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Process Parameter Optimization of End Milling Using Design of Experiment Considering Material Variation

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ABSTRACT

CNC Vertical End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. During the End milling process, the material is removed by the end mill cutter. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and other parameters. In the present study, experiments are conducted for two different work piece materials to see the effect of work piece material variation in this respect. An attempt has also been made to obtain Optimum cutting conditions with respect to roughness parameters considered in the present study with the help of design of experiment.

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I. INTRODUCTION

CNC Vertical End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and other parameters. The most important interactions, that effect surface roughness of machined surfaces, are between the cutting feed and depth of cut, and between cutting feed and spindle speed. Surface roughness at the same feed rate becomes higher when a small nose radius is used. Technological parameter range plays a very important role on surface roughness. There is a need of a tool that should allow the evaluation of the surface roughness before the machining of the part and which, at the same time, can easily be used in the production-floor environment contributing to the minimization of required time and cost and the production of desired surface quality. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. Material removal rate (MRR) is an important control factor of machining operation and the control of machining rate. It is also critical for production planners. MRR is a measurement of productivity & it can be expressed by analytical derivation as the product of the width of cut, the feed velocity of milling cutter and depth of cut. Traditionally, the experience of the operator plays a major role in the selection of optimum metal cutting conditions. However, attaining optimum values each time by even a skilled operator is difficult. The non-linear nature of the machining process has compelled engineers to search for more effective methods to attain optimization. It is therefore imperative to investigate the machinability behavior of different materials by changing the machining parameters to obtain optimal results. Process modeling and optimization are the two important issues in manufacturing products. The selection of optimal cutting parameters, like depth of cut, feed and speed, is a very important issue for every machining process. In workshop practice, cutting parameters are selected from machining databases or specialized handbooks, but the range given in these sources are actually starting values, and are not the optimal values. This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) on material removal rate and Surface removal rate in end milling. This experimental investigation outlines optimization methodology, which is applied to optimize MRR and surface roughness in end milling operation.

II. LITERATURE SURVEY

This chapter sets the background for up-coming sections. It is basically an assessment of the present state of art of the wide and complex field of optimization of milling by design of experiment and its application. Also this chapter separately reviews what has been done in the past in the area of application.

Joshi et al. [1] investigated the SR response on CNC milling by Taguchi technique. The output characteristic, surface finish is analyzed by software Minitab 15 and ANOVA is formed, which shows the percentage contribution of each influencing factor on surface roughness. Bajic et al. [2] performed the machining process for optimized the parameters for SR in face milling. The results of the performed research show that both feed and cutting speed influence on surface roughness but the feed is the most influential factor. Zhang et al. [3] investigated the Taguchi design application to optimize surface quality in a CNC face milling operation. The experimental results indicate that in this study the effects of spindle speed and feed rate on surface were larger than depth of cut for milling operation. Gologlu et al. [4] studied about pocket milling which is often encountered in plastic mould manufacture. The implementation and selection of cutting path strategies with appropriate cutting parameters have significant effect on surface roughness. Kopac and Krajnik [5] presented the robust design of flank milling parameters dealing with the optimization of the cutting forces, milled surface roughness and the material removal rate (MRR) in the machining of an Al-alloy casting plate for injection moulds. Anish Nair & P Govindan [6] conduct the study on application of Principal Component analysis (PCA) coupled with Taguchi method to solve correlated multi-attribute optimization of CNC end milling operation.PCA has been proposed to eliminate correlation between the responses and to estimate uncorrelated quality indices called principal components.

