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Erosion Resistance Behavior of SS304 Steel Hardfaced By SMAW With Addition of Molybdenum

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Abstract - **In this work the degradation of the steel SS304 used in pulverized coal burner nozzle is studied under the solid particle erosion conditions. Steel is hardfaced by tubular hardfacing electrodes of high chromium type and further Molybdenum content is added in the hardfacing electrode powder. The hardfacing is done by shielded metal arc welding process. Erosion test is conducted using Air Jet Erosion Testing Rig by varying the working temperatures (room temperature and 400°C) and impact angle of 30° and 90°. It is observed that by increasing the molybdenum content the degradation by erosion reduced at 90° impact angle at both room temperature and 400°C temperature. Microstructure characterization and microhardness analysis is also done along with SEM/EDS analysis. The elements in the hardfacing layer are uniformly distributed as observed by the EDS analysis and the content of tungsten and molybdenum increased in hardfacing layer than the substrate material. The increase in percentage of Molybdenum and tungsten improves the formation of carbides in hardfacing layer. Normally the harder materials have high erosion resistance at 30° impact angle but in our case the erosion resistance is maximum at 90° impact angle. The microstructure shows dendritic formation.**

Keywords: **Shielded Metal arc Welding, Solid Particle Erosion, Microhardness, Stainless Steel, Molybdenum.**

I. Introduction

The erosion is a process of degradation of material. Solid Particle Erosion (SPE) is the progressive loss of material that results from repeated impact of small, solid particles on a surface [1]. It is common problem for pulverized coal burner nozzle in thermal power plants. When pulverized coal strikes the burner nozzle at high velocity and material of nozzle get eroded after some time. The main variables that influence erosion are the size, shape, velocity, angle of impact, composition of the eroding particles, the properties of the surface being eroded, and the temperature of the system [2].

Hardfacing is a surface treatment to improve the surface properties of metals, in which a welding metal having excellent resistance to erosion and oxidation is deposited onto the surface of a substrate [3]. Hardfacing is the process which is used to regain the size and shape of the eroded metal surface. It also improved the various mechanical, thermal and wears properties of metal. Several welding techniques such as oxyacetylene gas welding (OAW), gas metal arc welding (GMAW), Shielded metal arc welding (SMAW) and submerged arc welding (SAW) can be used for hardfacing.

In the present work erosion behavior of hardfaced SS304 steel is studied by addition of molybdenum content in hardfacing electrodes (ET075). The hardfacing electrodes are of high chromium type tubular electrodes. Hardfacing process was done using Shielded Metal Arc Welding. The erosion test is performed using two temperature variables and two impact angles variables; room temperature, 400ºC temperatures and 30º, 90º angles respectively. Hardfacing process was done using Shielded Metal Arc Welding with the addition of different percentages of Molybdenum (Mo) in hardfacing electrodes. Microhardness, microstructure, SEM/EDS analysis was done on the hardfaced steel.

II. Experimentation

A. Substrate Material

SS304 steel was used as substrate material which is used in Indian thermal power plants for the coal burner nozzle material. The flat strip of substrate material was cut in 150x50x5 mm^3 size for the hardfacing formation. The chemical composition of the substrate material according to weight % is given in Table I.

TABLE I CHEMICAL COMPOSITION OF SUBSTRATE MATERIAL

Material	C	Mn	Si	P	S
SS304	.08	2	.75	.045	.03
Material	Cr	Al	Ni	Fe	
SS304	20	.1	10.5	Bal	

B.Hardfacing Formulation

Commercially available hardfacing tubular coated electrode (ET 075) was used for the purpose of hardfacing. ET 075 (Alloy 1) is in the form of tubular cored electrode of chromium carbide type, reinforced with alloying additives. On the flats of substrate material, double layer was deposited.

Two new compositions of hardfacing alloy were prepared by addition of 3%wt. and 5% wt. of Molybdenum powder into the commercially available alloy hardfacing tubular coated electrode powder. The electrodes get empty and mixed the alloy powders with 3% and 5% wt. of Mo (Alloy 2 and Alloy 3). These compositions again were filled into the tubular electrodes along with potassium silicate as binding agent. The chemical composition of hardfaced tubular electrode ET 075 (alloy1) and new prepared alloys is given in Table II.

