Advancement in Manufacturing Processes

Edited by
Rupinder Singh

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Preface

The manufacturing processes have been in evidence for the past hundred years and are being widely used in diverse areas. Among various manufacturing processes, casting, welding, forging, non- traditional manufacturing processes etc are commercially used as manufacturing solutions. This special issue provides an overview of emerging technologies to the areas of Rapid tooling, Rapid moulding, Rapid casting, Die castings, In-process measurement and monitoring for precision/ultra-precision processes, Surface characterisation, Metrology applied to precision/ultra-precision processes and Traditional and Non-Traditional machining processes. The readers from academics, researchers, industrial practitioners and university students specialising in castings, rapid prototyping, manufacturing processes, and related fields may get benefit from these specialized papers.

In-spite of the best of my efforts there is bound to be some mistakes. The same may kindly be brought to my notice for rectification.

I sincerely wish that the Special issue on advancement in manufacturing processes may come up-to the expectations of the readers on this vital subject of production technology.

Dr. Rupinder Singh

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Erosion behavior of Pulverized Coal Burner Nozzle material hardfaced by solid wire and flux cored wire electrode

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Keywords: Erosion, Hardfacing, Gas Metal Arc Welding, Pulverized Coal Burner Nozzle.

Abstract. In present study, an attempt was made to reduce the erosion rate of the Pulverized coal burner nozzle material. For better resistant to erosion, material was hardfaced by Gas Metal Arc Welding (GMAW) by using solid wire electrode and flux cored wire electrode under same welding conditions. The substrate steel hardfaced with flux cored wire electrode resulted in high microhardness as compare to solid wire electrode. The erosion study was conducted, using an air jet erosion test rig at a particle velocity of 50 m/s. Ductile erosion behavior is observed in the case when the substrate steels is hardfaced with solid wire whereas brittle erosion behavior is observed when the substrate steels is hardfaced with flux cored wire. At a low angle of impingement, the abrasive type cutting is the dominating factor for material removal, and at a higher angle of impingement, impact-type as well as abrasive-type cutting actions play critical roles. Plastic deformation characterized by pitting and cutting action was also observed. Scanning electron microscopy (SEM) technique was used to analyze the eroded surface. It was concluded that damaged surfaces of Pulverized coal burner nozzle material can be successfully hardfaced and improvement in erosion resistance was observed.

1 Introduction

Solid particle erosion implies the removal of material from the surface due to successive impact of solid and hard particles at considerably high velocities. A large number of engineering components are subjected to solid particle erosion. [1]. The operation of components in erosive environment associated to high temperature reduces its service life, increase the outage and the replacement cost. Consequently, the overall cost to industry is very high. Moreover, a new generation of industrial applications (energy production powerplants, steel industries etc.) requires materials that can preserve their structural integrity at very high temperatures, [2]. Reduced power plant efficiency due to solid particle erosion has led to various methods to combat SPE. One method is to apply hardfacing layers to the components subject to erosive environments [3].

Hardfacing or fusion surfacing is a technique that relies on a metallurgical bond between the coating and the substrate [4]. Weld hardfacing techniques are employed mainly to extend or improve the service life of engineering components andto reduce their cost, either by rebuilding or by fabricating in such a way as to produce a composite wall section. Hardfacing is primarily done to enhance the surface properties of the base metal (substrate) and hardfaced materials generally exhibit better wear, corrosion, and oxidation resistance than the base metal [5].Welding deposits can functionalize surfaces and reclaim components extending their service life [6]. It has been reported that both the welding technique and the temperature have great influence on the performance of hard faced components [7].

The high chromium iron base hardfacing alloy is employed in a wide range of industries to extend the service life of machine components subject to abrasive wear. The microstructures of high chromium iron base alloys mainly contain hypoeutectic, eutectic, and hypereutectic structures. The hypereutectic alloys are considered as the preferred hardfacing alloy for repairing the damaged components [8]. The coefficient of thermal expansion of chromium carbide more closely matches that of Fe and Ni, which constitute the bulk of the base metals on which the coatings are applied for high temperature applications [9].

2 Experimentation

2.1 Hardfacing of Substrate Material

The Steel flats of SS304 and SS310 measuring cross section of 150x50x5mm^{3}are taken as a substrate material. The chemical composition of the substrate material and Hardfacing electrode are shown in the Table 1. A hardfacing layer of thickness 3-4 mm is deposited over the substrate material by using Gas Metal Arc Welding as the hardfacing technique. The welding parameters for hardfacing are given in Table 2. Hardfaced specimen were cut along the cross-section, and then polished manually down to 1000 grit using SiC emery papers. The microstructural analysis of hardfaced steels across the cross section was carried after wheel cloth polishing with the help of image analyzer.

