Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

Fuzzy Logic Model Investigation on Wear Behaviour of Modified Stir Casting Process Generated Al-Mg-Sic Composite

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Abstract:
Metal matrix composites (MMC) are suitable substitutes for aluminium alloys as well as steel in a variety of automotive systems and parts. There are many ways to get light weight materials without compromising their strength and safety requirements. It is possible to conduct testing on dry sliding or unlubricated pin-on-disc tests to look at the wear characteristics of metal matrix composites made of aluminium. In the current work, experiments were carried out utilising a pin-on-disc tribometer to examine the behaviour of wear resistance during sliding of metal matrix aluminium composites (MMC) at sliding speeds of 2 m/s and weights of 15, 25, 35, and 45 N in a typical environment (Make: DUCOM tribometer). According to the findings, the wear rates of composites are lower than those of the matrix alloy and continue to decline as SiC content rises. Further SiC % and applied stress are taken into account as inputs to the fuzzy system, with wear rate being the output. When the output of the developed fuzzy model is compared to the outcomes of experiments, it is discovered that the variation is within 3.25 percent.

Keywords: Metal Matrix Composite (MMC);modified stir casting;wear, reinforcement; fuzzy logic

1. Introduction

A higher-yield strength structural material should ideally be totally substituted for an existing one, possibly with reinforcements. Because to the high cost of creating components with even the most straightforward shapes, the introduction of lightweight, high-performance metal matrix composites (MMCs) for the aerospace, automotive, and consumer sectors has proven challenging. Although there are a number of technical issues, powder metallurgy may be the solution to this problem. One of these issues that has a direct impact on the qualities and attributes of composite materials is achieving a uniform distribution of the reinforcement inside the matrix. A class of composite materials known as continuously reinforced aluminium MMCs has desirable characteristics like low density, high specific stiffness, high specific strength, controlled coefficient of thermal expansion, resistance to increased fatigue, and exceptional dimensional stability at high temperatures (Beheraetal.,2020,2019a,b;Mazahery and Shbani, 2012). The most popular type of MMC system uses silicon carbide-reinforced aluminium alloy as its base material (Garcla-Cordovilla et al., 1966; Ghosh et al., 2011). When compared to traditional materials or continuously reinforced composites, these composite materials have different amplification mechanisms (Uzkut, 2013; Narayan et al., 1995; Park et al., 2001; Prasad, 2007). As a result, much experimental and analytical research has been done to better understand the mechanical behaviour of these composite materials and their exceptional wear resistance.

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 performance 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

Themodified stir casting methodwasadoptedfortheproductionofcompositesamples. In this process, the main raw material is an aluminum matrix, which is reinforced withSiC. Also 2% Mg is added to increase the wettability of SiC.TheMMC has been strengthened by adding 1, 2, 5, 6, 8 & 10 wt% of silicon carbide in the metal matrix.

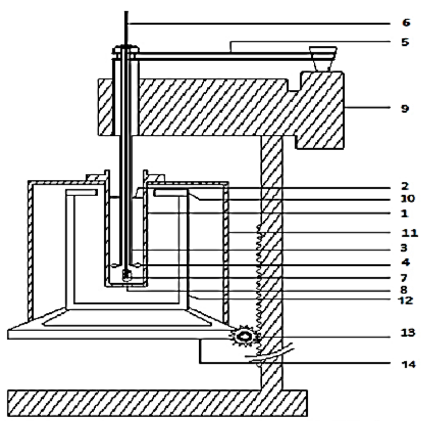

Figure 1: Diagram of Plunger Technique Apparatus to Prepare Aluminium-Magnesium Alloys

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

Auminium-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.

2.1 Specimen Sample Preparation for the Wear Test

The cylindrical pin samples shown in Figure 3 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 Figure 1 and Figure 2. 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
$W_r = \Delta w / L\rho$ in mm^3/m…………………………………………………….................…….. (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

