INVESTIGATION ON EROSION WEAR BEHAVIOUR OF Cr_2O_3 PLASMA THERMAL SPRAY COATING AND Ni BASED HARDFACING BY WELDING WITH TAGUCHI APPROACH

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Abstract: In the present investigation Cr_2O_3 coating deposited by plasma thermal spray technique and Ni based hardfacing coating deposited by manual metal arc welding on a SS304 substrate. Solid particle erosion is a complex surface damage process affected by a number of control parameters that together define the erosion rate. Using Taguchi optimization method, the process parameters of erosion test are optimized. It is found that discharge rate has the highest effect on the erosion rate of coated and uncoated samples. Most of the coatings and the uncoated sample had ductile type erosion behaviour. Impact angle has the least effect on the erosion rate. The present investigation deals in detail about its behaviour.

Key words: Plasma thermal spray; hardfacing; erosion wear; Taguchi technique.

1. INTRODUCTION

Erosion is caused by the impact of solids, liquids and the gasous or their combinations. Solid particle erosion gives significant degradation mechanism in many engineering systems, [1]. In wide variety of applications, mechanical components have to operate under severe conditions such as helicopter blades; high speed vehicles; coal and biomass fired boiler tubes and turbine blades; pump impeller blades and vanes operating in desert environment etc., [2]. In oil and gas production industry the components goes through severe conditions with presence of suspended sand particles resulting corrosion, erosion and overall wear of surface [3]. The solid particle problem results into the failure of machine and its components, personal risk and high maintenance cost [4-5]. Solid particle erosion is the progressive loss of original material from solid surface due to the mechanical interaction between the surface and solid particles [6]. Hence, some type of protection must be provided to overcome these problems i.e. degradation of equipment's and components by various types, surface modification is the technique used to overcome these degradation phenomena such as thermal spraying and the hardfacing by welding, [7-8].