2.2 Erosion Testing

The rig consisted of an air compressor, a particle feeder, an air particle mixing and accelerating chambers. Dry compressed air was mixed with the erodent particles, which were fed at a constant rate, in the mixing chamber and then accelerated by passing the mixture through a tungsten carbide converging nozzle. These accelerating erodent particles impacted the specimen. In the erosion testing first the sample is weighed using an electronic balance having a resolution of 0.0001 g. The sample was fixed in the sample holder of the erosion rig and eroded with alumina abrasive particle at the predetermined particle feed rate, impact velocity and impact angle for 1 hour. After the erosion testing the sample is again weighed. The change in weight gives the material being eroded. The different erosion test parameters are given in the Table 3.

Table 1 Chemical composition of substrate materials [wt%].

Element	C	Mn	Si	P	S	Cr	Al	Ni	Fe
SS304 steel	0.08	2	0.75	0.045	0.03	20	0.1	10.5	Bal
SS310 steel	0.25	2	1.5	0.045	0.03	26	0.1	22	Bal
Solid wire electrode	0.08	2	0.75	0.045	0.03	20	0.1	10.5	Bal
Flux cored wire electrode	22.72	0.52	0.55	---	----	11.37	1.43	---	Bal

Table 2 Welding parameters.

	Diameter [mm]	Arc voltage [V]	Welding current [Amp.]	Electrode polarity	Wire feed rate [m/min]	Shielding gas
Solid wire electrode	0.8	20	120	DCEP	3	-------
Flux core wire electrode	1.6	20	120	DCEP	3	Mixture of Ar and CO_2

Table 3 Erosion Test Parameters

Erodent material	Alumina, Al_20_3
Erodent size [μm]	50
Particle velocity [m/s]	50
Erodent feed rate [g/min]	4.75
Nozzle diameter [mm]	3
Impact angle	30° and 90°
Test temperature [^{0}C]	Room temperature and 400
Stand-off distance [mm]	10
Shape	Angular

3 Results & Discussion

3.1 Microhardness Analysis

The average microhardness value of substrate steel and hardfaced surfaces is presented in Fig. 1. The microhardness value of the flux core wire hardfacing is much higher than substrate steel. This may be due to the presence of needle like carbides present in the hardfacing. The SS304 and SS310 steel hardfaced with solid wire mainly consists of the primary austenite dendrites in the eutectic matrix. As expected this structure results in low hardness value.It is observed that SS310 and SS304 substrate steel shows the average hardness value 190 and 220HV respectively.

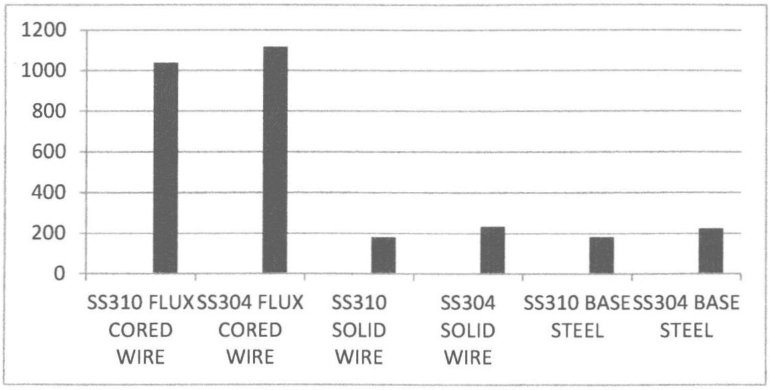

Fig. 1 The average Microhardness of substrate steel and hardfaced steel surfaces.

