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Prediction of Surface Roughness in Drilling of Al 7075/10% - SiCp Composite under MQL Condition using Fuzzy Logic

K. Anand Babu*, G. Vijaya Kumar and P. Venkataramaiah

Department of Mechanical Engineering, Sri Venkateswara University, Tirupati- 517502, India; kumba.anand@gmail.com, vijayluther2003@yahoo.co.in, pvramaiah@gmail.com

Abstract

The main aim of this study is to examine the influence of drilling parameters on Aluminium Metal Matrix Composite (Al7075/10% - SiCp). The Drilling experiments were conducted according to Taguchi L27 orthogonal array on Al7075/10% - SiCp composite with uncoated and coated HSS tools under MQL environment. The input parameters were used is speed, feed, tool material, point angle and cutting environment for 3 levels. This composite is fabricated using 53 μm sized SiC particles reinforced into aluminium matrix material via stir casting process. The surface roughness is considered as experimental result and it is predicted using fuzzy logic. The results specify that the predicted surface roughness values and experimental surface roughness values are close to each other and surface roughness can be predicated efficiently by fuzzy logic modeling technique.

Keywords: Al7075/10% - SiCp Metal Matrix Composite, Drilling, Surface Roughness (Ra), Fuzzy Logic Modeling, Stirr Casting

1. Introduction

Metal Matrix Composites (MMC) is widely used composite materials in aerospace, automotive, electronics and medical industries. They have outstanding properties like high strength, low weight, high modules, low ductility, high wear resistance, high thermal conductivity and low thermal expansion. These desired properties are mainly manipulated by the matrix, the reinforcement element and the interface[1].

In recent days many processing techniques have been developed and used to process particulate reinforced metal matrix composites. Among the variety of manufacturing processes, stir casting is generally accepted as a predominant liquid metallurgy technique, due its advantages like simplicity, flexibility and applicability to large quantity production[2]. It is also attractive because, in principle, it allows a conventional metal processing method to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most cost-effective method for metal matrix composite production[3], and allows very large sized components to be fabricated. As the matrix element, aluminium, Titanium and magnesium alloy is used, while the popular reinforcements are Silicon Carbide (SiC) and alumina (Al_2O_3). Aluminium-based SiC particle reinforced MMC materials have become useful engineering materials due to their properties such as low weight, heat-resistant, wear-resistant and low cost[4]. However, the final conversion of these composites into engineering products is always associated with machining, either by turning or by milling. The recurring problem with MMCs is that they are difficult to machine, due to the hardness and abrasive nature of the reinforcing particles[5]. The particles used in the MMCs are

*Author for correspondence

harder than most of the cutting tool materials. Most of the researchers reported that diamond is the most preferred tool material for machining MMCs[6,7].

The cutting conditions which influence the surface quality and machining process are coolant, tool type, speed, feed, depth of cut. Among those, coolant is an important factor largely affects the machining process[8,9]. The modern industries are therefore looking for a cooling system to provide dry (near dry), clean, neat and pollution free machining. Minimum Quantity Lubrication (MQL) refers to the use of cutting fluids of only a minute amount-typically of a flow rate of 50-500 ml/hour which is about three to four orders of magnitude lower than the amount commonly used in flood cooling, for example, up to 10 liters of fluid can be dispensed per minute. The concept of MQL, sometimes referred to as 'near dry lubrication' or 'micro lubrication' Machining under minimum quantity lubrication (MQL) condition is perceived to yield favorable machining performance over dry or flood cooling condition[8,9]. Tools with TiN, TiCN, CrN, and TiAlN coating also play a significant role in drilling to improve multi performance[10, 11]. Studied and presented the effect of drilling parameters on Torque in drilling of aluminium hybrid metal matrix composite (Al-15%SiC-4%Gr). The drilling parameters are used were spindle speed, feed rate, and drill diameter for 3 levels. The optimized parameter of aluminium hybrid composite was found by taguchi's L27 orthogonal array experimentation. The experiments are conducted on computer numeric control vertical machining centre using multifaceted carbide drills of 4 mm, 8 mm and 12 mm diameter under dry drilling conditions. Stir casting technique was used to fabricate this composite and the results indicated that feed rate is the main parameter which influences the Torque in drilling of hybrid metal matrix Composites[12]. An effort was made to fabricate a hybrid metal matrix composite, silicon carbide and titanium diboride reinforced in Al 6061 matrix using stir casting method. Microstructure and mechanical properties such as micro hardness and wear were studied for various compositions of reinforcements, 10% SiC and 2.5%, 5% and 10% TiB_2. The results indicate that the hardness value increases with the addition of the SiC and TiB_2 reinforcements to matrix Al6061, while the wear resistance increases up to certain amount and reduces drastically when crossed the transition load[13].

