Optimization of Surface Roughness and Material Removal Rate in Milling of Aluminum Alloy 7475 using Taguchi Technique

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Abstract - *Modern structural applications demands reduction in weight. Al alloys are the best choice for the reduction of weight. AA7475 alloy has many applications in aerospace industry due to its high strength to weight ratio.*

Milling is the mostly used machining process in all industries and machine shops for machining parts to precise sizes and shapes. In this thesis experiments are conducted to improve the surface finish quality, material removal rate of Aluminum alloy 7475 workpiece. L9 orthogonal array has been selected for conducting the experiment. A series of 9 experiments are conducted by varying the milling parameters spindle speed, feed rate, depth of cut, and to optimize the better machining parameters using Taguchi technique. Here we analyzed the taguchi's method and RSM method for the appropriate results.

Key Words: **Milling, AA7475, Orthogonal array, Surface Roughness, Material Removal Rate, Taguchi Technique, Optimization**

1.INTRODUCTION

Metal cutting is one of the most important and widely used manufacturing processes in engineering industries and in today's manufacturing scenario, optimization of metal cutting process is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing
demand of quality which has to be achieved at minimal cost. As flexibility and adaptability needs increased in the manufacturing industries, computer numerical control systems was introduced in metal cutting processes that provided automation of processes with very high accuracies and repeatability. Because of high cost of numerically controlled machine tools compared to their conventional counterparts, there is an economic need to operate these machines as effectively as possible. Product quality, productivity and cost became important goals in manufacturing industries.

Milling is the machining process of using rotary cutters to remove material from a work piece by advancing (or feeding) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes. In the vertical milling the spindle axis is vertically oriented milling cutters are held in the spindle and rotate on its axis. This is shown in fig 1.

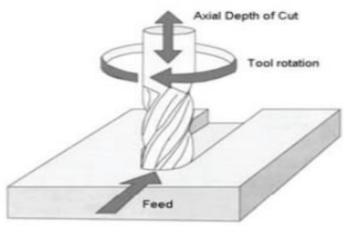

Fig1: Vertical Milling

The work done by P. V. Rangarao [1], describes a comparison of tool life between ceramics and cubic boron nitride(CBN) cutting tools when machining hardened steels using the Taguchi method. An orthogonal design, signal-to-noise ratio (S/N) and analysis of variance (ANOVA) were employed to determine the effective cutting parameters on the tool life. The results indicated that the V was found to be a dominant factor on the tool life, followed by the TH, lastly the f. The CBN cutting tool showed the best performance than that of ceramic based cutting tool. In

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addition, optimal testing parameter for cutting times was determined. The confirmation of Experiment was conducted to verify the optimal testing parameter. Improvements of the S/N ratio from initial testing parameters to optimal cutting parameters or prediction capability depended on the S/N ratio and ANOVA results. Moreover, the ANOVA indicated that the cutting speed was higher significant but other parameters were also significant effects on the tool lives at 90% confidence level. The percentage contributions of the cutting speed, tool's hardness, and feed rate were about 42.88, 32.44, and 24.22 on the tool life, respectively.

The work done by A.K Ghani[2], presents a study of tool life, surface finish and vibration while machining nodular cast iron using ceramic tool. A series of cutting tests have been carried out to verify the change in surface finish of the workpiece due to increasing tool wear. The tests have been done under various combinations of speed, feed and depth of cut. The effects of vibration on the flank wear both in the direction of main cutting force and radial cutting force have been investigated. The vibration was measured using two accelerometers attached to the tool holder and the parameters used to make the correlation with surface roughness were the amplitude and acceleration of the signals. The results show that the tool life of the alumina ceramic inserts is not satisfactory when machining nodular cast iron. In the speed range 364–685 m/min, maximum tool life achieved was only about 1.5 min. Surface finish was found to be almost constant with the progression of the flank wear under all cutting conditions. It has been observed that for the same flank wear, vibration during cutting decreases as the speed increases. At low depth of cut, vibration remains almost constant with the increase of flank wear.

2. Experimental Procedure

Aluminum alloy 7475 derived from AA 7075 provided excellent toughness for a broad variety of applications. This alloy offers several metal working options that include machining, forming and heat treating. Aluminum alloy 7000 series are alloyed with zinc, and can be precipitation hardened to the highest strengths of any Aluminum alloy. Most 7000 series alloys include magnesium and copper as well. The chemical composition of the AA7475 given in the table 1 and mechanical properties discussed in table 2.

