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FUZZY LOGIC MODEL ANALYSIS ON WEAR BEHAVOUR OF Al-Mg-SiC COMPOSITE PRODUCED BY MODIFIED STIR CASTING METHOD

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ABSTRACT

Metal matrix composites (MMC) are suitable replacements not only for steels but also for aluminum alloys in various automotive systems and components. There are many ways to get lightweight materials without compromising their strength and safety requirements. Tests on dry sliding or unlubricated pin-on-disc tests can be performed to examine the wear characteristics of metal matrix composites based on aluminum. In the present study, we studied the behavior of wear resistance during sliding of metal matrix aluminum composites (MMC) at sliding speeds of 2 m/s and loads 15, 25, 35 and 45 N in a normal environment, and experiments have been conducted using a pin-on-disc tribometer (Make: DUCOM tribometer). The results show that the wear rates of the composites are lower than those of the matrix alloy and decrease further with increasing SiC content. Further percentage of SiC and applied load are considered as input to the fuzzy system and wear rate as the output. The output from the developed fuzzy model is compared with experimental results, and the deviation is found to be within 3.25 percent.

KEY WORDS: Metal Matrix Composite (MMC), modified stir casting, wear, reinforcement, fuzzy logic

1. INTRODUCTION

Ideally, it is a common practice to completely replace an existing structural material with a higher–yield strength material with possible inclusion of reinforcements. The introduction of lightweight, high-performance metal matrix composites (MMCs) for the aerospace, automotive, and consumer sectors has been difficult due to the high cost of producing components of even minimally complex shape. Powder metallurgy can be the key to overcoming this obstacle, although there are several technical problems. Achieving a uniform distribution of the reinforcement within the matrix is one of these problems that directly affect the properties and quality of composite materials. Continuously reinforced aluminum MMCs are a class of composite materials that have desirable properties such as low density, high specific stiffness, high specific strength, controlled coefficient of thermal expansion, resistance to increased fatigue, and excel- lent dimensional stability at high temperatures (Behera et al., 2020, 2019a,b; Mazahery and Shbani, 2012). The most commonly used MMC system consists of an aluminum alloy reinforced with solid carbide particles, i.e., silicon carbide (Garcla-Cordovilla et al., 1966; Ghosh et al., 2011). These

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composite materials have different amplification mechanisms compared to conventional materials or continuously reinforced composites (Uzkut, 2013; Narayan et al., 1995; Park et al., 2001; Prasad, 2007). Thus, a lot of re- search has been carried out, both experimental and analytical; to better understand the mechanical behavior of these composites and their excellent resistance to wear.

We are dealing with an innovative technique of analyzing the wear behavior com- pared to the experimental values of the aluminum metal matrix composite (AMMC) products using fuzzy logic (Salguero et al., 2018; Zhang et al., 2007; Aruri et al., 2013; Alrobei, 2020; Pradhan et al., 2017; Kori and Chandrashekharaia, 2007). A pin-on-disc tribometer was used to conduct the experiment with varying load and sliding velocity for a particular time and distance; experimental design is used for analyzing the per- formance measures such as wear loss by using fuzzy logic in order to obtain minimum wear (Abdel-Kader, 2001). Several fuzzy rules were formulated (Yadav et al., 2002; Daws et al., 2008; Kannan and Padmanabhan, 2016) using experimental data, and input parameters were mapped to fuzzy rules using input trapezoidal membership functions to obtain fuzzy results and using trapezoidal membership functions on the output. The results show that the specific wear rate decreases with increasing loads. The novelty of the research is the consideration of new composite materials for the dry sliding wear test. Here, the matrix alloy is made of Al, Mg and SiC particles are added to the matrix alloy to prepare the MMCs, which improve the strength and hardness in order to improve the wear properties.

2. Experimental Procedure:

The modified stir casting method was adopted for the production of composite samples. In this process, the main raw material is an aluminum matrix, which is reinforced with SiC. Also 2% Mg is added to increase the wettability of SiC. The MMC has been strengthened by adding 1, 2, 5, 6, 8 & 10 wt% of silicon carbide in the metal matrix.