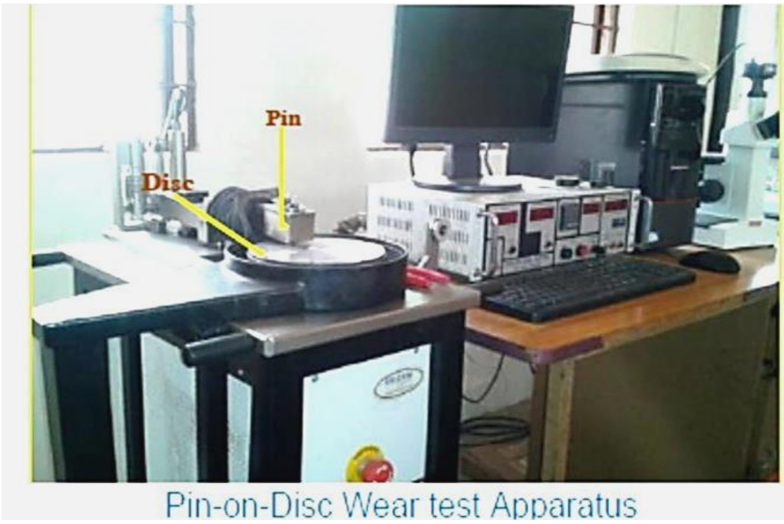

Figure 2: Pin-on-disc wear-test apparatus for the wear-test

Industrial Engineering Journal
ISSN: 0970-2555
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Figure 3: Sample specimen

3. 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 Figure4. 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.

3.1 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.

Table1: Slidingspeed2m/s,load15N,slidingdistance1000m

Exp. no.	SiCpercentage(%)	Wearrate[$mm^3/m(\times10^{-3})$]
1	1	6.6332
2	2	5.5143
3	5	4.2165
4	6	3.8563
5	8	2.0942
6	10	1.3468

Table2: Slidingspeed2m/s,load25N,slidingdistance 1000m

Exp. no.	SiCpercentage(%)	Wearrate[$mm^3/m(\times10^{-3})$]

1	1	8.8356
2	2	7.7614
3	5	4.9276
4	6	4.0114
5	8	3.7021
6	10	2.5627

Table3: Slidingspeed2m/s,load35N,slidingdistance 1000m

Exp. no.	SiCpercentage(%)	Wearrate[$mm^3/m(\times 10^{-3})$]
1	1	9.7621
2	2	8.9122
3	5	6.3774
4	6	5.9539
5	8	4.8973
6	10	4.0256

Table4: Slidingspeed2m/s,load45N,slidingdistance1000m

Exp. no.	SiCpercentage(%)	Wearrate[$mm^3/m(\times 10^{-3})$]
1	1	10.7815
2	2	9.0328
3	5	7.2986
4	6	6.8012
5	8	5.9324
6	10	5.8146

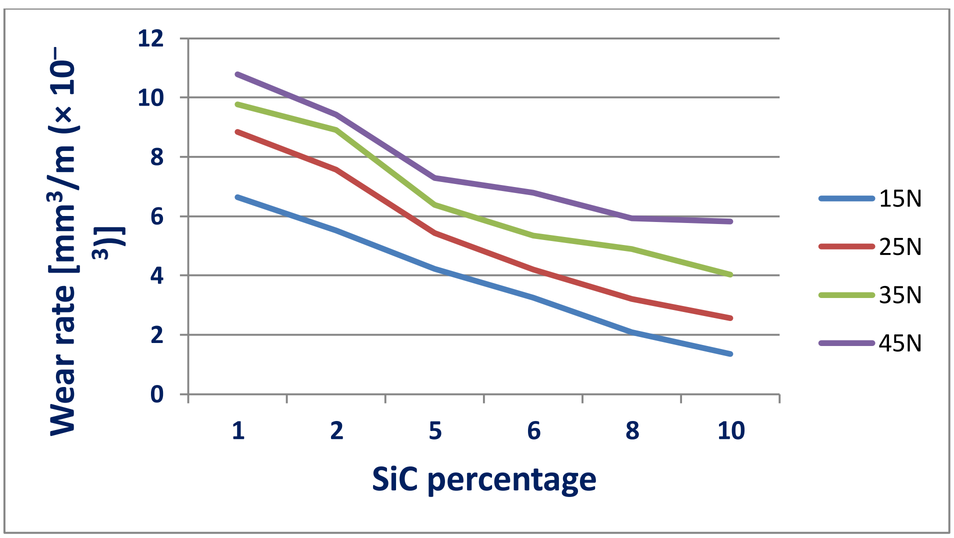

Figure 4: Graphicalpresentationofexperimentaldatarepresentingvariationofwearratewith the percentage of SiC

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.

