Minimization of Burr Height and Tool Wear in Drilling of Aluminium Metal Matrix Composites Using Desirable-Fuzzy Approach

G.Vijaya Kumar and P.Venkataramaiah

***Abstract*— This paper is focused on minimization of the burr height and Tool wear in drilling of Aluminium Metal Matrix Composites(AMMC) using "Desirable-Fuzzy" approach, which is developed by combining the Desirability Function Analysis and Fuzzy Logic. AMMC samples are prepared based on selected material parameters and drilling experiments are conducted on these samples as per Taguchi OA L27 which is designed based on material and drilling parameters. The experimental results: Tool wear and Burr height are measured for each experimental run. These results are analyzed using Desirable-Fuzzy approach and optimum influential factors combination is identified. The identified combination of influential factors is tested through confirmation experiment and is satisfactory.**

Index Terms:, Desirable-Fuzzy approach, Drilling of AMMC, Influential factors, Minimization of Burr Height and Tool Wear

I Introduction

Metal matrix composites (MMCs) represent a relatively new class of materials characterized by lighter weight and greater wear resistance than those of conventional materials. The particle-reinforced aluminium alloy composites which are among the most widely used composites materials are rapidly replacing the conventional materials in various industries like aerospace, marine, and automotive. The common applications are bearings, cylinder block linears, vehicle drive shafts, automotive pistons, bicycle frames, etc. because of their improved properties over those of non-reinforced alloys [1–3]. Aluminium oxide (Al_2O_3) or silicon carbide (SiC) particles which are having high hardness are commonly used to reinforce the aluminium alloys, but the full application of such MMCs is, however, cost sensitive because of the high machining cost with respect to the hardness and abrasive nature of the reinforcement particles [4, 5]. Channakesavarao et al. [6] have experimented on AMMCs with different cutting tools and reported that the crater wear is not appreciable in K10 tools and is having superior wear resistance and produce continuous chips.

G.Vijaya Kumar is Research scholar with S V University College of Engineering, Tirupati, Andhra Pradesh, India. (corresponding author phone: +91-9948012585, and +91-8801958778; e-mail: vijayluther2003@yahoo.co.in).

P.Venkataramaiah, Associate professor with S V University College of Engineering, Tirupati, Andhra Pradesh, India (e-mail: pvramaiah@gmail.com).

Hocheng et al. [7] have studied the effect of speed, feed, depth of cut, rake angle and cutting fluid on the chip form, forces, wear and surface roughness. Tool life, surface quality and cutting forces have been studied by Chambers [8]. Yuan and Dong [9] have investigated the effect of percentage volume reinforcement, cutting angle, feed rate and speed in machining of MMCs. El-Gallab and Sklad [10] have used several tool materials to compare its effectiveness. Davim [11] studied the drilling of metal matrix composites based on Taguchi technique to find the influence of cutting parameters on tool wear, torque and surface finish and the interactions between these factors. Uday et al. [13] presented an elaborative experimentation using Taguchi methods on four Al/SiC composites to analyze the effects of size (15 and 65 μm) and volume fraction (20% and 30%) of the reinforcements in the composites on machining forces and machined surface roughness. However, Taguchi method has shown some defects in dealing with the problems of multiple performance characteristics [14-16]. Optimum machining characteristics in turning Al-15%SiC metal matrix composites for minimizing the surface roughness and power consumption was determined using desirability function approach [12]. The responses in drilling of Al6061 are analyzed using hybrid approach (Grey-Fuzzy) and optimum controllable parameter combination is identified [17]. Optimum parameters are identified to develop an Aluminium metal matrix composite with respect to mechanical properties by using Grey Relational Analysis [18]. The cutting conditions which influence the machining process are coolant, tool type, speed, feed, depth of cut. Among those, coolant is an important factor largely affects the machining process. The modern industries are therefore looking for a cooling system to provide dry or near dry, clean and pollution free machining. Machining under minimum quantity lubrication (MQL) condition which having flow rate of 50-500 ml/hour is performed favorable machining over dry or flood cooling condition in which 5 liters of fluid can be dispensed per minute [19, 20].

