Optimization of Machining Parameters in CNC Turning of Hybrid Metal Matrix Composites Using Different Techniques: A Review

Vaibhav Sharma, Ravi Butola*
Department of Mechanical Engineering, Delhi Technological University, Bawana Road, New Delhi-110042, India

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Abstract

Metal Matrix Composites is a subject of interest from last 6 decades and it is finding wide applications in many fields like Aerospace, Automobile, Spaceship, Piston and Sports Equipment etc. Adding a new element in the Metal Matrix Composite makes it Hybrid. HMMC's provide better machinability and tribological properties. In CNC turning process, Surface Roughness and MRR are two main parameters. The Objective of the present paper review is to determine the optimum machining parameters in CNC turning of HMMC using different algorithms and techniques. This can be achieved by finding the optimum cutting parameters by Minimizing the Surface Roughness and Maximizing the Metal Removal Rate. For this we have reviewed Taguchi's Design experiment. The main cutting parameters considered are Cutting Speed, Feed rate and Depth of Cut. Also we have reviewed Response Surface Methodology and Grey-Fuzzy Algorithm.

1. Introduction

Turning is defined as the machining process which is used to produce rotational parts by removal of unwanted material from the work piece. It requires a turning machine (lathe machine), work piece and cutting tool in position with its fixture. The cutting tool used is basically a single point cutting tool and it is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the work piece or along a certain path to make complex rotational shapes. For material removal in Turning process, the primary motion is the rotation of workpiece and the secondary motion is the feed motion. CNC machines are highly accurate and precise for machining different materials. An appropriate setting of CNC machine depends on Operator's experience and manufacturer guidelines. However, manufacturer guidelines are not meant for recently developed HMMC's and thus the cutting parameters are required to be optimized. This is also required because in developing nations, the machines in the manufacturing industries are not working at their optimal operating conditions. In these industries, handbooks are being used at the process of planning level due to which due to which productivity decreases as a result of partially optimal use of machining capability [1].There is a direct relation between change in surface roughness and the cutting conditions and thus Surface Roughness is one of the main parameter which needs to be monitored [2]. The tool and the work piece are subjected to specific deformation due to relative motion between them, both in the cutting speed direction. Thus, as a result the tool is under thermal loads on those faces which are in contact with the workpiece and the chip. When chips are formed, the work piece is under compression and undergoes plastic deformation. The main objective of metal cutting is to solve the practical problems related to efficient metal removal in the process. Therefore, knowledge of principle of metal cutting process is essential for selecting optimum machining conditions for different cases [3].

The most often applied techniques for optimization of machining parameters are Taguchi technique, Response Surface Methodology, Artificial Neural Network (ANN), Grey Relational approach, Fuzzy Logic approach, Scatter Search technique and Genetic algorithm [4]. The main machining parameters taken into consideration for optimization of CNC turning operation are Cutting speed, Depth of cut and Feed Rate. Daniel applied Taguchi technique for optimization of surface roughness obtained by CNC turning. The machining parameters considered were spindle speed, feed rate and depth of cut. From the experiment, he concluded that the feed rate was most significant parameter followed by spindle speed and depth of cut had insignificant effect in machining [5]. Nalbant used Taguchi's experimental method and L_9 orthogonal array for optimizing surface roughness in turning of AISI 1030 carbon steel. The parameters used were insert radius, feed rate and depth of cut. The results revealed that insert radius and feed rate are more significant parameter affecting surface roughness of AISI 1030 carbon steel [6].Yanda studied the optimization of MRR, Surface Roughness and Tool life in the process of conventional dry turning by FCD700. The conclusion was that optimum MRR is achieved when cutting speed and feed rate are high while the optimum surface roughness was obtained at high cutting speed and low feed rate. For optimum tool life, cutting speed and feed rate were less [7]. Palani kumar observed the characteristics of surface roughness on Al-HMMC. Input parameters considered for machining were feed rate, cutting speed and depth of cut. The results revealed that surface roughness increases with increase in feed rate and decreases with increase in cutting speed [8].Krishnamurthy and Venkatesh experimented on TiB_2 particles reinforced Al6063 metal matrix composites to optimize surface roughness and MRR. The results showed that cutting speed is affects surface roughness while in MRR, cutting speed and feed rate are important parameters [9]. Vikas performed experiment on EN8 steel to optimize machining parameters by using Taguchi and ANOVA. The results revealed that normal tool shape, medium cutting speed, lowest feed and lower depth of cut are the optimum machining parameters [10]. Senthil Kumar and Rajendran optimized CNC turning parameters on Al-HMMC using Taguchi's Design. They concluded that for better surface finish feed rate is the most significant parameter followed by cutting speed as the second significant parameter and depth of cut as the third significant parameter. For optimum MRR the order of significance decreases from feed rate to cutting speed to depth of cut [11].

