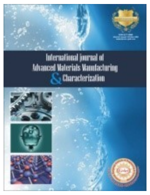

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Evaluation Of Erosive Wear Rate Of Al_2o_3/Cu Composite Through Taguchi Method

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ABSTRACT

In transportation of pipes, pipes are subject to flow of fluids, erosive wear is an important phenomena that affecting the life of these pipes. This paper investigates the effect of wear parameters on Erosive wear rate of aluminium oxide/copper (Al_2O_3/Cu) composite using Taguchi method. The scanning microscope (SEM) image shows that the presence of Al_2O_3 particle. Spindle speed, impact angle, slurry weight % and sand particle size were taken in this study as controlled parameters. The erosive wear rate was measured using self designed pot tester. Taguchi's L_8 orthogonal array was used as experimental trial run purpose. The signal-to-noise (S/N) ratio and the analysis of variance were carried out in order to find most influential parameter that affect on erosive wear. The contour plot was used to evaluate the interaction effect of factors on erosive wear. Finally, confirmation test has been conducted to examine the validity of the predicted result. The S/N ratio shows the optimum combination of parameters and their levels was $A_1B_1C_1D_1$. The results of mean S/N ratio and ANOVA indicate that the factor impact angle has most effective factor that affect erosive wear followed by Spindle speed. The optical surface images shows that the samples were brittle fractured and particles are fragmented out from the surface during erosion test. Finally a regression equation was developed.

Keywords: Alumina/Copper composite; Erosive Wear Rate; Taguchi Method; Analysis of Variance.

1. Introduction

Wear is progressive loss of material when two surfaces move relative to each other which causes damage to one or both surfaces. The loss by wear is relatively small that can be enough to cause complete failure of mechanical part [1]. Erosive wear is caused on bodies by the impacting of solids, liquids, gases or a combination of these [2-3]. Erosion is serious problem in many engineering parts including pumps, turbines, valves and pipes as a slurry erosion. Copper is a metal which is used for the transportation of fluid materials or slurry through pipes. And whenever there is relative motion between slurry and pipes which can damage pipes since friction and wear are always there [4].

Copper has good electrical, thermal and excellent corrosion resistance material but poor mechanical and tribological properties. Improvement of mechanical and tribological properties of Cu metal is done through addition of ceramic particles [5]. Al_2O_3 has excellent tribological properties and act as filler material for preparation of Al_2O_3/Cu Composite. Zhou & Ding prepared copper–alumina composite materials by powder metallurgy using nano-Cu/Al_2O_3 powder and found that the wear loss of the composite was lower than that of copper [6]. Miyazaki & Funakura carried

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out experiments to examine the effects of fiber volume fraction, type of reinforcement and impact angle on solid particle erosion behavior of metal matrix composite [7]. Using plasma spray method Ramesh et al. developed coated copper substrate with Titania-30wt% Inconel718 and found that the coated copper exhibited higher wear resistance compared to uncoated copper [8]. Hussain et al. fabricated Cu and different wt% of Al_2O_3 composites by using powder metallurgy method. They concluded that the wear resistance of composite depend on mass density, hardness, and formation of green protective carbonate layer on the surface of composite [9].

Erosion process is a complex phenomena and involves number of wear parameters that affect erosive resistance of materials. It depends on erosion conditions, particle size, shape, composition, velocity; striking velocity and temperature [10]. Yildizli et al. experimentally studied the solid particle erosion wear behaviour of hard austenitic-manganese deposited layers on the low carbon steel surface. The results indicated that the erosion rate was a function of the impact angles and wear rate was maximum at 90^0 impact angle [10].For ductile materials, the maximum wear rate is found when the impact angle nearly 30° and for brittle materials the maximum wear rate occurs when the angle of attack is 90^0 to specimen surface [11]. Therefore, optimization of erosive wear parameters are necessary for successful implementation of materials in engineering applications.

Taguchi's method is widely used as process parameter optimization problems as it provides a considerable reduction of time and effort to determine the optimal parameters combination [12-13]. Mishra et al. fabricated ZA-27 metal matrix composite reinforced with silicon carbide by using stir casting method and investigated the solid particle erosion behavior of the composite by using Taguchi method [14]. The results indicate that erosion wear rate of this composite is influence more by impact velocity and filler content respectively compare to others factors. Lidija et al. studied solid particle erosion of cold iso-statically pressed Al_2O_3. The results also indicated that the hard, angular SiC particles caused more damage than soft rounded SiO_2 particles. It was also found that the maximum erosion occurs at an attack angle of 90^0 [15].

