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Influence of silicon nitride, hafnium carbide and molybdenum disulfide to the wear behavior of Al 7075 hybrid composites

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The objective of the present research is to enhance the wear behavior of silicon Nitride (Si_3N_4), Hafnium carbide (HfC) and Molybdenum Disulfide (MoS_2) reinforced with Al 7075. The secondary particles like Si_3N_4 (2, 5 & 8), HfC (0.5, 1.25 & 2) and MoS_2 (2, 3.5 & 5) are reinforced in base material Al7075 alloy using Powder Metallurgy (PM) technique. The sintered composites were characterized using Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS). Dry sliding wear test was conducted for the sintered samples. The parameters of the experimentation are applied load (20 N, 40 N & 60 N), sliding velocity (1.5 m/s, 2 m/s & 2.5 m/s) and keeping sliding distance (1000 m) as constant. The results revealed that after reinforcing the secondary particles, it directly influenced the minimization of wear behavior. The worn surface analysis of the fabricated samples was viewed using SEM. Further, the process parameters of the wear behavior were optimized using Response Surface Methodology (RSM). Also, the maximum influencing process parameters were identified using analysis of variance (ANOVA).

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Keywords: Al 7075, Silicon nitride, Hafnium carbide, Molybdenum disulfide, Wear, RSM

1. Introduction

Aluminum hybrid metal matrix composites are now a day used in various industrial sectors such as automotive and aviation industries due to its light weight [1]. Aluminum alloy is having very unique properties such as low density, ease to fabricate and good corrosion resistance. W, WC, TiC etc. are used as secondary in-order to enhance the mechanical and tribological properties [2-3]. There are many fabrication techniques are there in-order to fabricate the composites such as liquid metallurgy, powder metallurgy and infiltration. Nevertheless compare to other methodology, powder metallurgy is easy and time consumes process and wastage of material is very less [4]. In other hand, aluminum has poor wear behavior and also it encompasses of high friction. In automotive industries, the rotatory equipment's are mainly depends on wear resistance behavior. In practical applications, these two are the main problems. Further, the wear evolution are mainly depends on the secondary particles wt. %.

Many researchers are done their research in aluminum metal matrix composites [5-8]. But hybrid aluminum metal matrix composites wear analysis is so limited and not very informative. Hence therefore, the current study carry out the analyze the wear behavior of aluminum hybrid metal matrix composites. Al 7075 alloy was reinforced with Si_3N_4 (2, 5 & 8), HfC (0.5, 1.25 & 2) and MoS_2 (2, 3.5 & 5) through Powder Metallurgy (PM) technique. The fabricated samples were characterized using SEM and EDS. Dry sliding wear behavior of Al 7075 hybrid composites were evaluated. Further, after wear test, the worn surface morphology was evaluated in-order to view the wear mechanism. In addition, the process parameters of the wear behavior were evaluated using RSM.

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2. Materials and Methods

The elemental powders such as Al 7075 and alloying elements such as (Si, Fe, Cu, Mn, Mg, Cr, Zn, Ti and Al) are purchased from Coimbatore metal mart, Coimbatore. The chemical composite of Al 7075 are displayed in table 1. The reinforcing elements such as silicon Nitride (Si_3N_4), Hafnium carbide (HfC) and Molybdenum Disulfide (MoS_2) are purchased from Alfa Aesar, USA having the particle size of ≤ 44µm. The defined amount of elemental powders are mixed using ball milling machine in-order to attain the homogenous mixture. Afterwards, the mixed powders are compacted using Universal Testing Machine (UTM) to fabricate the green compacts. Later, the green compacts are sintered using muffle furnace having the temperature of 500°C for 1 hr. following to that it will annealing inside the furnace till the room temperature was attained.

The dry sliding wear test was conducted for the fabricated samples. The parameters of the experimentation are applied load (20 N, 40 N & 60 N), sliding velocity (1.5 m/s, 2 m/s & 2.5 m/s) keeping sliding distance (1000 m) as constant. Wear rate and coefficient of friction of the samples were evaluated using the following empherical relation. After experimentation, the worn surfaces of the weared samples were viewed using SEM.

$$\text{Wear rate} = \text{Volume loss}/\ \text{Sliding distance}$$
$$\text{Coefficient of friction} = \text{Frictional force}/\ \text{Applied load}$$

Likewise, the process parameters are to be optimized for the responses such as wear rate and coefficient of friction using Response Surface Methodology (RSM). By using perturbation plot and ramp plot the parameter optimization was performed.