Response Surface Methodology was introduced by G.E.P. Box and K.B. Wilson in 1951. It helps in relating independent input variables with output response variables.The principal approach of RSM is to apply a sequence of designed experiment to obtain an optimum response. For this, a second degree polynomial model is used. Suresh made a second order quadratic model of surface roughness. Using RSM technique, he concluded that optimum machining parameters of Al-SiC-Gr composite for minimum surface roughness is at 113 m/min of cutting speed, 0.250 mm/rev of feed rate and 0.2 mm of depth of cut [12].

Deng used Grey Relational analysis to work with incomplete and uncertain output [13]. It helped in solving complex inter relationships in multiple responses. The basic purpose of Grey relational analysis is to optimize multiple responses to determine the appropriate input parameters according to the conditions [14]. P. Suresh used Grey-fuzzy algorithm to minimize surface roughness and flank wear of the tool and to maximize the material removal rate. This logic provided optimum input machining parameters with multi performance characteristics [15]. Paulo Davim concluded that surface roughness during turning is directly proportional to an

Correspoding author,
E-mail address:ravibutola33855@gmail.com
Phone No--+91-8750305182

increase in feed rate and inversely proportional to cutting speed [17].

2. Methodology Analysis

2.1Taguchi's Design

In this method, CNC turning was performed on Aluminium hybrid metal matrix composite workpiece by a Ceramic tool. The workpiece composition of Al-SiC-Gr is 80% Al 7015, 17% SiC and 3% Gr by weight. In the papers reviewed, mostly L_{27} orthogonal array is used which is based on Taguchi's Technique. The input machining parameters considered were Cutting speed, Feed rate and Depth of cut while the output machining parameters considered were Surface roughness and Metal Removal Rate. Instruments like Surftest 211 Mitutoyo was used to measure Surface Roughness while MRR was evaluated using Analytical Method. For this, the input parameters were allocated based on 3 different levels such as minimum, medium and maximum. S/N ratio was evaluated to determine optimum machining parameter and ANOVA was used to determine significance of the parameter based on Taguchi design and helped to establish the relationship between input and output machining parameters.

Table 1. Chemical Composition of Aluminium 7015 [11]

Al	91.3-93.9%	Other each	<=0.050%
Cu	0.060-0.15%	Other total	<=0.15%
Cr	<=0.15%	Si	<=0.20%
Fe	<=0.30%	Ti	<=0.10%
Mg	1.3-2.10%	Zn	4.6-5.20%
Mn	<=0.10%	Zr	0.10-0.20%

Table 2. Different Symbols and Levels of Parameter [11]

S.NO.	SYMBOL	INPUT MACHINING PARAMETER	LEVELS 1, 2, 3
1.	A	Cutting Speed (S)	100,125,150
2.	B	Feed Rate (F)	0.1,0.2,0.3
3.	C	Depth of Cut (DoC)	0.5,0.75,1.0

2.1.1 Results

(a)For Surface Roughness

To determine significant parameters through ANOVA, signal to noise ratio needs to be calculated first. According to Taguchi's technique, Lower value of S/N ratios indicates better the surface roughness.