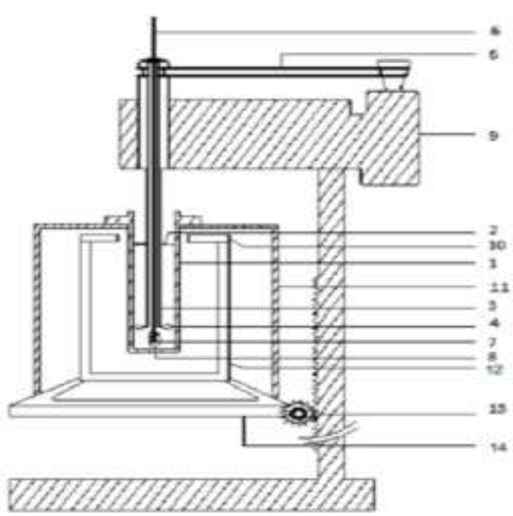

Fig.1: Diagram of Plunger Technique Apparatus to Prepare Aluminium-Magnesium Alloys

1. Heating pot
2. Melt Level
3. Hollow Spindle
4. Impeller Blade
5. V-belt Drive
6. Plunger Rod
7. Capsule
8. Mg turnings and SiC Particle
9. Gear Assembly and Motor
10. Split Cover
11. Crucible Holder
12. Electric Furnace
13. Rack and Pinion Arrangement
14. Base Plate

Aluminium-2%Mg-silicon carbide composite was manufactured by plunger technology which has been published elsewhere. Here plunger rods are used to introduce silicon carbide particle to the Al-Mg alloy melt and the composites are manufactured as per required composition. The furnace temperature has great influence on hardness and wear properties.

Specimen Sample Preparation for the Wear Test

The cylindrical pin samples shown in Fig. 2 are cut to a size of 10 mm in diameter and 30 mm in length. Sliding wear is conducted in dry condition using Pin-On–Disc method where pin is the sample, remain stationary during operation. The instrument used is DUCOM-PIN-ON-DISC apparatus as shown in Fig-2 and Fig-3. The pin (sample) and disk (EN31 steel) was cleaned by Emory paper so that smooth contact will take place between pin and disk. The loads are applied by the self-loading system to press the pin against the disc. The rotational speed of the disc or motor can be changed by the controller. The test was conducted using the standard ASTM G-99 at room temperature.

The dry sliding wire test was conducted at sliding velocity 2m/s and at various loads of 15N, 25N, 35N & 45N for sliding distance of 1000m.

The mass loss of the sample made of prepared composite is calculated by measuring the initial mass and final mass using the weight balance. The wire rate is calculated using the formula 1.

The wear rate (Wr) of the materials were calculated by

$$\mathbf{W_r = \Delta w/L\rho} \quad \text{in } mm^3/m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where Δw= weight loss of the pin (MMC) in mg

L= sliding distance in meter

ρ = density of the MMC in mg/mm^3

Fig. 2- Pin-on-disc wear-test apparatus for the wear-test.

Fig. 3- Sample

RESULT AND DISCUSSION:

The fuzzy wear behavior expert system uses a fuzzy if–then rule consisting of a set of initiative fuzzy rules that interpret input data and produce a crisp output. In this study, the output is significantly influenced by the input variables, which are sliding speed, sliding distance, and load.

Experiments with different samples of reinforced SiC were performed at constant speed and sliding distance with varying loads and obtained the results shown in Tables 1–4. The variability of the wear rate with the change of the percentage of SiC content is illustrated in Fig. 4. It is shown that the wear rate increases with the reduction in percentage of SiC for any given load for a constant sliding speed of 2 m/s and a sliding distance of 1000 m.

Application of Fuzzy Approach for Evaluation of Wear Rate of the Composites

A fuzzy approach is one of the elements of artificial intelligence, which is gaining popularity and is used in control systems and experimental recognition. This approach is based on the observations obtained from experiments on the basis of imprecise and numerical information. These models are capable of recognizing, representing, manipulating, interfering, and using data and information that are unclear and uncertain.