The majority researches on metal matrix composite machining shows that minimizing the surface roughness was a serious task. In order to identify the surface quality and dimensional properties, it is necessary to use theoretical models for prediction purpose. The fuzzy logic modeling technique is used for prediction. The theory of fuzzy logics, initiated by Zadeh, has proven to be useful for dealing the uncertain and vague information[14]. This theory has proved to be an effective means for dealing with objectives that are linguistically specified. Linguistic terms, such as 'low,' 'medium' and 'high' may be defined by fuzzy sets[15]. Since its introduction, fuzzy set theory has attracted the attention of researchers in mathematical and engineering fields[16]. Studied the factors influenced on the surface roughness in drilling of Al/SiC/Graphite hybrid composite material and analyzed the surface roughness of 'coated carbide twist drill', 'multifaceted drill' and 'step drill' bits. The results indicated that the step drill performed better than the other drills[17].

In the present study, the fuzzy logic modeling technique is used as an efficient approach to predict the surface roughness values in drilling of Al7075/10% - SiCp metal matrix composite and the drilling experiments are conducted as per Taguchi L_{27} with uncoated and coated HSS tools under MQL environment.

2. Experimental Details

2.1 Composite Preperation

In this study aluminum alloy (Al7075) is used as the matrix metal for the fabrication of the composite that has been reinforced with 10 wt. % of Silicon Carbide particles (SiCp) of average 53 µm size. This composite is fabricated using stir casting technique because it is best and low cost method for producing the MMC materials[18]. The melting was carried in a stir casting furnace (Figure 1) in a range of 750±20°C. The melt has mechanically stirred by using a graphite stirrer with motor, during this the pre-heated SiCp (about 8000C to make their surfaces oxidized) and 1% of magnesium as a wetting agent (to reduce the surface tension of aluminium and to increase the wetting property between matrix and reinforcement material) was added gradually into the molten metal. The stirring process is carried out at a temperature of 750°C with a stirring speed 600 rpm and time of 10 min[19]. Finally, The molten metal - SiCp slurry poured into the mild steel die, which is preheated to about 300°C. After solidification the Al7075/10%-SiCp metal matrix composite was

Table 1. Physical and Mechanical Properties of Al7075/10%-SiCp

Material	Tensile strength [Mpa]	Impact Strength [Mpa]	Hardness [BHN]	Density [gms/cm^3]
Al7075/ 10%-SiCp	58.34	632.9	229.5	3.1323

Figure 1. Stir Casting Furnace.

Figure 2. Steel die with cast product.

obtained with size (rectangular plate of 25mm thickness 45 mm width and 60 mm long) shown in Figure 2. It is highly used in aeronautical and automobile industries because of their high strength to weight ratio, mechanical and physical properties compared to monolithic material. Table 1 shows the physical and mechanical properties of Al7075/10%-SiCp.

2.2 Experimental Design and Drilling of Work Material

The main objective of this experiment is to determine the influence of machining parameters on Al7075/10%-SiCp composite during drilling operation using radial drilling machine with HSS, TIN and TiAlN coated HSS tools (Figure 3) under Dry and MQL environment by considering different speed, feed, cutting fluid and point angle combinations. The surface roughness is considered as an output response for analyzing the machining process, which is mostly used in industries. The surface roughness is measured using stylus type (Mitutoyo Corporation, Japan) Taly-Surf (SJ-201P) surface roughness measuring instrument and drilled specimen of Al7075/10%-SiCp composite as shown in Figure 4 and Figure 5.

