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Selection of influential factors in drilling of Aluminium Metal Matrix Composites using Fuzzy Logic

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ABSTRACT

This paper is focused on selection of optimal parameters in drilling of Aluminium Metal Matrix Composites (AMMC) using "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: power consumption, temperature, surface roughness, and burr height are measured for each experimental run. These results are analyzed using Fuzzy Logic and optimal parameters combination is identified. The identified combination of influential factors is tested through confirmation experiment and is satisfactory.

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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 [3,10,12]. 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 [8, 17]. Channakesavarao et al. [2] 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.

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 [1]. Yuan and Dong [20] have investigated the effect of percentage volume reinforcement, cutting angle, feed rate and speed in machining of MMCs. El-Gallab and Sklad [5] have used several tool materials to compare its effectiveness. Davim [4] 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. [18] 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 [9, 13, 14]. 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 [16]. The responses in drilling of Al6061 are analyzed using hybrid approach (Grey-Fuzzy) and optimum controllable parameter combination is identified [6]. Optimum parameters are identified to develop an Aluminium metal matrix composite with respect to mechanical properties by using Grey Relational Analysis [19]. 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 [11, 15].

After review the above literature, present work has been defined to optimize the parameters in drilling of AMMC for minimizing the power consumption, temperature, surface roughness, and burr height using Grey Relational Analysis.

Experimental design and drilling of AMMCs

For minimizing the experimental cost Taguchi design of experiments OA L27 is used. Various parameters such as Base 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 thrust force, temperature and surface roughness are considered and each parameter is set at three levels. The Experimental design (OA L27) shown in the Table.2 is developed by considered the factors and their levels shown in the Table.1. As per the design of experiments AMMC samples are prepared using stirr casting method and Drilling tests have been performed on AMMCs using radial drilling

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machine under MQL environment. Drilled work pieces are shown in the Figure1.

Figure 1. Drilled AMMC

Measurement of power consumed, temperature, surface roughness and burr height

Amount of power consumed during the drilling process is measured by connecting the watt meter to the power supply which gives the power to the drilling machine (Figure 2). During drilling process the temperature is produced due to the friction between the tool and the metal. This temperature is measured using infrared pyrometer (Fig.3). It is used to measure the temperature by focusing the infrared rays onto a point where the temperature is to measure. After that the rays will be reflected back to the pyrometer. The variation in intensity of the beam will indicate the temperature on the surface of the work piece.

Figure 2: Watt meter

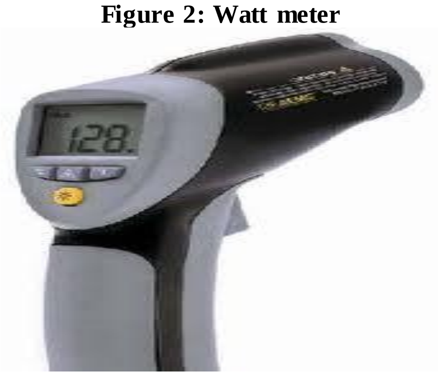

Figure 3. Infrared pyrometer

Surface roughness refers to the magnitude of irregularities of material resulted during machining operation. There are several ways to describe surface roughness. One of them is Average roughness, which is denoted as R_a. R_a is the most commonly used and internationally recognized parameter for measuring surface roughness. The surface roughness is measured using stylus type (Mitutoyo Corporation, japan) Taly-Surf (SJ-201 P) surface roughness measuring instrument (Figure 4)

Fig 4. Talysurf surface meter

Fig 5. Tool makers microscope

Burr height is embossing of the metal around the drilled hole on the surface of the metal on which drilling is performed. It is measured using tool makers microscope (Figure 5).

Optimization using Fuzzy Logic

Using Fuzzy logic, the test results are analyzed and optimum influential factor combination is identified as follows

Calculating S//N ratios for experimental results

For different data sequences the data should be normalized and is depends upon the quality of the response, whether it is to be minimized or maximized or a nominal value (smaller the better or larger the better or Nominal the better).

i)The Smaller-The-Better

The Signal-To-Noise ratio for the Smaller-The-Better is:

S/N = -10 *log (mean square of the response)

$$\frac{S}{N} = -10\log_{10}\left(\frac{\sum y^2}{n}\right) \quad (1)$$

ii) The Larger-The-Better

The Signal-To-Noise ratio for the Larger-the-better is:

S/N = -10*log (mean square of the inverse of the response)

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right) \quad (2)$$

iii) Nominal-the-best

The Signal-To-Noise ratio for the Nominal-the-best is:

S/N = 10 * log (the square of the mean divided by the variance)

$$\frac{S}{N} = 10\log_{10}\left(\frac{y^2}{s^2}\right) \quad (3)$$

In the present work, the "**lower is better"** characteristic is applicable for power consumed, temperature surface roughness and burr height, because these are to be minimized and hence S/N values are calculated using Eqn.2 and values are recorded (Table 4).