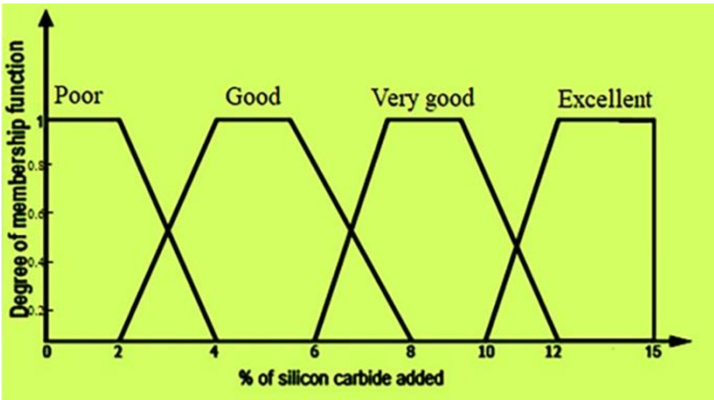

Figure 5: Trapezoidalmembershipfunctionswithinputasapercentageof SiC

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 Figure 6 changes the crisp input data into a set of fuzzy input data using the trapezoidal input membership function. Fuzzification 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 calculations have been established through the experiment in close proximity, $\Delta WR=0.1$,and form fuzzy rules with a close range of wear rates.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 03, March : 2022

Fuzzy logic is used to assess the wear behavior of an aluminum matrix composite and it evaluates the wear rate which is illustrated in Figure 7 to Figure 10. Shows a logical approach to the experimental results used to assess the wear rate. The fuzzy inferenceenginemapseachelementofthefuzzyinputsettoeachrule-basedruleto 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 multi variate 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.

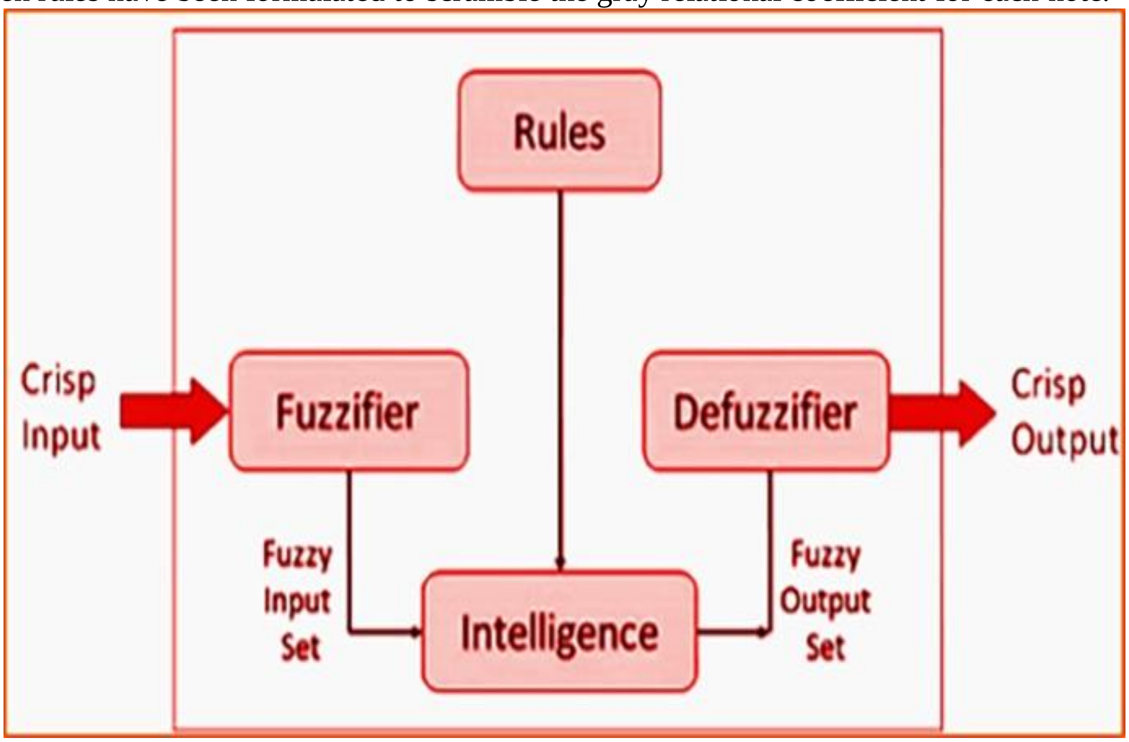

Figure 6: Fuzzyinferencesystem

Table5: Fuzzyrules

Sl.no.			Rulebox		
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=SiCreinforcement(%),V=speed(m/s),L=load(N),SD=slidingdistance(m), WR=wearrate [$mm^3/m(\times 10^{-3})$]

A major benefit of the fuzzy logic–based approach is the high interpretability of fuzzyif–thenrules. 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 15N to 45N 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 showninFigure7-10.Thesefiguresshowthatwhentheinputdataareuncertainorfuzzy, 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 wearrate 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.