In this experiment five controllable parameters are considered and each parameter is set at three levels. The machining parameters and their levels are listed in Table 2. For full factorial design, the experimental runs required are (levels) (factors) equal to $3^5 = 243$. To minimize the experimental cost, fractional factorial design is chosen, i.e., $3^{5-2} = 27$ runs. Therefore Taguchi experimental design L_{27} chosen for conducting experiments. Experiments are performed according to this design and the Surface Rughness values (SR) are given in Table 4.

Table 2. Machining Parameters and their levels

Parameters	Level 1	Level 2	Level 3
Speed (rpm), N	500	630	760
Feed (mm/Rev), F	0.2	0.3	0.36
Tool Material (TM)	TIN COATED HSS	TiAlN COATED HSS	HSS
Point Angle (Deg), PA	90	118	135
Cutting Environment (CE)	Dry (D)	Diesel (DIE)	Vegetable Oil (VG.OL)

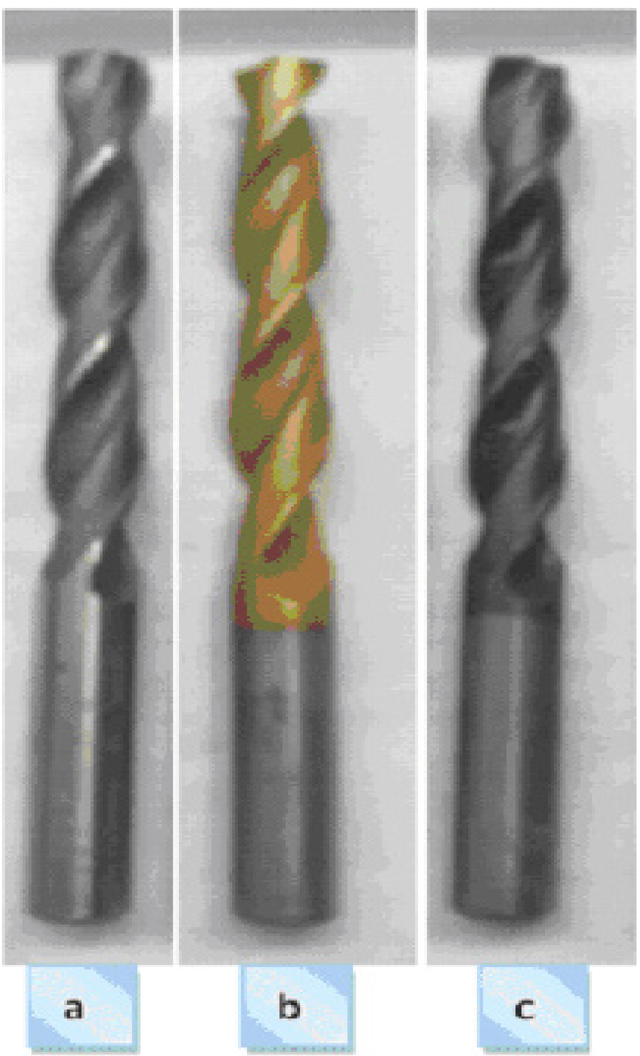

Figure 3. Drill bits (a) HSS (b) TIN and (c) TiAlN coated HSS tool.