2.0 Selection of parameters and orthogonal array selection

In this study, four process parameters viz. Spindle speed, impact angle, slurry weight % and sand particle size are taken as controlled parameters. Each parameter has two levels as shown in table 1. In this study L_8 orthogonal array is selected for experimental trial run.

Table1. Parameters and their levels

Sym bol	Parameters	Unit	Level-1	Level-2
A	Spindle speed	r.p.m	250	500
B	Impact angle	Deg.	70	90
C	Slurry weight %	wt/wt	3	7
D	Particle size	mm	~0.5	~0.75

3.0 Experimental Work

3.1 Materials

The Al_2O_3 particles were used as filler material and matrix material used was Cu powder.

3.2 Fabrication of Al_2O_3/Cu composite

Powder metallurgy has been used for the fabrication of composite [16-17]. Accordingly, 5 wt% of Al_2O_3 powder (average particle size ~3-5 μm) were mixed with Cu powder (average particle size ~10-15 μm) and the mixture was mechanically mixed with a designed ball milling container [17]. The ball milling container was attached to Automatic Lathe Machine and rotated at 200 rpm for two hour. The mixed powders were then compacted in a hydraulic press machine with compaction pressure of 200 MPa. All the composite samples are heated at 675^0C in a Muffle furnace and cooled slowly in furnace atmosphere.

3.3 Measurement of Erosive wear rate

Drilling machine is used as erosive wear tester. The erosive wear test has been conducted as per level combination. The specimen holder as shown in figure 1 is attached with motor shaft at speed varies from 250-500 rpm as shown in figure. The sample holding device is fabricated using a shaft (diameter 25mm, 250mm long), thick metal strips, nut-bolt and washer. The sample holding apparatus is welded with a metal strip which is drilled to fix bolts in them which hold the sample with the help of washers. This apparatus is connected to the vertical drilling machine and dipped in the vessel filled with slurry. The slurry mixture containing 3-7 wt. % of silica sand having average particle size varies from ~ 0.5-0.75 mm and distilled water having density at 28^0C ~996 kg/m^3 is filled in stainless steel container of 4 liter capacity. The slurry strikes on samples at an impact angle varies from 70^0-90^0 for 3 hours duration. After erosion test the samples are dried at 70 ^{0}C in a laboratory oven for 2 hours. The erosive wear rate of the samples were computed from rate of mass loss measurement.

Figure:1 Specimen holder

4.0 Result and discussion

4.1 Surface Morphology of Al_2O_3/Cu

The SEM morphology as shown in figure 2 shows that the white particles which indicate the presence of Al_2O_3 particles in the Al_2O_3/Cu composite.

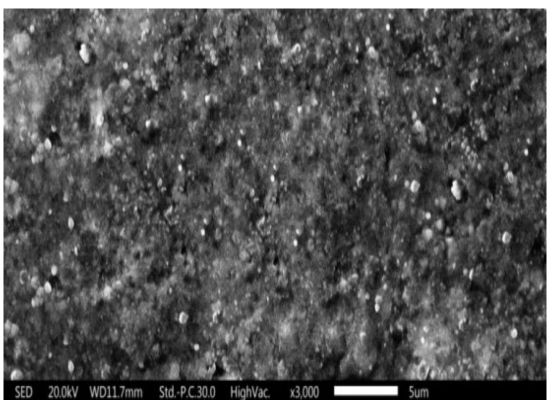


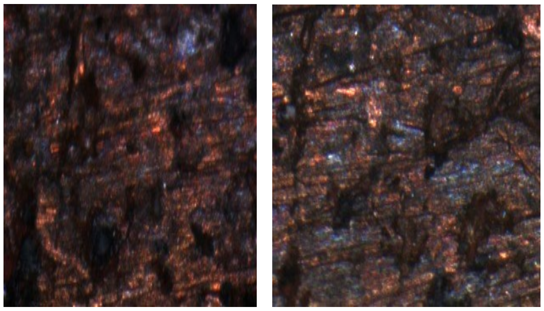
Figure:2 SEM surface morphograph of Al_2O_3/Cu composite for exp.1