TABLE 1: Sliding speed 2 m/s, load 15 N, sliding distance 1000 m

Exp. no.	SiC percentage (%)	Wear rate [mm^3/m ($\times 10^{-3}$)]
1	1	6.6332
2	2	5.5143
3	5	4.2165
4	6	3.8563
5	8	2.0942
6	10	1.3468

TABLE 2: Sliding speed 2 m/s, load 25 N, sliding distance 1000 m

Exp. no.	SiC percentage (%)	Wear rate [mm^3/m ($\times 10^{-3}$)]
1	1	8.8356
2	2	7.7614
3	5	4.9276
4	6	4.0114
5	8	3.7021
6	10	2.5627

TABLE 3: Sliding speed 2 m/s, load 35 N, sliding distance 1000 m

Exp. no.	SiC percentage (%)	Wear rate [mm^3/m ($\times 10^{-3}$)]
1	1	9.7621
2	2	8.9122
3	5	6.3774
4	6	5.9539
5	8	4.8973

6	10	4.0256

TABLE 4: Sliding speed 2 m/s, load 45 N, sliding distance 1000 m

Exp. no.	SiC percentage (%)	Wear rate [mm^3/m (× 10^{-3})]
1	1	10.7815
2	2	9.0328
3	5	7.2986
4	6	6.8012
5	8	5.9324
6	10	5.8146

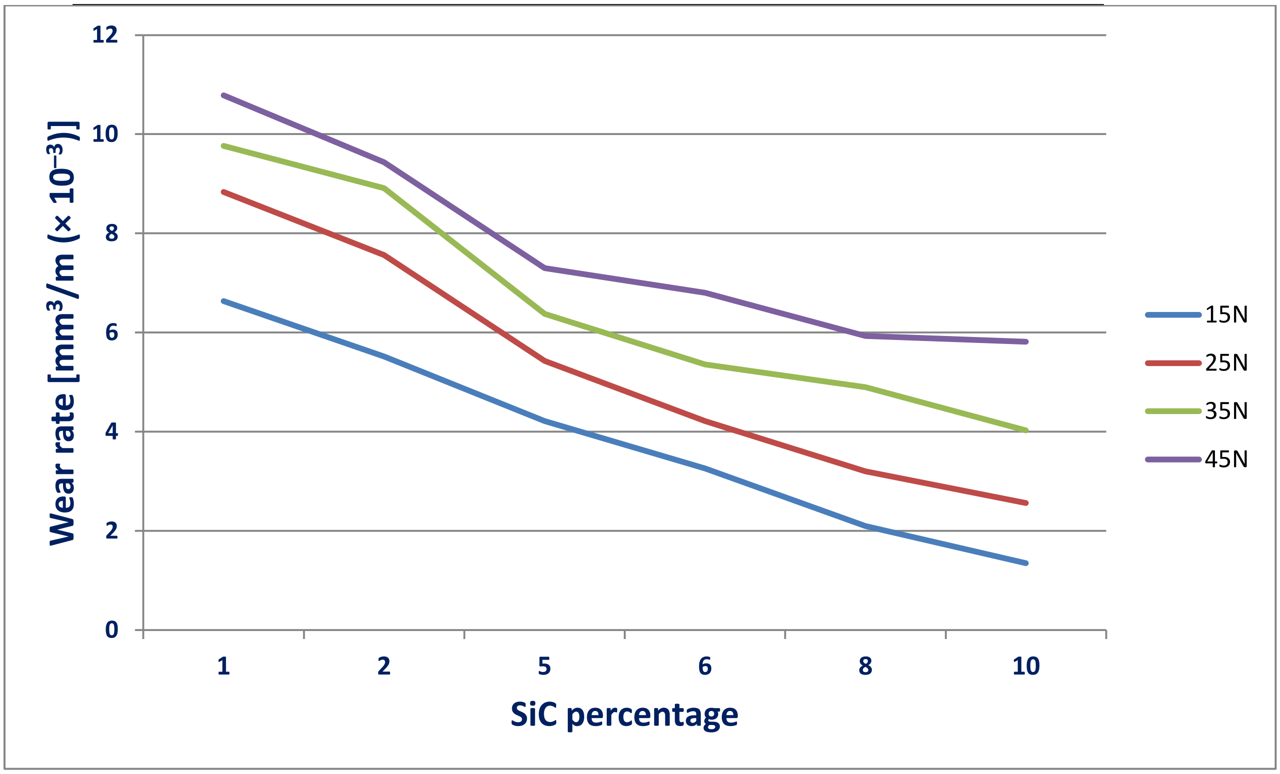

FIG. 4: Graphical presentation of experimental data representing variation of wear rate with the percentage of SiC.