Figure 4. Talysurf surface meter

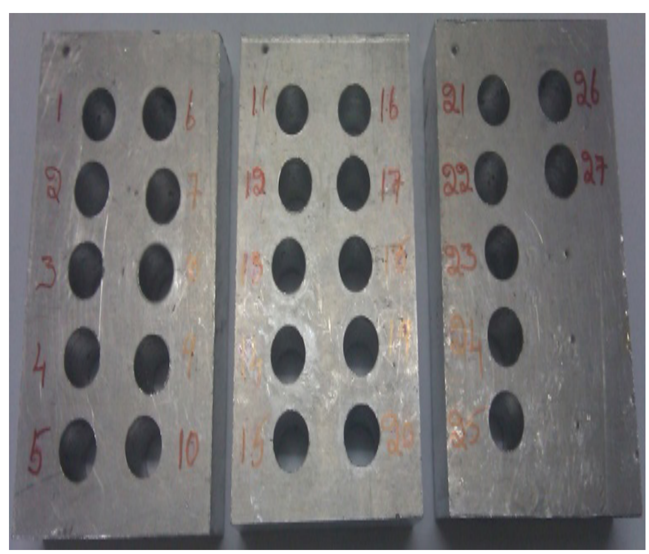

Figure 5. Drilled Al7075-10%SiCp pieces.

3. Fuzzy Modeling

Among various methods available for modeling and optimization of machining process, fuzzy logic modeling technique has been widely used for the prediction of machining responses such as surface roughness, cutting forces, tool wear, tool life and dimensional deviation[20]. Lotfi Zadeh[14] was first introduced the Fuzzy logic technique based on fuzzy set theory in the year 1965. In the recent years, the number and variety of applications of fuzzy set theory in engineering field have developed significantly including the area of Artificial Intelligence (AI).

The process of fuzzy inference is based on four basic concepts such as fuzzy sets, linguistic variables, possibility distributions and fuzzy IF–THEN rules, the former three are fundamental concepts in fuzzy logics, and the later one is the important concept using in most of the industrial applications. Generally construction of rule base is done by using two types of fuzzy logic rules such as Mamdani type or Sugeno type rules[21].

In the present work, a surface roughness prediction model is developed using fuzzy logic methodology for drilling of Al7075/10%-SiCp composite. In this work Mamdani type Fuzzy Inference Systems (FIS) is used for modeling[22] and Mamdani's fuzzy inference method is the most commonly used fuzzy methodology. Mamdani's method was the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. The fuzzy logic prediction model is developed using Fuzzy Logic toolbox available in MATLAB software.

3.1 Fuzzification

The fuzzifier uses triangular membership functions to fuzzify the input and output variables. Triangular membership functions are easy to use and require only three parameters to define. It is defined as a triangular shape which is a function of vector x that depends on three parameters a, b and c and is mathematically expressed as shown in Equation (1)[17].

$$\text{Triangle}\,(x;\ a,\ b,\ c) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases} \quad (1)$$

The input variables such as speed (500, 630, 760 rpm), feed (0.2, 0.3, 0.36 mm/rev), Tool Material (HSS, TIN, TiAlN) Point Angle (90, 118, 135) and Coolant (Dry, Diesel, Veg. Oil) are fuzzified into three fuzzy sets i.e. Low (L), Medium (M) and High (H) as shown in the Figure 6.