After reviewing the above literature, present work has been done to optimize the parameters in drilling of AMMC for minimizing the burr height and tool wear using Desirable-Fuzzy approach

II. Experimental Design and Drilling of Work Material

For minimizing the experimental cost Taguchi design of experiments OA L27 is used. Various factors like Base

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material, reinforcement materials, size of reinforcement particles, percentage of reinforcement particles, spindle speeds, feeds, drill tool materials, drill tool point angles and different cutting fluids which influences the tool wear and burr height are considered and each influential factor is set at three levels. The Experimental design (OAL27) shown in the Table.2 is developed by considering the factors and their levels shown in the Table.1. As per the design of experiments AMMC samples are prepared and Drilling tests have been performed using radial drilling machine under MQL environment. Drilled work pieces are shown in the Figure 1.

Table 1. Influential Factors and their levels

Sl.No	Influential factors	Level 1	Level 2	Level 3
1	Base material (BM)	Al6061	Al6063	Al7075
2	Reinforcement material (RM)	SiC	Al_2O_3	Al_4C_3
3	Percentage of reinforcement particle (PRP)	5	10	15
4	Size of Reinforcement particles (SRP)-μm	53	63	75
5	Speed(S)-rpm	450	560	630
6	Feed(F)-mm/rev	0.15	0.2	0.3
7	Tool Material(TM)	TCHSS	M32HSS	M42HSS
8	Point Angle(PA)	90^O	118^O	135^O
9	Cutting Environment(CE)	D	VO	SO

Table: 2 Experimental Design

Exp Run No	AMMC Sample No.	Material parameters				Drilling Parameters				
		BM	RFM	SRFM	PRFM	S	F	TM	PA	CF
1		6061	SIC	53	5	450	0.15	TCHSS	90	D
2	01	6061	SIC	53	5	560	0.2	M32HSS	118	VO
3		6061	SIC	53	5	630	0.3	M42HSS	135	SO
4		6061	Al2O3	63	10	560	0.2	TCHSS	90	D
5	02	6061	Al2O3	63	10	630	0.3	M32HSS	118	VO
6		6061	Al2O3	63	10	450	0.15	M42HSS	135	SO
7		6061	Al4C3	75	15	630	0.3	TCHSS	90	D
8	03	6061	Al4C3	75	15	450	0.15	M32HSS	118	VO
9		6061	Al4C3	75	15	560	0.2	M42HSS	135	SO
10		6063	SIC	63	15	560	0.15	TCHSS	118	SO
11	04	6063	SIC	63	15	630	0.2	M32HSS	135	D
12		6063	SIC	63	15	450	0.3	M42HSS	90	VO
13		6063	Al2O3	75	5	630	0.2	TCHSS	118	SO
14	05	6063	Al2O3	75	5	450	0.3	M32HSS	135	D
15		6063	Al2O3	75	5	560	0.15	M42HSS	90	VO
16		6063	Al4C3	53	10	450	0.3	TCHSS	118	SO
17	06	6063	Al4C3	53	10	560	0.15	M32HSS	135	D
18		6063	Al4C3	53	10	630	0.2	M42HSS	90	VO
19		7075	SIC	75	10	630	0.15	TCHSS	135	VO
20	07	7075	SIC	75	10	450	0.2	M32HSS	90	SO
21		7075	SIC	75	10	560	0.3	M42HSS	118	D
22		7075	Al2O3	53	15	450	0.2	TCHSS	135	VO
23	08	7075	Al2O3	53	15	560	0.3	M32HSS	90	SO
24		7075	Al2O3	53	15	630	0.15	M42HSS	118	D
25		7075	Al4C3	63	5	560	0.3	TCHSS	135	VO
26	09	7075	Al4C3	63	5	630	0.15	M32HSS	90	SO
27		7075	Al4C3	63	5	450	0.2	M42HSS	118	D

Figure 1. Drilled AMMC

III MEASUREMENT OF BURR HEIGHT AND DRILL TOOL WEAR

Burr height of hole is measured with the help of Tool makers' micro scope (Figure 2) and tool wear is measured using mat-lab image processing which is described below.

Figure 2 Tool makers microscope

A setup (Figure 3) is fabricated for capturing of drill tool images before and after drilling of holes. It has a flexibility to change the focal length as well as height of the camera. In this arrangement camera is fixed in front of tool holder which hold the tool in a fixed position for capturing the image of tool.

In this work, before starting drilling, the drill tool is fixed in the tool holder and image of tool is captured. After drilling the drill tool is removed from drilling machine and fixed in the tool holder for capturing the image. The difference between pixel region of the image before drilling (Figure 4) and after drilling (Figure 5) is considered as the tool wear (Figure 6). This procedure is used for measuring tool wear in all experimental runs (Table 3).