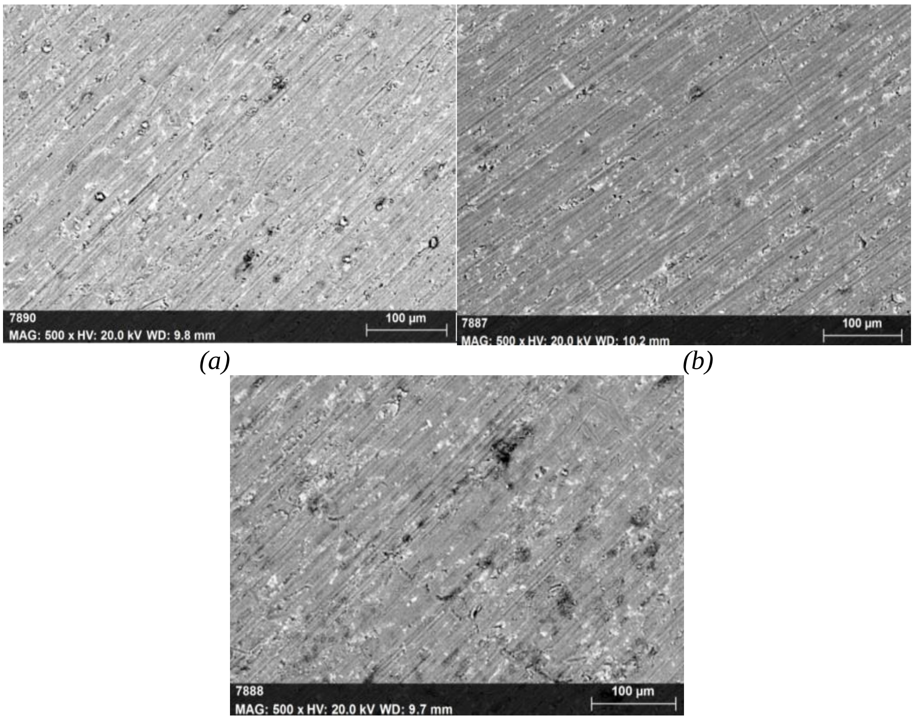
Table 1. Chemical compositions of Al7075.

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt. %	0.4	0.5	2	0.3	2.9	2	6.1	0.2	Bal.