Table6: Percentagedeviationoffuzzyresultsfromexperimentalresults;load=15N, speed=2m/s,and slidingdistance=1000 m

No. of observations	Percentageof SiC added	Wearrate[$mm^3/m(\times 10^{-3})$]		Percentageof deviation offuzzyresultfrom 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

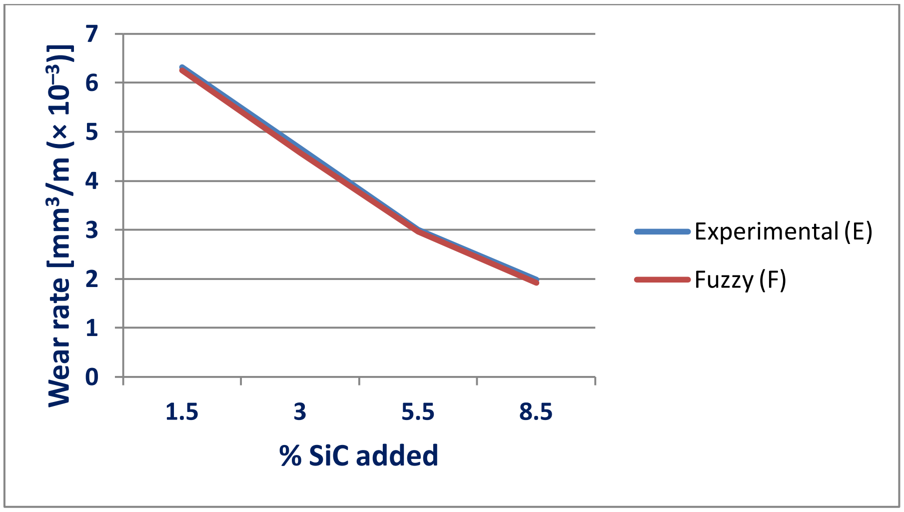

Figure 7: Validationofwearrateofexperimentalresultswithfuzzyresultsforload=15N, speed=2m/s,and slidingdistance=1000 m

Table7: Percentagedeviationoffuzzyresultsfromexperimentalresults;load=25N speed=2m/s,and slidingdistance=1000 m

No. of observations	Percentageof SiC added	Wearrate[mm^3/m($\times 10^{-3}$)]		Percentageof deviation offuzzyresultfrom 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

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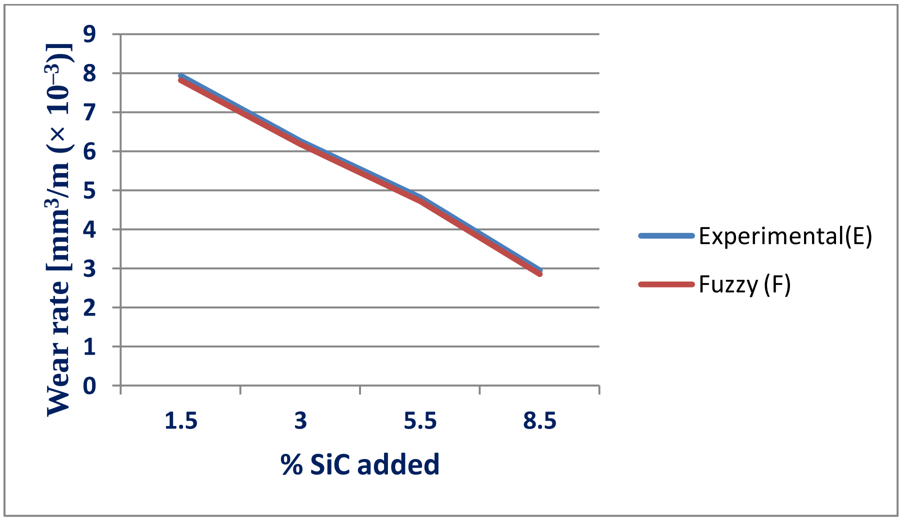

Figure 8: Validationofwearrateofexperimentalresultswithfuzzyresultsforload=25N, speed=2m/s,and slidingdistance=1000 m