The following equation was used to determine S/N ratio:

$$ratio(S/N) = -10\log(1/r\sum yi\wedge 2)$$

From the observations, following response graph is Obtained in figure 1.

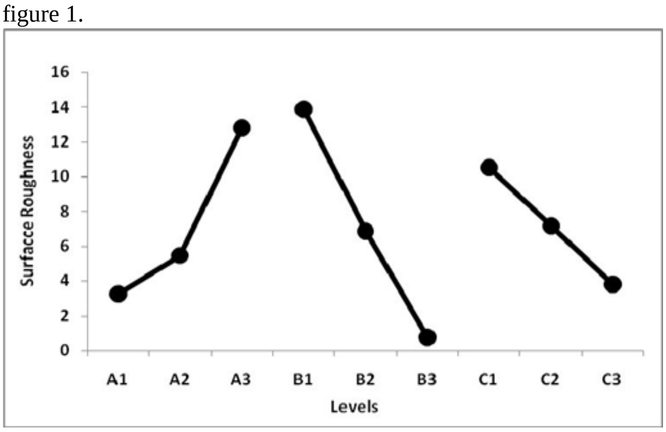

Fig.1 Different Parameters Effect on Surface Roughness [11]

Therefore it can be stated that minimum surface roughness is achieved when machining parameters combination used are A3, B1 and C1 i.e, 150 m/min cutting speed, 0.1 mm/rev feed rate and 0.5 mm depth of cut respectively. Thus it is the optimal combination for given experimental review.

The purpose of the ANOVA is to determine the significant machining parameter for minimum surface roughness. ANOVA was performed to evaluate contribution of different parameters affecting surface roughness of Al-HMMC during Turning Operation. F-test was performed with 95% confidence level to identify the significant parameter. The result is shown in following pie chart in fig.2.

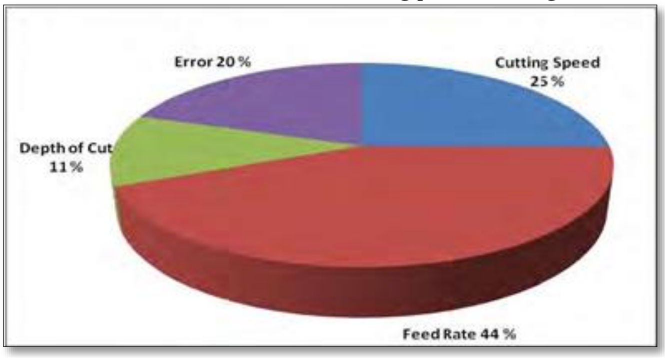

Fig. 2 Percentage Contribution for surface roughness [11]

(b) For Metal Removal Rate

The S/N ratio is used to evaluate MRR through ANOVA to identify significant parameter. Higher value of this ratio indicates higher MRR.The equation used to find this ratio is:

$$ratio(S/N) = -10\log(1/r\sum 1/yi\wedge 2)$$

The Optimum combination of parameters for maximum MRR can be concluded from fig.3. and it clearly shows that A3, B3 and C3 i.e., 150 m/min cutting speed, 0.3 mm/rev feed rate and 1 mm depth of cut respectively.

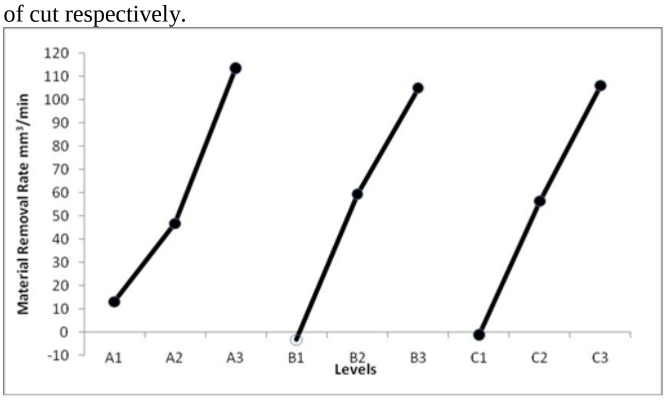

Fig.3 Main Parameter effect on MRR [11]