Thermal spraying coating found very stable even in erosion, abrasion and heavy load conditions [5, 9]. Hardfacing coatings are more resistive to spalling because of strong metallurgical bond between the coating and the substrate and can be used wide variety of alloys to get best performance in wear conditions [8]. Ni based alloys provides excellent resistance to erosion and corrosion, [10]. Hardfacing by welding is a common method used for functioning surfaces subjected to wear, corrosion and oxidation, [11]. Jae Hyung et al., [1] evaluate solid particle erosion behaviour of the WC-Ni coating with CFD simulation and he concludes that erosion rate increases as the hardness of the substrate material increases. Mishra et al [6] uses Taguchi optimization method to optimize the process parameters such as impact angle, impact velocity, size of erodent and stand of distance and concludes that among these parameters impact angle has the maximum effect on the erosion rate. Mayank patel et al., [12] evaluate the effect of impact angle on the erosion rate of SS304 substrate material and conclude that maximum erosion occurs at 30° impact angle indicating the ductile type erosion behaviour of SS304. Hazoor singh et al [10] investigated the solid particle erosion behaviour of the NiCr and stellite-6 coating deposited by HVOF process. They conclude that NiCr coating provides better protection against erosion than that of stellite-6 coating. Jianling et al., [4] deposited the CrSiCN coating by pulsed DC magnetron sputtering process with variation of Si content for erosion resistance, after experiments he conclude that at 30° impact angle coating shows improvement to the erosion resistance than SS304 bare substrate. For uncoated sample erosion rate increases linearly as erosion time increase. Ivosevic et al., [13] studied the SPE for polymer matrix composites coated by WC-Co and conclude that as the impact angle increases erosion rate also increases and high temperature it was found that higher erosion rate than that of room temperature. Al-Fadhli et al., [3] evaluate the erosion behaviour of thermally sprayed Inconel-625 on different metallic surfaces and he concludes that coating on composite surfaces had highest erosion as compared to other metallic surfaces. S.B. Mishra et al., [2] carried out erosion behaviour of different metallic coatings deposited on Ni based superalloy by plasma spraying and concludes that at 30° impact angle erosion rate was higher for all samples then 90° impact angle. Ni_3Al has the lower erosion rate than that of Ni-20Cr coating because of lower porosity presents in coating. S. Chatterjee et al [8] evaluate SPE of the hardfacing deposited on cast iron with different erodent particles i.e. quartz sand and iron ore particles and he conclude that quartz had the highest effect on the erosion rate than that of iron ore particles which are softer in nature relative to quartz particles. Sudhir et al., [9] studied the erosion behaviour Ni based thermal spray coatings with 60% Al_2O_3 and conclude that maximum erosion rate is observed at lower impact angles and on increasing impact angle, wear rate decreases. As the impact pressure increase the erosion rate also increases. Ajit Behera et al., [5] evaluate the erosion behaviour of plasma sprayed coatings by different impact pressure and impact angles. They conclude that for 18 KW and 21 KW; maximum erosion occurs at 60° impact angle for 1 bar pressure. Paulo kankwo et al., [14] investigate the effect of particle velocity and impact angle on erosion mechanism after he conclude that as the impact velocity increases erosion rate also increases and at 90° impact angle ploughing mechanism and at low angle prevailing mechanism was observed. Gaganpreet et al., [11] evaluate erosion behaviour of Cr based hardfacing deposited by MMAW process and he concludes that at higher temperature with low impact angle erosion rate was maximum observed. Sapate et al., [15] carried out the SPE of weld hardfacing of cast iron with different erodent i.e. cerement clinker, blast furnace sinter, silica sand and alumina particles with different impact angles and then conclude that erosion rate is dependent on the hardness of the erodent particles and maximum erosion occurs at 60°-90° impact angles. The less erosion rate is the ultimate aim of the coatings deposited by plasma spraying and hardfacing by welding. To obtain certain values of erosion rate accurately and repeatedly, the parameters which affect the process have to be controlled accordingly. In this process the parameters are too large and the correlation between the parameter and the property does not always known. Hence statistical method can be useful for the identification of the control parameters for optimization the process. Hence, in this work, Taguchi experimental design method was implemented to examine the effects of impact velocity, angle, coating material and the discharge rate of erodent on erosion wear rate of different coatings.

2. EXPERIMETAL

Cr_2O_3 Plasma spray coating deposited by atmospheric plasma spray process and Ni based hardfacing alloy coating was deposited by manual metal arc welding on SS304 substrates. The operating parameters for two coating during deposition are given in Table 1 and Table 2.

Table 1. Operating parameters of the hardfacing by welding process

Parameters	**Range**
Current	160 A
Voltage	60 V
Stand off distance	5-7 mm

Table 2. Operating parameters of the plasma spray process

Parameters	**Range**
Current	450-500 A
Voltage	60-66 V
Plasma gas (Ar) flow rate	18 lpm
Powder feed rate	50 g/min
Carrier gas (Ar) flow rate	12 lpm
Torch to base distance	64 mm

Table 3. Chemical composition (Wt. %) for substrate steel

Type of steel	C	Si	Mn	P	S	Ni	Cr	Fe
SS 304	0.08	1	2	0.045	0.030	8-10.50	18-20	Balance

Table 4. Composition (Wt. %) for hardfacing welding electrode

Elements		C	Cr	Ni	Mo	Mn	Si	V	W	F
Composition (%)	Base Material	0.03	16-18	10-14	2-3	2	0.75	-	-	balance
	Coating	0.018	15.01	56.72	15.42	0.61	0.33	0.51	3.8	6.95

Alumina erodent was used for the erosion test which had the 50µm size. Using standard double disc method, the velocity of the eroding particles was determined. The coatings were eroded with alumina particle at different impact angle (i.e. 30°, 45°, 60°, and 90°) and Erosion rate was given by ratio of mass loss to the mass of erodent particle causing the erosion. With a precision electronic balance having 0.01 mg accuracy was used for weighing.

