Application of Grey Taguchi Optimization for surface roughness and hardness in end milling

S.Muralidharan*, N.karthikeyan
Department of Mechanical Engineering, SRM University, Kattankulathur – 603203, India
***Corresponding author: E-Mail: muralidharan.s@ktr.srmuniv.ac.in**

ABSTRACT

Selecting proper machining parameters is vital in determining product quality. This experimental work was done to investigate and optimize the machining parameters like helix angle, feed rate, spindle speed and axial depth of cut on performance characteristic (surface roughness and hardness) in end milling using Taguchi method and grey relational analysis. End milling machining was carried out under dry cutting condition using HSS end mill cutter. Based on Taguchi L9 Orthogonal array, nine experiments was conducted on Al-6351.Analysis of variance (ANOVA) was used to find the influence of these machining Parameters on surface roughness and hardness. Using grey relational analysis grade was obtained. Optimal cutting parameters were determined using the grey relational grade as the performance index. A confirmation test was carried out with these optimal levels of machining parameters to illustrate the effectiveness of Grey Taguchi optimization method.

Keywords: Surface roughness, Hardness, ANOVA, grey relational analysis.

1. INTRODUCTION

End milling is a cutting process that uses an end mill cutter to remove material from the surface of a workpiece. In current scenario, most of industries were moving towards dry machining to reduce the cost of the product so identifying the machining parameters which yields quality product is important task. Aluminium is widely used metal in aviation industries and in engine components of automobiles for its light weight, ductile and can machined to glossy finish. Surface roughness is important parameters which not only affect aesthetic appearance but also function of a component. Poor finish product will have more asperities which increase friction and hence it generate more heat. The amounts of heat generated have a greater influence on hardness of machined components. A component with high hardness has good serviceability. Therefore this work is done to identify the machining parameter which gives minimum surface finish and maximum hardness. This can be achieved by taguchi-grey relational analysis which is multi objective optimization technique. Analysis of variance (ANOVA) is a statistical method to find the amount (in %) of influence of these machining parameters on the surface roughness and hardness. Various researches were done in end milling using different materials and methods. The literature survey related to this work is presented here. H.S Lu and C.K Chang (2009) analysed tool life and MRR in machining of tool steel and identified the optimal process parameters using grey taguchi method. Eyup Bagci and Seref Aykut (2008) the effect of parameters like feed, speed, depth of cut on surface roughness was studied .The signal-to-noise (S/N) ratio was used to the find the optimal levels and analysis of variance (ANOVA) are used to find the contribution of the milling parameters on surface roughness. Hasan Oktem (2006) studied the influence of feed, cutting speed, axial-radial depth of cut, and machining tolerance and taguchi optimization method was applied to find the optimal process parameters which minimize surface roughness during the mold surface milling of a 7075-T6aluminum block. P.S.Sivasakthivel, V.Vel murugan and Sudhakaran (2012) had studied the effect of helix angle, speed, feed, axial and radial depth of cut on surface roughness in end milling of Al-6063 using response surface methodology. Results indicate helix angle and spindle speed are major parameter that influence surface roughness of the material. T.Muthuramalingam and B.Mohan (2014) used grey relational analysis with Taguchi method for multi response optimization of the electrical discharge machining process to derive optimal combination of electrical process parameters. Ansalam and Narayanan (2009) used cutting parameter such as speed, feed, depth of cut and nose radius to predict surface roughness using Taguchi method. The optimization was done to obtain proper combination of machining parameters to get minimum surface roughness using improved GA.

2. EXPERIMETAL SETUP

The work material used in this experiment was aluminium alloy (Al6351), widely used in automotive parts. This alloy has high percentage of manganese content in them hence it has more strength than aluminium 6-series and some 7-series alloy, so industries were widely using it. Spectroscopy had done to verify Al6351 chemical composition and results were tabulated in table-1. A 9 specimen (figure-1) based on L_9 Orthogonal Taguchi design each of the dimensions 32 mm × 32 mm in cross section and 40 mm in length is used.