Shahzad Ahmad et al. [7] studied the machining parameters namely depth of cut, cutting speed, feed rate and tool diameter are optimized with multiple performance characteristics, such as maximum material removal rate and maximum surface finish and concluded that the S/N ratio with Taguchi's parameter design is a simple, systematic, reliable and more efficient tool for optimizing multiple performance characteristics of CNC milling process parameters. J.Pradeep Kumar & K.Thirumurugan [8] had studied The end milling of titanium alloys, for the investigation of the optimum parameters that could produce significant good surface roughness whereby reducing tooling cost and concluded that The significant factors for the surface roughness in milling CP Ti Grade 2 were the spindle speed and the tool grade, with contribution of 30.347 and 29.933 respectively. Reddy S [9] had conducted the study to deals with optimization of surface roughness and delamination damage on GFRP material during end milling using grey- based taguchi method. From the results of ANOVA, it was concluded that cutting speed and depth of cut are the most significant factors affecting the surface roughness and delamination damage factor and their contribution in an order of 26.84% and 40.44% respectively. Amir Mahyar Khorasani et al [10] the aim of study was to discover the role of machining parameters in tool life prediction in milling operations by using artificial neural networks and Taguchi design of experiment. Form the study it is observed and conclude that all the significant factors were included in the (DOE) process. PR.Periyanan et al [11] had carried out to focus the taguchi technique for the optimization in micro-end milling operation to achieve maximum metal removal rate (MRR) considering the spindle speed, feed rate and depth of cut as the cutting parameters. The analysis of the result shows that the optimal combination for higher metal removal rate (MRR) is medium cutting speed, high feed rate and high depth of cut. Sadasiva Rao T et al [12] had carried out the study the effect of process parameters such as speed, feed, and depth of cut and approach angle of the cutter on cutting force, tool life and surface roughness in face milling of Inconel 718. The feed was identified as the most influential process parameter on cutting force and surface roughness. Cutting speed is identified as the most influential process parameter on tool life. Pinki Maurya et al [13] focus to the study of CNC end milling, considering influence of various machining parameters like, tool feed (M), tool speed (N), tool diameter (O) and depth of cut (P). They conclude that order of significant of main parameter decreasing order is M3>N2>O2>P1.Piyush pandey et al [14] conducted an experiments to perform the parametric optimization of CNC end milling machine tool in varying condition. Results showed that cutting speed and feed rate are the powerful control parameters for the material removal rate and depth of cut and feed rate calculated as powerful factors for controlling the surface finish of Mild Steel.

Praveen Kumar & Deepak Chaudhari [15] had conducted the study to optimize the cutting parameters in vertical CNC milling machine while machining Hot Die steel H-13 with Solid carbide tool under semi finishing and finishing condition. The results shows that DOC has more effect than SS, and SS has more effect than FR in controlling the MRR & the FR has more effect than SS, and SS has more effect than DOC in controlling the Ra.P. Praveen Raj and A. Elaya Perumal [16] had conducted a study of surface roughness, precision and delamination factor in use of Ti-N carbide K10 end mill, Solid carbide K10 end mill and Tipped Carbide K10 end mill. The experimental results of this indicate that the depth of cut is recognized to make the most significant contribution to the overall performance as compared to cutting velocity and feed rate. K. Barman, P. Sahoo [17] had conducted an experimental study of fractal dimension characteristics of surface profile produced in CNC milling and optimization of machining parameters based on Taguchi method. From Taguchi analysis, it is observed that spindle speed has got the most significant influence in controlling fractal dimension characteristics of surface profile. It is also observed with increase in spindle speed the fractal dimension increases. Jatin, Pankaj Sharma [18] has conducted the study to find the effect of different machining parameters like cutting speed, feed, and depth of cut on Surface Roughness in end milling. In end milling, increase in cutting speed, decrease in feed rate and increase in depth of cut will decreases the surface roughness within specified test range. Low cutting speed should be used for long cutter life. High cutting speed and low feeds give best surface finishes; depth of cut should be low but not so low that it led to the vibration of tool. S.B.Chawale et al [19] had conducted to study experimentally the influence of depth of cut, cutting speed, and feed and work piece material type on cutter temperature during milling process. From the Data analysis it was concluded that, the cutting speed is most contributory factor, work material is second important factor and Feed rate is third important factor.Abhishek Dubey et al [20] had conducted study for the multiple response optimization of end milling parameter using grey based taguchi method. The feed rate was identified as the most influential process parameter on surface roughness. R. Ramanujam et al [2] conduct the study to investigate the parameter optimization of end milling operation for Inconel 718 super alloy with multi-response criteria. Analysis of variance shows that the cutting velocity is the most significant machining parameter followed by feed rate affecting the multiple performance characteristics with 56.88% and 34.64% influence, respectively.