Figure 3 Setup for capturing the images of drill tool

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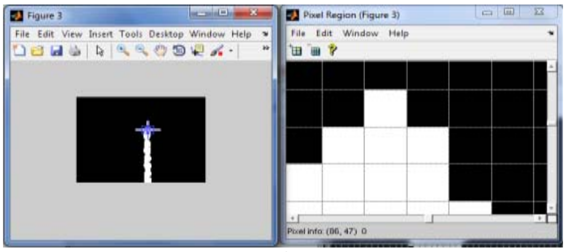

Figure 4: Pixel region of un machined drill tool

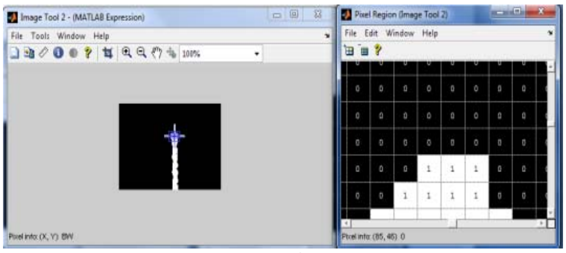

Figure 5: Pixel region of machined drill tool

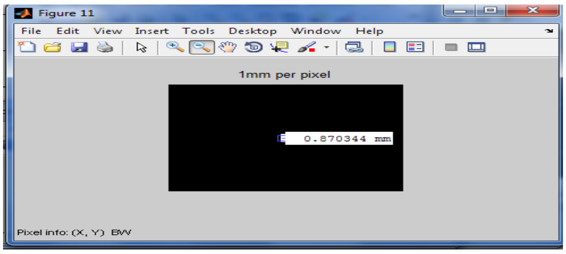

Figure 6: Image showing Drill tool wear

Table.3 Experimental Results

Expt Run No	Burr Height (mm)	Tool Wear (mm)	Expt Run No	Burr Height (mm)	Tool Wear (mm)
1	2.43	0.878	20	1.54	0.75
2	1.17	0.913	21	1.31	1.55
3	1.17	1.927	22	1.86	1.35
4	1.35	1.015	23	2.33	1.40
5	1.47	0.985	24	1.33	1.24
6	3	1.054	25	2.45	1.80
7	1.37	0.858	26	1.29	1.34
8	1.31	0.830	27	1.39	2.08
9	1.31	0.874			
10	1.32	0.882			
11	1.23	2.020			
12	1.31	0.715			
13	2.89	2.236			
14	1.26	0.756			
15	1.29	0.637			
16	3.12	1.847			
17	1.40	1.895			
18	1.35	0.903			
19	1.58	0.493			

IV OPTIMIZATION USING DESIRABLE-FUZZY APPROACH:

Desirable-Fuzzy approach is used to identify the optimal parameters for minimizing the Tool Wear and Burr Height. This approach is developed by combining Desirability Function Analysis and the Fuzzy Logic techniques. The Steps are as follows.

A. Step I calculation of individual desirability values for drill tool wear and burr height

The individual desirability values (d_i) for the corresponding responses are calculated with the formulae which are used by R. Ramanujam et al (12). There are three forms of the desirability functions according to the type of response characteristics.

(a)The nominal-the-best:

The value of ŷ is required to achieve a particular target T. when the ŷ equals to T, the desirability value equals to 1; if the departure of ŷ exceeds a particular range from the target, the desirability value equals to 0, and such situation represents the worst case. The desirability function of the nominal-the-best can be written as given in Eq. 1

$$d_i = \begin{cases} \left(\frac{\hat{y}-y_{min}}{T-y_{min}}\right)^s, & y_{min} \le y \le T, \quad s \ge 0 \\ \left(\frac{\hat{y}-y_{min}}{T-y_{min}}\right)^t, & T \le \hat{y} \le y_{min}, \quad t \ge \\ 0 & \end{cases} \quad \text{...... (1)}$$

Where the y_{max} and y_{min} represent the upper and lower tolerance limits of ŷ and s and t represent the indices.