Table -1: Chemical Composition of AA7475

Titanium	0.06%
Manganese	0.06%
Silicon	0.10%
Iron	0.12%
Magnesium	1.9-2.6%
Chromium	0.18-0.25%
Copper	1.2-1.9%
Zinc	5.2-6.2%
Aluminum	balance

Table 2 Mechanical Properties of AA7475

Density	2.81 g/cm^3
Poisons ratio	0.33
Elastic modulus	70-80 Gpa
Tensile strength	525 Mpa
Yield strength	460 Mpa
Elongation	12%
Hardness	140 Brinell

Tempered High Speed Steel (M2) tool was used that consisted of a cutting diameter of 15mm and length of cut 20mm.

In this project A CNC vertical milling machine was used for milling of AA7475 metal. Taguchi's design of experiment approach is employed to plan the experiments. Experiments have been performed by machining Aluminum alloy 7475 in order to investigate the effects of one or more factors of the process parameters (spindle speed, feed rate and depth of cut) on the surface finish of the machined surface and material removal rate.

Fig.2. Experimental setup

The experimental studies were performed on Feeler CNC vertical milling machine and the specifications are depicted in table 3. The milling process parameters and their levels are shown in table 4 and L9 orthogonal array has been selected for conducting the experiments. The machining was performed to make slots and MRR was measured using weight loss method. The roughness of the machined surface has been assessed with the help of Mitutoyo surface roughness tester (SJ-210).

Table3: Machine specifications

Description	Details
Machine make	Feeler
X axis movement(mm)	1000
Y axis movement(mm)	500
Z axis movement(mm)	500
Spindle speed(rpm)	10000
Length of table(mm)	700
Width of table(mm)	400

The experiments runs have been performed as per L9 orthogonal array to examine the importance of input process variables on material removal rate and surface roughness. The opted orthogonal array and experimental observations were shown in table 5. An effort has been taken to determine the best possible process variables for attaining the effective machining process. In milling process higher material removal rate and lower surface roughness are the indicators of superior performance measure. So MRR is considered as larger the better criterion and roughness of the machined surface is considered as smaller the better criterion. S/N ratio and Means are calculated and various graph for analysis is drawn by using Minitab 17 software. The S/N ratio for MRR and surface roughness are calculated on Minitab 17 Software using Taguchi Method.

Table 4: Parameters and their levels for milling of AA 7475

Factors	**Units**	**Level 1**	**Level 2**	**Level 3**
Cutting speed, N	**Rpm**	2000	3000	4000
Feed Rate, f	**mm/min**	200	400	600
Depth of cut, d	**mm**	0.3	0.4	0.5

.**Table 5**: L9 Orthogonal Array and Experimental Observations

Job No.	**Cutting speed (rpm)**	**Feed rate (mm/min)**	**Depth of cut (mm)**	**Surface Roughness R_a (µm)**	**S/N Ration of SR**	**MRR (mm³/sec)**	**S/N Ration of MRR**
1	2000	200	0.3	3.253	-10.2457	30. 8198	29.7766
2	2000	400	0.4	2.853	-9.1060	37.1441	31.3978
3	2000	600	0.5	3.826	-11.6549	43.9178	32.8528
4	3000	200	0.4	1.773	-4.9742	46.0313	33.2611
5	3000	400	0.5	3.280	-10.3175	54.5092	34.7294
6	3000	600	0.3	3.295	-10.3571	51.7794	34.2831
7	4000	200	0.5	2.358	-7.4509	58.9731	35.4131
8	4000	400	0.3	3.173	-10.0294	58.2740	35.3095
9	4000	600	0.4	2.662	-8.5042	61.0602	35.7152