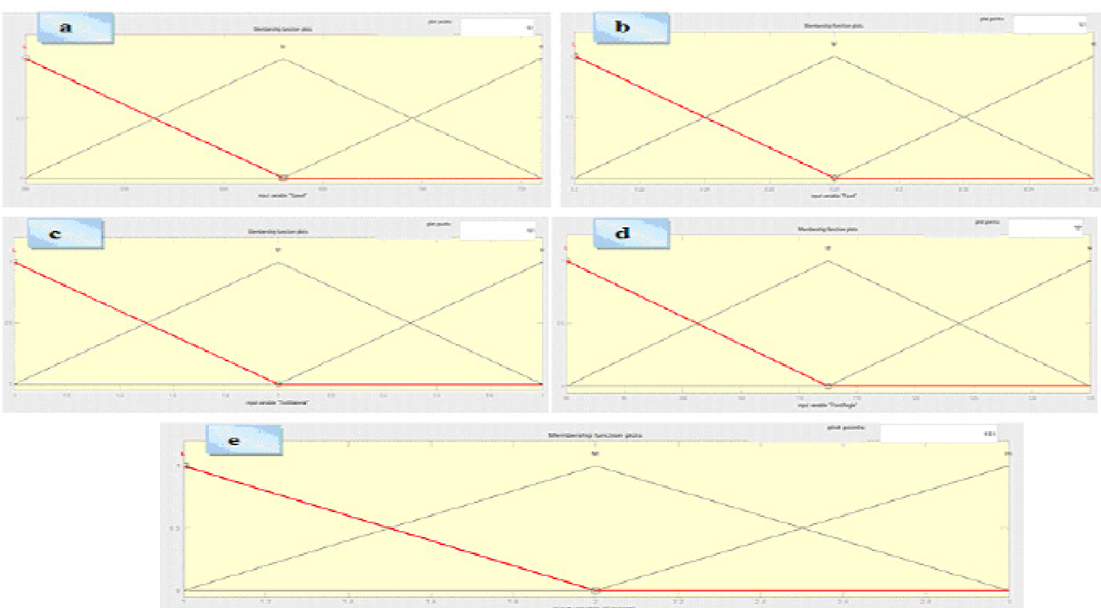

Figure 6. Membership functions for input variables (a) speed (b) feed (c) tool material (d) Point angle (e) Coolant.

The output variable (surface roughness) is fuzzified into nine fuzzy sets as shown in Figure 7 i.e. Very Very Low (VVL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H) Very High (VH) and Very Very High (VVH) to increase the prediction accuracy.

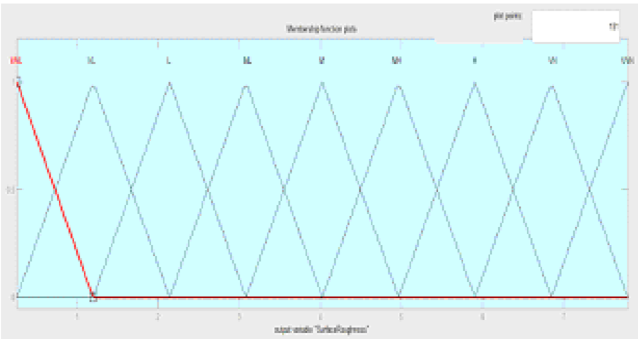

Figure 7. Membership Functions for output variable (surface Roughness).

3.2 Generation of 'if –then' Rules

The fuzzy rules are generated based on experimental results and 27 fuzzy rules were developed for 27 experimental results by taking the max-min compositional operation. The fuzzy rule base consists of a group of IF-THEN statements with five inputs (x1, x2, x3, x4, and x5) and one output y.

Rule 1: if x1 is A1 and x2 is B1 and x3 is C1 and x4 is D1 and x5 is E1 then y is F1

else

Rule 2: if x1 is A2 and x2 is B2 and x3 is C2 and x4 is D2 and x5 is E2 then y is F2

else

…………………………………………………………

……..…………………………………………………..

Rule n: if x1 is An and x2 is Bn and x3 is Cn and x4 is Dn and x5 is En then y is Dn.

Ai, Bi, Ci, Di, Ei and Fi are the fuzzy subsets defined by the corresponding membership functions, i.e. μ_{Ai} , μ_{Bi} ,μ_{Ci} μ_{Di} μ_{Ei} and μ_{Fi}. The 27 fuzzy rules are generated using these rules and as shown in Figure 8.

3.3 Defuzzification

Finally the fuzzy output is transformed into a non-fuzzy value y_0 using defuzzification method because the output response of the fuzzy process is available in fuzzy values only. For this purpose, the centroid defuzzification

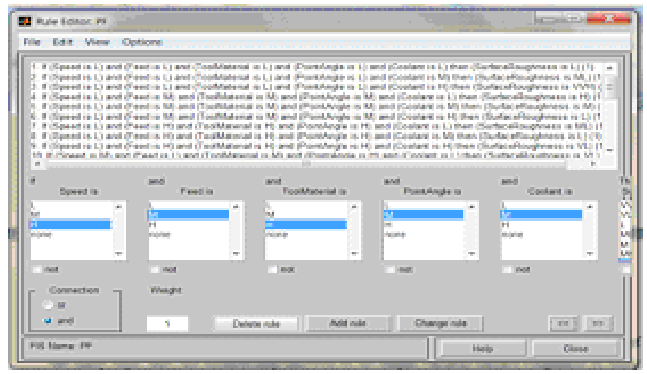

Figure 8. Fuzzy rules for input and output variable.