3. Results and Discussion

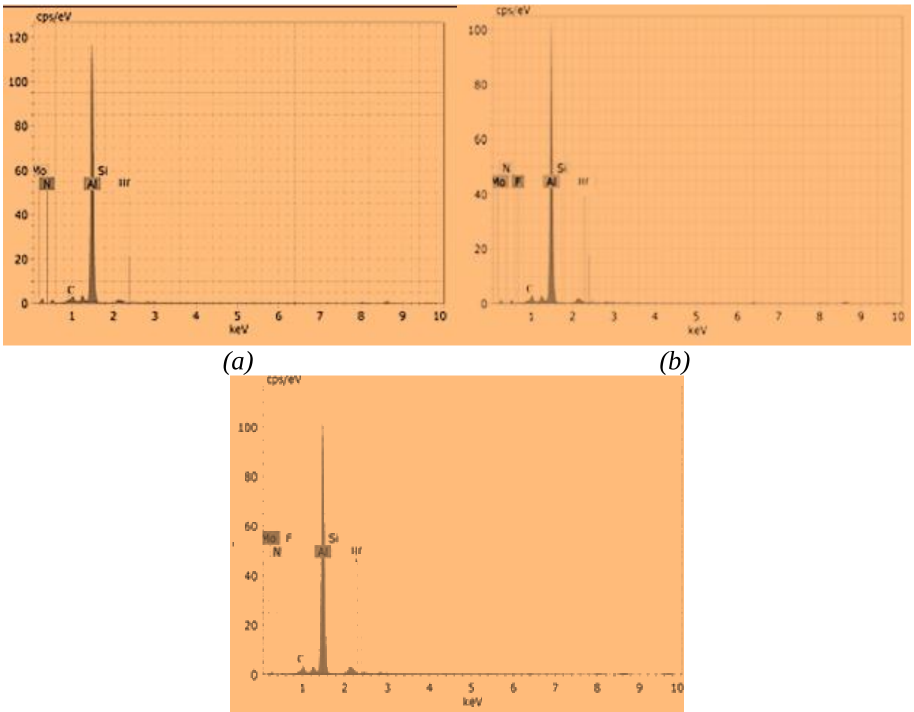
3.1. Microstructural Examination

Fig.1 (a-c) shows the SE micrograph of various sintered samples namely, Al-2 Si_3N_4-0.5 HfC- 2 MoS_2, Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 and c) Al-8 Si_3N_4-2 Hf- 5 MoS_2. From the images it illustrates that the secondary particles are evenly distributed in the matrix. No agglomeration was found on the images. It directly influences the wear behavior of the Al 7075. The corresponding EDS analysis spectrum was displayed in fig. 2 (a-c). It illustrates that Si, N, Fe, Mo, S, C and HF was present. Based upon the composition level, the intensity of the elements were varied and confirms that the presence of all the elements.



(a) (b) (c)

Fig. 1. (a-c) SE micrograph images of sintered samples a) Al-2 Si_3N_4-0.5 HfC- 2 MoS_2, b) Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 and c) Al-8 Si_3N_4-2 HfC- 5 MoS_2.



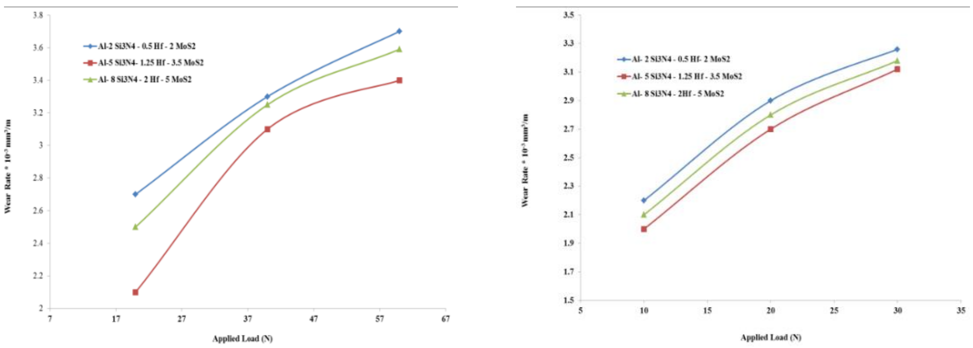
(a) (b) (c)

Fig. 2(a-c) EDS spectrum of sintered samples a) Al-2 Si_3N_4-0.5 HfC- 2 MoS_2, b) Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 and c) Al-8 Si_3N_4-2 HfC- 5 MoS_2.

3.2. Wear Analysis

3.2.1. Wear rate

The relationship between wear rate and applied load are illustrated in Fig. 3 (a & b). It was shown that increasing the load led to increasing the wear rate irrespective of the composites. Composite having Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 displays low wear rate, due to the presence of 1.25 HfC- 3.5 MoS_2 was homogenously mixed with Al. During sliding, it acts as an obstacle and decreases the wear rate [9-10]. Likewise, for sliding velocity situations, increasing the sliding velocity led to decrease in wear rate because of the specimen- disc contact was not in proper manner.



(a) *(b)*

Fig. 3. (a) SWR vs applied load and b) SWR vs SV.

3.2.2. Coefficient of friction

The connection between the coefficient of friction Vs. applied load are portrayed in Fig. 4 (a & b). It is determined that increasing the load led to the steady increase in coefficient of friction irrespective of the composites. Composite with Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 displays least coefficient of friction, due to the uniform mixture of 1.25 HfC- 3.5 MoS_2 with Al. Primarily, the metal interaction was high between the specimen and disc. It raises the heat and led to increase in friction. Likewise, for sliding velocity conditions, increasing the sliding velocity led to decrease in coefficient of friction as the specimen-disc interaction was not good condition [11-12].