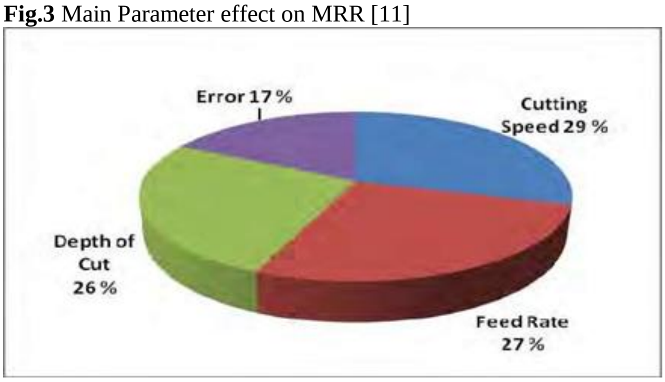

Fig.4 Percentage contribution of parameters on MRR [11]

ANOVA results are represented in fig.4.The contribution of different parameters for optimum MRR is calculated. Again F-test with 95% confidence level was used to determine significant parameter for optimum MRR.

2.2 Response Surface Methodology

RSM is used to establish relationship between input machining variables with output response variables. The principal approach of RSM is to apply a sequence of designed experiment to obtain an optimum response. The Workpiece material is Al-HMMC with Al6061 as the base material reinforced with 10% SiC and 3% Gr by weight. Final Design Matrix can be developed using RSM. The RSM can be used to find optimum parameters of turning for output responses like surface roughness and MRR. In RSM, Central Composite Design was selected to perform experiment and to evaluate the impact of process parameters. In this experimental study review, we have selected four parameters i.e, speed, feed, depth of cut and tool material (insert). To determine the parameter which significantly affected the responses surface roughness and MRR, certain perturbation graphs were drawn. From these graphs, we observed that MRR and surface roughness were directly influenced by feed, depth of cut and TNMG2000 tool insert [16]. For optimization of which tool insert had maximum MRR and minimum surface roughness, 3-D graphs were drawn to correlate process parameter with response variables. The following inferences can be made from study review:

2.2.1 Effect of Speed with Tool insert on MRR and surface roughness:

From fig.5 we can observe that both MRR and surface roughness decreases linearly with increase in speed.

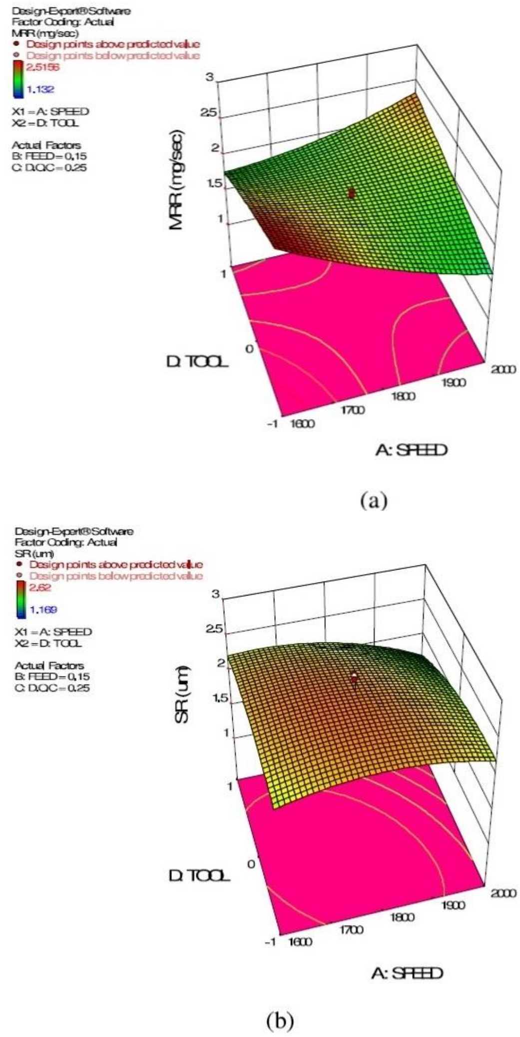

Fig. 5 3-D graph (a) MRR (b) SR(surface roughness) [16]