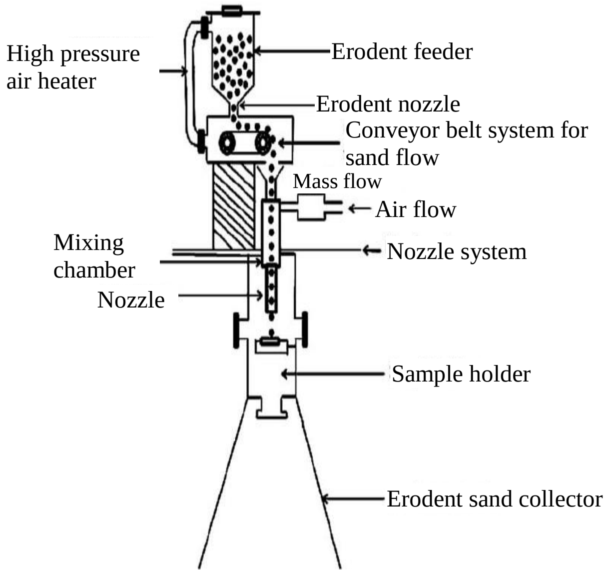

Fig. 1. A schematic diagram of erosion test rig

A standard Taguchi experimental design with L16 array was selected as four process factors with four levels each and the operating parameters under which erosion tests were carried out is shown in table 5. In conventional experiments the effect of these combinations can be examined in the〖 4〗^4=256 runs, whereas Taguchi's experimental method reduces the runs to only 16 runs, which have a great advantage in terms of experimental time and cost. The results of erosion rate are further converted into signal-to-noise (S/N) ratio. There are three type of S/N ratios available depending on the type of performance characteristics as Lower-the-better, Higher-the-better and Nominal-the-best, The S/N ratio for minimum erosion rate can be expressed as ''lower is better'' characteristic, which is calculated as logarithmic transformation of loss function as per equation 1.

Lower-the-better characteristics:

$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2\right) \qquad (1)$$

where: n is the number of observation and y is the observed data. For minimum erosion rate above characteristics is suitable i.e. lower-the-better.

Table 5. Variable parameter used in erosion experiments

Factors	Levels				Units
	I	II	III	IV	
A) Coating Material	Bare	NiCrMo4	NiCrMo4-Al	Cr_2O_3	-
B) Impact velocity	30	45	60	90	m/s
C) Impact Angle	30	45	60	90	Degree
D) Feed rate	2.5	5	7.5	10	g/min

3. RESULTS AND DISCUSSION

The erosion wears rates for coated and uncoated samples at different test conditions and S/N so obtained according to Taguchi experimental design are given in table 6.

Table 6. Orthogonal array for erosion

Sr. No	Coating Materials (A)	Impact Velocity (B) (m/s)	Impact Angle (C) (Degree)	Feed Rate (D) (g/min)	Erosion Rate (mg/kg)	S/N ratio
1	Bare SS304	30	30	2.5	744	-57.4315
2	Bare SS304	45	45	5	604	-55.6207
3	Bare SS304	60	60	7.5	536	-54.5833
4	Bare SS304	90	90	10	416	-52.3819
5	NiCrMo4	30	45	7.5	701.33	-56.9184

6	NiCrMo4	45	30	10	690	-56.7770
7	NiCrMo4	60	90	2.5	704	-56.9515
8	NiCrMo4	90	60	5	644	-56.1777
9	NiCrMo4-Al	30	60	10	580	-55.2686
10	NiCrMo4-Al	45	90	7.5	488	-53.7684
11	NiCrMo4-Al	60	30	5	872	-58.8103
12	NiCrMo4-Al	90	45	2.5	832	-58.4025
13	Cr_2O_3	30	90	5	1004	-60.0347
14	Cr_2O_3	45	60	2.5	1024	-60.2060
15	Cr_2O_3	60	45	10	602	-55.5919
16	Cr_2O_3	90	30	7.5	285.33	-49.1069

The optimization was done using Minitab14 software. Response table was calculated for the orthogonal array and the influence of the various factors was found (table 7). ANOVA table also created to find the percentage contribution of each factor.