Table.1.Aluminium compositions

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.70	0.60	0.10	0.30	0.90	0.20	0.20	0.10	Remainder

Figure.1.Work piece-Al 6351

HSS end mill cutter (figure-2) with diameter of 12mm, four flute and helix angle each 35°, 40°, 45° is used. Based on the L_9 Taguchi design, three tools with different helix angle is required to conduct the experiment. Experiments were conducted on LVM vertical machining centre with high-speed steel end mill cutter under dry condition.

Figure.2.HSS end mill cutter

Maximum spindle speed of the machine is 4000rpm; table length and width were 1213mm and 267mm. The average roughness value R_a is measured using surfcom roughness tester. Surface of the component is traced by the diamond probe with diameter 2µ.The measured and cut-off length for the measurement of Ra were kept as 4mm and 0.8mm. Hardness of the machined work piece is tested using brinell hardness instrument. In this test a predetermined test load of 1000kgf was applied by carbide ball of fixed diameter (D) for a predetermined time period and then removed.

Experimental design: The actual numbers of experiments to be conducted for Four factors and three levels was 3^4 i.e. 81.With the help of taguchi design, number of experiments needed to be conducted was reduced to 9.There are 4 parameters, (helix angle, speed, feed, depth of cut) and each one has 3 levels and the three levels were coded as 1(lower level), 2(middle level), 3(highest level). L_9 orthogonal array was selected for experimentation. The range for the spindle speed, feed rate and depth of cut was fixed by conducting a trial run on the machine whereas limits for helix angle is identified from literature [4].The measured surface roughness and hardness value were listed in the table-2.In all experiments radial depth of cut was kept as 4mm(constant). The change hardness value is calculated by finding the difference between hardness of the material before and after the experiment

Table.2.L_9 orthogonal array for response

Trail No	Factors									
	Helix angle		Spindle speed		Feed rate		Depth of cut		Surface roughness	Hardness
	Level	Degree	Level	rpm	Level	mm/min	Level	mm	µm	BHN
1	1	35	1	2500	1	1500	1	2	0.470	3
2	1	35	2	3000	2	2000	2	3	0.495	3.77
3	1	35	3	3500	3	2500	3	3	0.773	4.94
4	2	40	1	2500	2	2000	3	3	0.440	3.2
5	2	40	2	3000	3	2500	2	2	0.430	3.51
6	2	40	3	3500	1	1500	1	3	0.540	2.97
7	3	45	1	2500	3	2500	2	3	0.460	3.1
8	3	45	2	3000	1	1500	3	3	0.401	2.98
	3	45	3	3500	2	2000	1	2	0.5	2.8

Analysis of variance: It is statistical tool used to find the variation between or among the groups. The calculation was done to find the percentage contribution of each parameter on the response (hardness and roughness) . Validation of this method is done by compare the calculated F-ratio with standard F-ratio.Table-3 and Table-4 show % contribution of parameters on the surface roughness and hardness respectively.

Table.3.ANOVA for surface roughness

Source of variation	Sum of Squares	DOF	Mean Square	Calculated F-ratio	Standard F-ratio	Contribution %
SSA	0.0281	2	0.0141	281.00	4.2	28.94
SSB	0.0485	2	0.0243	485.00	4.2	49.95
SSC	0.013	2	0.0065	130.00	4.2	13.39
SSD	0.0076	2	0.0038	76.00	4.2	7.83
SSE	1.00E-04	2	5.00E-05	----		
SST	0.0971	10				

For surface Roughness, Speed is contributing the maximum by 49.95% followed by Helix angle with 28.94%, Feed rate with 13.39% and Depth of cut with 7.83 %.

Table.4.ANOVA for hardness

Source of variation	Sum of Squares	DOF	Mean Square	Calculated F-ratio	Standard F-ratio	Contribution %
SSA	1.4189	2	0.7095	14189.00	4.2	40.31
SSB	0.3458	2	0.1729	3458.00	4.2	9.82
SSC	1.1779	2	0.5889	11778.00	4.2	33.46
SSD	0.5773	2	0.2886	5772.00	4.2	16.40
SSE	-0.0001	2	-0.00005	----		
SST	3.5198	10				

In case of Hardness, Helix angle is contributing the maximum by 40.31% followed by Feed rate with 33.46%, Depth of cut with 16.40% and speed with 9.82%.