4.2 Signal-to-noise (S/N) ratio

The S/N ratio for criteria "the-lower-the-better". is used to optimize erosive wear rate. The experimental results for Erosive wear rate of 5 wt% Al_2O_3/Cu composite based on Taguchi orthogonal array and the corresponding S/N ratios are shown in table 2 and evaluated using MINITAB 18 . Figure 3(a)-3(b) shows that fractured surface of Al_2O_3/Cu composite at different experimental condition. The figure also shows that the samples are fragmented out from composite surface during erosion test. The S/N ratio analysis as shown in figure 4 and table 3 shows that the optimal combination of Erosive wear parameters is $A_1B_1C_1D_1$ i.e. the experiment has been conducted at spindle speed of 250 r.p.m, impact angle of 70^0, slurry wt% of 3 and sand particle size of 0.5mm. The response table 3 shows that the impact angle has most influential parameter that affect erosive wear rate followed by spindle speed.

Table 2. Experimental results and (S/N) ratio

Exp. No.	Spindle speed (r.p.m)	Impact angle (^{0})	Slurry weight %	Particle Size (mm)
1	250	70	3	0.5
2	250	70	7	0.75
3	250	90	7	0.5
4	250	90	3	0.75
5	500	70	7	0.5
6	500	70	3	0.75
7	500	90	3	0.5
8	500	90	7	0.75
Exp. No.	Erosive wear rate*10^{-6} (gm/s)		S/N Ratio (dB)	
1	0.04453		27.02695	
2	0.04685		26.58581	
3	0.05126		25.80443	
4	0.04976		26.06239	
5	0.047344		26.4947	
6	0.04878		26.23516	
7	0.05564		25.09226	
8	0.05346		25.43942	



(a) Exp. 2 (b) Exp.5

Figure 3(a)-3(b) Fractured Surface morphograh

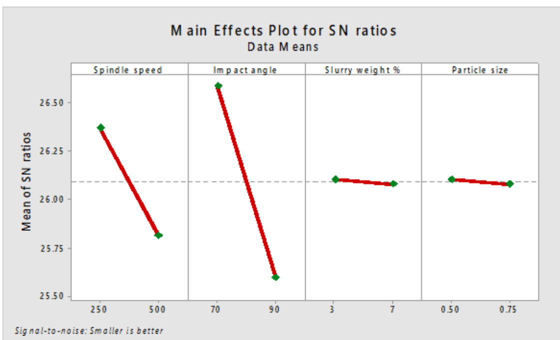


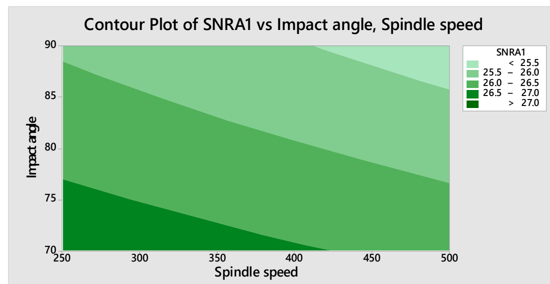
Figure:4 Main effects plots for S/N ratio

Table 3 Response Table for Signal to Noise Ratios

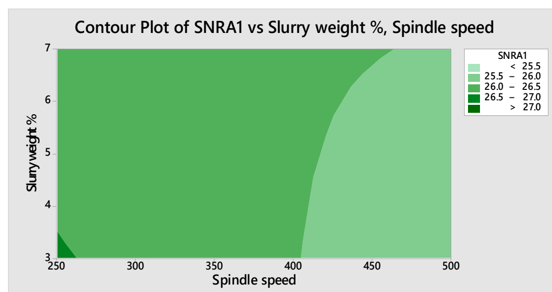
Smaller is better criteria				
Level	Spindle speed	Impact angle	Slurry weight %	Particle size
1	26.37	26.59	26.1	26.1
2	25.82	25.6	26.08	26.08
Delta	0.55	0.99	0.02	0.02
Rank	2	1	4	3