In the present problem, to achieve the accuracy of output (wear rate), the trapezoidal function (see Fig. 5) has been used for its mathematical simplification and approximation, as evident from the evaluated results. A set of experiments has been conducted considering load (N) as the input parameter and wear rate as the output parameter under the variation of SiC weight percentage. Before the fuzzy model was developed, the experimental data were collected to frame the fuzzy if–then rules. The input variables, i.e., wt% of SiC and load (N), were given to the fuzzy inference system, which mapped the input data with the fuzzy rules through fuzzifications and developed a set of fuzzy output data as wear rate through the defuzzification process by using input and output trapezoidal membership functions. The boundary trapezoidal functions place the extreme lateral sides orthogonal to the base due to the fact that the extreme left-side fuzzifier represents a poor linguistic variable with a maximum wear rate at 0% SiC. Furthermore, the extreme lateral side of the right fuzzifier represents an excellent linguistic variable, i.e., minimum wear rate at 10% SiC. So, in the present study, the fuzziness manifests its role on the collection of a set of experimental data obtained from a wear test.

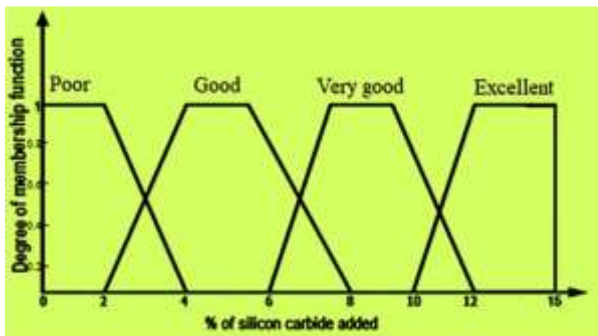

FIG. 5: Trapezoidal membership functions with input as a percentage of SiC

The percentage of silicon carbide is varied at a given load; both are considered as input parameters for a given constant sliding speed of 2 m/s and sliding distance 1000 m, which calculates the intensity of wear as the output parameter in the proposed fuzzy model. The fuzzy inference system represented in Fig. 7 changes the crisp input data into a set of fuzzy input data using the trapezoidal input membership function. Fuzzifi- cation is done by mapping the input data with the set of if–then fuzzy rules to create a set of fuzzy output data. The defuzzification process is done using the output trapezoidal membership function. The defuzzification process converts a set of fuzzy outputs into crisp values, i.e., wear rates as output parameter. Table 5 shows the if–then rules based on the experimental results. The table represents fuzzy rules that have been formulated by considering the results from the experiments. Additionally, several wear-rate calcula- tions have been established through the experiment in close proximity, $\Delta WR = 0.1$, and form fuzzy rules with a close range of wear rates.

Fuzzy logic is used to assess the wear behavior of an aluminum matrix composite and it evaluates the wear rate which is illustrated in Fig. 7 to Fig. 10. Shows a logical approach to the experimental results used to assess the wear rate. The fuzzy inference engine maps each element of the fuzzy input set to each rule-based rule to produce the fuzzy output set. The optimization of the input parameters of the wear test on the pin-on-disc tribometer from the gray relational analysis can be used to obtain a better quality, minimizing the loss of wear and the frictional force. The concept of fuzzy logic is then incorporated into this multivariate system to obtain an improved fuzzy gray score. The fuzzy inference system includes a triangular membership function, and the if–then rules have been formulated to scramble the gray relational coefficient for each note.