method is used as it is the most popular method used in most of the fuzzy logic applications[23].

$$y_0 = \frac{\Sigma y \mu_{D_0}(y)}{\Sigma \mu_{D_0}(y)} \quad (2)$$

The non fuzzy value gives the output response (surface Roughness) value in numerical form and the fuzzy predicted values are tabulated in Table 4.

4. Results and Discussion

In drilling, the surface roughness characteristic plays an important role in determining the drilling accuracy. In the present work the surface roughness characteristic of Al7075/10%-SiCp composite mainly depends on machining parameters such as cutting speed, feed, tool material, point angle, and cutting environment. The influence of machining parameters on surface roughness of Al7075/10%-SiCp composite can be studied by using response graph and response table as shown in Figure 9 and Table 3.

From Figure 9 the surface roughness is observed at high cutting speed is low as compared to low cutting speed. The experimental results indicated that the surface roughness parameter is low at high feed as compared to the low feed. The effect of tool material on drilling of Al7075/10%-SiCp composite indicated that the surface roughness reduces with use of TiAlN coated tool as compared with HSS tools. Also the experimental result indicates that low surface roughness is observed for high point angle and Diesel as cutting environment. The response table (Table 3) for surface roughness, shows the effect of different cutting parameters and it can be stated that feed is the main influential parameter which affect the surface roughness.

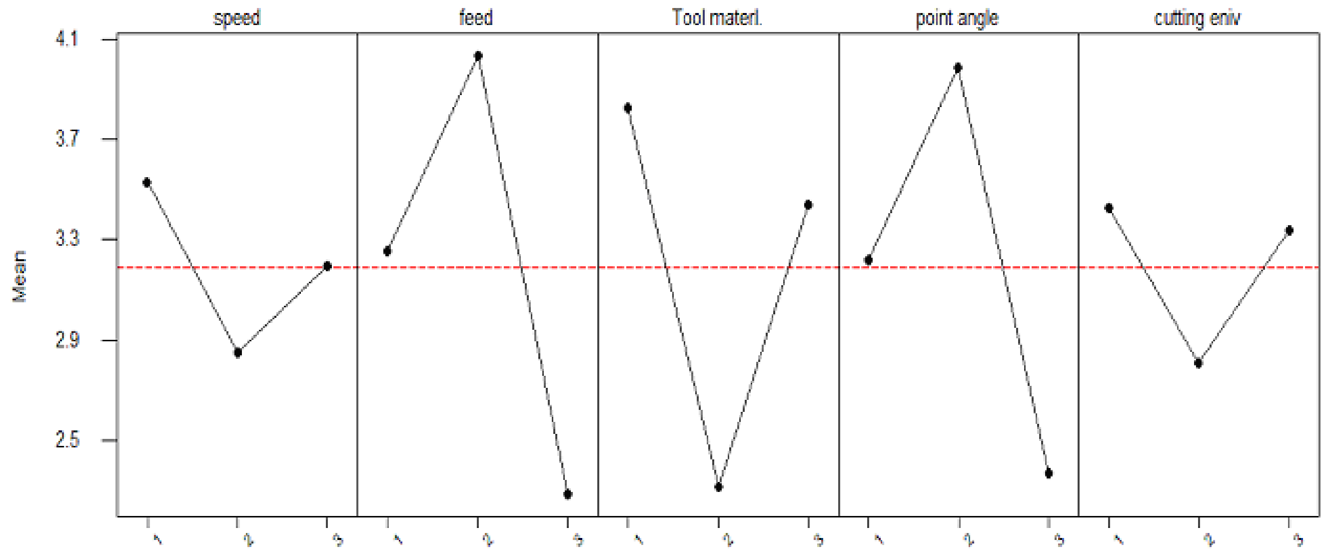

Figure 9. Response Graph for surface Roughness in drilling of Al7075/10%-SiCp composite.