3.2 Microstructural Analysis of Hardfacings

The microstructure of the SS310 and SS304 sample hardfaced with flux cored wire is shown in the Fig. 2(a) and 2(b). The micrograph reveals the presence of a high amount of re-precipitated spine-like carbides (Cr_7C_3) resulting from the extensive carbide dissolution in the matrix. The results are inconsistence with the observation made by [10]. These carbide particles are very likely incoherent to the matrix. Some of the polygonal carbides agglomerated to coarser or needle-like morphology, which might result in a slight rise in the hardness value as reported by [11]. The hardness value of SS304 substrate hardfaced with flux cored wire is slightly higher than the SS310 substrate hardfaced with flux cored wire (Fig. 1 and 2) due to presence of dense carbide needles. Fig. 2(c) and 2(d) shows the microstructure of SS310 and SS304 hardfaced with solid wire. It is observed that the SS3010 and SS304 show similar microstructure. The primary austenite dendrites can be observed in the eutectic matrix. It is observed that this structure results in low hardness.

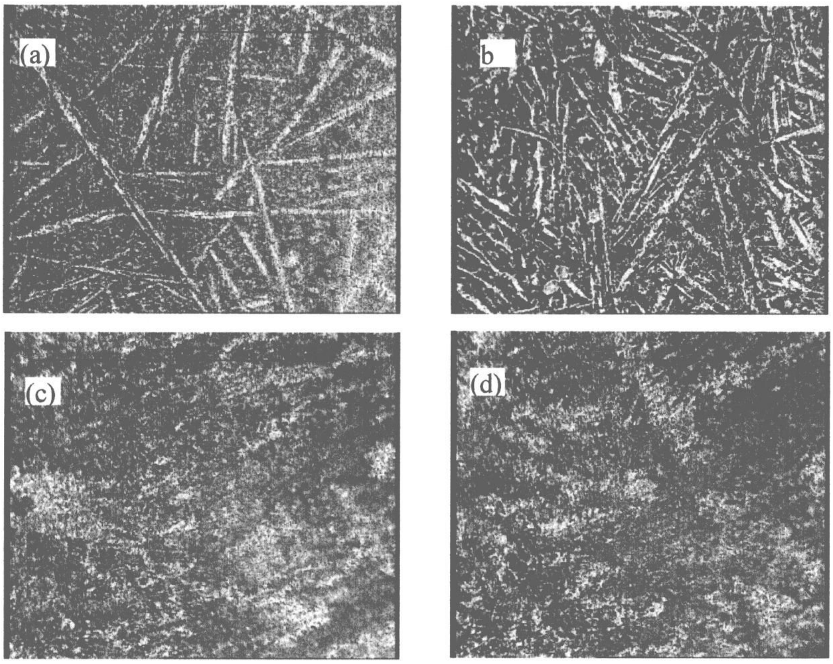

Fig. 2 Microstructure of the weldment (a) SS310 hardfaced with flux cored wire (b) SS304 hardfaced with flux cored wire, (c) SS310 hardfaced with solid wire (d) SS304 hardfaced with solid wire

3.3 SEM / EDS Analysis of Cross Section

SEM/EDS analysis along the cross section of hardfaced SS304 with the flux cored electrode wire is shown in the Fig. 3. EDS analysis of point 1, 2 and 3 shows the composition of base metal with high presence of iron and chromium with traceable amount of nickel. The point 4, 5, 6, 7 and 8 shows the composition of the hardfacing. The hardfacing mainly consists of iron, carbon and chromium with small amount of manganese and silicon. It is observed that the various elements in the hardfacing are uniformly distributed. SEM/EDS analysis along the cross section of hardfaced SS310 with solid electrode wire is shown in the Fig 4. The point 1, 2 and 3 shows the composition of base metal SS310 whereas the point 4, 5,6,7,8 and 9 shows the composition of the hardfacing. The weld deposit mainly consists of iron, carbon, nickel and chromium with small amount of silicon and manganese. It is seen that the various elements in the hardfacing are uniformly distributed. EDS analysis reveals that there is not so much difference between the composition of the base metal and weld deposit.

3.4 XRD Analysis

Fig. 5 shows the XRD pattern of hardfaced SS304 steel with flux cored wire electrode and hardfaced SS310 steel with solid wire electrode respectively. The XRD analysis is done at 0.2°/s goniometric speed. The specimen is scanned in 2θ in the range from 5° to 110°. The target used was H_2 (Hydrogen) and Cu (Copper). The diffractometer interfaced with software provides 'd' values directly on the diffraction pattern. The major peaks in the XRD pattern reveal the presence of iron.

