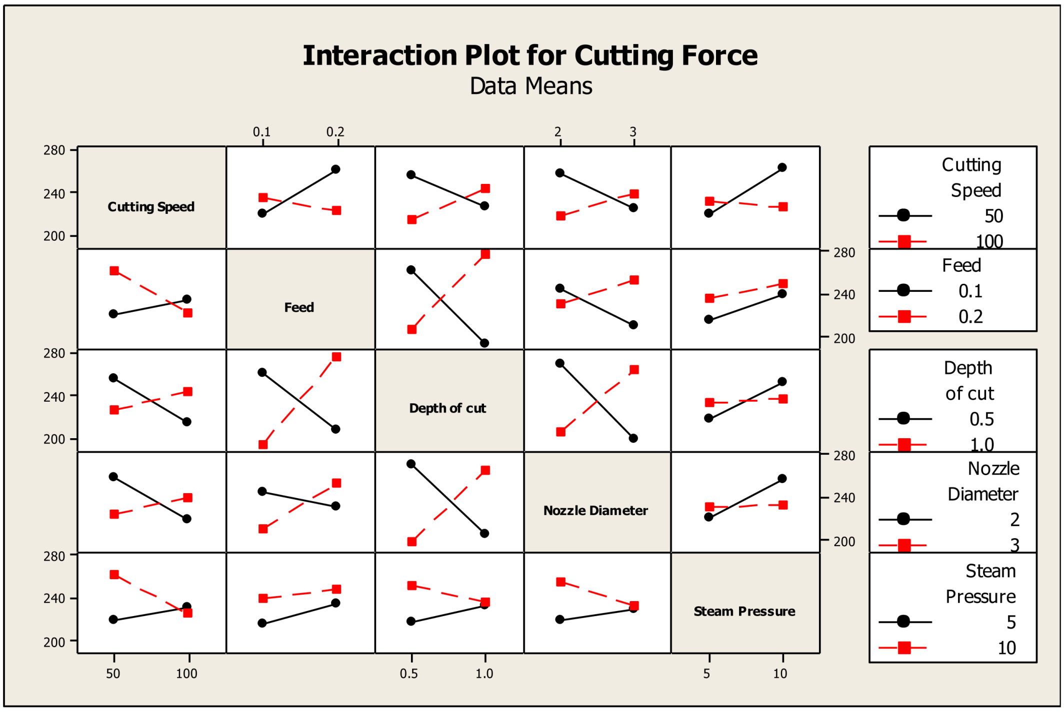

Fig. 4. Interaction plot for cutting force.