Table 3. Response Table for surface Roughness

Level	speed	feed	Tool material	Point angle	Cutting environment
1	3.52667	3.25556	3.82556	3.21778	3.43
2	2.85333	4.03667	2.31222	3.98667	2.80778
3	3.19556	2.28333	3.43778	2.37111	3.33778
Delta	0.67333	1.75333	1.51333	1.61556	0.62222
Rank	4	1	3	2	5

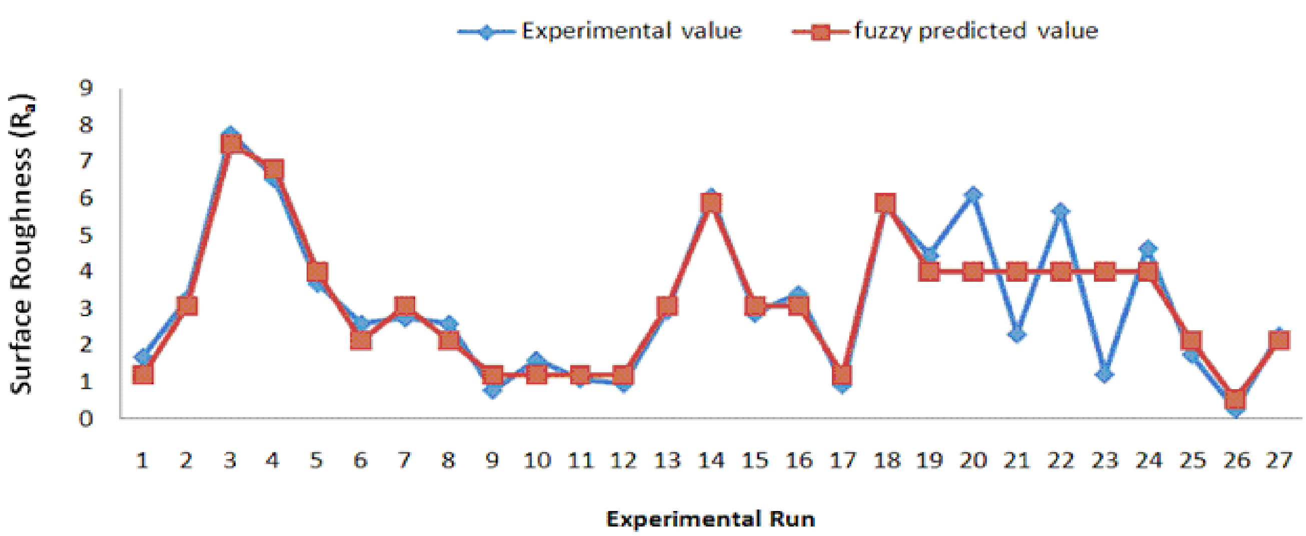

Figure 10. Correlation between experimental value and fuzzy predicted values of R_a.

Table 4. Experimental Plan and Ra values obtained from experiments and fuzzy prediction