(b) ***The larger-the-better***: The value of ŷ is expected to be the larger the better. When the ŷ exceeds a particular criteria value, which can be viewed as the requirement, the desirability value equals to 1; if the ŷ is less than a particular criteria value, which is unacceptable, the desirability equals to 0. The desirability function of the larger-the-better can be written as given in Eq. 2:

$$d_i = \begin{cases} 0, & \hat{y} \le y_{min} \\ \left(\frac{\hat{y}-y_{min}}{y_{max}-y_{min}}\right)^r, & y_{min} \le \hat{y} \le y_{max}, \quad r \ge 0 \\ 1, & \hat{y} \ge y_{max} \end{cases} \quad \text{.... (2)}$$

Where the y_{min} represents the lower tolerance limit of ŷ, the y_{mx} represents the upper tolerance limit of ŷ and r represents index.

*(c)**The smaller-the-better**:* The value of ŷ is expected to be the smaller the better. When the ŷ is less than a particular criteria value, the desirability value equals to 1; if the ŷ exceeds a particular criteria value, the desirability value equals to 0. The desirability function of the smaller-the-better can be written as given in Eq. 3:

$$d_i = \begin{cases} 1, & \hat{y} \le y_{min} \\ \left(\frac{\hat{y}-y_{max}}{y_{min}-y_{max}}\right)^r, & y_{min} \le \hat{y} \le y_{max}, r \ge 0 \\ 0, & \hat{y} \ge y_{min} \end{cases} \quad \text{...... (3)}$$

where the y_{min} represents the lower tolerance limit of ŷ, the y_{max} represents the upper tolerance limit of ŷ and r represents the weight. The s, t and r in Eq.1, 2, and 3 indicate the weights and are defined according to the requirement of the user. If the corresponding response is expected to be closer to the target, the weight can be set to the larger value; otherwise, the weight can be set to the smaller value. In the present work, the **smaller-the-better** characteristic is applicable for both burr height, and tool wear, because these are to be minimized. The individual desirability values are determined using Eq.3 and tabulated in the Table 4.

Table 4 Individual Desirability and Desirable-Fuzzy grade values

Expt Run	Individual desirability values		Desirable-Fuzzy grade
	BH	TW	
1	0.3538	0.7791	0.4206
2	1.0000	0.7590	0.8937
3	1.0000	0.1773	0.7976
4	0.9077	0.7005	0.7706
5	0.8462	0.7177	0.7343
6	0.0615	0.6781	0.2598
7	0.8974	0.7906	0.7633
8	0.9282	0.8067	0.7897
9	0.9282	0.7814	0.7892
10	0.9231	0.7768	0.7843
11	0.9692	0.1239	0.7399
12	0.9282	0.8726	0.7904
13	0.1179	0	0.1920
14	0.9538	0.8491	0.8209
15	0.9385	0.9174	0.8027
16	0	0.2232	0.1037
17	0.8821	0.1956	0.6760
18	0.9077	0.7648	0.7713
19	0.7897	1.0000	0.7560
20	0.8103	0.9782	0.7549
21	0.9282	0.2542	0.7205
22	0.6462	0.9174	0.6835
23	0.4051	0.9082	0.4684
24	0.9179	0.1974	0.7024
25	0.3436	0.7424	0.4109
26	0.9385	0.3867	0.7481
27	0.8872	0.1647	0.6739

Table 5 Fuzzy rules

1. If (burrheight is L) and (toolwear is L) then (desirable-fuzzygrade is VVL)
2. If (burrheight is L) and (toolwear is M) then (desirable-fuzzygrade is VL) (1)
3. If (burrheight is L) and (toolwear is H) then (desirable-fuzzygrade is L) (1)
4. If (burrheight is M) and (toolwear is L) then (desirable-fuzzygrade is ML) (1)
5. If (burrheight is M) and (toolwear is M) then (desirable-fuzzygrade is M) (1)
6. If (burrheight is M) and (toolwear is H) then (desirable-fuzzygrade is MH) (1)
7. If (burrheight is H) and (toolwear is L) then (desirable-fuzzygrade is H) (1)
8. If (burrheight is H) and (toolwear is M) then (desirable-fuzzygrade is VH) (1)
9. If (burrheight is H) and (toolwear is H) then (desirable-fuzzygrade is VVH) (1)