3. Results And Discussions

3.1 Optimization Of Process Parameters Using Taguchi

3.1.1 Determination of Optimum process parameters for surface roughness

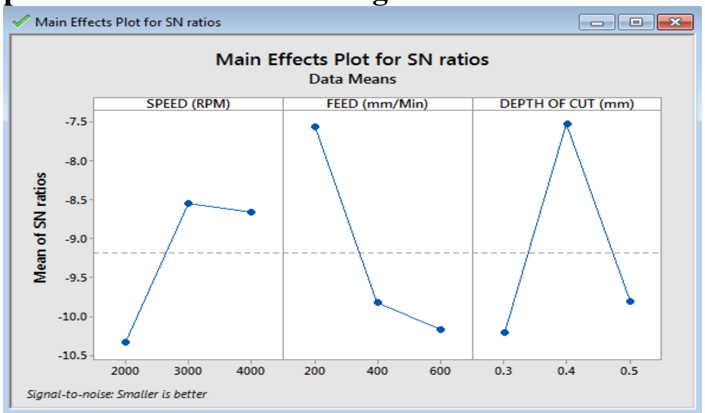

Fig 3. Effect of Machining Parameters On Surface Roughness For S/N Ratio

Table 6: Taguchi Analysis-Response Table for Surface Roughness

Levels	Means			S/N Ratio		
	Cutting speed	Feed	Depth of cut	Cutting speed	Feed	Depth of cut
1	3.311	2.461	3.240	-10.336	-7.557	-10.211
2	2.783	3.102	2.429	-8.550	-9.818	-7.528
3	2.731	3.261	3.155	-8.661	-10.172	-9.808
Delta	0.580	0.800	0.811	1.786	2.615	2.683
Rank	3	2	1	3	2	1

Fig.3 illustrates the main effects plot for surface roughness during milling process. Taguchi's response analysis has been performed for surface roughness and the results are depicted in table 6. Regardless of the category of the performance characteristics, a smallest S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the smallest value. In summary, the best possible machining variables to obtain minimum surface roughness are 3000 rpm, 200 mm/min, 0.4mm. This means optimum level for surface roughness is: speed at intermediate level, feed at minimum level and depth of cut at intermediate level. From the above response table it is clear that depth of cut is most contributing parameter, followed by feed and speed.

3.1.2 Determination of Optimum process parameters for Material Removal Rate

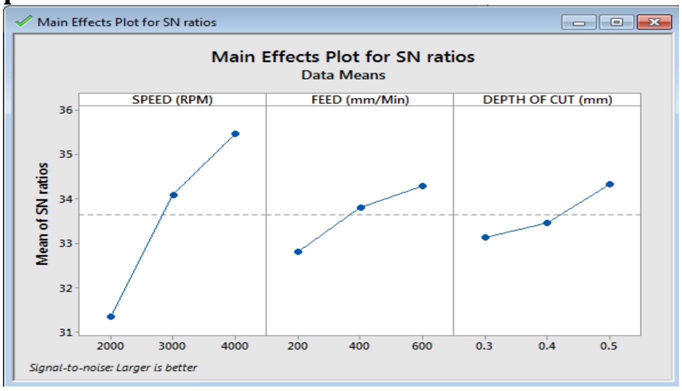

Fig. 4 Effect Of Machining Parameters On MRR For S/N Ratio

Table 7: Taguchi Analysis-Response Table for MRR

Levels	Means			S/N Ratio		
	Cutting speed	feed	Depth of cut	Cutting speed	feed	Depth of cut
1	37.29	45.27	46.96	31.34	32.82	33.12
2	50.77	49.98	48.08	34.09	33.81	33.46
3	59.44	52.25	52.47	35.48	34.28	34.33
Delta	22.15	6.98	5.51	4.14	1.47	1.21
Rank	1	2	3	1	2	3

Fig.4 illustrates the main effects plot for Material removal rate during milling process. Taguchi's response analysis has been performed for Material removal rate and the results are depicted in table 7. Regardless of the category of the performance characteristics, a greater S/N value corresponds to a better performance. Therefore, the optimal level of the machining parameters is the level with the greatest value. In summary, the best possible machining variables to obtain higher Material Removal Rate are 4000rpm, 600mm/min, 0.5mm. This means optimum level for MRR is: speed at maximum level, feed at maximum level and depth of cut at maximum level. From the above response table it is clear that spindle speed is most contributing parameter, followed by feed and depth of cut.

3.2 Optimization of Process Parameters Using Response Surface Methodology

3.2.1 Determination of Optimum process parameters for surface roughness

The 3D response surface plot is a graphical representationof the regression equation. It is plotted to understand the interaction of the variables and locate the optimal level of each variable for maximal response.