Sl. No	Experimental plan					Experimental value of Ra (μm)	Fuzzy predicted Ra value	Error
	N	F	TM	PA	CE			
1	1(L)	1(L)	1(L)	1(L)	1(L)	1.69 (VL)	1.2014	0.4886
2	1(L)	1(L)	1(L)	1(L)	2(M)	3.27 (ML)	3.0843	0.1857
3	1(L)	1(L)	1(L)	1(L)	3(H)	7.79 (VVH)	7.5008	0.2892
4	1(L)	2(M)	2(M)	2(M)	1(L)	6.56 (VH)	6.8489	-0.2889
5	1(L)	2(M)	2(M)	2(M)	2(M)	3.70 (M)	4.025	-0.325
6	1(L)	2(M)	2(M)	2(M)	3(H)	2.6 (L)	2.143	0.457
7	1(L)	3(H)	3(H)	3(H)	1(L)	2.75 (ML)	3.0843	-0.3343
8	1(L)	3(H)	3(H)	3(H)	2(M)	2.60 (L)	2.143	0.457
9	1(L)	3(H)	3(H)	3(H)	3(H)	0.78 (VL)	1.2014	-0.4214
10	2(M)	1(L)	2(M)	3(H)	1(L)	1.61 (VL)	1.2014	0.4086
11	2(M)	1(L)	2(M)	3(H)	2(M)	1.09 (VL)	1.2014	-0.1114
12	2(M)	1(L)	2(M)	3(H)	3(H)	0.95 (VL)	1.2014	-0.2514
13	2(M)	2(M)	3(H)	1(L)	1(L)	2.95 (ML)	3.0843	-0.1343
14	2(M)	2(M)	3(H)	1(L)	2(M)	6.08 (H)	5.9074	0.1726
15	2(M)	2(M)	3(H)	1(L)	3(H)	2.88 (ML)	3.0843	-0.2043
16	2(M)	3(H)	1(L)	2(M)	1(L)	3.41 (ML)	3.0843	0.3257
17	2(M)	3(H)	1(L)	2(M)	2(M)	0.92 (VL)	1.2014	-0.2814
18	2(M)	3(H)	1(L)	2(M)	3(H)	5.79 (H)	5.9074	-0.1174
19	3(H)	1(L)	3(H)	2(M)	1(L)	4.46 (M)	4.025	0.435
20	3(H)	1(L)	3(H)	2(M)	2(M)	6.13 (H)	4.025	2.105
21	3(H)	1(L)	3(H)	2(M)	3(H)	2.31 (L)	4.025	-1.715
22	3(H)	2(M)	1(L)	3(H)	1(L)	5.68 (H)	4.025	1.655
23	3(H)	2(M)	1(L)	3(H)	2(M)	1.22 (VL)	4.025	-2.805
24	3(H)	2(M)	1(L)	3(H)	3(H)	4.66 (MH)	4.025	0.635
25	3(H)	3(H)	2(M)	1(L)	1(L)	1.76 (L)	2.143	-0.383
26	3(H)	3(H)	2(M)	1(L)	2(M)	0.26 (VVL)	0.5495	-0.2895
27	3(H)	3(H)	2(M)	1(L)	3(H)	2.28 (L)	2.143	0.137

Average % error = 0.33%

Note: Speed (N): 1 is 500, 2 is 630 and 3 is 760
Feed (F): 1 is 0.2, 2 is 0.3 and 3 is 0.36
Tool Material (TM): 1 is TiN coated, 2 is TiAlN coated and 3 is HSS
Point Angle (PA): 1 is 90°, 2 is 118° and 3 is 135°
Cutting Environment (CE): 1 is Dry, 2 is Diesel and 3 is Veg. oil.

Figure 10 shows the correlation graph for surface roughness obtained from experimental and fuzzy predicted values. It is verified that the correlation exists between the surface roughness values obtained from experimental results and fuzzy modeling is highly satisfactory.

5. Conclusion

Fuzzy logic modeling technique has been developed for predicting the surface roughness in drilling of Al7075/10%-SiCp composite using triangular membership. Based on the experimental and fuzzy predicted results, the following conclusions are drawn.

- The predicted fuzzy values and experimental values of surface roughness are fairly close to each other, which indicate that the surface roughness values can be predicated efficiently by fuzzy logic modeling technique in drilling of Al7075/10%-SiCp composite.
- The feed is the prevailing parameter which affects the surface roughness of Al7075/10%-SiCp composite, followed by point angle, tool material, speed and cutting environment. Cutting environment shows a minimal effect on surface roughness compared to other parameters.
- The prediction accuracy of fuzzy logic modeling technique can be further improved by increasing the number of membership functions, number of variables and wider range of cutting conditions.

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