2.2.2Effect of feed with tool insert on MRR and SR

From fig.6 we observed that MRR increases immediately as the value of feed increases while SR decreases slightly with increase in feed.

2.2.3 Effect of depth of cut with tool insert on MRR and SR

From fig.7, it is observed that MRR increases linearly with increase in depth of cut while surface roughness decreases with increase in depth of cut.

From these graphs we observed that maximum MRR was obtained on TNMG160408 Tool insert while minimum Surface Roughness was obtained on TNMG2000 Tool insert.

Confirmation test runs were carried out by the suggested model.

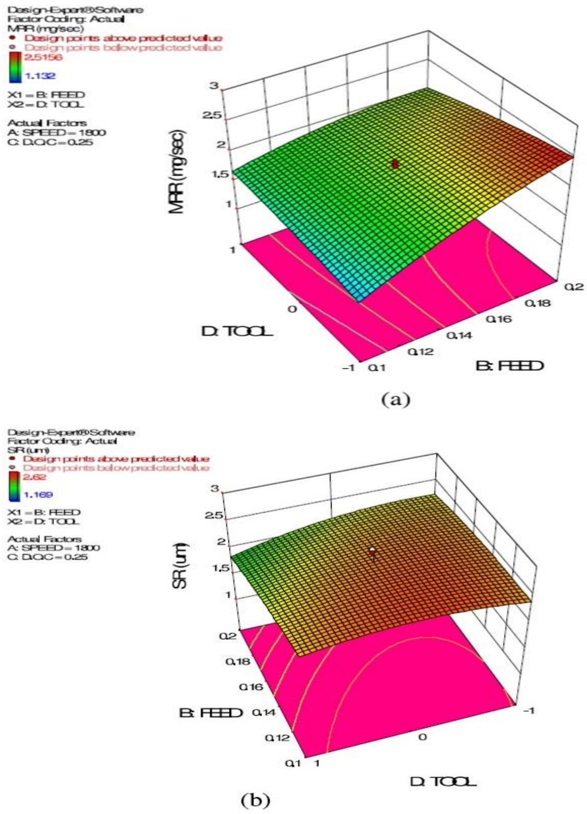

Fig.6 3-D graph (a) MRR (b) SR(surface roughness) [16]