4.3 Contour plots

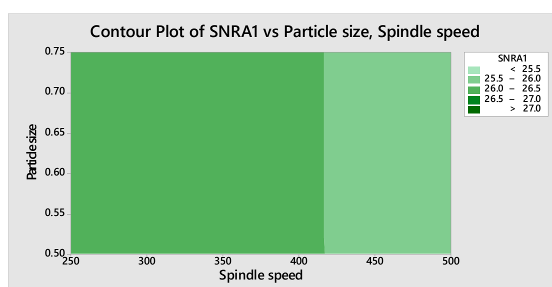
The contour plots, shown in figure 5(a)-5(d), show that the minimum erosive wear rate appears at dark green region.The contour plot between spindle speed, impact angle on S/N ratio of Erosive wear rate as shown in figure 5(a) shows that at low level of spindle speed and low level of impact angle the composite samples behave maximum S/N ratio of > 27. From the figure 5(a), it is also observed that the slope gradient of impact angle is higher compare to spindle speed. Therefore, the factor impact angle has more effect compare to spindle speed. There may be interaction effect between variables due to formation of curvature as shown in figure 5(b) and 5(e). From figure 5(c) and 5(d) shows that the factor spindle speed and impact angle have more effect on Erosive wear rate compare to other parameters. The effect of slurry wt% and particle size is insignificant on Erosive wear rate depicted in figure 5(f).



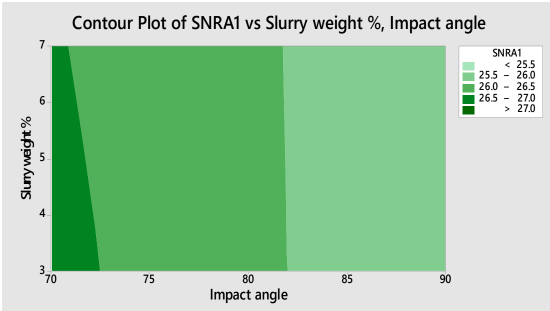
(a)Erosive wear rate vs. impact angle, spindle speed



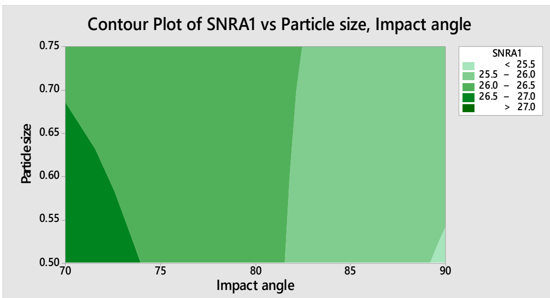
(b)Erosive wear rate vs. slurry wt%, spindle speed



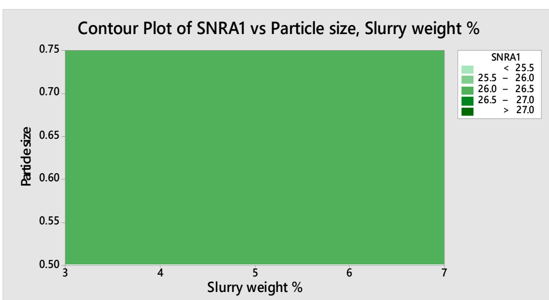
(c)Erosive wear rate vs. particle size, spindle speed



(d)Erosive wear rate vs. slurry wt%, impact angle



(e)Erosive wear rate vs. particle size, impact angle



(f)Erosive wear rate vs. particle size, slurry wt%

Figure 5(a)-5(f) Contour plots for Erosive wear rate for varying wear parameters

4.4 Analysis of variance (ANOVA)

The analysis of Variance as shown in table 4 shows that the parameter impact angle and spindle speed are significant since P-value<0.05 at 95% confidence interval. The effect of other parameters: particle size, slurry wt% and interaction effect between slurry wt% and spindle speed is insignificant. Tables 4 also shows that the percentage contribution of wear parameter impact angle on Erosive wear rate is highest compare to other factors considered and its contribution is 69.21073% followed by spindle speed of 21.88820%. The contribution of other two factors are insignificant on Erosive wear rate. The contribution of error is 8.822409% which depicts that the effect of interaction between factors on Erosive wear rate is insignificant.

Table 4 Analysis of Variance

Source	DF	SS	MS	F-Value
Spindle speed	1	0.61496	0.61496	35.41
Impact angle	1	1.94451	1.94451	111.97
Slurry weight %	1	0.00107	0.00107	0.06
Particle size	1	0.00114	0.00114	0.07
Spindle speed*Slurry weight %	1	0.21314	0.21314	12.27
Error	2	0.03473	0.01737	
Total	7	2.80955		

Source	P-Value	% contribution
Spindle speed	0.027	21.8882
Impact angle	0.009	69.21073
Slurry weight %	0.827	0.038084
Particle size	0.822	0.040576
Spindle speed*Slurry weight %	0.073	7.586268
Error		1.236141

4.5 Error Measurement

4.4.1 Estimated S/N ratio for response

Mean S/N Ratio=$\bar{\eta}$ =26.09264dB

Estimated value of S/N ratio= $\bar{\eta} + (\bar{\eta}_{A_1} - \bar{\eta}) + (\bar{\eta}_{B_1} - \bar{\eta}) + (\bar{\eta}_{C_1} - \bar{\eta}) + (\bar{\eta}_{D_1} - \bar{\eta})$

=26.882dB

The estimated signal to noise ratio is 26.882dB dB and corresponding Erosive wear rate is 0.04630x10^{-6} gm/s.