Table8: Percentagedeviationoffuzzyresultsfromexperimentalresults;load=35N, speed=2m/s,and slidingdistance=1000 m

No. of observations	Percentageof SiC added	Wearrate[mm^3/m(×10^{-3})]		Percentageof deviation offuzzyresultfrom experimental results $\Delta=\frac{E-F}{E}\times100$
		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

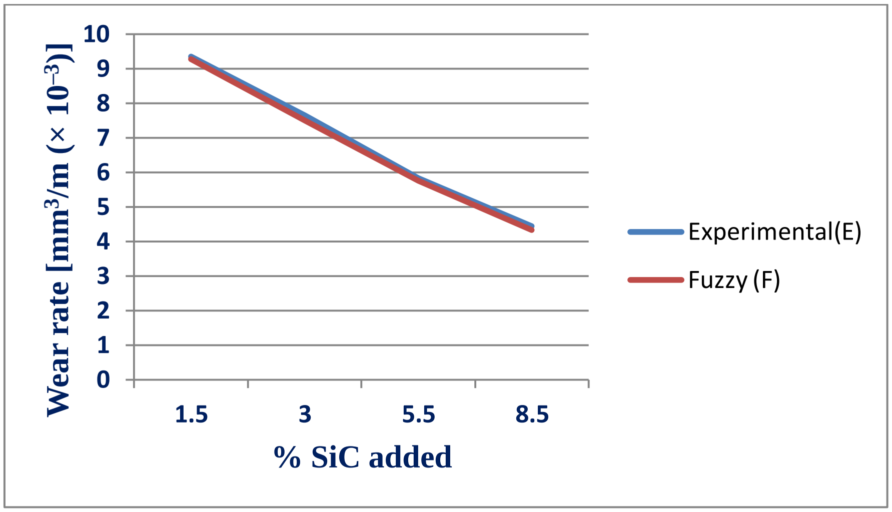

Figure 9: Validationofwearrateofexperimentalresultswithfuzzyresultsforload=35N, speed=2m/s,and slidingdistance=1000 m

Table9: Percentagedeviationoffuzzyresultsfromexperimentalresults;load= 45 N, speed=2m/s,and slidingdistance=1000 m

No. of observations	Percentageof SiC added	Wearrate[$mm^3/m(\times 10^{-3})$]		Percentageof deviation offuzzyresultfrom 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

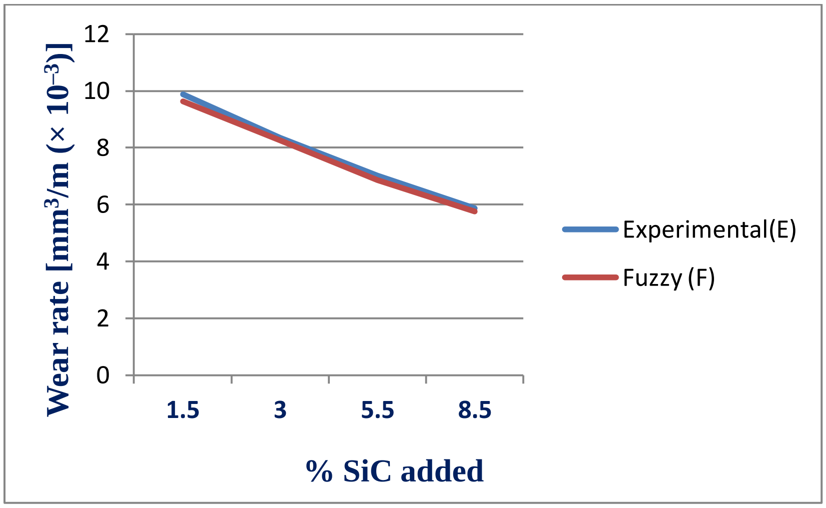

Figure 10: Validationofwearrateofexperimentalresultswithfuzzyresultsforload=45N, speed=2m/s,and slidingdistance=1000 m

4. Conclusions

The investigation into the estimated study of the MMC's dry sliding wear rate led to the following findings:

• The greater the percentage of SiC, given a sliding distance and speed, the greater the wear resistance in a metal matrix composite.
• The percent-age deviation of the fuzzy results, when compared to experimental results, is not greater than 3.25 percent.
• The suggested approach minimises composite wear rate while being very competitive in terms of the quality of the solution.

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