B. Step II Obtain the Desirable-Fuzzy grade

A fuzzy logic unit comprises a fuzzifier, membership functions, a fuzzy rule base, an inference engine and a defuzzifier. In the fuzzy logic analysis, the fuzzifier uses membership functions to fuzzify the individual desirability value first. Next, the inference engine performs a fuzzy reasoning on fuzzy rules to generate a fuzzy value. Finally, the defuzzifier converts the fuzzy value into a Desirable-Fuzzy grade values (Table 4). The structure built for this study is a two input- one-output fuzzy logic unit as shown in Fig. 7. The function of the fuzzifier is to convert outside crisp sets of input data into proper linguistic fuzzy sets of information. The input variables of the fuzzy logic system in this study are the individual desirability values for Burr Height and Drill Tool wear. They are converted into linguistic fuzzy subsets using membership functions of a triangle form, as shown in Fig. 8, and are uniformly assigned into three fuzzy subsets—small (S), medium (M), and large (L) grade. The fuzzy rule base consists of a group

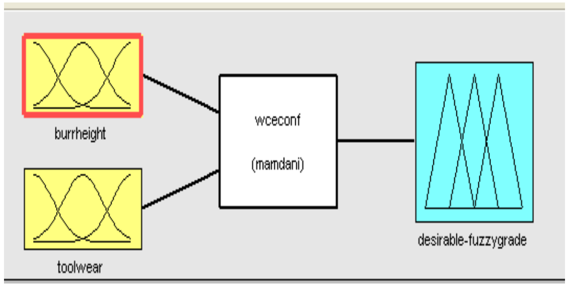

Fig. 7 Two Input- one-Output fuzzy logic unit

of if-then control rules to express the inference relationship between input and output. A typical linguistic fuzzy rule called Mamdani is described as

Rule 1: if x_1 is A_1 and x_2 is B_1 then y is E_1 else
Rule 2: if x_1 is A_2 and x_2 is B_2 then y is E_2 else
…………………………………………………………………..
…………………………………………………………………
Rule n: if x_1 is A_n and x_2 is B_n then y is E_n else

In above Ai and Bi, are fuzzy subsets defined by the corresponding membership functions i.e., α/4Ai and α /4Bi. The output variable is the Desirable-Fuzzy grade yo, and also converted into linguistic fuzzy subsets using membership functions of a triangle form, as shown in Fig.9. Unlike the input variables, the output variable is assigned into relatively nine subsets i.e., very very low (VVL), very low (VL), small(S) medium low(ML),medium (M), medium high(MH) high(H), very high (VH), very very high(VVH) Then, considering Two performance characteristics for input variables, nine fuzzy rules are defined and tabulated in the Table5. The fuzzy inference engine is the kernel of a fuzzy system. It can solve a problem by simulating the thinking and decision pattern of human being using approximate or fuzzy reasoning. In this paper, the max-min compositional operation of Mamdani is adopted to perform calculation of fuzzy reasoning. Suppose that x_1, x_2, x_3 and x_4 are the input variables of the fuzzy logic system, the membership function of the output of fuzzy reasoning can be expressed as

$$\mu_{C_0}(y) = \left(\mu_{A_1}(x_1)\Lambda\mu_{B_1}(x_2)\Lambda\ \mu_{C_1}(x_3)\Lambda\mu_{D_1}(x_4)\Lambda\ \mu_{E_1}(y)\right)\mathrm{v}$$
$$\ldots\left(\mu_{A_n}(x_1)\Lambda\mu_{B_n}(x_2)\Lambda\ \mu_{C_n}(x_3)\Lambda\mu_{D_n}(x_4)\Lambda\ \mu_{E_n}(y)\right)$$

Where V is the minimum operation and Λ is the maximum operation.

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C Step III Identification of the optimal combination of influential factors

The Desirable-Fuzzy grade values are calculated for each factor at each level (Table 6) and the optimal level for each factor is identified based on their individual Desirable-Fuzzy grade values. The optimal level of any influential factor has highest Desirable-Fuzzy grade value among their considered levels. After analysis (Fig.10 and Table.6), the optimal influential factors combination is identified as: BM1 RFM1 SRFM3 PRFM3 S2 F1 TM2 PA2 CF2**,** which means

BM1 **:** Base Material at level 1(Al6061)
RFM1 **:** Reinforcement Material at level 1(SiC)
SRFM3 **:** Size of the Reinforcement Particles at level 3(75μ)
PRFM3 **:** Percentage of Reinforcement Material at level 3 (15%)
S2 **:** Drilling Speed at level 2(560 rpm)
F1 **:** Feed at level 1(0.15)
TM2 **:** Tool Material at level 2 (M32HSS)
PA2 **:** Point Angle at level 2(118^{O})
CF2 **:** Cutting Fluid at level 2(Diesel)