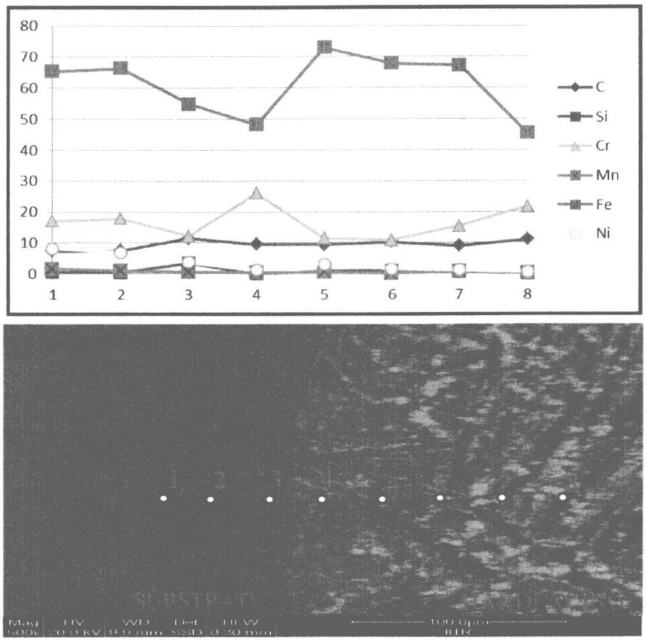

Fig. 3 Cross sectional EDS analysis of SS304 Sample hardfaced with Flux cored wire at various points

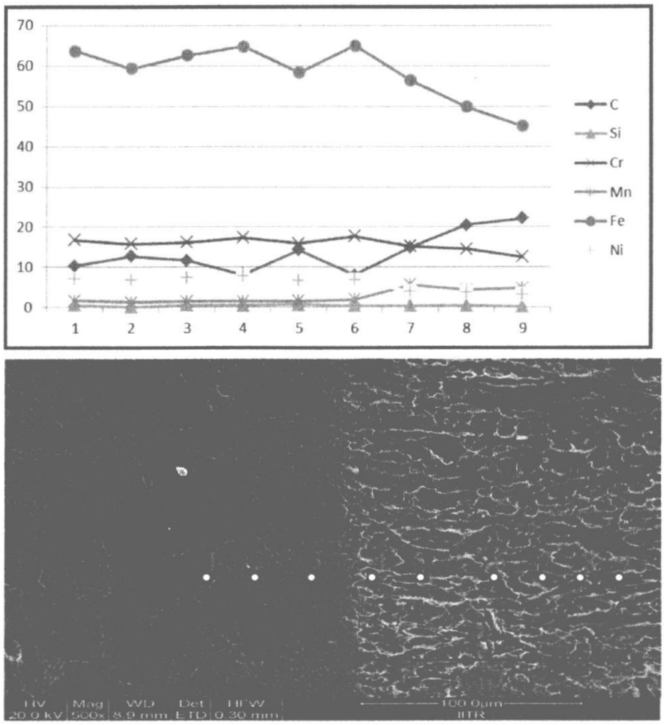

Fig. 4 Cross sectional EDS analysis of SS310 Sample hardfaced with solid wire at various points