3. GRAPHS AND DISCUSSION

In this work effect of helix angle, spindle speed, feed rate, and axial depth of cut was studied. The graph (figure-3) it is clear that these parameters have significant impact on surface roughness.

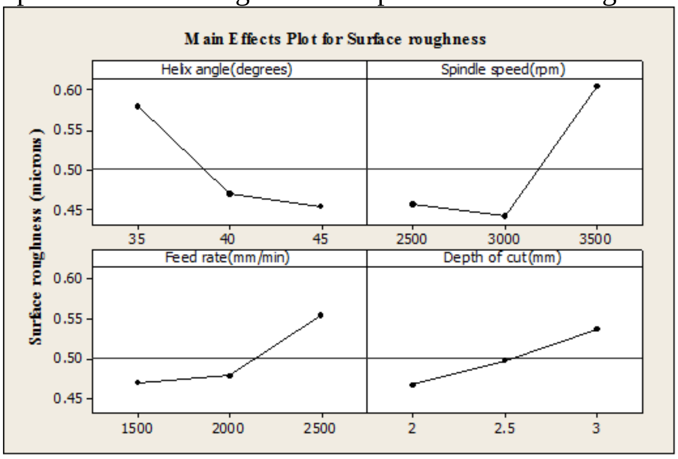

Figure.3.Influence of process parameter on surface roughness

From the graph it is evident that by increasing the helix angle surface roughness decreases and it is minimum at 45°.Increasing the helix angle reduces the built up edge (P.S.Sivasakthivel, 2012). The built up edge formation is major factor which determine surface finish and tool life in machining. Decreasing the built up formation will yield good finished product. It is understandable that surface roughness is less for spindle speed of 3000 rpm. Due to the tendency of chatter vibration, increasing the speed beyond 3000 rpm increases the surface roughness. The direct effect of feed rate on surface roughness indicates that finish will be poor for larger feed rate. The surface roughness was maximum for the feed rate of 2500 mm/min. This is because feed marks on the work piece will be prominent for a higher feed rate. Owing to the fact that less depth of cut reduces vibration and feed mark a similar trend was observed for depth cut same as feed rate. Surface roughness increases with increasing the depth of cut from 2 mm to 3mm.

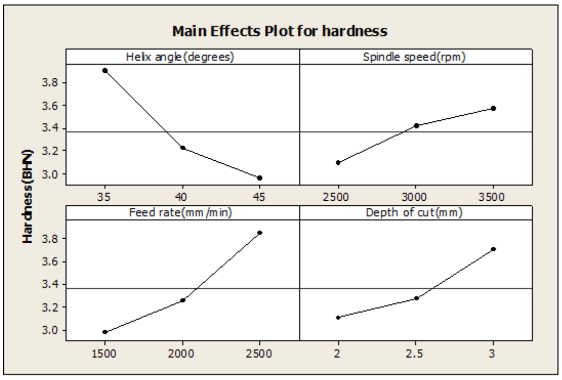

Figure.4.Influence of process parameter on Hardness

The figure-4 exhibits direct effect on machining parameter on change in hardness. The heat generated during machining will change grain structure on the surface of machined component. So the hardness of the aluminium is increased after the machining. Increasing the helix angle results in a downward trend for hardness. Relief angle of the tool is decreases with increase in helix angle [7]. Smaller relief angle result in more heat generation. Hence hardness is high for the helix angle with 35°.A upward trend for hardness was observed for the speed as more amount of heat will developed during machining with high speed. In the case of feed rate and depth of cut, hardness increases with increase in these parameters. High temperature will develop as large amount of material is removed in a single pass. Therefore hardness will high for feed rate of 2500 mm/min and depth of cut of 3 mm.

Grey relation approach: In this study grey relation was used to study the multi performance characteristic (roughness and hardness).The steps involved in this method are as follows.

Step 1: Calculate Signal to noise ratio for the response. While calculating the S/N ratio for roughness equation 1 was used as it is smaller the better kind .Since high hardness is required larger the better quality characteristic equation 2 is selected.

S/N ratio = -10log (M_i^2) (1)

S/N ratio = -10log (1/M_i^2) (2)

Where M_i is the response of the i^{th} trail

Step 2: The S/N ratio value have to be normalized between 0 to 1. Normalized S/N ratio for hardness and surface roughness was calculated by equation 3 and 4 respectively.