TABLE II CHEMICAL COMPOSITIONS OF HARDFACING TUBULAR ELECTRODES

	Alloy 1	Alloy 2	Alloy 3
C	3.5	3.5	3.5
Si	2.2	2.2	2.2
Cu	0.12	0.12	0.12
Ni	0.19	0.19	0.19
Cr	28.5	28.5	28.5
Mo	13.5	16.5	18.5
W	7.3	7.3	7.3
Fe	Bal	Bal	Bal

After the preparation of new alloy powder and filled in the electrodes, the electrodes were dried at 80°C for 4 days. The binding agent used was volatile in nature and evaporate by continue heating the electrodes and prepared alloys of electrode powder and Molybdenum content remained in the electrodes.

The manual metal arc welding (MMAW) is used for hardfacing purpose onto SS310 steel substrate, after dried the electrodes. The welding parameters given in table 3, used were kept constant during whole process [5].

TABLE III WELDING PARAMETER

Welding Current/A	Welding Voltage/V	Electric current mode
120	22	DCEP

C.Sample Preparation

Samples were prepared by cutting the hardfaced SS304 steel in 15x10x6mm size. The samples were polished using silicon carbide emery papers of grade 220-2000, then again polished using 0.3μm alumina polishing powder suspended in distilled water.

D. Erosion Testing

Erosion testing was done with Air Jet Erosion Testing Rig using different parameters as shown in Table IV given below.

TABLE IV PARAMETERS FOR EROSION TESTING

Erodent Material	Alumina, Al_2O_3
Erodent Size	50μm
Particle Velocity	50 m/s
Erodent Feed Rate	4.75 g/min
Nozzle Diameter	3 mm
Impact Angle	30º and 90º
Test Temperature	Room Temperature and 400ºC
Stand of Distance	10 mm
Shape	Angular

The weight of samples is done before and after the erosion test at both the temperature and impact angles. Difference between weight before and after the erosion test is the degradation rate of the hardfaced sample.

E.Microstructure Characterization

For microstructure characterization, the specimens were polished and then etched using HCL, NHo_3 with addition of water. The analysis was done using optical microscopy. The microstructure of the hardfaced layer changed with addition of Molybdenum powder. The microstructure becomes dendritic and bright.

F.SEM/EDS Analysis

The SEM/EDS analysis was analyzed from cross section of the prepared hardfaced specimens. The element distribution in the hardfaced layer and in substrate material is analyzed.

G. Microhardness Analysis

The microhardness is analyzed using vicker's microhardness tester under 1kg of load. The microhardness is analyzed at various points on each alloy hardfacing. The microhardness varies from substrate to the hardfacing layer and it also varies with change in alloys.

III. Result and Discussion

A. SEM/EDS Analysis

The EDS result given in figure1 and figure2, shows that the elements after hardfacing are uniformly distributed. In hardfacing layer percentage of Molybdenum and Tungsten is more than substrate material. It also increases the hardness in hardfacing layer. Elements such as Ti, V, Nb, Mo, and W to further improve hardenability of the material [6].