The critical review of the literature suggested that many researchers are engaged in the study optimization of single material and there is scope of multi objective optimization of the end mill. Based on the above literature review following things has been identified,

(a)CUTTING PROCESS PARAMETERS

It has been generally observed that the process of metal cutting or the machining of the work piece is greatly influenced by relative velocity between the work piece and edge of the cutting tool. The displacement of the cutting edge of the tool along the work surface for the period of time is called as feed while the rate of traverse of work surface past the cutting is called as the cutting speed. The cutting speed is given by V= **(πDN)/1000, where 'D' is the diameter of milling cutter in mm and 'N' is the rotational speed of cutter in RPM. From the literature review it is observed that all the scientific papers are aimed to investigate the effect of the machining parameters on the surface roughness, the proportionality of cutting parameters which influence the surface roughness is presented through Figure 1. Regarding the material which is under study of the various researchers it can be found that AL 6061 covers the majority of the percentage followed by Al7075 due to their superior mechanical and chemical properties as compared to other alloys and their technological manufacturing processes, which is presented through Figure 2**

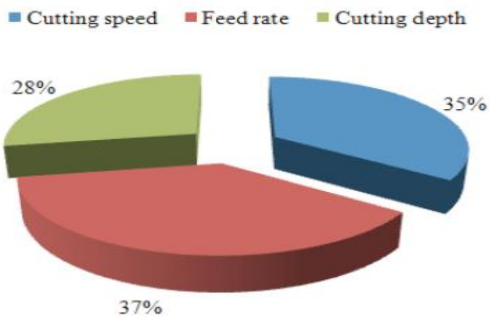


Fig.1. Effect of machining parameters on surface roughness

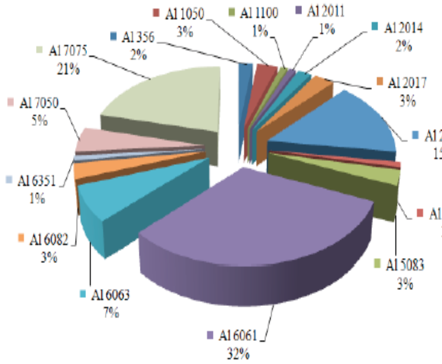


Fig.2 Percentage comparison for frequency of Material used

III.PROBLEM STATEMENT

The present work focuses on optimization of two different materials namely steel EN18 & aluminium considering the various process parameters**.**" From the literature survey it is found that many researchers had worked considering the single material for particular objective function, to optimize either surface roughness or Material Removal Rate (MRR).

(c)SCOPE

Surface roughness and MRR are very important which rely on many parameters, its need of hour to have the experimental investigation for optimum values by satisfying the desired constraints to achieve particular objective. The program for such optimum values either in any scripting language leads to more accuracy of the work.

OBJECTIVES

1)To find the optimum values for the input parameters like speed (N), feed (f) ,depth of cut(d),tool diameter and its effect on the surface finish for achieving the minimum surface roughness**.** Objective function for first objective is to Minimize Surface roughness (R_a) subjected to minimum and maximum range of input parameters like speed (N), feed (f), depth of cut (d), and tool diameter.

2)To select the order of input parameters to get the maximum MRR. The Objective function is to; Maximize Material removal rate (MRR) subjected to minimum and maximum range of input parameters like speed (N), feed (f), and depth of cut (d) & tool diameter.