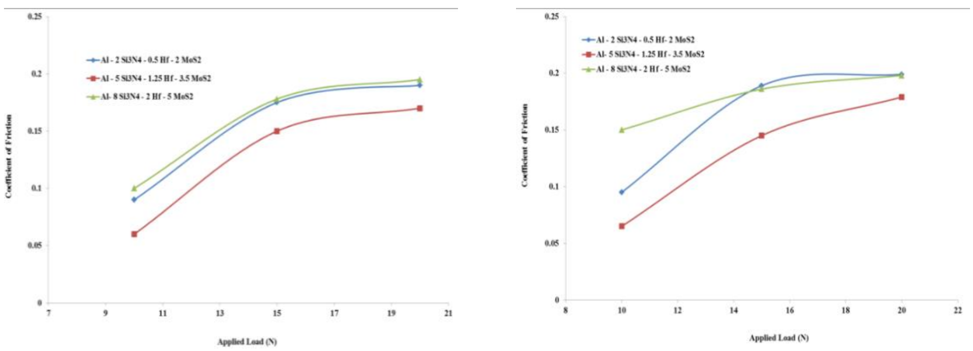
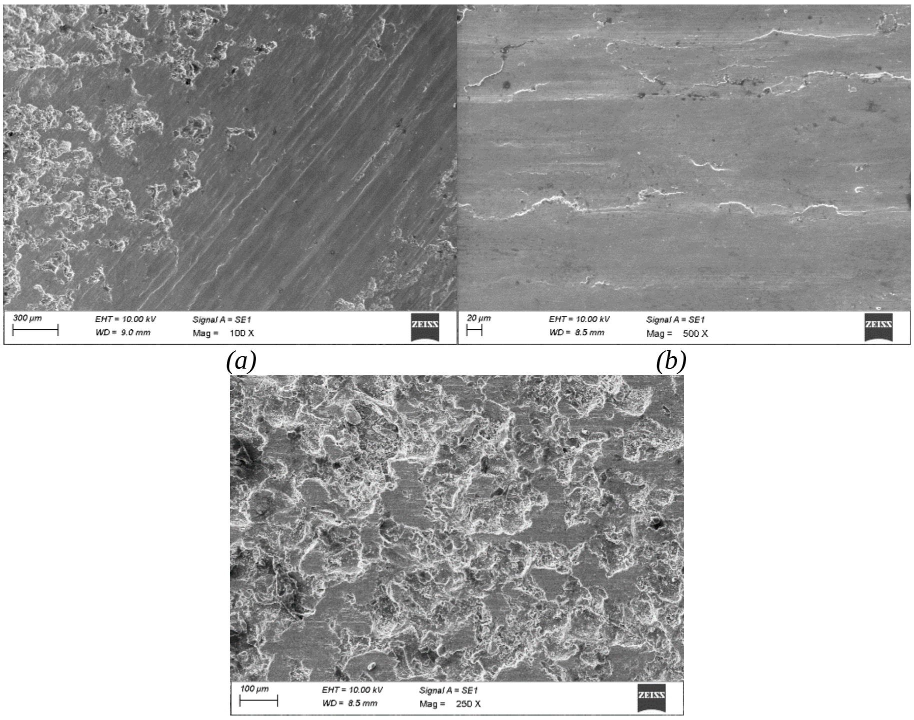


Fig. 4. (a) COF vs applied load and b) SWR vs SV.

3.3. Surface Morphology

The surface morphology of Al-2 Si_3N_4-0.5 HfC- 2 MoS_2, Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 and Al-8 Si_3N_4-2 HfC- 5 MoS_2 are showed in fig. 5(a-c) and the heavy material ploughing was perceived for Al-2 Si_3N_4-0.5 HfC- 2 MoS_2 samples. The increase in wear rate is clearly proved [13]. While increasing the HfC and MoS_2 in to base sample, the material ploughing was reduced and few spots were also observed for the composites. It reduces the wear rate. It is clearly associated with the (Fig. 5 (a & b)).



(a) (b) (c)

Fig. 5. Surface morphology after wear test a) Al-2 Si_3N_4-0.5 HfC- 2 MoS_2, b) Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 and c) Al-8 Si_3N_4-2 HfC- 5 MoS_2

3.4. Arithmetic Analysis

The process parameters are to be optimized using RSM for the following responses such as wear rate and coefficient of friction. The process parameters and it levels taken for this research is shown in table 2. Further, the design of experiments and its measurements such as factors and responses levels which was taken by Design Expert software and exhibited in table 3.

Table 2. Process parameters and its level.

	Name	Units	Low	High	-alpha	+alpha
A [Numeric]	Load	N	20	60	20	60
B [Numeric]	Velocity	m/s	1.5	2.5	1.5	2.5
C [Numeric]	Si_3N_4	wt. %	2	8	2	8
D [Numeric]	HfC	wt. %	0.5	2	0.5	2
E [Numeric]	MoS_2	wt. %	2	5	2	5

Table 3. Design of Experiments with Measurements.