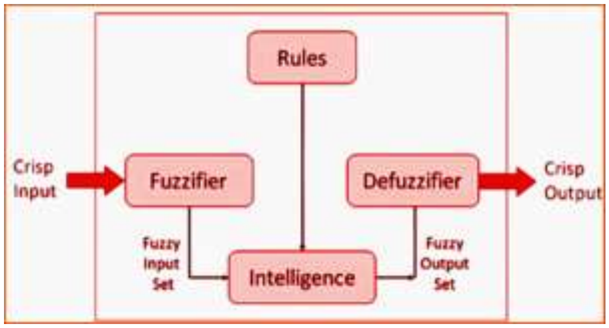

FIG. 6: Fuzzy inference system

TABLE 5: Fuzzy rules

Sl. no.			Rule box		
1	If, SiC = 1	*V* = 2	SD = 1000	*L* = 15	Then, 6.6 < WR < 6.7
2				*L* = 25	Then, 8.8 < WR < 8.9
3				*L* = 35	Then, 9.6 < WR < 9.8
4				*L* = 45	Then, 10.6 < WR < 10.8
5	If, SiC = 2	*V* = 2	SD = 1000	*L* = 15	Then, 5.4 < WR < 5.6
6				*L* = 25	Then, 7.4 < WR < 7.6
7				*L* = 35	Then, 8.8 < WR < 9.0
8				*L* = 45	Then, 9.3 < WR < 9.5
9	If, SiC = 5	*V* = 2	SD = 1000	*L* = 15	Then, 4.1 < WR < 4.3
10				*L* = 25	Then, 5.3 < WR < 5.5
11				*L* = 35	Then, 6.2 < WR < 6.4
12				*L* = 45	Then, 7.1 < WR < 7.3
13	If, SiC = 6	*V* = 2	SD = 1000	*L* = 15	Then, 3.1 < WR < 3.3
14				*L* = 25	Then, 4.1 < WR < 4.3
15				*L* = 35	Then, 5.2 < WR < 5.4
16				*L* = 45	Then, 6.7 < WR < 6.9
17	If, SiC = 8	*V* = 2	SD = 1000	*L* = 15	Then, 1.9 < WR < 2.1

18				L = 25	Then, 3.1 < WR < 3.3
19				L = 35	Then, 4.7 < WR < 4.9
20				L = 45	Then, 5.8 < WR < 6.0
21	If, SiC = 10	V = 2	SD = 1000	L = 15	Then, 1.2 < WR < 1.4
22				L = 25	Then, 2.4 < WR < 2.6
23				L = 35	Then, 3.9 < WR < 4.1
24				L = 45	Then, 8.7 < WR < 5.9

SiC = SiC reinforcement (%), V = speed (m/s), L = load (N), SD = sliding distance (m), WR = wear rate [mm^3/m (× 10^{-3})]

A major benefit of the fuzzy logic–based approach is the high interpretability of fuzzy if–then rules. Tables 6–9 represent the percentage deviation of fuzzy results from the experimental results at different variables, where the specific wear rate of the composite sample decreases when increasing the load from 15 N to 45 N at a constant sliding speed of 2 m/s; and at a constant sliding speed under dry conditions, when the SiC reinforcement increases.

The validation of the wear rate on the basis of experimental and fuzzy results is shown in Figs. 7-10. These figures show that when the input data are uncertain or fuzzy, the wear rate changes. When the difference between the maximum and minimum values is large, the wear rate increases or decreases considerably. It increases or decreases depending on the nature of the bevel. If the input is biased toward the maximum, wear is likely to increase, but if the input is biased toward the minimum, it has the opposite effect. The proposed method shows that the wear rate will be an increased or decreased value depending on the load axis with constant sliding speed. It can be seen that with 0%, or a crisp number of fuzzy input data, the proposed method approaches the optimal value more quickly. The proposed method is very competitive in terms of the quality of the solution, minimizing the wear rate of the composite.

TABLE 6: Percentage deviation of fuzzy results from experimental results; load = 15 N, speed= 2 m/s, and sliding distance = 1000 m

No. of observations	Percentage of SiC added	Wear rate [mm^3/m (× 10^{-3})]		Percentage of deviation of fuzzy result from experimental results $\Delta = \frac{E-F}{E} \times 100$
		Experimental (*E*)	**Fuzzy (*F*)**	
1	1.5	6.321	6.2505	1.11
2	3	4.662	4.5744	1.87