III.DESIGN OF EXPERIMENTS

The basic principle in using any design of experiment (DOE) technique is to first identify the key. Variables in the process and then actively probe those variables to determine their effects on the process output. A typical DOE process consists of three distinct phases, screening, characterization and optimization; although not all three phases are used in every study. Orthogonal designs are particularly useful because the estimate of the effect of a factor is unaffected by which other factors are under consideration. Factorial designs, which involve all possible combinations of levels of all the factors, can be investigated simultaneously**.** This technique also saves time and money because large number of factors can be investigated simultaneously one type of complete factorial experiment is 2^{k} factorial designs; k is the number of factors investigated at two levels. In order to calculate the number of runs, e.g. if k=7 then the number of runs is 2^{7} =128 experimental runs. The number of run increases as the k value increases. In order to reduce the number of experimental runs, fractional factorial was introduced which use only a fraction of the total possible combinations of levels. The number of run is given by 2^{k-1}, e.g. if k=7, $2^{(7-1)}$ =2^{6} =64 experimental runs. By using the fractional factorial the number of run has been reduced by half.

4.1 TAGUCHI METHOD FOR DESIGN OF EXPERIMENT

Taguchi‘s method adopts the fundamental idea of DOE but simplifies and standardized the factorial and fractional factorial designs so that experiments conducted will produce more consistent results. Taguchi‘s comprehensive system of quality engineering is one of the greatest engineering achievements of the 20th century. His methods focus on the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production and market place. Shop-floor techniques provide cost based real time methods for monitoring and maintaining quality in production. The farther upstream a quality method is applied, the greater leverages it produces on the improvement, and the more it reduces the cost and time. Taguchi proposes an off-line strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. Taguchi's main success has been to emphasize the importance of quality in design and to simplify the use of experimental design as a general purpose tool for quality engineers. Amongst the many criticisms of the Taguchi method is the use of the signal-to-noise (S/N) ratio as a performance measure statistic. S/N ratio measures the functional robustness of products and processes. The S/ N ratios have been criticized as providing misleading results in certain cases. Although the classical experimental design has a much wider appeal than the Taguchi method, the Taguchi method does provide the practical engineer with a useful starting point for quality improvement. This is fundamentally because the former is more focused on the statistical aspects whereas the latter is primarily focused on the engineering aspects of quality. The beauty of Taguchi method lies in the fact that it integrates statistical methods into the powerful engineering process.

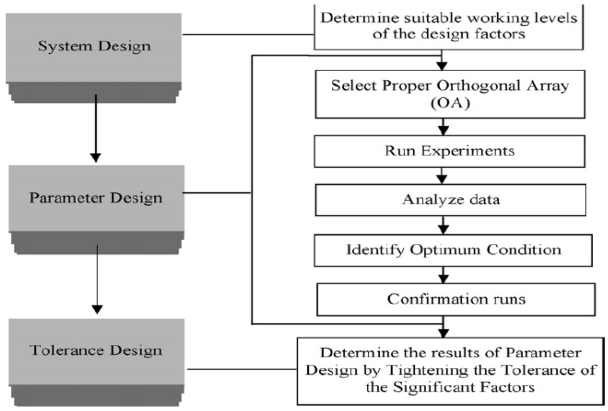


Fig. 3 Flowchart of the Taguchi Method

V. EXPERIMENTATION METHODOLOGY

a) The trials are going to conduct on the 3 Axes Vertical Milling Center (VMC), the technical specifications are of which are as follows.

1) Table 1- Machine details

Make and Model	MAKINO-S 56
Controller	Fanuc
Technical Specifications	
Table size	1000*500mm
Spindle RPM	13000
Maximum Work piece	890*500*450
Maximum Payload	1100lbs
ATC Capacity	20


Fig4. MAKINO-S 56

c) Material

For the present work the material use are block of Steel EN 18 and Aluminum 6061 in the dimensions 125 mm × 80 mm × 25 mm. The physical properties of the material are as follows.

