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Erosion Behavior of Cold Sprayed Ni based Coating on Boiler Steel

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Abstract - *Erosion is a severe and most common problem in boiler tubes of power plant boiler, aircraft engine, and steam and jet turbines. Erosion wear causes the loss of material from the component gradually, reduces the performance and thus, finally leads to failure of component. Coating of the boiler steel (substrate) is one of the effective methods to reduce the erosion wear. The paper aims to use high pressure cold spray technology to coat the boiler steel. Cold spray is a promising technology for depositing protective coatings. In this current research work of boiler steel, two coating powders 70Ni-30Cr & 50Ni-50Cr was coated over GrA1 boiler steel substrate by cold spray coating technology. The boiler steel, both coated and uncoated was subjected to jet erosion test at high temperature at an impact angle of 30° & 90° along with SEM, EDS and XRD characterization. Erosion rate is observed more for impact angle of 30° than 90°. It is observed that the coated specimen showed better wear resistance than uncoated ones.*

Key Words: Erosion, Coating, Boiler steel Cold spray, Jet erosion test

1. INTRODUCTION

Erosion is the process of surface wearing in which material gets removed from solid surface by the action of particles impinging on it. Erosion occurs when hard solid particles are entrained in fluid and strike the surface [1, 2]. Each particle contacting the surface cuts a tiny particle from the surface. Individually, each particle removed is insignificant, but a large number of particles removed over a long period of time can produce staggering degrees of erosion. Erosive wear can be expected and is a major problem in many engineering systems which include aircraft engine, steam & jet turbines and boiler tubes [1, 2]. Thermal spraying coating technique has been a source of providing protection to large diameter shafts and worn out parts ranging from turbines power plants and pumps [3].Thermal spray represents an important technique for enhancing the properties of engineering parts to increase their life and performance at various working environment. However, thermal spraying involves partially or fully melting of feedstock powder before the deposition. This causes oxidations of coating, decarburization, and phase transformations of coating materials which significantly deteriorates the coating mechanical properties and wear resistance performance [4-6]. Thus, to encounter this problem cold sprayed thermal coating technology has been utilized most frequently in recent time in order to produce numerous coating possessing superior qualities [7]. Cold spray (also known as cold gas dynamic spray, Kinetic spray or supersonic particle deposition) is an emerging low temperature particle deposition process which can be used as coating technology and also an additive manufacturing technology [8]. In this process high temperature of thermal spray is replaced by high velocity to produce dense coatings [3]. In cold spray process, a carrier gas such as air nitrogen or helium is used to carry powder particles which are accelerated through de Laval nozzle [9]. The carrier gas gets supersonic velocity (Mach number > 1) after passing through nozzle which further helps to propel the powder particles at very high velocity by momentum transfer principle [10]. Upon impact with the substrate, the particles experience extreme and rapid plastic deformation which disrupts the thin surface oxide films that are present on all metals and alloys. This allows intimate conformal contact between the exposed metal surfaces under high local pressure, permitting bonding to occur and thick layers of deposited material to be built up rapidly. Thus, cold spray is more of mechanical process unlike thermal spray.

2. EXPERIMENTAL PROCEDURE:

2.1 Selection and Preparation of Substrate Material.

GrA1 Boiler steel from Raichur Thermal Power plant was selected as substrate material and it was prepared to the required size of 75*25*5 mm (for cold spray). The chemical composition of substrate material is shown in Table 1.

2.2 Coating Powder and Deposition Techniques

The *70Ni-30Cr & 50Ni-50Cr* Cold spray coating was done at indigenously developed cold spray system. The parameters involved in cold spray coating are shown in Table 2. The thickness of coating over substrate is 100μm. The coated specimen was wire cut to the dimension of 25*25*5. The stand off distance between the nozzle exit and the substrate over which coating was done was set 40 mm while transverse gun speed was 32 mm/s. Four coated and uncoated sample of the above mentioned dimension was prepared for the jet erosion test.

Table 1: Nominal Composition of the Test Steel Specimen.