Determination of the Comprehensive Output Measure with fuzzy logic

The fuzzy logic unit consist 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 normalized values 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 Comprehensive Output Measure (COM).

The input variables of the fuzzy logic are converted into linguistic fuzzy subsets using membership functions of a triangle form, and are uniformly assigned. The fuzzy rule base consists of a group 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 x1 is A1, x2 is B1 ,x3 is C1, x4 is D1, then y is E1 else

Rule 2: if x1 is A2, x2 is B2 ,x3 is C2, x4 is D2, then y is E2 else

……………………………………………………………………..

Rule n: if x1 is An, x2 is Bn ,x3 is Cn, x4 is Dn, then y is En else

In above Ai, Bi, Ci, Di are fuzzy subsets defined by the Corresponding membership functions i.e., α/4Ai, α /4Bi, α /4Ci, α /4Di The output variable is the COM; yo, and also converted into linguistic fuzzy subsets. Using membership functions of a triangle form. Unlike the input variables, the output variable is assigned into some number subsets. Then, considering the conformity of performance characteristics for input variables, 'n' number fuzzy rules are defined. 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. For this research, the max-min compositional operation of Mamdani is adopted to perform calculation of COM.

The structure built for this study is a four input- one-output fuzzy logic unit as shown in Fig. 6. The input variables of the fuzzy logic system in this study are the S/N ratios of responses: power consumed, temperature, surface roughness and burr height. They are converted into linguistic fuzzy subsets using membership functions of a triangle form, as shown in Fig. 7, and are uniformly assigned into three fuzzy subsets –Low(L), Medium (M), High(H) The output variable of this analysis is the comprehensive output measure (COM). Membership functions used for this research are of a triangle form, as shown in Fig. 8. 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) grade. Then, considering the conformity of four for input variables, 81 fuzzy rules are defined and shown in the Fig.9. In this analysis, the max-min compositional operation of Mamdani is adopted to perform calculation of COM.