3	5.5	3.007	2.9681	1.29
4	8.5	1.979	1.9149	3.23

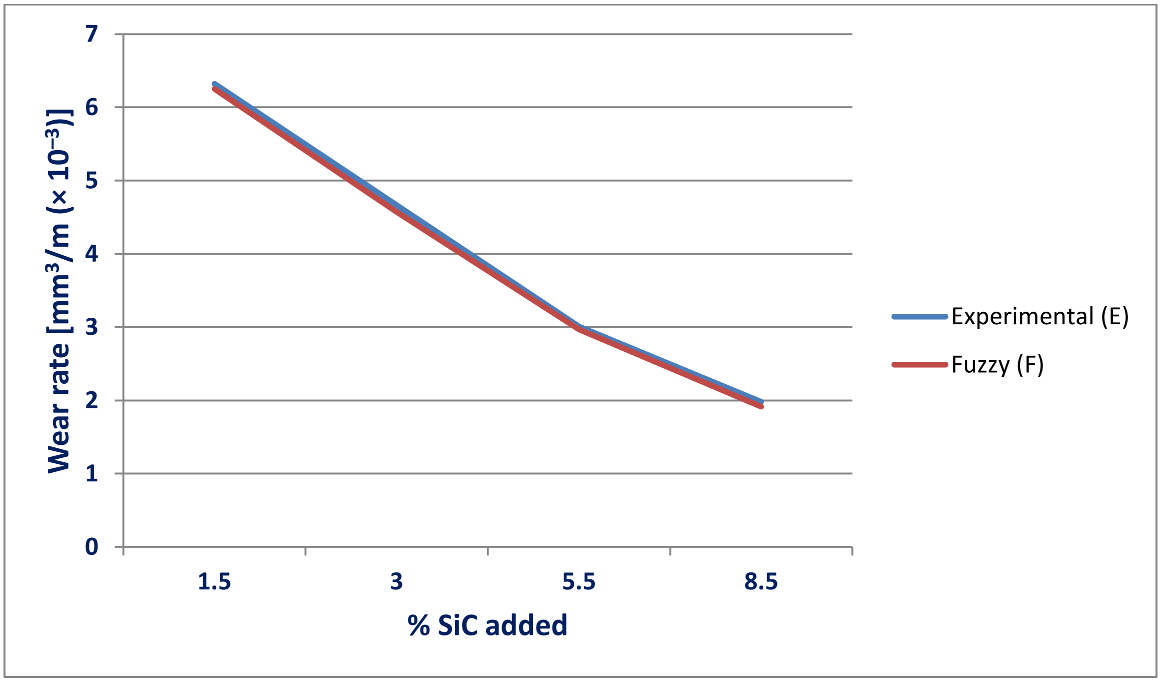

FIG.7: Validation of wear rate of experimental results with fuzzy results for load = 15 N, speed = 2 m/s, and sliding distance = 1000 m

TABLE 7: Percentage deviation of fuzzy results from experimental results; load = 25 N speed= 2 m/s, and sliding distance = 1000 m

No. of observations	Percentage of SiC added	Wear rate [mm^3/m ($\times 10^{-3}$)]		Percentage of deviation of fuzzy result from experimental results $\Delta = \frac{E-F}{E} \times 100$
		Experimental (*E*)	**Fuzzy (*F*)**	
1	1.5	7.9387	7.8205	1.48
2	3	6.7623	6.1744	1.40
3	5.5	4.8166	4.7181	2.04

