CHARACTERISATION AND BEHAVIOUR OF AlCrN NANO-COATINGS DEPOSITED ON SS316WITH RESPECT TO EROSIVE WEAR

Jasmaninder Singh Grewal[1],Saravjot Singh[2]
[1]Professor and Head of Department, [2]Student
Production Engineering Department
Guru Nanak Dev Engineering College, Ludhiana – 141006, Punjab, India.

Abstract:The power generating plants often experiences the downtime because of the erosion-corrosion in the boiler tubes generally made up of boiler steels in coal based boilers. Replacement and repairing of these tubes is a time consuming process and also quite expensive. After studying the literature it has been observed that nanostructured erosion preventive coatings is the one of the cheaper and effective solution in preventing the erosion of boiler tubes. In this research two different types of coatings namely AlCrN-monolayer and AlCrN-multilayer coatings have been deposited on SS316 using Physical Vapour Deposition (PVD) process. A very uniform layer of these coatings were successfully deposited on the substrates of SS316. These coatings were deposited at a temperature range of 450-500°C. Different properties of the substrates such as roughness of the surface, thermal behaviour, hardness of the coatings and porosity were analysed. The prepared samples were analysed through X- Ray Diffraction (XRD) and Scanning Electron Microscopy/Energy Dispersive Analysis X- Ray (SEM/EDAX) to study the properties of the surface. The aim of this research work is to advance the surface properties of prepared samples to reduce the amount of erosive wear and thus increasing the life. Both uncoated and as-coated substrates were tested in simulated environment by impinging erodent particles at angle of 30° and 90° with a flow rate of 3 g/min. The worn out substrates were again analysed through SEM/EDAX to study the change in properties of the surfaces after experimentation.The rate of erosion was calculated w.r.t loss in weight of the worn out substrates. The substrates coated with multilayer AlCrN coatings experiences lesser erosion of material from the surface than the substrates coated with monolayer coatings as well as uncoated substrates.

***Index Terms*: Erosion-Corrosion, PVD, SEM/EDAX, Erosive test, XRD, Impingement angle, AlCrN based monolayer and multilayer coatings.**

1. INTRODUCTION

In today's world where the focus is on to use the non-conventional sources of energy, most of the world's total power is generated with the help of conventional sources of energy like fossil fuels and biofuels. Coal is one of the major fossil fuel which is used to produce the 80% of world's total power demand. On burning coal large amount of non-combustible and harmful particles are produced which affects the different components of the thermal power plants. Boiler tubes, super-heaters, economizers are the different components which are mostly affected due to these burnt particles [1-3]. Burning of coal produces large amount of ash particles which consists of silica and alumina particles. These particles are generally hard which causes erosion of boiler tubes further leading to reduction in power generation due to failure of components [4-8]. This eroding of surface from the components is known as erosive wear.

Generally ash is produced in thermal plants when coal is burnt and get settled on the surface of boilers and other components of the system. This manuscript basically deals with the peculiar type of wear named as erosive wear. The ash particles produced in the boilers are very hard and on hitting the surface of components, it produces contact stresses because these particles strike the surface at very small area. But the force exerted by the particles on striking is very large and it removes the material from the surface. This removal of material is generally because of friction generated when ash particles strike the steel parts of the boilers. High temperature is also a major factor other than ash particles responsible for failure of boiler components [9, 10].

Different types of methods are used to limit the damage caused by erosive wear such as electroplating, galvanizing, plating of nickel and chromium and many more. But these methods have very adverse effects on the environment and to the workers also [11].Apart from these old traditional methods thermal spray coatings are widely used but they do not provide much protection because of very thin layer of coating of about few hundred µm. This thin layer is not able to protect the surface of components perfectly [12, 13]. Thermal spray coatings has many limitations as they provide poor surface finish due to which cracks in the microstructures has been observed by various researchers. The poor surface finish of these thermal coatings further increase the erosive wear.

In recent times a new technique of depositing the coatings has been developed namely Physical Vapour Deposition(PVD). This technique is capable of depositing a very uniform layer of nano structured coatings. Monolayer and multilayer coatings can be deposited through PVD process where multilayer coatings possess higher strength and perform better at high temperature conditions as compared to monolayer coatings [14, 15]. So two AlCrN based monolayer and multilayer coatings have been selected for this work.