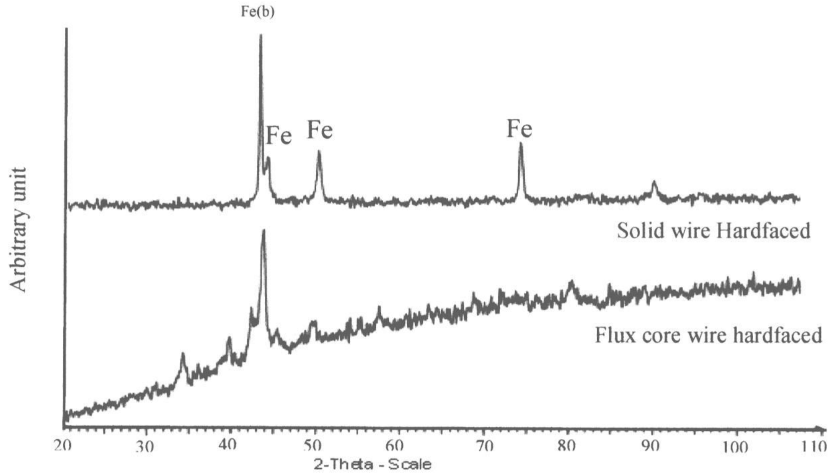

Fig. 5 XRD pattern of hardfaced surface

3.5 Erosion Testing

The Fig. 6 and 7 shows weight changes for all hardfaced and base steels subjected to solid particle impacts at the lower and higher test temperatures, to give a general view of the erosion behavior. The erosion rate of the hardfaced and base steels at room temperature and at 30° and 90° impact angle is shown in Fig 6.From the graphs, it can be inferred that at 30° impact angle the erosion rate of the sample SS304 hardfaced with flux cored wire shows lesser erosion rate than SS310 base steel hardfaced with flux cored wire. The SS304 sample hardfaced with solid wire shows the higher erosion rate at 30° impact angle among the hardfaced samples. At 90° impact angle it is observed that the erosion rate of SS304 & SS310 hardfaced with solid wire is lesser even than the base metal. Fig. 7 shows the erosion behavior of the samples at 400°C temperature and at 30° and 90° impact a.ngle. At 30° impact angle it is observed that the erosion rate of SS304 hardfaced with flux cored wire shows less erosion rate. However, the SS310 base metal sample shows higher erosion rate. It is seen that at 90° impact angle the SS310 sample hardfaced with solid wire also shows less erosion.
In solid particle erosion, ductile materials commonly shows higher material loss rates at a shallow impact angle than at steeper ones, whereas brittle materials introduce relatively higher wear rates at steep angles as proposed by [12]. The weight change data of this study (Fig. 6 and 7) shows that the SS310 and SS304 steel hardfaced with flux core wire shows the brittle erosion behavior at the high and low temperature whereas the SS310 steel hardfaced with solid wire shows ductile erosion behavior at low temperature. At high temperature SS310 steel hardfaced with solid wire shows ductile erosion behavior but SS304, does not clearly follow ductile or brittle behavior. At high temperature, the bond strength between grains decreases which may be resulted in higher erosion rate. The base steels SS310 and SS304 show the ductile erosion behavior at high and low temperature.