Substrate	ASTM code	C	Mn	Si	P	S	Cr	Fe
GrA1	ASTM SA210	0.2	0.93	0.5-1.0	0.025	0.035	0.055	Bal

2.3 Material Characterization

The physical dimensions of coated and uncoated specimens were measured using digital micrometer gauge. To access microstructure (SEM) and elemental analysis (EDS) the cold sprayed coating sample were prepared using standard metallographic procedure. The specimen were given mirror polish finish using emery papers followed by fine polishing using 3μm, and 1μm diamond pastes. Further, final finishing was given using 0.05μm silica. The characterization of surface morphology and microstructure of coating was done using SEM & EDS analysis (CMTI, Bangalore). The beam of electron used in SEM and EDS analysis was of 2kV.

The hardness of the coating and substrate was obtained using digital micro Vickers hardness tester (CMTI, Bangalore) using a load of 300g. The hardness of the steel substrate at the surface was found to be 169 Hv while the hardness of coated sample at the surface was found to be 400Hv for 70Ni-30Cr and 450 for 50Ni-50Cr coating. The X-ray diffraction (XRD) analysis of coating powder was done in Advanced Materials Research Centre, BMSCE, Bangalore. The XRD of Cold Spray coating powder was analyzed in X-ray diffractometer using copper source at a current of 30 mA and a voltage of 45 kV with scan step size(2θ) of 0.03° The deposition efficiency of the coating was calculated as the ratio of weight gain to the weight of powder sprayed and was found to be 70%.

Table-2: Parameters of Cold Spray Process

Parameters	Specifications
Gun Pressure	12 bar
Temperature	400°C
Carrier Gas	Compressed Air
Gas Flow Rate	1.96 m^3/min
Heat Power Source	30 kW
Coating Thickness	100μm

Table-3: Parameters on Jet Erosion Test

Parameters	Specifications
Impact/particle velocity	40 m/s
Angle of Impingement	30°,90°
Nozzle Diameter	1.5 mm
Sample Size	25*25*5
Temperature	400C
Erodent Material	Silica
Erodent Feed Rate	5 g/min
Air supply pressure	0.15 MPa
Erodent Size	50μm

2.4 Jet Erosion Test

Erosion wear test of these coatings were investigated using Air Jet erosion test Rig (As per ASTM G76) in DUCOM, Bangalore. For erosion study, only a small area of the sample was exposed to particle erosion, while the rest of the sample was wrapped in polyester tape, which allows impact of particle only in the exposed area. The specimen were given mirror polish finish using emery papers followed by fine polishing using 3μm, and 1μm diamond pastes before it was subjected to jet erosion test. Fine size silica particles of size 50μm were eroded over the specific exposed area for specific amount of time. The velocity of erodent particle was found 40 m/s using air pressure of 0.15 MPa in nozzle. The nozzle diameter was 1.5mm. The erosion test unit was turned on and the stand off distance between the nozzle exit and the substrate over which coating was done was set 20 mm for jet erosion test. The impact angle on the specimen was kept 30° and 90° and was adjusted by turning the alignment of sample holder.

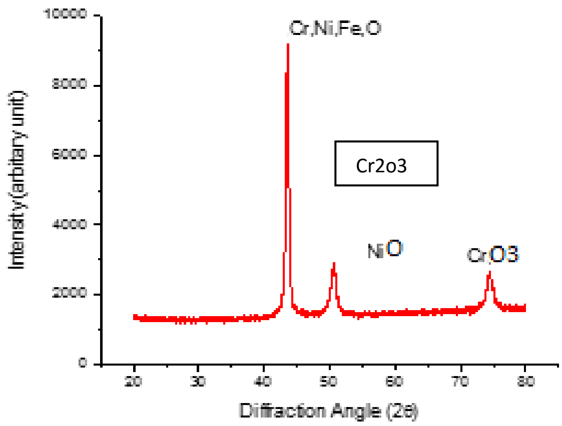
High temperature erosion wear test were performed on all the samples at a constant temperature of 400°c till steady state erosion was achieved. The samples after the end of the test were subjected to air blasting to remove the entrapped silica particles on the eroded surface. Furthermore, the tested specimen was properly cleaned with acetone, dried and weighed using an analytical balance with high resolution. The difference between the weight of specimen before and after the test gives the loss of material or weight loss due to erosion. The specifications of various parameters involved in jet erosion test are shown in Table 3.