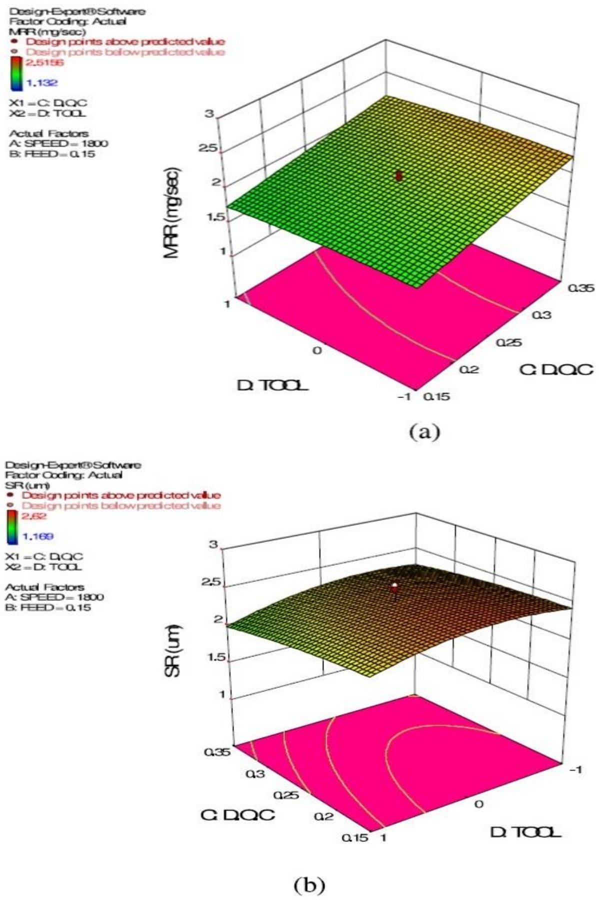

Fig.7 3-D graph (a)MRR and (b)SR(surface roughness) [16]

2.3 Grey-Fuzzy Algorithm Analysis

When grey-fuzzy output is obtained by integrating grey relational coefficients with fuzzy approach is termed a grey-fuzzy reasoning analysis. MATLAB tool was used for this analysis. Work piece material is Al-SiC-Gr hybrid metal matrix composite.Surface roughness, material removal rate and flank wear are assigned with triangular membership resulting into nine grey output. For fuzzy interference system activation, rules are evaluated. Since there is reduction in uncertainty in data found by grey relational approach. Due to reduced fuzziness, grey-fuzzy reasoning grade is higher in comparison with grey relational grade. The relation between average fuzzy reasoning grade with different levels of machining parameter is shown in fig8.In this experimental review, results reveal that feed rate has a greater influence when compared with other parameters. At high cutting speed surface roughness is reduced and increased flank wear of tool. The highest value of grey-fuzzy reasoning grade indicates optimal level machining parameters. The optimal setting should be: cutting speed at level 3 (200 m/min), feed rate at level 1 (0.075mm/rev) and mass fraction of SiC-Gr at level 3(10%)[15].

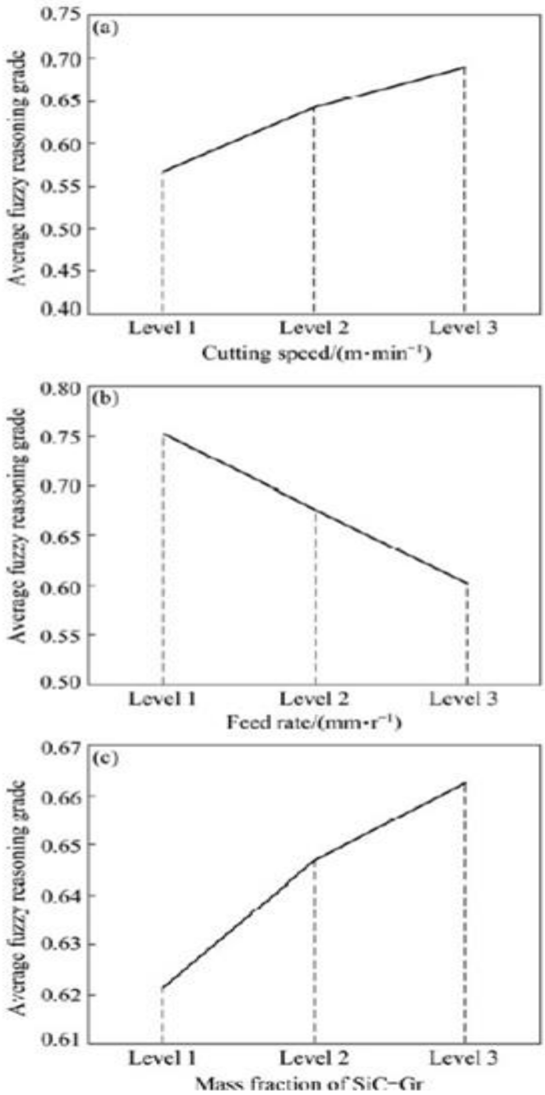

Fig 8. Response Graph for different level of machining parameters: (a)Cutting Speed; (b)Feed Rate; (c)MassFraction of SiC-Gr [15].