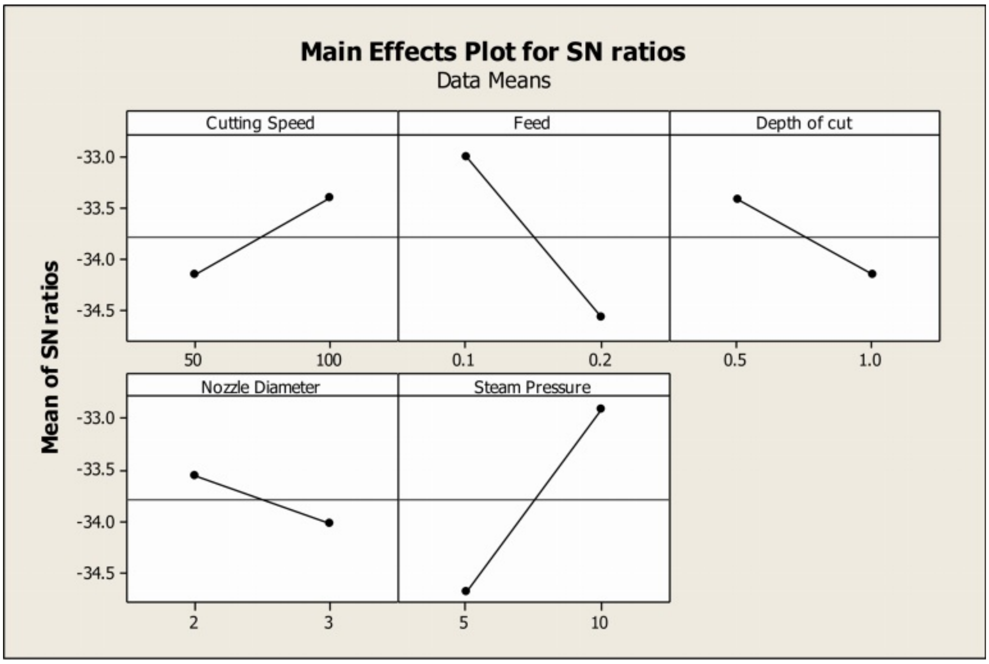

Fig. 5. Main effects plot for Thrust force.

ratio as shown in Table 7 and it is found that the steam pressure is ranked first and it is followed by feed rate, cutting speed, depth of cut and nozzle diameter. The main effects plot and interaction plots for feed force, cutting force and Thrust force are plotted as shown in the Figs. 1-6.

Conclusion

In this work, stir casting process is employed and the specimens are prepared in the cylindrical form and the turning process is carried. The process parameters considered are cutting speed, feed, depth of cut, nozzle diameter and steam pressure. The cutting force, feed

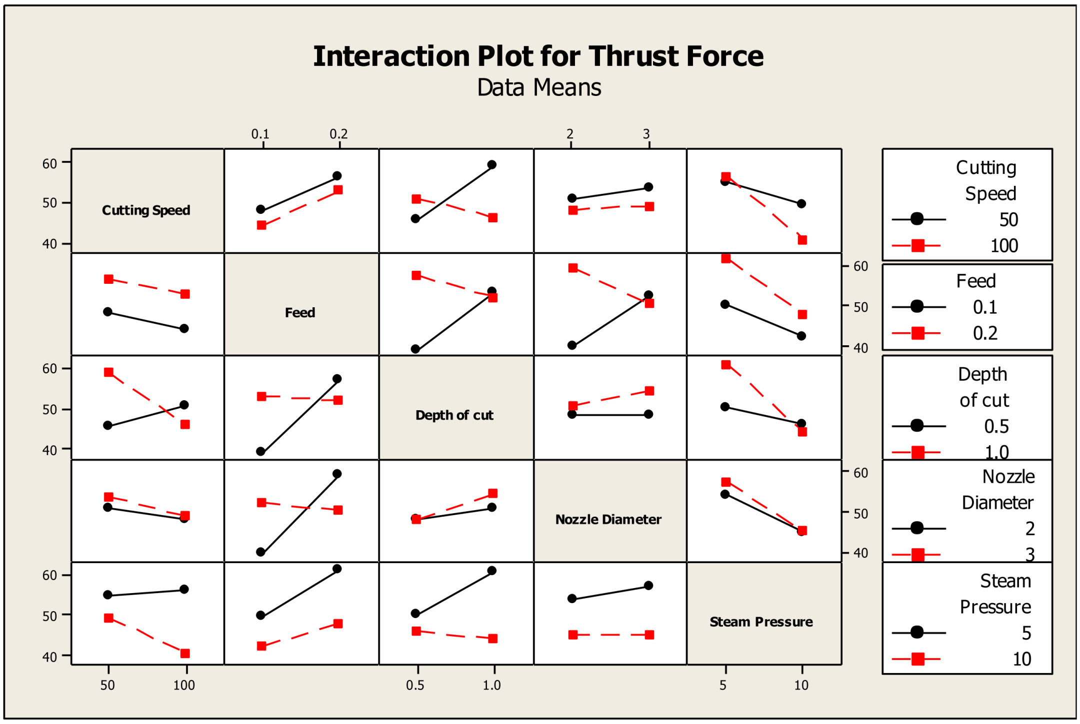

Fig. 6. Interaction plot for Thrust force.

force and thrust force are considered as the responses. Taguchi analysis is carried to minimize the cutting force, feed force and Thrust force. It is found that the most influencing parameter in the optimization of cutting force, feed force and thrust force is the steam pressure. The response tables are discussed and the main effects and interactions plots are plotted and discussed.

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