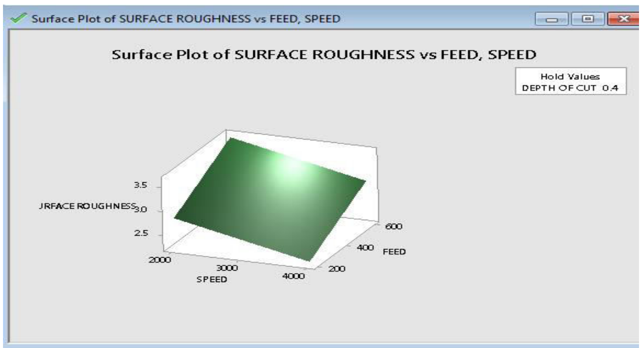

Fig 5 Surface Plot of Surface Roughness Vs speed and feed

By observing above graph, to minimize surface roughness, the speed on should be set at 4000rpm and feed at 200mm/min.

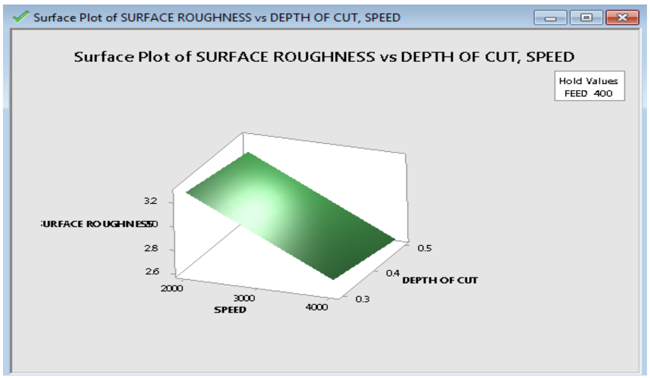

Fig 6 Surface Plot of Surface Roughness Vs depth of cut, speed

By observing above graph, to minimize surface roughness, the depth of cut should be set at 0.5mm and speed at 4000rpm.

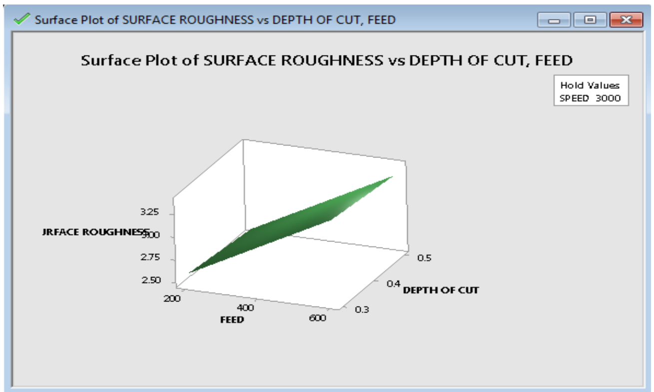

Fig 7 Surface Plot of Surface Roughness Vs depth of cut, feed

By observing above graph, to minimize surface roughness, the depth of cut should be set at 0.5mm and feed at 200mm/min. In summary, the best possible machining variables to obtain minimum Surface Roughness are 4000rpm, 200mm/min, 0.5mm.

3.2.2 Determination of Optimum process parameters for Material Removal Rate

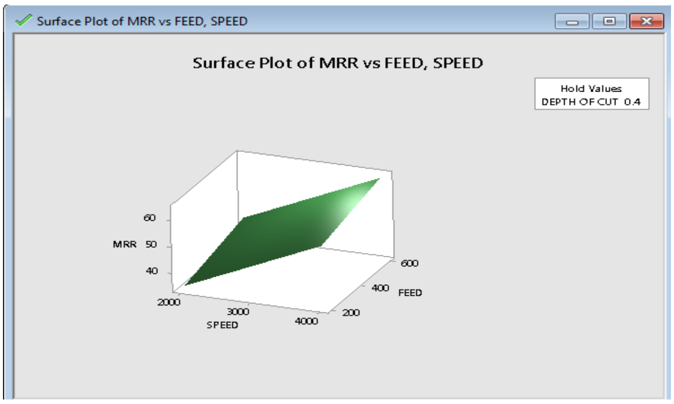

Fig. 8 Surface Plot of MRR speed, feed

By observing above graph, to maximize MRR, the feed should be set at 600mm/min and speed should be set at 4000rpm.