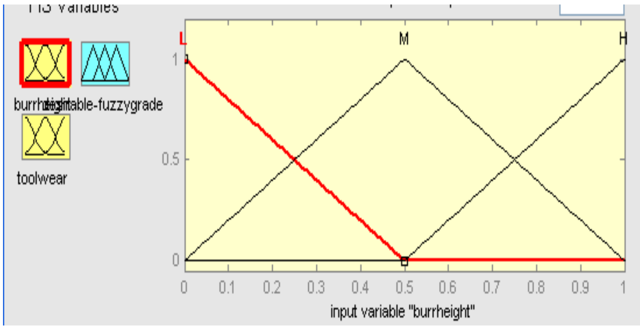

Fig.8 Membership functions of burr height and tool wear

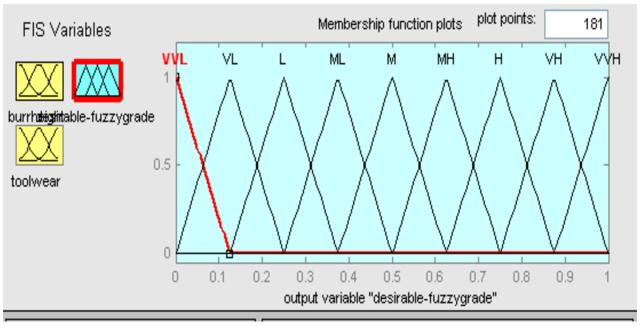

Fig.9 Membership functions of Desirable-Fuzzy Grade

Table 6 desirable-fuzzy grade for each parameter at each level

Influential factor no	**1**	**2**	**3**	**4**	**5**
Level	BM	RFM	SRFM	PRFM	S
1	**0.690978**	**0.739767**	0.613022	0.640044	0.542767
2	0.631244	0.603844	0.656911	0.616344	**0.736211**
3	0.657622	0.636233	**0.709911**	**0.723456**	0.700867
Delta	0.059733	0.135922	0.096889	0.107111	0.193444
Rank	9	3	6	5	1
Influential factor no	**6**	**7**	**8**	**9**	
Level	F	TM	PA	CF	
1	**0.698922**	0.698678	0.659956	0.5886	
2	0.621611	**0.736944**	**0.696556**	**0.701811**	
3	0.659311	0.544222	0.623333	0.689433	
Delta	0.077311	0.192722	0.073222	0.113211	
Rank	7	2	8	4	

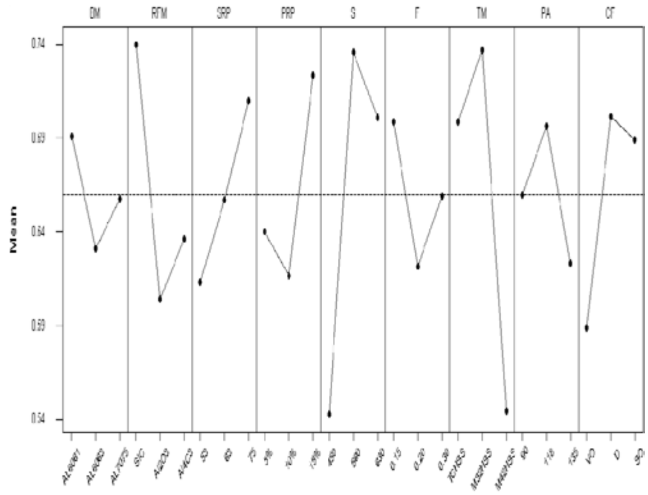

Figure 10. Desirable-Fuzzy grade for each parameter at each level

V RESULTS AND DISCUSSIONS

After identifying the optimum combination of influential factors, the confirmation experiment is conducted and the results are recorded (Table7). The burr height and tool wear are minimized successfully using Desirable-Fuzzy approach. From the Table.6, it is evident that the spindle speed, tool material and reinforcement material are highly influencing the burr height and tool wear. Cutting fluid, percentage of reinforcement particles, and size of reinforcement particles have medial influence on the burr height and tool wear. Feed, point angle and base material have low influence on the burr height and tool wear.

Table 7 results of confirmation experiment

Combination of influential factors	**Burr height**	**tool wear**
BM1 RFM1 SRFM3 PRFM3 S2 F1 TM2 PA2 CF2	1.2mm	0.63mm

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