Table 7. Response table for erosion

Level	Coating Material	Impact Velocity	Impact Angle	Feed Rate
1	-55.00	-57.41	-55.53	-58.25
2	-56.71	-56.59	-56.63	-57.66
3	-56.56	-56.48	-56.56	-53.59
4	-56.23	-54.02	-55.78	-55.00
Delta	1.70	3.40	1.10	4.65
Rank	3	2	4	1

Factor combination A1, B4, C1 and D3 gives the minimum erosion rate; this is concluded from the analysis of the result. This is proved from the figure 2 Further, looking at the response table of signal to noise ratio feed rate has the highest influence on the erosion rate followed by impact velocity, coating materials and impact angle. Hence from the response table we can conclude that impact angle has the least effect on erosion rate.

To find out the statistical influence of the various parameters like coating materials (A), impact velocity (B), impact angle (C) and feed rate (D) on the erosion rate analysis of variation (ANOVA) is performed on the data.

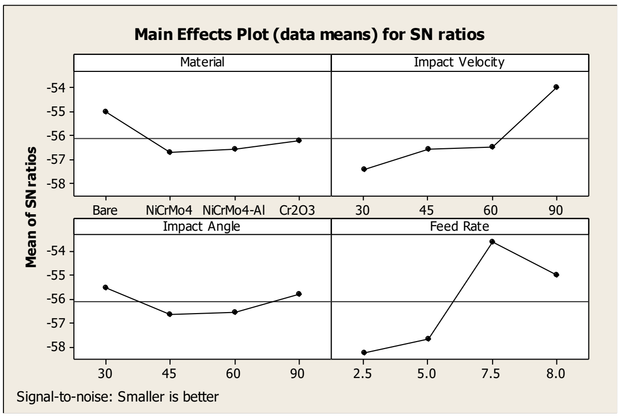

Fig. 2. Main effect plots for S/N ratio

Table 8 gives the results of the ANOVA with the erosion rate. For 90% confidence level this analysis was taken. Percentage contribution of each factor is shown in last column. From the ANOVA it is clear that feed rate has the highest contribution on erosion rate and impact angle has the least contribution on erosion rate.

The eroded region at lower impact angle is seemed like elliptical shape whereas the region formed by higher impact angle is of spherical type [12, 16].

Table 8. ANOVA table for erosion

Source	DF	Sum of Squares	Adj. SS	Adj. MS	F	P	Contribution (%)
Coating Material	3	52938	52938	17646	0.38	0.775	8.93
Impact Velocity	3	97932	97932	32644	0.71	0.609	16.50
Impact Angle	3	6703	6703	2234	0.05	0.983	1.13
Feed Rate	3	297045	297045	99015	2.14	0.274	50.07
Error	3	138635	138635	46212			
Total	15	593254					