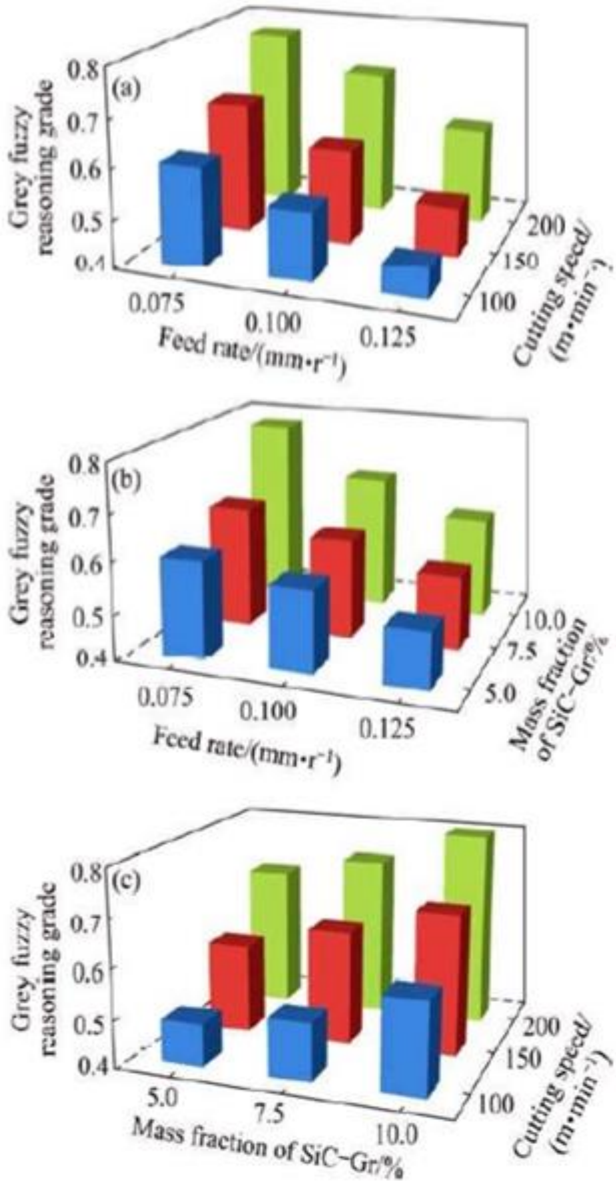

Fig.9 Effect of Grey-fuzzy reasoning gradeon machining parameters:
(a) feed rate and cutting speed
(b) feed rate and mass fration of SiC-Gr
(c)mass fraction of SiC-Gr and Cutting speed[15].

3. Conclusions

From this paper review, effect of machining parameters on HMMC's can be concluded as following:

1. In Taguchi's technique to determine the significance of each of the cutting parameters on Surface Roughness and MRR, we have used Signal to Noise Ratio (S/N) and Analysis of Variance (ANOVA). It was found that feed rate was most significant parameter followed by cutting speed as second and depth of cut as third significant parameter on surface roughness.For optimization of MRR, it was found as feed rate as most significant parameter followed by cutting speed and depth of cut as second and third significant parameter respectively.

2.Using Response Surface Methodology, 3-D graphs were plotted and effect of process parameters were analysed:

(i)Metal Removal Rate increases with increase in feed and depth of cut while it decreases with increase in speed.

(ii)Surface Roughness decreases with increase in speed while it decreases with increase in feed and depth of cut.

3.Using Grey-Fuzzy logic approach, uncertainty in output was reduced. Increase in grey fuzzy reasoning grade indicated optimization of parameters.It was found that Al-10%(SiC-Gr) provided improved machinability with minimum surface roughness and flank wear, and maximum metal removal rate as compared with 5% and 7.5% mass fraction of SiC-Gr. The optimal parameter setting was having cutting speed at level 3,feed rate at level 1 and mass fraction of SiC-Gr at level 3 at a constant depth of cut (1 mm) throughout the turning process.