3. RESULT AND DISCUSSION

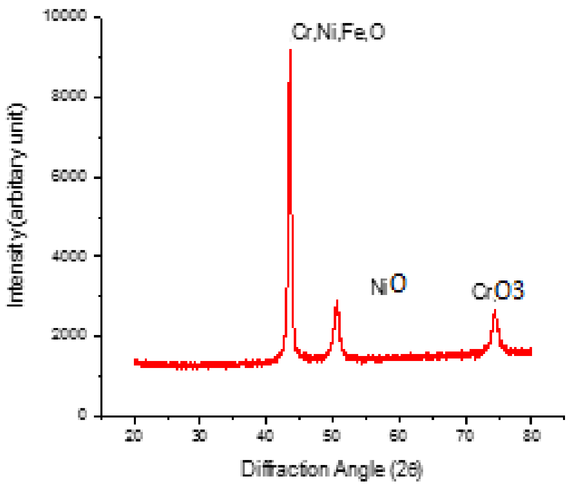
3.1 XRD Analysis of Cold Sprayed Coatings:

The XRD analysis of cold sprayed coatings is shown in fig.1 and fig.2 respectively. The XRD pattern of both the coatings before the erosion test clearly shows the absence of oxygen. This indicates no any oxides have been formed on the coatings during cold spray unlike conventional coating technology. However, oxides of nickel and chromium are formed for both coating powder after jet erosion test at 400°C.

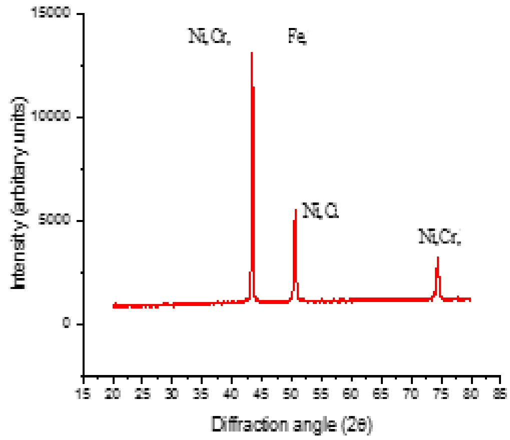
(a)



(a)

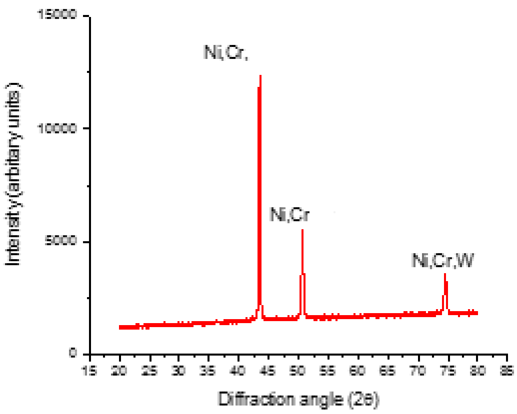


(a]



(b)

Fig -2. XRD profiles of Coating powder 2 (a) after erosion test (b) before erosion test



(b)

Fig.1. XRD profiles of coating powder 1 (a) after erosion test (b) before erosion test

3.2 Micro hardness:

The profiles of microhardness along the cross section of both the coatings are shown in the fig 3 as a function of distance from coating substrate interface. The graph clearly reveals that the hardness of coating is higher compared to the substrate and there has been a clear improvement in the hardness of material due to coating. The peak value of microhardness of the coatings was found to be 400 Hv and 450 Hv respectively.

3.3 SEM and EDS Analysis

1) Before Jet Erosion.