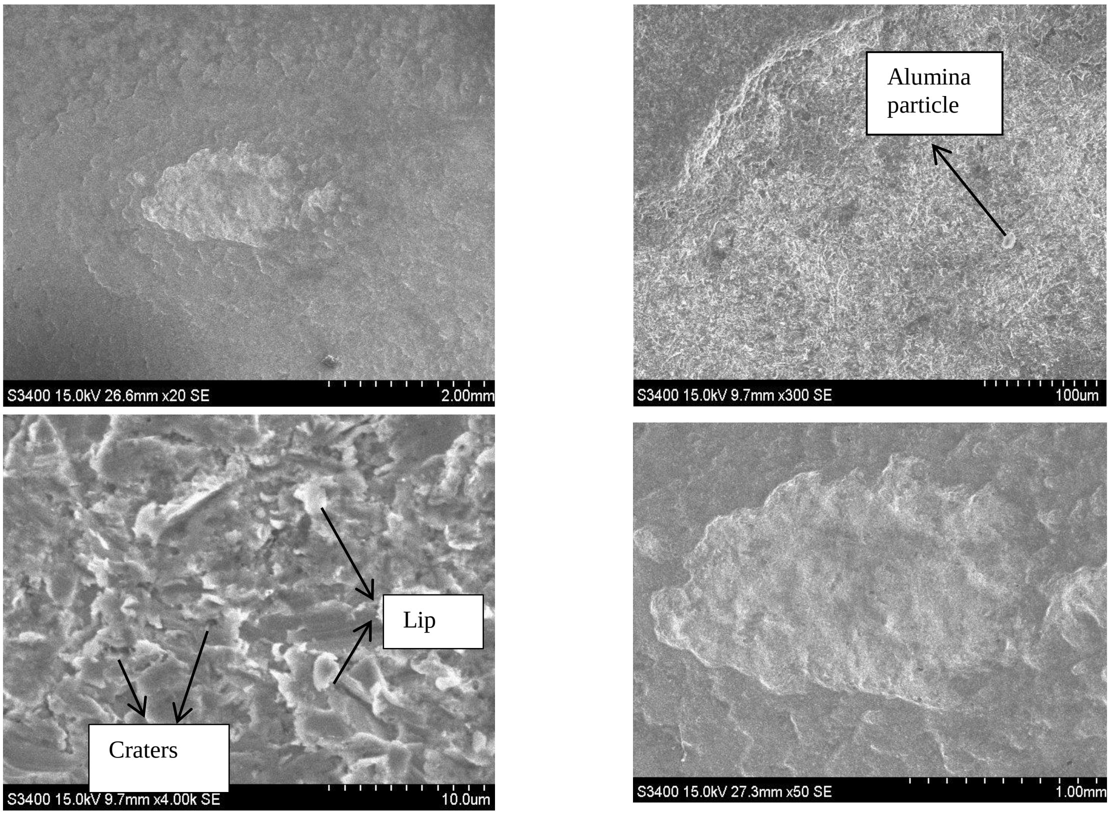

Fig. 3. SEM images of minimum erosion rate sample at different magnification.