Table 2.Physical properties of materials

Physical Properties	EN18	Al6061
Density	7861Kg/m3	2700Kg/m3
Hardness(Brinell)	123	65
Hardness(Knoop)	138	120
Hardness(Rockwell B)	70	40
Ultimate Tensile strength	505MPA	241MPA
Yield strength	215MPA	207MPA
Properties	High quality & high tensile alloy steel.	Combines relatively high strength, good workability, and high resistance to corrosion

Table 3.The chemical compositions of the material

Component	AISI 304(EN18)	AL-6061
Percentage Weight		
C	Max 0.08	-
Cr	18 – 20	0.04-0.35
Fe	66.345 – 74	Max 0.7
Al	-	95.8-98.6
Mn	Max 2	Max 0.15
Ni	8 - 10.5	-
P	Max 0.045	-
S	Max 0.03	-
Si	Max 1	0.4-0.8
Cu	-	0.15-0.4
Mg	-	0.8-1.2
Ti	-	Max 0.15
Zn	-	Max 0.25

c) Experimental Set-up

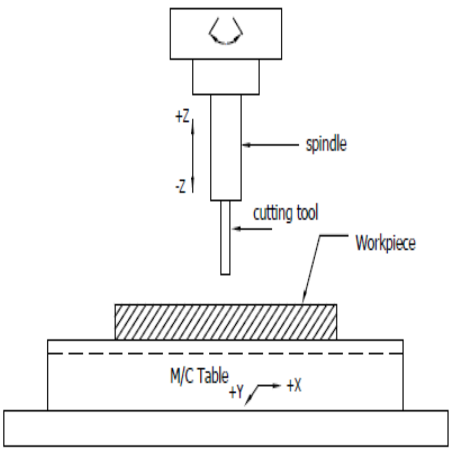


Fig 5-Experimental Set up

d) Cutting Tool

It is decided to use the HSS end mill cutter of varying diameter like 8mm, 10mm & 12mm for the present work, which is used to make the grove of 10mm in the work piece for given speed, feed & depth of cut.

e) Input parameters & their levels

Based on the literature review the preferred values for the current experiment are selected as follows. In end milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtained better surface finish for the specific test range in a specified material. The solid carbide tool with the varying diameter used to perform the experiment

Table 1 .Selection of machining parameters.

EN-18			
Speed(RPM)	1600	1800	2000
Feed(mm/min)	150	200	250
Depth of cut(mm)	0.25	0.5	0.75
Tool diameter(mm)	8	10	12
Aluminum -6061			
Speed(RPM)	2000	3000	4000
Feed(mm/min)	300	500	700
Depth of cut(mm)	1	1.5	2
Tool diameter(mm)	8	10	12

f) Selection of orthogonal array

Orthogonal arrays are special standard experimental design that requires only a small number of experimental trials to find the main factor effects on output. Before selecting an orthogonal array, the minimum number of experiments to be conducted shall be fixed which is given by: NTaguchi = 1+ NV (L – 1) where, N Taguchi = Number of experiments to be conducted, NV = Number of variables = Number of levels. Four machining parameters are considered as controlling factors – namely, cutting speed, feed rate, depth of cut and Tool diameter and each parameter has three levels – namely low, medium and high, denoted by 1,2 and 3, respectively. Standard OAs available are L4, L8, L9, L12, L16, L18, L27, etc once the orthogonal array is selected, the experiments are selected as per the level combinations. The number of DOF for orthogonal array should be greater than or equal to the number of DOF required. For the present work L27 orthogonal array with one time approach is used