$Z_{nj} = (X_{nj} - \min (X_{nj})) / (\max (X_{nj}) - \min (X_{nj}))$ (3)

$Z_{nj} = (\max (X_{nj}) - X_{nj}) / (\max (X_{nj}) - \min (X_{nj}))$ (4)

Where Z_{nj} is the normalized value of n^{th} trail for jth dependent response. X_{nj} is S/N ratio of the response.

Step 3: Calculation of grey relation coefficient

$GC_{nj} = (\Psi_{min} + \Delta\Psi_{max)} / (\Psi_{nj} + \Delta\Psi_{max})$ (5)

Since the multi response involves both larger and smaller the better Δ is assumed as 0.5. GC_{nj} is grey relation coefficient of n^{th} trail for jth dependent response.

Step 4: Calculation of grey relation code and rank it.

$Gn = (1/N) \sum GCnj$ (6)

Where N is number of responses, GCnj is the grey co-efficient for nth trail for jth dependent response

Table.5.Grey relation results

Trail No	S/N ratio		Normalized S/N ratio		Grey relation coefficient		Grade	Rank
	Surface roughness	Hardness	Surface roughness	Hardness	Surface roughness	Hardness		
1	6.558	9.542	-0.7581	0.1225	0.803	0.524	0.663	3
2	6.108	11.52	-0.679	0.523	0.487	0.424	0.455	9
3	2.236	13.87	0	1	0.333	1	0.665	2
4	7.131	10.1	-0.858	0.235	0.68	0.368	0.524	7
5	7.331	10.91	-0.893	0.3912	0.561	0.358	0.459	8
6	5.352	9.45	-0.5465	0.103	0.829	0.477	0.653	4
7	6.745	9.83	-0.791	0.1823	0.735	0.387	0.561	6
8	7.937	9.48	-1	0.1228	0.806	0.333	0.569	5
9	6.021	8.94	-0.664	0	1	0.429	0.714	1

4. CONCLUSION

Following conclusions were made from the result of this study:

The optimal parameters obtained using grey relation technique is Helix angle (45°), Spindle speed (3500rpm), Feed rate (2000 mm/min), Depth of cut (2mm).With these optimal parameters confirmation test were conducted to validate the results.

From ANOVA calculation for surface roughness, we identified that spindle speed is contributing the maximum with 49.95%, followed by helix angle (28.94%), feed rate (13.39 %) and depth of cut (7.83 %).Where as in case of hardness, Helix angle is contributing the maximum with 40.31%, followed by feed rate (33.46%), depth of cut (16.40 %) and spindle speed (9.82 %).

Increasing the helix angle decrease the surface roughness and hardness. For feed rate and depth of cut a upward trend is observed for hardness and depth of cut.

REFERENCES

Ansalam Raj TG and Narayanan Namboothiri VN, An improved genetic algorithm for the prediction of surface finish in dry turning of SS 420 materials, Int. J. Adv. Manuf.Technol, 2009, DOI 10.1007/s00170-009-2197-2.

Donaldson C, Lecain GH and Goold VC, Tool Design, Tata McGraw-Hill Publishing Company Limited, 1957, 52–58.

Eyup Bagci, Seref Aykut, A study of Taguchi optimization method for identifying optimum surface roughness in CNC face milling of cobalt-based alloy (stellite 6)"International Journal of Advanced Manufacturing Technology, 29, 2008, 940–947

Hasan Oktem, Tuncay Erzurumlu, Mustafa Col, A study of the Taguchi optimization method for surface roughness milling in finish of mould surfaces, International Journal of Advanced Manufacturing Technology, 28, 2006, 694-700.

Lu HS, Chang CK, Hwang NC, Chung CT, Grey relation analysis coupled with principal component analysis for optimization design of cutting parameters in high speed end milling" Journal of materials processing technology, 209, 2009, 3808-3817.

Muthuramalingam T, Mohan B, Application of taguchi-grey multi responses optimization on process parameters in electro erosion, Measurement 58, 2014, 495-502

Sivasakthivel PS, Vel Murugan V and Sudhakaran, Experimental evaluation of surface roughness in end milling of Al-6063, International Journal of Manufacturing Research, 7(1), 2012.