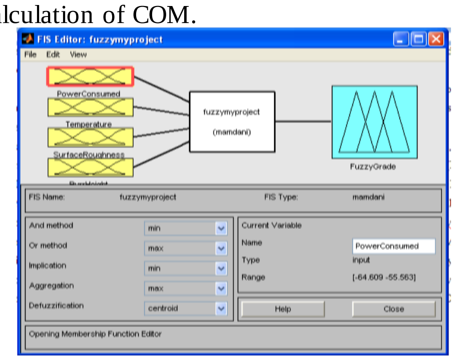

Fig 6. four input- one-output fuzzy logic unit

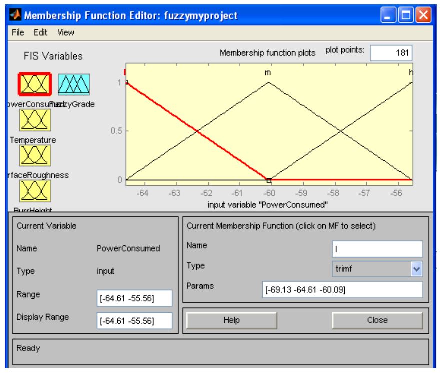

Fig 7. Membership functions of inputs

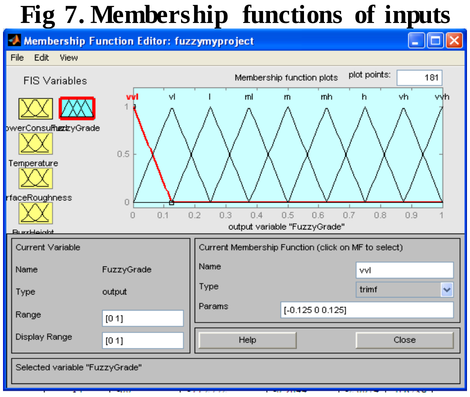

Fig 7. Membership functions of COM

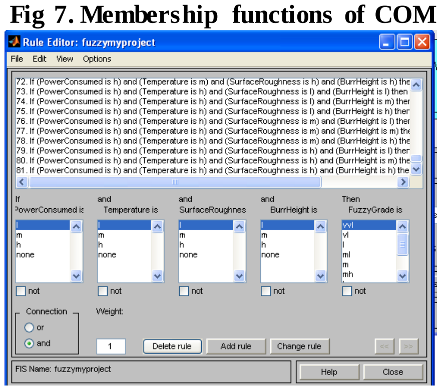

Fig 8. Fuzzy rules

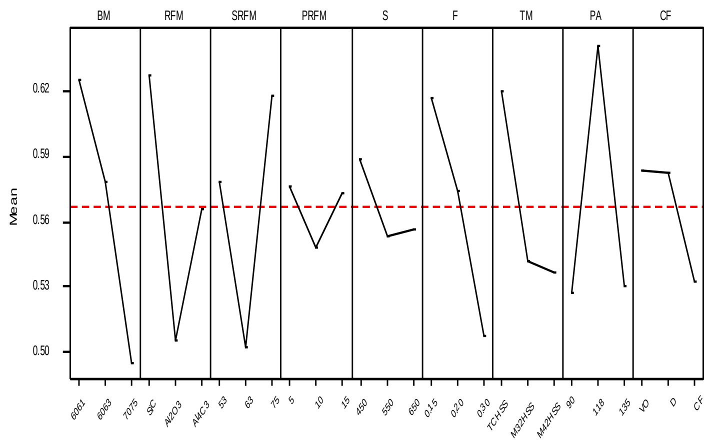

Figure 6. COM for each parameter at each level

Identification of the optimal combination of influential factors

The COM values are calculated for each factor at each level (Table 5) and the optimal level for each factor is identified based on their COM values. The optimal level of any influential factor has highest COM value among their considered levels. After analysis (Fig.6 and Table.5), the optimal influential factors combination is identified as:

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 Fluid (CF)	VO	D	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	01	6061	SIC	53	5	450	0.15	TCHSS	90	VO
2		6061	SIC	53	5	560	0.2	M32HSS	118	D
3		6061	SIC	53	5	630	0.3	M42HSS	135	SO
4	02	6061	Al2O3	63	10	560	0.2	TCHSS	90	D
5		6061	Al2O3	63	10	630	0.3	M32HSS	118	SO
6		6061	Al2O3	63	10	450	0.15	M42HSS	135	VO
7	03	6061	Al4C3	75	15	630	0.3	TCHSS	90	SO
8		6061	Al4C3	75	15	450	0.15	M32HSS	118	VO
9		6061	Al4C3	75	15	560	0.2	M42HSS	135	D
10	04	6063	SIC	63	15	560	0.15	TCHSS	118	D
11		6063	SIC	63	15	630	0.2	M32HSS	135	SO
12		6063	SIC	63	15	450	0.3	M42HSS	90	VO
13	05	6063	Al2O3	75	5	630	0.2	TCHSS	118	SO
14		6063	Al2O3	75	5	450	0.3	M32HSS	135	VO
15		6063	Al2O3	75	5	560	0.15	M42HSS	90	D
16	06	6063	Al4C3	53	10	450	0.3	TCHSS	118	VO
17		6063	Al4C3	53	10	560	0.15	M32HSS	135	D
18		6063	Al4C3	53	10	630	0.2	M42HSS	90	SO
19	07	7075	SIC	75	10	630	0.15	TCHSS	135	SO
20		7075	SIC	75	10	450	0.2	M32HSS	90	VO
21		7075	SIC	75	10	560	0.3	M42HSS	118	D
22	08	7075	Al2O3	53	15	450	0.2	TCHSS	135	VO
23		7075	Al2O3	53	15	560	0.3	M32HSS	90	D
24		7075	Al2O3	53	15	630	0.15	M42HSS	118	SO
25	09	7075	Al4C3	63	5	560	0.3	TCHSS	135	D
26		7075	Al4C3	63	5	630	0.15	M32HSS	90	SO
27		7075	Al4C3	63	5	450	0.2	M42HSS	118	VO

Table 3. Experimental Results

Expt Run No	Power consumed (W)	Temperature (^{O}C)	Surface Roughness (µm)	Burr height (mm)
1	600	42	0.84	2.43
2	800	48	0.63	1.17
3	1100	46	0.86	1.17
4	800	39	0.70	1.35
5	1100	51	2.31	1.47
6	1300	62	0.85	3.00
7	600	42	0.65	1.37
8	900	43	1.44	1.31
9	1000	42	1.23	1.31
10	900	44	0.78	1.32
11	1400	54	1.98	1.23
12	1100	45	0.87	1.31
13	700	44	0.65	2.89
14	1000	46	1.12	1.26
15	1100	52	5.25	1.29
16	900	45	1.34	3.12
17	1200	40	0.88	1.40
18	900	48	1.10	1.35
19	900	60	1.42	1.58
20	700	46	0.73	1.54
21	1400	48	0.68	1.31
22	1100	47	0.55	1.86
23	1000	54	1.23	2.33
24	1500	61	1.12	1.33
25	1200	64	1.55	2.45
26	1400	55	1.16	1.29
27	1700	43	0.47	1.39