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References

[1] HM Somashekara, NLakshmana. Optimizing Surface Roughness in Turning Operation using TAGUCHI Technique and ANOVA, International Journal of Engineering Science and Technology, 4(5), 2012

[2] Ilhan, Ali. Development of a Neural Network Based Surface Roughness Prediction System using cutting Parameters and an Accelerometer in Turning, Department of Mechanical Education, Faculty of Technical Education, University of Seljuk, Turkey, IEEE, 2010.

[3] Rakesh K Patel, HR Prajapati. Parametric Analysis of Surface Roughness and Material Removal Rate of Harden Steel on CNC Turning using ANOVA Analysis. International Journal of Engineering Science and Technology, 4(7), 2012.

[4] Aman A, Hari S. Optimization of machining techniques–A retrospective and literature review, Sadhana, 2005.

[5] Daniel Kirby E. A Parameter Design Study in a Turning Operation Using the Taguchi Method, Industrial technology program, Department of Agricultural and Biosystems Engineering, The technology Interface 2006.

[6] Nalbant M , Gokkaya H ,Sur G. Application of Taguchi Method in the Optimization of Cutting parameters for surface roughness in Turning; Materials and Design, 28, 2007, 1379-1385.

[7] Yanda, JA Ghani, MNAM Rodzi, K. Othman, CHC Haron. Optimization of Material Removal Rate, Surface Roughness and Tool Life on Conventional Dry Turning of FCD700, International Journal of mechanical and Materials Engineering , 5(2), 2007, 182-190.

[8] Sasimurugan T, Palanikumar K. Analysis of Machining Characteristics on Surface Roughness of a Hybrid Aluminium Metal Matrix Composite (Al6061-SiC-Al_2O_3), Journal of Minerals and Materials Characterization and Engineering, 10(13), 2011, 1213-1224.

[9] Krishnamurthy K, Venkatesh J. Assessment of surface roughness and material removal rate on machining of TiB_2 reinforced Al-6063: A Taguchi's Approach, International Journal of Scientific and Research Publications, 3(1), 2013, 1-6.

[10] Vikas B Magdum, Vinayak R Naik. Evaluation and Optimization of Machining Parameter for Turning of EN 8 Steel, International Journal of Engineering Trends and Technology, 4(5), 2013, 1564-1568.

[11] Senthil Kumar, Rajendran. Optimization of CNC Turning Parameters on Aluminium 7015 Hybrid Metal Matrix Composite Using Taguchi Robust Design, International Journal of Engineering and Technology, 6(4), 2014.

[12] Suresh P, Marimuthu K, Ranganathan S, Arunkumar G. Evaluation of Parameters Influencing Surface Roughnesson Turning of Al-SiC-Gr Hybrid Composites, International Journal of Advanced Engineering Applications, 2(3), 2013.

[13] Deng J L. Introduction to grey system, J Grey System, 1989.

[14] Ranganathan S, Senthilvelan T. Multi-response Optimization of Machining Parameters in hot turning using grey analysis, Int J Adv Manuf Technol, 2011.

[15] P Suresh, K Marimuthu, S Ranganathan, T Rajmohan, Optimization of Machining Parameters in Turning of AL-SiC-Gr Hybrid Metal Matrix Composites using Grey-Fuzzy Algorithm,2014.

[16] A Kumar, H Singh, HK Garg. Optimization of MRR and SR while Turning of Hybrid Aluminium Metal Matrix Composite on CNC lathe using Response Surface Methodology, International Journal on Emerging Technologies, 2016.

[17] Paulo Davim J. Design of Optimization of cutting parameters for turning metal matrix composite based on the orthogonal arrays, J Mater Process Technol, 132, 2003, 340-344.