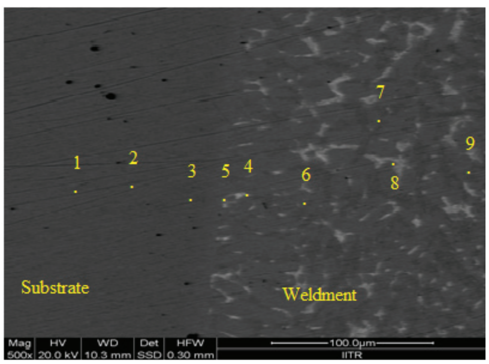

Fig.1 EDS diagram cross section hardfaced with alloy3

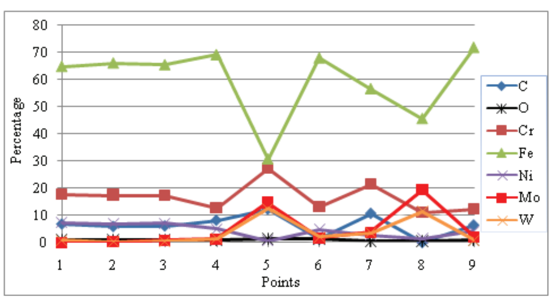

Fig.2 EDS line chart of cross section hardfaced with alloy3

B.Microhardness Analysis

By contrast, metallic materials have ductile and constructive properties, but they lack high hardness [7]. Borawski discovered that although higher hardness increased the erosion resistance of ductile materials, it decreased the erosion resistance of brittle materials [4]. Brittle materials are more resistant to low-impact-angle erosion (30°), whereas ductile materials have better performance at high impact angles (90°) [8]. The hardness graph in figure 3 shows that microhardness of alloy1 is more than alloy2 hardfaced layer but lesser than hardfacing layer of alloy3. This can be due to the change in microstructure of the hardfacings.

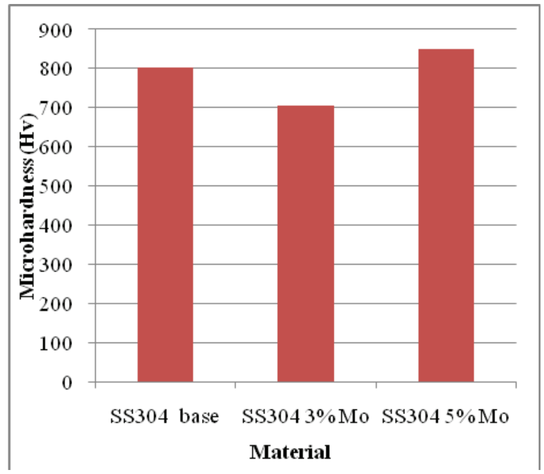

Fig.3 Microhardness of SS304 hardfaced steel

C.Microstructure Characterization

Microstructure of Mo free hardfacing has fine structure than 3%wt. Mo addition and due to fine structure the microhardness also higher. This study of **Shin** reveals that addition of molybdenum induces microstructural changes, which results in the increase of hardness of hardfacing alloys. The hardness originates principally from the hard M_7C_3, $M_{23}C_6$ and M_6C type carbides [9]. In figure4 the microstructure of hardfaced alloy shown and hare the microstructure reveals that with increase in Mo with 5%wt. in alloy powder the structure become dendritic which is due to significantly increase in carbide content. With addition of 3%wt. of Mo in alloy powder the microstructure formed coarse and bright where the elements of Mo present. The coarse grains possessed low microhardness. It reveals that the addition of Mo content produces the microstructural changes in hardfacings.

D.Erosion Analysis

The mechanism by which material is removed from the hardfaced layer under erosive conditions may be either ductile or brittle. The ductile erosion occurs by cutting and deformation mechanism, whereas brittle erosion occurs by cracking and chipping mechanism of the fractured and loosened pieces [12]. It can be analyzed that the erosion of hardfaced material at 30° is more than 90° impact angle, it indicates that the hardfaced behaving in a ductile manner.

In our case the hardness of the hardfacing with alloy3 is increased but its erosion resistance is better at 90 impact angle as shown in figure5. This is mainly due to the formation of carbide particles by the cooling effect on material but by injecting the erodent particles the carbide particles removed with higher percentage.