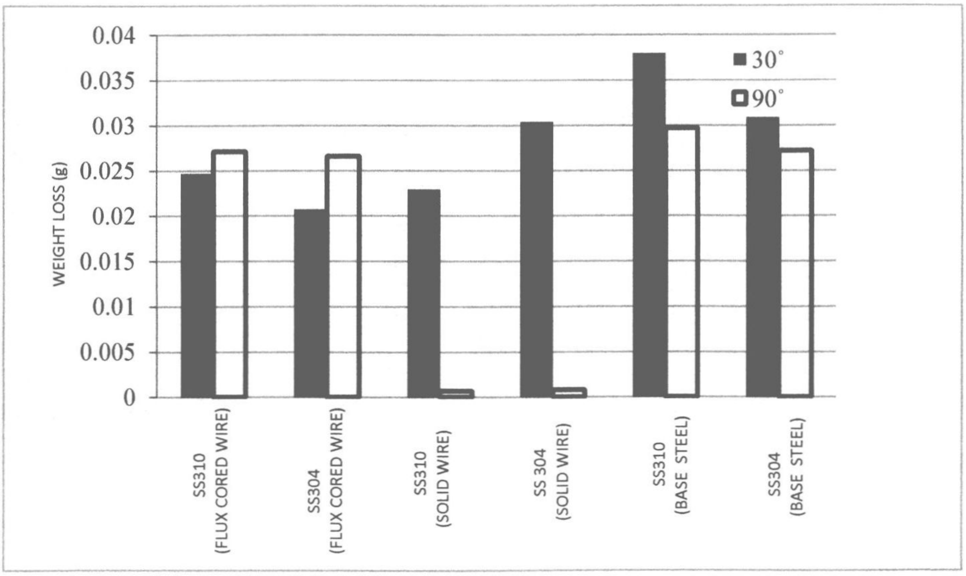

Fig. 6 Erosion of hardfaced and base steels at Room temperature

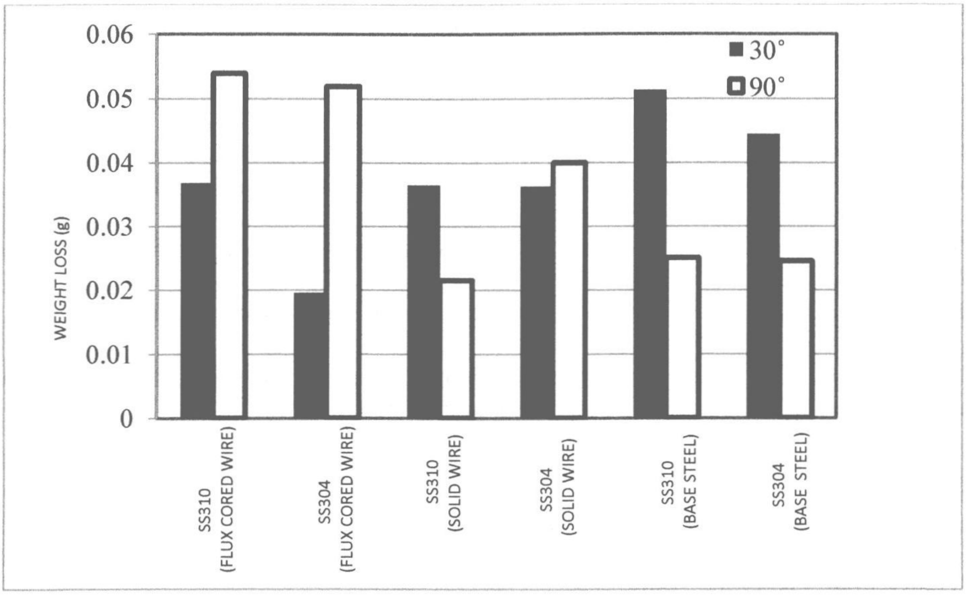

Fig. 7 Erosion of hardfaced and base steels at 400°C temperature

3.6 SEM / EDS Analysis of the Eroded Surface

The Fig. 8 shows the SEM micrograph of SS310 steel hardfaced with solid wire at 30^0 and 90° impact angle. It is observed from the SEM micrograph that the material goes under plastic deformation. Plastic deformation characterized by pitting and cutting action was observed.In the SEM micrograph lips and craters can be seen.The ductile erosion occurs by cutting and deformation mechanism as proposed by [13].The ductile nature of the specimen may be due to the low hardness value.

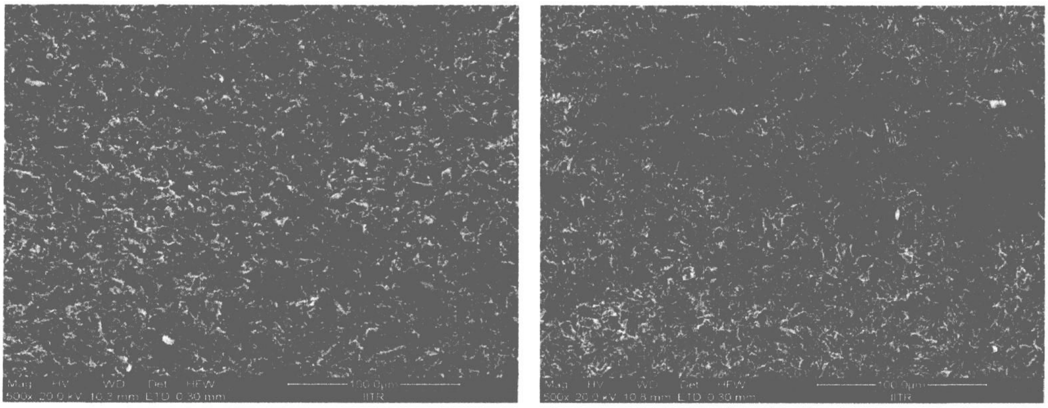

Fig. 8 SEM micrograph showing the surface morphology of surfaces of SS310 steel hardfaced with solid wire eroded at room temperature

4 Conclusions

- Solid particle erosion of the substrate steel hardfaced with solid wire shows lesser erosion rate at 90° and higher erosion rate at 30°, which reveals the ductile nature of the coating whereas Substrate steel hardfaced with flux cored wire shows lesser erosion rate at 30° and higher erosion rate at 90° which reveals the brittle erosion behavior of the hardfacing. Plastic deformation characterized by pitting and cutting action was also observed.
- The microstructure of Substrate steels SS304 and SS310 hardfaced with flux cored wire shows a high amount of re-precipitated spine-like carbides (Cr_7C_3) resulting from the extensive carbide dissolution in the matrix which results in higher microhardness whereas the Substrate steels SS310 and SS304 hardfaced with solid wire shows austenitic dendrite structure which results in lower microhardness.
- Erosion rate of solid wire hardfaced substrate is lesser than flux cored wire hardfacing at 90° impingement angle.
- The Hardfacing improve the erosion resistance of steel and can be successfully used to re-build the eroded surfaces of pulverized coal burner nozzle material.

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