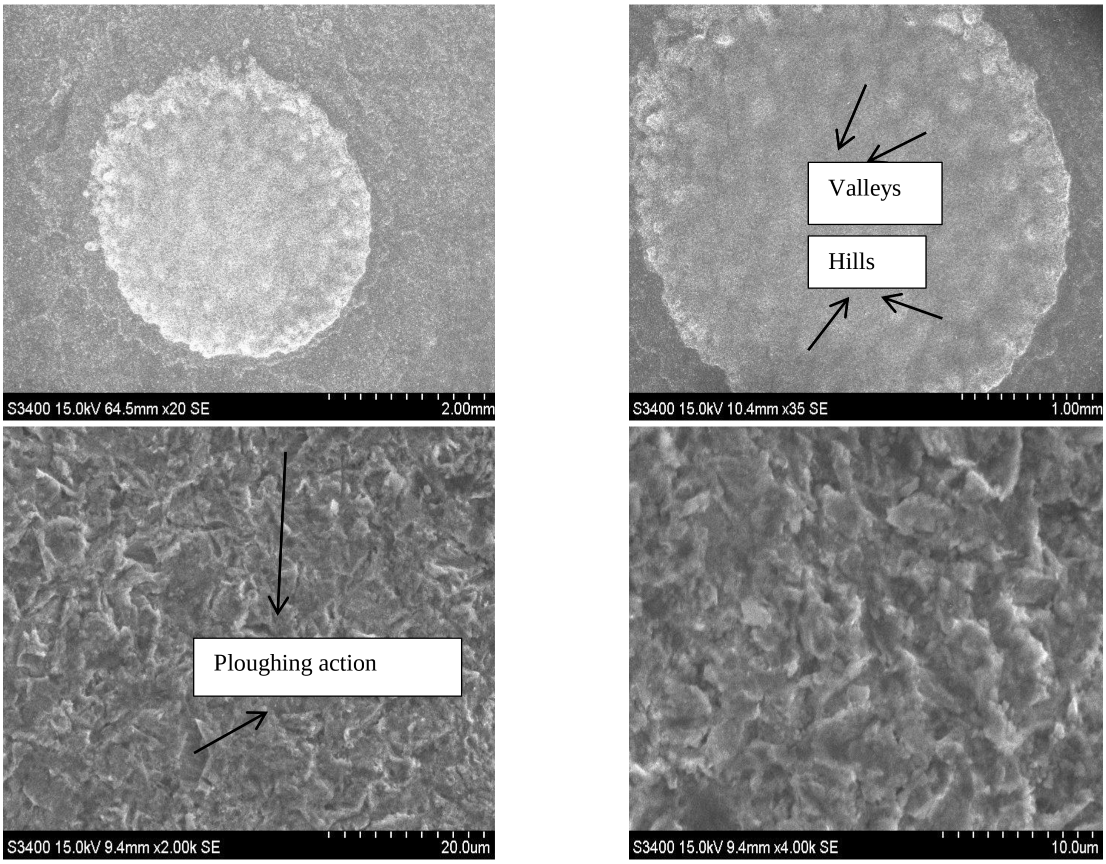

Fig. 4. SEM images of maximum erosion rate sample at different magnification

From the different coating minimum erosion rate observed at 30° impact angle for Cr_2O_3 (figure 3) coating which means the erosion behaviour of coating was brittle in nature and at 60° impact angle maximum erosion rate was obtained (figure 4), same result was obtained for SS304 material by Juan R. Laguna-Camacho, [16]. The numbers of craters were more so large material removal was observed. This suggest plastically deform area due to impact of erosion particles. At 60° impact angle due to sliding effect maximum erosion occurs. At high angle of impact there was no such type of long furrows and more ploughing action were observed in SEM images which indicate the brittle type erosion behaviour. More chipping activities were present at 60° impact angle which indicates more material removal than lesser angle. Plastically deformed hills and valleys were formed due to flow distribution after impact at outer region of eroded species. The outer ductile type erosion was because of abrasion at very low impact. Due to the oblique angle of impact hills and valleys may be created.

For bare material the erosion rate was higher for 30° impact angle which means the erosion behaviour of the uncoated sample was ductile in nature [10]. For NiCrMo4 hardfacing coating minimum erosion was found at 60° impact angle and maximum erosion rate at 90° impact angle. Hence it is difficult to conclude that the erosion behaviour whether pure ductile or brittle. This may be due to different combination of angles with different feed rate in the same table or due to the formation of different phases in the alloy, among which some of them like metal alloys might be eroded in ductile manner and the others like oxides formed on the coating eroded in brittle manner. For NiCrMo4-Al hardfacing coating minimum erosion was found at 90° impact angle and maximum at 30° this indicate that the erosion nature of the coating is pure ductile type [10].

4. CONCLUSION

The erosion test of the coatings and bare samples were done at room temperature by varying various process parameters which influence the erosion rate identified from literature review. Coated samples shows better erosion resistance than bare SS304 material. The erosion resistance was higher for Cr_2O_3 coating followed by NiCrMo4-Al, NiCrMo4 and Bare SS304. Factors like feed rate and impact velocity has the most effect on the erosion rate among selected one. Impact angle does not have much influence over erosion rate. The bare sample shows ductile type of erosion behaviour , NiCrMo4 shows minimum erosion at 60° impact angle and maximum at 90°, hence is difficult to predict the erosion behaviour whether it is pure ductile or pure brittle. With addition of Al to the NiCrMo4 hardfacing coating, the ductile type erosion behaviour shows by it. Whereas Cr_2O_3 coating shows minimum erosion rate at 30° impact angle and maximum at 60° hence we can conclude that erosion behaviour is brittle type.

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