4	8.5	2.9465	2.8621	2.86

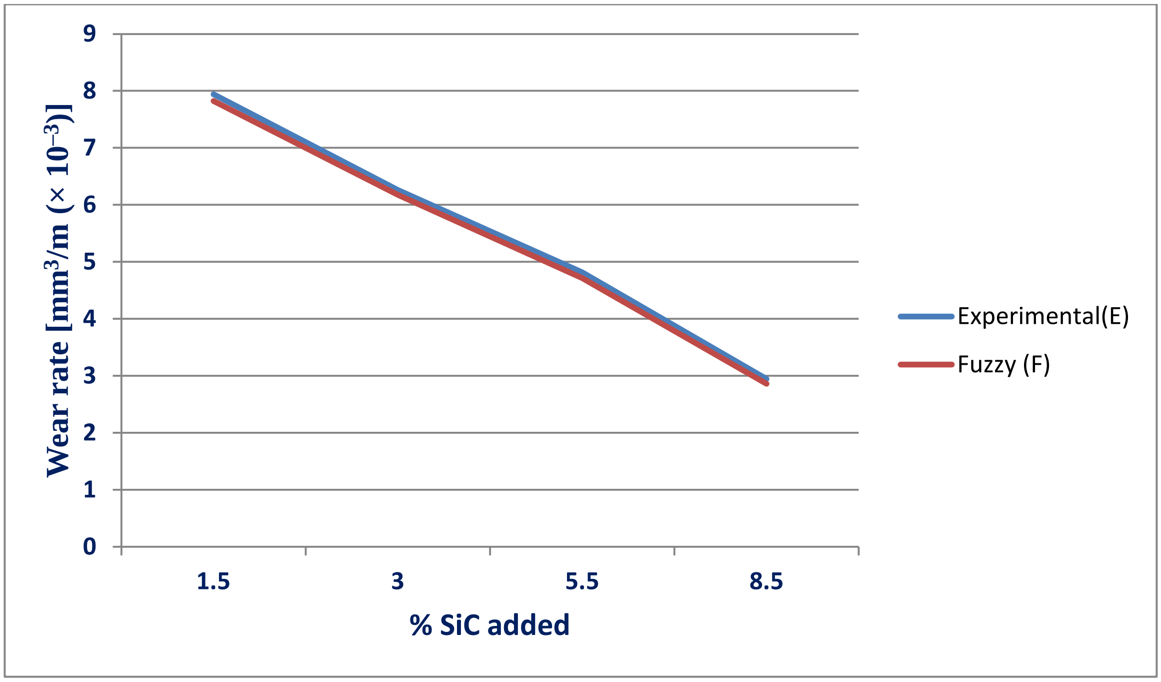

FIG. 8: Validation of wear rate of experimental results with fuzzy results for load = 25 N, speed = 2 m/s, and sliding distance = 1000 m

TABLE 8: Percentage deviation of fuzzy results from experimental results; load = 35 N, speed= 2 m/s, and sliding distance = 1000 m

No. of observations	Percentage of SiC added	Wear rate [mm^3/m ($\times 10^{-3}$)]		Percentage of deviation of fuzzy result from experimental results $\Delta = \frac{E-F}{E} \times 100$
		Experimental (*E*)	**Fuzzy (*F*)**	
1	1.5	9.3456	9.2798	0.70
2	3	7.6421	7.4978	1.88

3	5.5	5.8347	5.7613	1.25
4	8.5	4.4433	4.3188	2.80

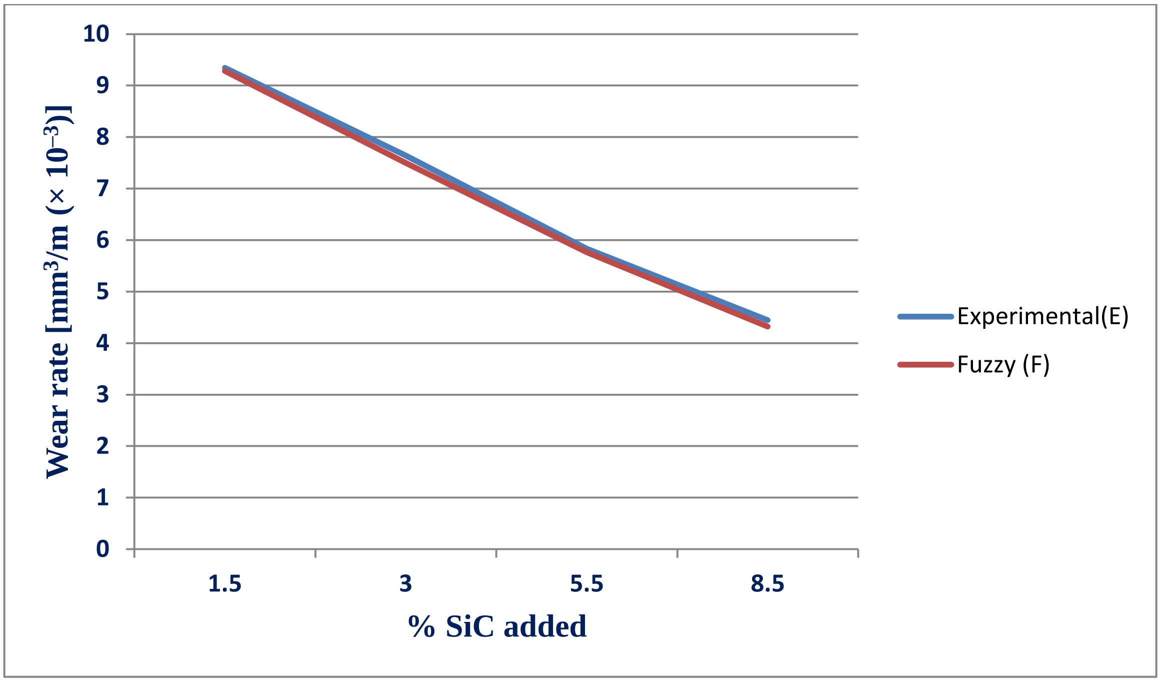

FIG. 9: Validation of wear rate of experimental results with fuzzy results for load = 35 N, speed= 2 m/s, and sliding distance = 1000 m