Sl.no	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Response 1	Response 2
	A:Load	B:Velocity	C:Si_3N_4	D:HfC	E:MoS_2	Wear rate (10^3)	Coefficient of Friction
	N	m/s	wt. %	wt. %	wt. %	mm^3 /m	
1.	20	1.5	2	0.5	2	131	0.068
2.	20	1.5	8	2	5	133	0.07
3.	40	2	2	1.25	3.5	91	0.094
4.	40	2	5	1.25	3.5	21.8	0.066
5.	20	2.5	8	2	2	132	0.1
6.	60	1.5	8	0.5	5	133	0.174
7.	60	2.5	8	0.5	2	175	0.152
8.	40	2	5	1.25	3.5	49.2	0.051
9.	40	2	5	1.25	3.5	89	0.049
10.	60	1.5	8	2	2	129	0.175
11.	40	2	5	1.25	5	91	0.0835
12.	40	2	5	1.25	3.5	35.6	0.0161
13.	40	2.5	5	1.25	3.5	90.5	0.078
14.	20	2.5	8	0.5	5	133.2	0.091
15.	40	2	5	1.25	2	91.4	0.089
16.	60	2.5	2	2	2	174.6	0.143
17.	40	2	5	2	3.5	90.9	0.092
18.	60	1.5	2	2	5	133.7	0.128
19.	40	2	5	0.5	3.5	89.1	0.099
20.	20	2.5	2	2	5	129.6	0.072
21.	60	2	5	1.25	3.5	90	0.079
22.	20	2	5	1.25	3.5	0.16	0.015
23.	40	2	8	1.25	3.5	89.6	0.12
24.	60	2.5	2	0.5	5	174.9	0.16
25.	40	1.5	5	1.25	3.5	5.2	0.0158
26.	40	2	5	1.25	3.5	66.2	0.074

3.5. Analysis of variance test for wear rate and CoF

Anova – Analysis of variance is one of the best statistical techniques adopted by many researchers for identifying the parameter for the selected objective with 95% of confidence level. Sliding velocity, significance of load, Si_3N_4, MoS_2, HfC are analyzed for the wear rate and CoF (output responses) using the Probability ‘P’ value and F value. The F values for output response wear rate are found to be 0.050934, 0.043229, 0.96817, 0.990903 and 0.959085 for the input parameters sliding velocity, load, Si_3N_4, MoS_2, HfC respectively. By comparing all the input parameters, the F value is more significant for MoS_2. The F values for output response CoF are also found to be 3.694394, 3.911311, 0.645519, 0.028886 and 0.046791 for the input parameters sliding velocity, load, Si_3N_4, MoS_2, HfC respectively. On comparing all the input parameters, the F value is more significant for load. From the report it is evident that R-squared values are achieved above 95 % for both the output responses, which reveals that model is significantly fit. For both wear rate and CoF. The perturbation plot for SWR and CoF is depicted in the Fig 6 (a & b) and it is apparently proven that all the three data points meets at one single point [14]. The developed model is significant and the errors are in acceptable limit [15].

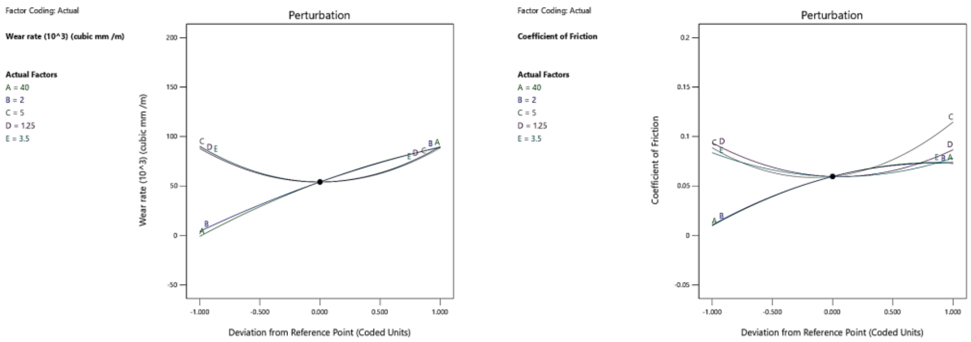


Fig. 6. Perturbation plot a) SWR and b) CoF.

Fig. 7 shows the complete desirability function of output responses such as wear rate and coefficient of friction [16-18]. Further, the ramp plot shows that the optimum level of parameters are applied load was 29.11544N, sliding velocity was 1.647721m/s and wt. % of secondary particles was Si_3N_4 (5.757569), HfC (1.303285) and MoS_2 (3.64062) in-order to found the minimum wear rate of 3.64062* 10^{-3} mm^3/N-m and coefficient of friction 0.01073 and it shown in table 3.