To study surface morphology of cold sprayed coatings, SEM was done. The SEM micrograph of cold sprayed coatings are shown in fig. 4. The surface seems to be irregular and uneven along with some evident presence of voids. There has been a change in original round morphology of the particles. It is because of deformation of the particles which is particularly due to high impact energy involved in cold spray process. From the EDS analysis, no any significant change in the composition of deposition was observed. Elemental composition of coating deposition after cold spray is shown in fig 4 and was found to be almost similar to that of the coating powder.

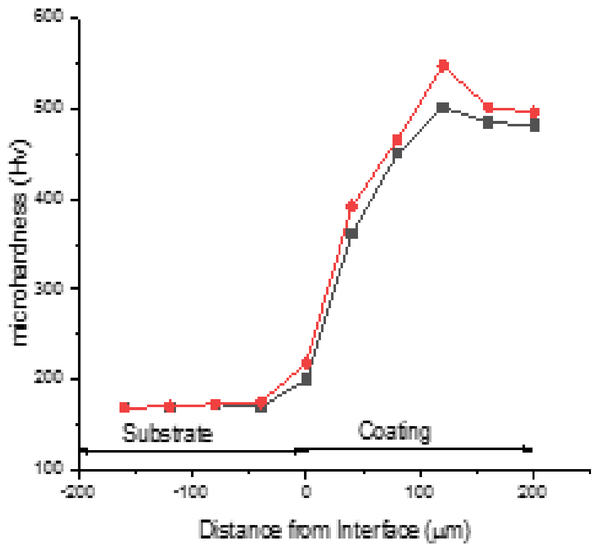
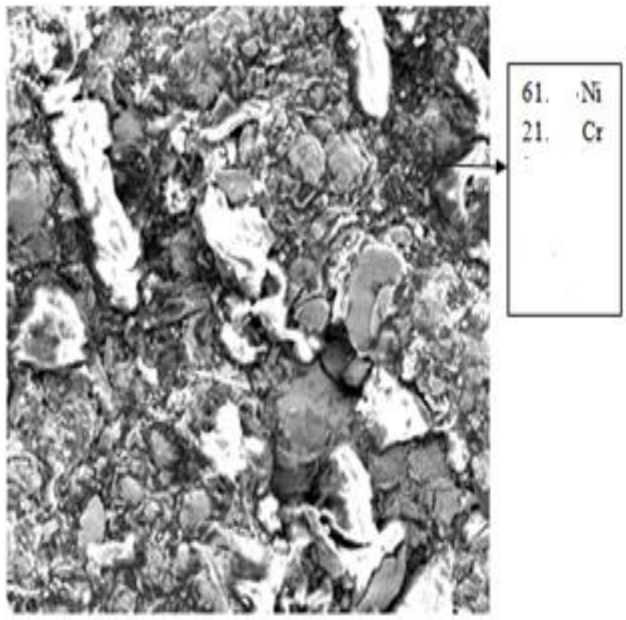
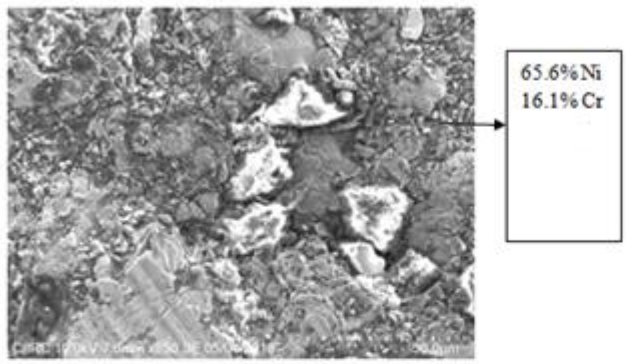


Fig-3. Microhardness profiles of cold sprayed Coating.



(a)



(b)

Fig-4. SEM image of cold spray coating deposition before erosion

2) After Jet Erosion

The SEM analysis along with elemental composition from EDS of the jet eroded coated samples for the impact angle of 30° and 90° is shown in the fig 6. Analysis of worn out surface clearly shows the craters and lips. (fig 6). Impact angle of 30° causes oblique/angular impact while impact angle of 90° causes normal impact. Formation of the craters and lips is the typical characteristics feature of ductile erosion for which erosion rate is the function of impact angle [11]. At normal impact, deformation scratches were observed due to plastic deformation and even material removal at higher magnification. However, at an oblique impact cutting action along with scooping a chip out of the surface was predominant. Embedded erodent particles (silica) were observed more frequently on the surface of samples at an impact angle of 90° compared to samples at an angle of 30° (fig 6).