TABLE 9: Percentage deviation of fuzzy results from experimental results; load = 45 N, speed= 2 m/s, and sliding distance = 1000 m

No. of observations	Percentage of SiC added	Wear rate [mm^3/m ($\times 10^{-3}$)]		Percentage of deviation of fuzzy result from experimental results $\Delta = \frac{E-F}{E} \times 100$
		Experimental (*E*)	**Fuzzy (*F*)**	
1	1.5	9.8768	9.6312	2.48
2	3	8.3465	8.2463	1.20

3	5.5	7.0243	6.8714	2.17
4	8.5	5.8736	5.7621	1.89

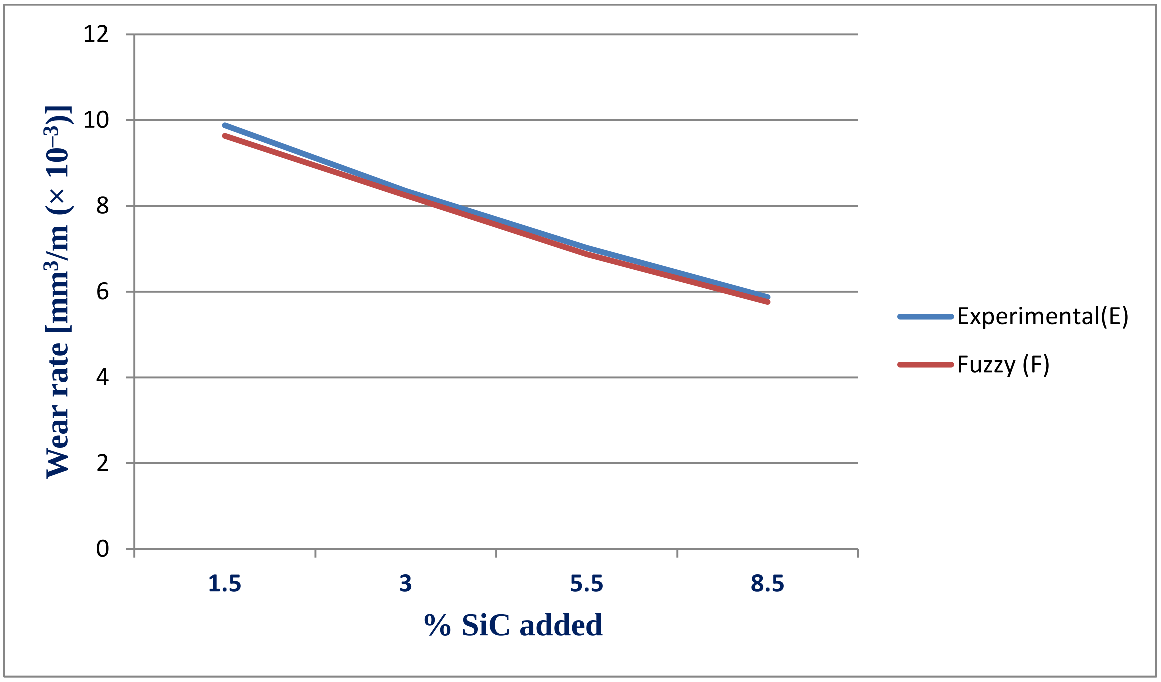

FIG. 10: Validation of wear rate of experimental results with fuzzy results for load = 45 N, speed= 2 m/s, and sliding distance = 1000 m

CONCLUSIONS

The estimated analysis of the dry sliding wear rate of MMC was investigated, and the following conclusions have been drawn:

1. For a given sliding speed and sliding distance, the higher the percentage of SiC, the higher will be the wear resistance in a metal matrix composite.
2. The fuzzy result has been compared with experimental results, and the percent- age deviation does not exceed 3.25 percent.
3. The proposed method is very competitive in terms of the quality of the solution, minimizing the wear rate of the composite.

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