Table 4. S/N Ratios and COM values

Expt Run. No.	S/N Ratios				COM Values
	Power consumed	Temperature	Surface Roughness	Burr height	
1	-55.563	-32.465	1.5144	-7.7121	0.6841
2	-58.0618	-33.6248	4.0132	-1.3637	0.7595
3	-60.8279	-33.2552	1.31	-1.3637	0.6851
4	-58.0618	-31.8213	3.098	-2.6067	0.7839
5	-60.8279	-34.1514	-7.2722	-3.3463	0.3935
6	-62.2789	-35.8478	1.4116	-9.5424	0.2739
7	-55.563	-32.465	3.7417	-2.7344	0.7924
8	-59.0849	-32.6694	-3.1672	-2.3454	0.6355
9	-60	-32.465	-1.7981	-2.3454	0.6271
10	-59.0849	-32.8691	2.1581	-2.4115	0.7066
11	-62.9226	-34.6479	-5.9333	-1.7981	0.3933
12	-60.8279	-33.0643	1.2096	-2.3454	0.6494
13	-56.902	-32.8691	3.7417	-9.218	0.6127
14	-60	-33.2552	-0.9844	-2.0074	0.6289
15	-60.8279	-34.3201	-14.4032	-2.2118	0.5
16	-59.0849	-33.0643	-2.5421	-9.8831	0.42
17	-61.5836	-32.0412	1.1103	-2.9226	0.6623
18	-59.0849	-33.6248	-0.8279	-2.6067	0.6344
19	-59.0849	-35.563	-3.0458	-3.9731	0.4557
20	-56.902	-33.2552	2.7335	-3.7504	0.7084
21	-62.9226	-33.6248	3.3498	-2.3454	0.6089
22	-60.8279	-33.442	5.1927	-5.3903	0.6091
23	-60	-34.6479	-1.7981	-7.3471	0.3635
24	-63.5218	-35.7066	-0.9844	-2.477	0.3898
25	-61.5836	-36.1236	-3.8066	-7.7833	0.2403
26	-62.9226	-34.8073	-1.2892	-2.2118	0.4376
27	-64.609	-32.6694	6.558	-2.8603	0.6454

Table 5. COM for each parameter at each level

Influential factor no	**1**	**2**	**3**	**4**	**5**
Level	BM	RM	SRFM	PRFM	S
1	0.62611	0.62789	0.57864	0.57707	0.589422
2	0.57862	0.50614	0.50266	0.54900	0.553611
3	0.49541	0.56611	0.61884	0.57408	0.557111
Max-Min	0.13070	0.12174	0.11619	0.02807	0.035811
Rank	1	2	3	9	8
Influential factor no	6	7	8	9	
Level	F	TM	PA	CF	
1	0.617078	0.62100	0.52728	0.58386	
2	0.574656	0.54193	0.64153	0.58357	
3	0.508411	0.53721	0.53133	0.53272	
Max-Min	0.108667	0.08379	0.11426	0.05113	
Rank	5	6	4	7	

BM1 RM1 SRFM3 PRFM1 S1 F1 TM1 PA2 CF1,
This means,

BM1	: Base Material at level 1(Al6061)
RM1	: Reinforcement Material at level 1 (SiC)
SRFM3	: Size of the Reinforcement Particles at level 3 (75μ)
PRFM1	: Percentage of Reinforcement Material at level 1 (5%)
S1	: Drilling Speed at level 1 (450 rpm)
F1	: Feed at level 1 (0.15)
TM1	: Tool Material at level 1 (TC HSS)
PA2	: Point Angle at level 2 (118^{O})
CF1	: Cutting Fluid at level 1(VO)

Results and discussions

After identifying the optimum combination of influential factors, the confirmation experiment is conducted and the results are recorded (Table6). The power consumed (PC), temperature (T), surface roughness (SR) and burr height(BH) are minimized successfully using Fuzzy Logic. From the Table.5, it is evident that the base material, reinforcement material and size of reinforcement material are highly influencing the power consumed, temperature, surface roughness and burr height. Point angle, feed, and tool material has medial influence on the power consumed, temperature, surface roughness and burr height. Cutting fluid, Speed and percentage of reinforcement material has low influence on the power consumed, temperature, surface roughness and burr height.

Table 6. Results of confirmation experiment

Combination of parameters	PC	T	SR	BH
BM1 RM1 SRFM3 PRFM1 S1 F1 TM1 PA2 CF1	500	37	0.39	0.85

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