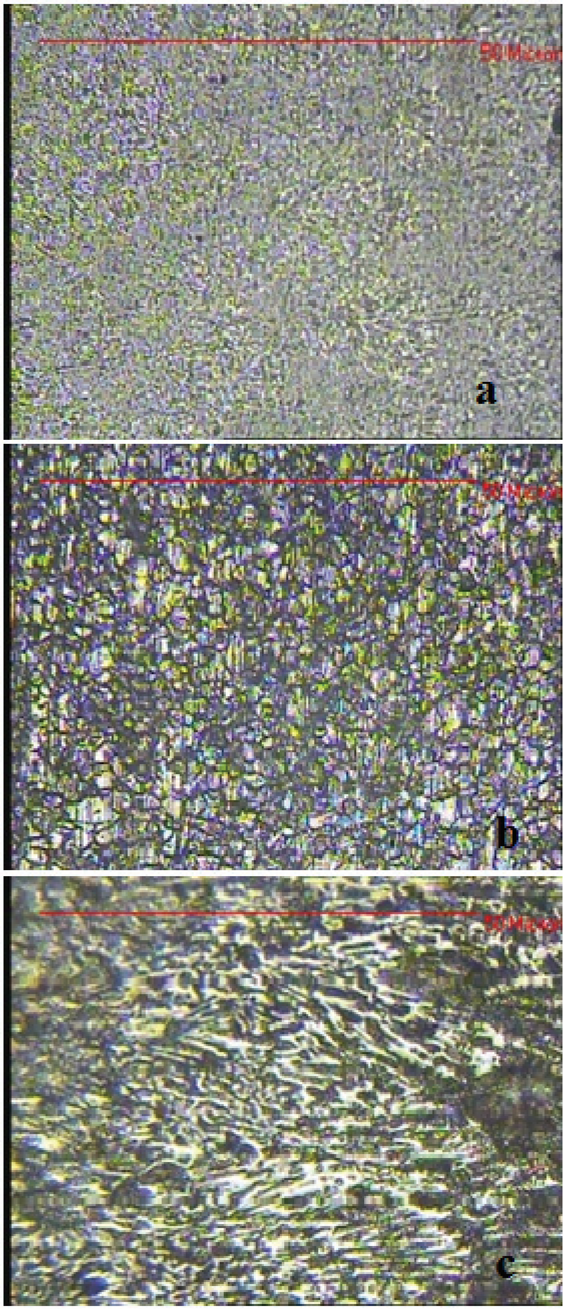

Fig.4 Microstructure of SS304 hardfaced with (a) alloy1, (b) alloy2, (c) alloy3.

Same in case of erosion at 400°C temperature, the weight loss in low impact angle is high as compare to normal impact angle. In general, the magnitude of losses increased with increase in temperature, giving the greatest losses at the highest temperature [10].

The erosion–corrosion resistance was further improved for Fe_3Al-based alloys by the addition of molybdenum, and the weight loss or average thickness reduction of the specimens decreased significantly with an increase in molybdenum [13]. Generally, the resistance of erosion was related to the hardness of materials [11].

The matrix erosion rate is also expected to be relatively higher with alumina particles, due to their greater angularity. This is reflected in erosion rates of hardfacing alloys, which were observed to be 1.5 times greater as compared to those with silica sand particles, at 30° impingement angle [14].

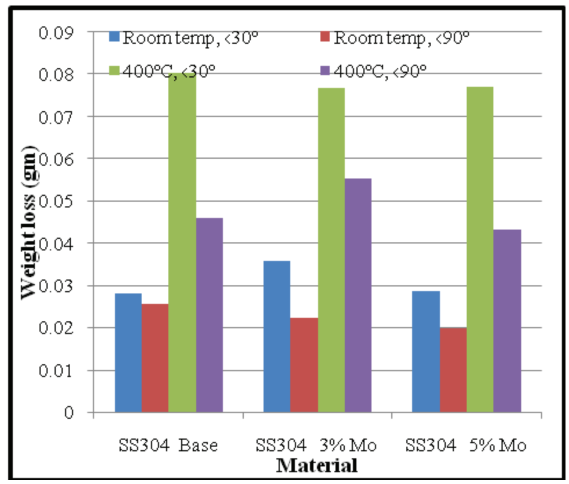

Fig.5 Weight loss of different alloy hardfacings under erosion test

In general, the magnitude of losses increased with increase in temperature, giving the greatest losses at the highest temperature [10].

IV. Conclusion

- The element distribution is uniform when hardfaced with addition of Mo in electrode powder is done.
- The lesser microhardness gives better resistance to solid particle erosion at 90º impact angle.
- The erosion with 5%wt addition of Mo powder is lesser as compare to other even it has high microhardness. This may be due to the direct impact and removal of grains of carbides.
- Addition of Mo content improves the uniformity and grain formation of the hardfaced steel. This helps to decrease the degradation (erosion) rate at room temperature as well as at 400º temperature.

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