4.4.2 Confirmation experiment for response variable

Table 5 indicates the result of confirmation experiment using the optimal level of the parameters for minimum Erosive wear rate which is first trial run of experiment . The optimum level combination gives Erosive wear rate of 0.044530x10^{-6} gm/s and S/N ratio of 27.026946 dB. Figure 6 shows the eroded surface at optimum parameter level considered experimentally. Further the % error between estimated and experimental S/N ratio is 0.539%

Table 5. Confirmation experiment

A	B	C	D	Experimental Erosive wear rate	S/N ratio (dB)
1	1	1	1	0.044530x10^{-6}	27.026946

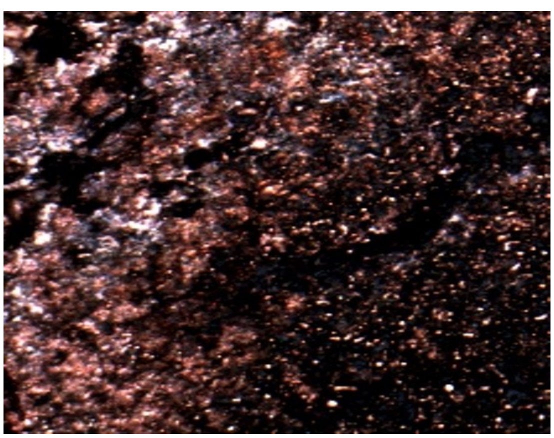


Figure:6 Fractured Surface morphograh at optimal condition of Al_2O_3/Cu composite

4.6 Regression Equation

The regression analysis with respect to different factors gives an estimated value of hardness. The regression equation is given below

Erosive wear rate= 0.02217 + 0.000013 Spindle speed + 0.000283 Impact angle + 0.000013 Slurry weight % + 0.00008 Particle size.

Figure 7 shows the predicted erosive wear rate by using regression equation is nearly same as experimental erosive wear rate.

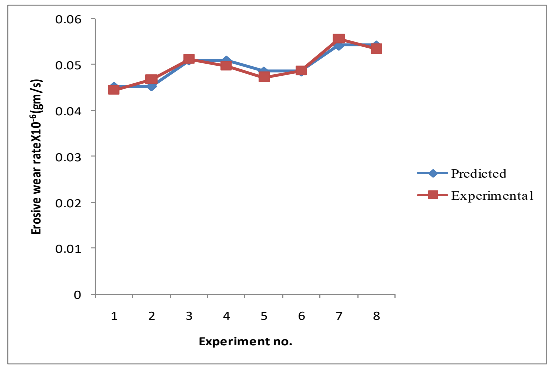


Figure:7 variation of predicted and experimental Erosive wear rate with experiments.

5.0 Conclusion

This article investigate the effect of different factors that affect Erosive wear of Al_2O_3/Cu composites with 5wt% of loading of Al_2O_3 particle using Taguchi technique. The SEM surface morphology shows that the presence of white Al_2O_3 particle in the composite. The Taguchi result show that the optimum controlled factors level for minimizing Erosive wear rate is $A_1B_1C_1D_1$ i.e. the experiment is performed at spindle speed of 250 r.p.m, impact angle of 70^0, slurry wt% of 3 and silica sand particle size of 0.5mm. The response table shows that the impact angle is most influential factor that affect erosive wear rate followed by spindle speed. The Contour plots also show that the factor impact angle has most influential parameter that affect on response. The percentage contribution of all factors confirmed that the factor impact angle has highest contribution in experimental condition and its contribution is 69.21073%, followed by spindle speed. At optimal condition the Erosive wear rate is 0.044530x10^{-6} gm/s. Further the % error between estimated and experimental S/N ratio is 0.539%.

The surface morphograph show that the small particles are fragmented out from composite surface. Finally the regression analysis gives relationship between Erosive wear rate and controlled factors which is well agreed with experimental erosive wear rate.

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