Table 2.L 27 Orthogonal Array For EN18 with one variable time approach

EN 18				
Sr No	SPEED	FEED	DOC	TOOL DIA
1	1600	150	0.25	8
2	1600	200	0.75	8
3	1600	250	0.5	8
4	1600	150	0.25	10
5	1600	200	0.75	10
6	1600	250	0.5	10
7	1600	150	0.25	12
8	1600	200	0.75	12
9	1600	250	0.5	12
10	1800	250	0.25	8
11	1800	200	0.5	8
12	1800	150	0.75	8
13	1800	250	0.25	10
14	1800	200	0.5	10
15	1800	150	0.75	10
16	1800	250	0.25	12
17	1800	200	0.5	12
18	1800	150	0.75	12
19	2000	150	0.5	8
20	2000	200	0.25	8
21	2000	250	0.75	8
22	2000	200	0.25	10

23	2000	150	0.5	10
24	2000	250	0.75	10
25	2000	150	0.5	12
26	2000	200	0.25	12
27	2000	250	0.75	12

Table 3.L 27 Orthogonal Array For AL 6061 with One variable at a time approach

AL-6061				
Sr NO	SPEE D	FEED	DOC	TOOL DIA
1	2000	300	1	8
2	2000	500	2	8
3	2000	700	1.5	8
4	2000	300	1	10
5	2000	500	2	10
6	2000	700	1.5	10
7	2000	300	1	12
8	2000	500	2	12
9	2000	700	1.5	12
10	3000	300	2	8
11	3000	500	1.5	8
12	3000	700	1	8
13	3000	300	2	10
14	3000	500	1.5	10
15	3000	700	1	10
16	3000	300	2	12
17	3000	500	1.5	12
18	3000	700	1	12
19	4000	300	1.5	8
20	4000	500	1	8
21	4000	700	2	8
22	4000	300	1.5	10
23	4000	500	1	10
24	4000	700	2	10
21	4000	300	1.5	12
26	4000	500	1	12
27	4000	700	2	12

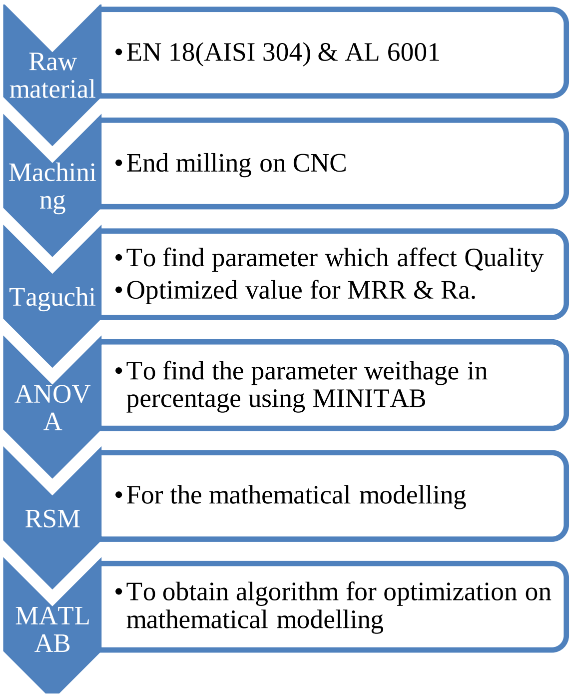
g) S/N ratio

The S/N ratio is a concurrent quality metric linked to the loss function. By maximizing the S/N ratio, the loss associated can be minimized. The S/N ratio determines the most robust set of operating conditions from variation within the results. The S/N ratio is treated as a response (transform of raw data)of the experiment. Through S/N data analysis aided by the raw data analysis Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. . The loss function for the lower gives better performance characteristic and can be expressed as

$$\left(S/_{N}\right) = -10\log\left(1 \Big/ n\sum_{i}^{n} y_i^2 \right)$$

IV. CONCLISION

In order to achieve the desired objective that is minimum surface roughness and maximum material removal rate for the optimization of two different materials EN18 & AL 606 , the method of the design of experiment is identified and the proposed algorithm to achieve the desired objective function is as follows



REFERENCE

[1]Joshi, Amit and Kothiyal, Pradeep, " Investigating effect of machining parameters of CNC milling on surface finish by taguchi method" International Journal on Theoretical and Applied Research in Mechanical Engineering, Volume-2, Issue-2, pp. 113-119, 2013

[2]Bajic, D., Lele, B. and Zivkovic, D., "Modeling of machined surface roughness and optimization of cutting parameters in face milling." Vol.47, pp.331-334, 2008..