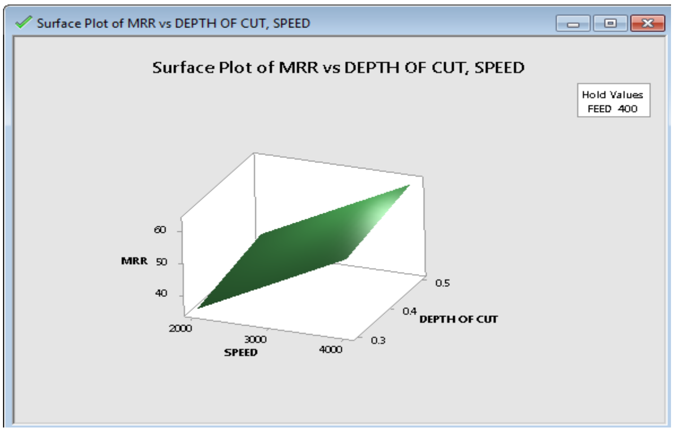

Fig. 9 Surface Plot of MRR Vs depth of cut, speed

By observing above graph, to maximize MRR, the depth of cut should be set at 0.5mm and speed at 4000rpm.

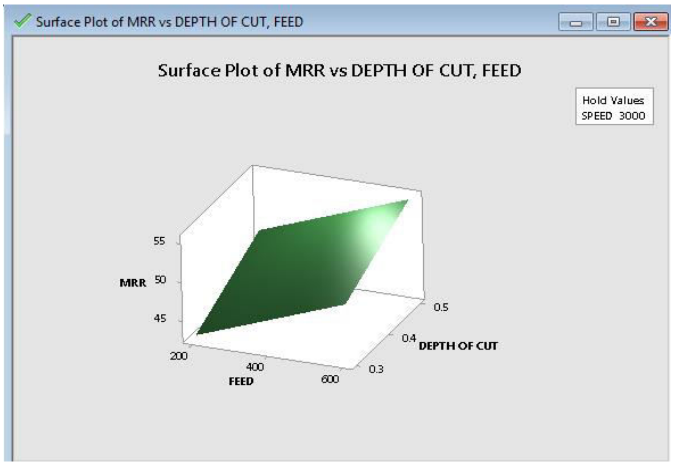

Fig. 10 Surface Plot of MRR Vs depth of cut, feed

By observing above graph, to maximize MRR, the depth of cut should be set at 0.5mm and feed should be set at 600mm/min. In summary, the best possible machining variables to obtain higher Material Removal Rate are 4000rpm, 600mm/min, 0.5mm.

4. CONCLUSIONS

Experiments are conducted on the Aluminum alloy 7475 by varying parameters. The process parameters varied and their respective values are feed rate 200mm/min, 400mm/min, 600mm/min, spindle speeds are 2000rpm, 3000rpm, 4000rpm and depth of cut 0.3mm, 0.4mm and 0.5mm. The optimization is done by using Taguchi technique considering L09 orthogonal array. Optimization is done in Minitab software. By observing the experimental results and by optimizing the parameters, the following conclusions can be made:

From Taguchi's analysis it is depicted that the Depth of Cut is considered as the predominant machining variable for surface roughness and it is followed by feed, cutting speed. For Material Removal Rate the cutting speed is most contributing parameter, followed by feed and depth of cut.

From the Taguchi method, the following results can be obtained:

- For surface roughness are speed should be set at 3000rpm and feed should be set at 200mm/min and the depth of cut is at 0.4mm.
- From the results of optimized parameters of MRR the speed should be set at 4000rpm and feed should be set at 600mm/min and the depth of cut is at 0.5mm.

From the Response Surface method, the following results can be obtained:

- For Minimum Surface Roughness, the optimum speed should be set at 4000rpm and feed should be set at 200mm/min and the depth of cut is at 0.3mm.
- For Maximum MRR, the optimum speed should be set at 4000rpm and feed should be set at 600mm/min and the depth of cut is at 0.5mm.

In summary it is corroborated from taguchi's response analysis have close relationship with the results of RSM. Taguchi's single response analysis determines the best possible process variables for attaining improved machining rate and surface quality. The present exploration helps the industries to improve production rate and quality of product in vertical milling process.

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