3.4 Erosion Wear Analysis:

The steady state erosion rate for both coated and uncoated specimens are shown in the column graph (fig 5). The erosion rate for bare specimen was much higher compared to that of coated specimen. The erosion behaviour for both impact angles was similar. However, the erosion resistance of normal impacted specimen was higher than oblique impacted specimen. It might be due to more fractions of erodent particles (silica) embedded in the normal impacted specimen compared to oblique impacted specimen. The more frequent deposition of silica on the 90° eroded surface imparts better shielding effect against further impact. This is the factor that explains the dependence of erosion rate on the impact angle for the ductile materials. The better erosion resistance of the coating material over the bare ones at high temperature is due to formation of thin film oxide over the substrate that prevents the further contact with the atmosphere.

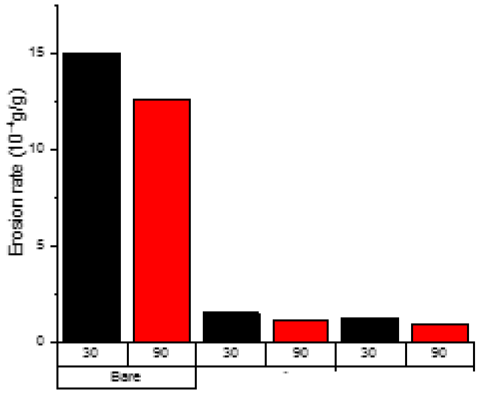
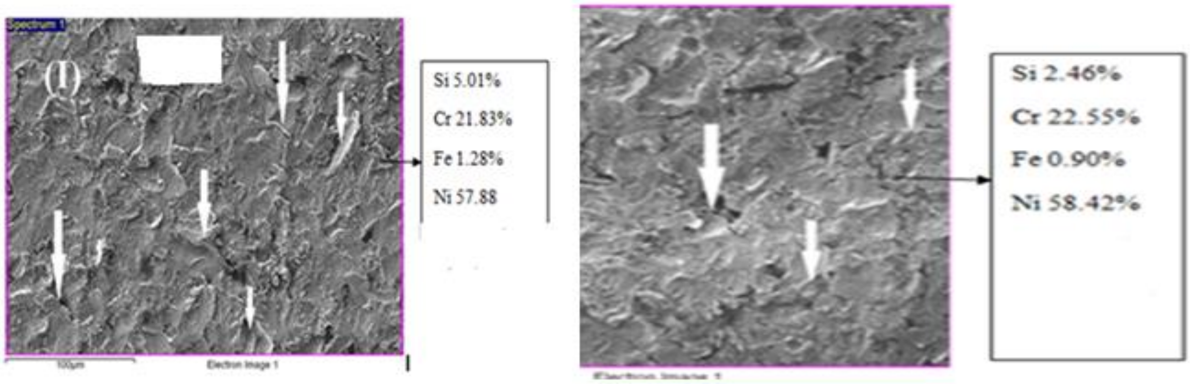


Fig-5. Column diagram illustrating steady state erosion rate



(a) (b)

Fig-6. Surface Morphology of Eroded samples at an impact angle of (a) 90° (b) 30°

4. CONCLUSIONS

At the end, following points summarizes the research conclusion

1) Cold spray process was used to deposit powder over the GrA1 boiler steel substrate successfully.

2) The coating deposit over the substrate was found to be free from oxide. Thus, cold spray process proves to be an effective coating technique as the properties and composition of coating remains intact.

3) The Erosion rate for the given coatings are dependent on impact angle and is more for the oblique impact angle (30°) than the normal impact angle (90°).

4) The cold sprayed coatings of the given powders provided better erosion resistance at high temperature (400°C) than the bare boiler steel substrate.

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