[3] Zhang, Julie Z., Chen, Joseph C. and Kirby, E. Daniel," Surface roughness optimization in an end-milling operation using the Taguchi design method."Journal of Materials Processing Technology Vol.184, pp. 233–239, 2007.

[4]Gologlu, Cevdet and Sakarya, Nazim, "The effects of cutter path strategies on surface roughness of pocket milling of 1.2738 steel based on Taguchi method." Journal of materials processing technology Vol.206,pp. 7–15, 2008.

[5]Kopac J. and Krajnik P., 2007. Robust design of flank milling parameters based on grey-Taguchi method, Journal of Material Processing Technology, Vol. 191, No. 1-3, pp. 400-403.

[6]Anish Nair & P Govindan, "Optimization of CNC end milling of brass using hybrid taguchi method using PCA

and grey relational analysis" International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN 2249-6890 Vol. 3, Issue 1, Mar 2013, 227-240.

[7]Shahzad Ahmad , Harish Kumar Sharma, Atishey Mittal, "Process Parametric Optimization of CNC Vertical Milling Machine Using ANOVA Method in Mild Steel – A Review, International Journal of Engineering Sciences & Research Technology pp 137-146, http: // www.ijesrt.com

[8]J.Pradeep Kumar & K.Thirumurugan, "Optimization of machining parameters for Milling titanium using taguchi method", International Journal of Advanced Engineering Technology Vol.III/ Issue II/April-June, 2012/108-113 ,E-ISSN 0976-3945

[9]Reddy Sreenivasulu, "Multi response characteristics of process Parameters during end milling of GFRP using grey based Taguchi method", Independent Journal of Management & Production (IJM&P)http://www.ijmp.jor.br v. 5, n. 2, February – May 2014.ISSN: 2236-269X DOI: 10.14807, pp.299-313.

[10]Amir Mahyar Khorasani, Mohammad Reza Soleymani Yazdi and Mir Saeed Safizadeh, "Tool Life Prediction in Face Milling Machining of 7075 Al by Using Artificial Neural Networks(ANN) and Taguchi Design of Experiment", IACSIT International Journal of Engineering and Technology, Vol.3, No.1, February 2011,ISSN: 1793-8236,pp 30-35

[11]PR.Periyanan, U.Natarajan, S.H.Yang, "A study on the machining parameters optimization of micro-end milling process", International Journal of Engineering, Science and Technology ,Vol. 3, No. 6, 2011, pp. 237-246

[12]Sadasiva Rao T., Rajesh V., Venu Gopal A, "Taguchi based Grey Relational Analysis to Optimize Face Milling Process with Multiple Performance Characteristics", International Conference on Trends in Industrial and Mechanical Engineering (ICTIME'2012) March 24-25, 2012 Dubai.

[13]Pinki Maurya, Dr. Pankaj Sharma, Bijendra Diwaker, " Implementation of Taguchi methodology to Optimization of CNC end milling process parameters of AL6351 –T6", International Journal of Modern Engineering Research (IJMER) www.ijmer.com Vol. 2, Issue. 5, Sep.-Oct. 2012 pp-3530-3533 ISSN: 2249-6645

[14] Piyush pandey, Prabhat kumar sinha, Vijay kumar, Manas tiwari, "Process Parametric Optimization of CNC Vertical Milling Machine Using Taguchi Technique in Varying Condition IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, Volume 6, Issue 5 (May. - Jun. 2013), PP 34-42 www.iosrjournals.org.