Table 3. Desirability value.

Load	Velocity	Si_3N_4	HfC	MoS_2	Wear rate	Coefficient of Friction	Desirability
29.11544	1.647721	5.757569	1.303285	4.074338	-3.64062	0.01073	1

3.6. Prediction Versus Actual comparison

The accuracy of the predicted values is analyzed by comparing with the experimental values. The deviation in predicted and experimental values is depicted in the Fig. 8 and the data point shows the higher precision. The deviation point at the lower level from the mean line reveals that the developed model had lower percentage of residuals [17]. For the wear rate and CoF, the overall residual falls between -1.5 to 1.52, which is also and evident for the higher precision.

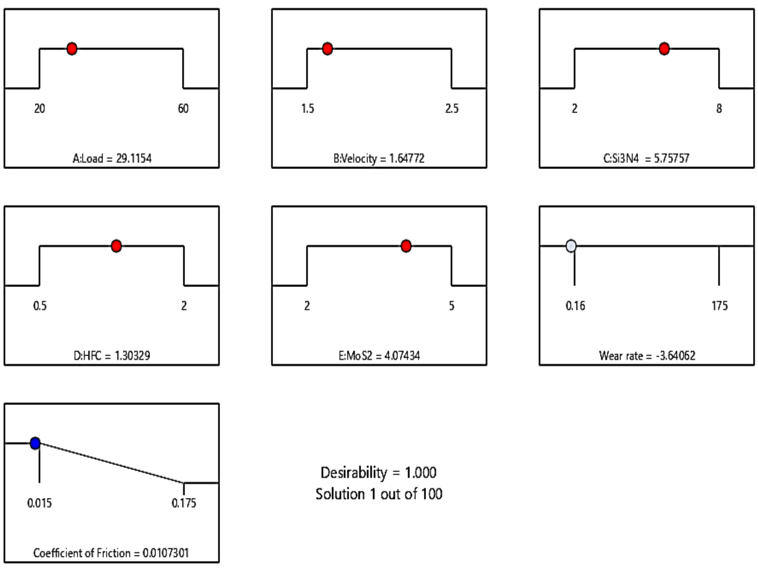


Fig. 7. Ramp plot for SWR and CoF.

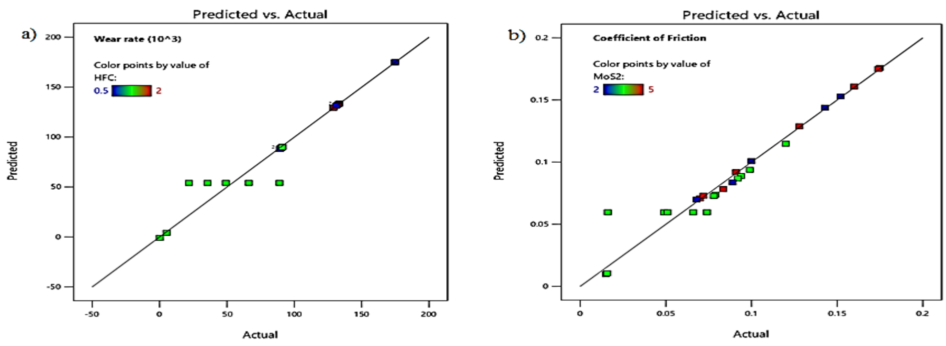


Fig. 8. Prediction Versus Actual.

4. Conclusion

- SE micrograph of various sintered samples namely; Al-2 Si_3N_4-0.5 HfC- 2 MoS_2, Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 and c) Al-8 Si_3N_4-2 Hf- 5 MoS_2 are successfully fabricated through P/M technique.
- Increasing the load led to increasing the wear rate and coefficient of friction, irrespective of the composites. Composite having Al-5 Si_3N_4-1.25 HfC- 3.5 MoS_2 displays low wear rate and coefficient of friction, due to the presence of 1.25 HfC- 3.5 MoS_2 was homogenously mixed with Al.
- Heavy material ploughing was perceived for Al-2 Si_3N_4-0.5 Hf- 2 MoS_2 samples and it led to having more wear rate.
- The ramp plot shows that the optimum level of parameters are applied load was 29.11544N, sliding velocity was 1.647721m/s and wt. % of secondary particles was Si_3N_4 (5.757569), HfC (1.303285) and MoS_2 (3.64062) in-order to found the minimum wear rate of 3.64062* 10^{-3} mm^3/N-m and coefficient of friction 0.01073.

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