[15]Praveen Kumar & Deepak Chaudhari, "Optimization of Quality Characteristics of CNC Milling Machine Using the Taguchi Method on Hot Die Steel H-13", Indian journal of applied research, Volume : 3 | Issue : 11 | Nov 2013 | ISSN - 2249-555X,pp 190-191

[116]P. Praveen Raj and A. Elaya Perumal, "Taguchi Analysis of surface roughness and delamination associated with various cemented carbide K10 end mills in milling of GFRP", Journal of Engineering Science and Technology Review 3 (1) (2010) 58-64.

[117]T. K. Barman, P. Sahoo, "Fractal dimension modeling in CNC milling using taguchi method", Proceedings of the International Conference on Mechanical Engineering 2009(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

[118]Jatin et al, "Effect of machining parameters on output characteristics of CNC milling using Taguchi optimization technique",International Journal of Engineering, Business and Enterprise Applications, 6(1), September-November., 2013, pp. 64-67

[119] S.B.Chawale, V.V.Bhoyar, P.S.Ghawade, T.B.Kathoke, "Effect of Machining Parameters on Temperature at Cutter-Work Piece Interface in Milling", International Journal of Engineering and Innovative Technology (IJEIT) Volume 2, Issue 12, June 2013, pp 85-88.

[220] Abhishek Dubey, Devendra Pathak, Nilesh Chandra, Rajendra Nath Mishra, Rahul Davis, " A Parametric Design Study of End Milling Operation using Grey Based Taguchi Method", International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com ,ISSN 2250-2459,ISO 9001:2008Certified Journal, Volume 4, Issue 4, April 2014,pp 1140-1146.

[221]R. Ramanujam, Lohithaksha M. Maiyar, K. Venkatesan and Mithun Vasan. "Multi-Response Optimization using ANOVA and desirability function analysis: A Case study In end Milling of Inconel alloy", ARPN Journal of Engineering and Applied Sciences, Vol. 9, No. 4, April 2014 ISSN 1819-6608,pp 457-463.

22]Shahzad Ahmad , Harish Kumar Sharma, Atishey Mittal, "Process Parametric Optimization of CNC Vertical Milling Machine Using ANOVA Method in Mild Steel – A Review, International Journal of Engineering Sciences & Research Technology pp 137-146, http: // www.ijesrt.com

23]J.Pradeep Kumar & K.Thirumurugan, "Optimization of machining parameters for Milling titanium using taguchi method", International Journal of Advanced Engineering Technology Vol.III/ Issue II/April-June, 2012/108-113 ,E-ISSN 0976-3945

24]Reddy Sreenivasulu, "Multi response characteristics of process Parameters during end milling of GFRP using grey based Taguchi method", Independent Journal of Management & Production (IJM&P)http://www.ijmp.jor.br v. 5, n. 2, February – May 2014.ISSN: 2236-269X DOI: 10.14807, pp.299-313.

25]Amir Mahyar Khorasani, Mohammad Reza Soleymani Yazdi and Mir Saeed Safizadeh, "Tool Life Prediction in Face Milling Machining of 7075 Al by Using Artificial Neural Networks(ANN) and Taguchi Design of Experiment", IACSIT International Journal of Engineering and Technology, Vol.3, No.1, February 2011,ISSN: 1793-8236,pp 30-35

26]PR.Periyanan, U.Natarajan, S.H.Yang, “A study on the machining parameters optimization of micro-end milling process”, International Journal of Engineering, Science and Technology ,Vol. 3, No. 6, 2011, pp. 237-246

27]Sadasiva Rao T., Rajesh V., Venu Gopal A, “Taguchi based Grey Relational Analysis to Optimize Face Milling Process with Multiple Performance Characteristics”, International Conference on Trends in Industrial and Mechanical Engineering (ICTIME'2012) March 24-25, 2012 Dubai