II. MATERIAL AND METHODS

2.1 Selection of substrate material

AISI 316 boiler steel has been selected for this research work to improve the problem of erosive wear as it is widely used in the boiler tubes and heat exchanger tubes. Nominal and actual chemical composition of SS316 has been compared with the help of Atomic Emission Spectrometer (AES-DV4) at Research and Development Centre for Bicycle and Sewing Machine, Ludhiana

Table 1:Chemical Composition (Weight %) of the SS-316 Steel Substrate

SS316	C	S	P	Si	Mn	Cr	Ni	Mo
Nominal	<0.08	<0.030	<0.045	<1.00	<2	16-18	8-12	2.00-3.00
Actual	0.07	0.015	0.021	0.464	1.59	17.45	11	2.5

Specimens for this work were prepared from rectangular strip of SS316 of different sizes i.e. 25*25*6 mm and 25*20*6 mm. Specimens were cut with the help of diamond cutter and after that polished with the help of different emery papers to achieve a super finish of about of 0.016 µm so that coatings can be uniformly deposited on the prepared specimens.

2.2 Deposition of Coatings

AlCrN based monolayer and multilayer coatings were successfully deposited on prepared substrates of different sizes with the help of DC Magnetron Sputtering PVD (Physical Vapour Deposition) process. The coatings were deposited at Oerlikon Balzers Coating India Pvt Ltd., Manesar, Gurugram. Coatings deposited on the prepared samples are named as BAILINIT ALCRONA PRO and BAILINIT ALTENSA. Table 2 shows the process parameters selected to deposit the coatings onto the prepared substrates.

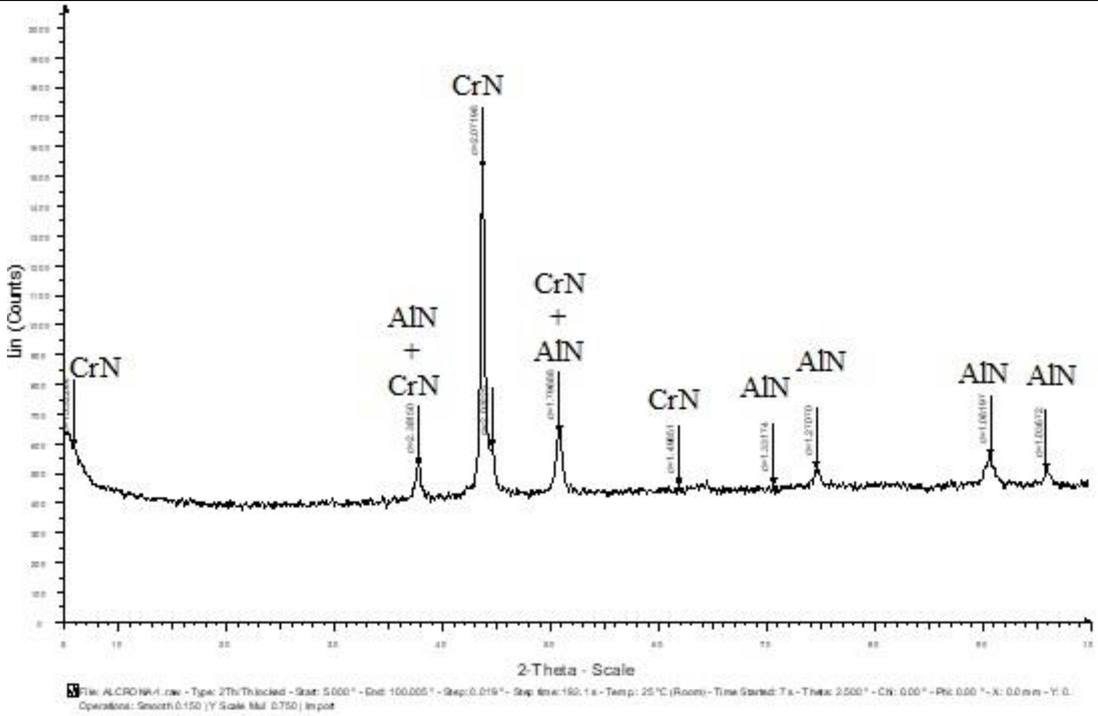
Table 2:Summary of Nanostructured thin coatings deposition parameters

	AlCrN (monolayer)	AlCrN (multilayer)
Type of machine	Inlinea BAI 1200 XL	RCS – Rapid coating system
Make	Oerlikon Balzers	Oerlikon Balzers
Coating deposition temperature(°C)	450	480-500
Pressure in vacuum chamber (mbar)	10^{-3}	10^{-3}
Target	Al and Cr	Al,Ti and Cr
Cycle time(h)	8-10	8-10
Micro-hardness(HV)	3200	3400
Max. service temperature(°C)	1100	>1100
Coating thickness(µm)	2-6	6-12

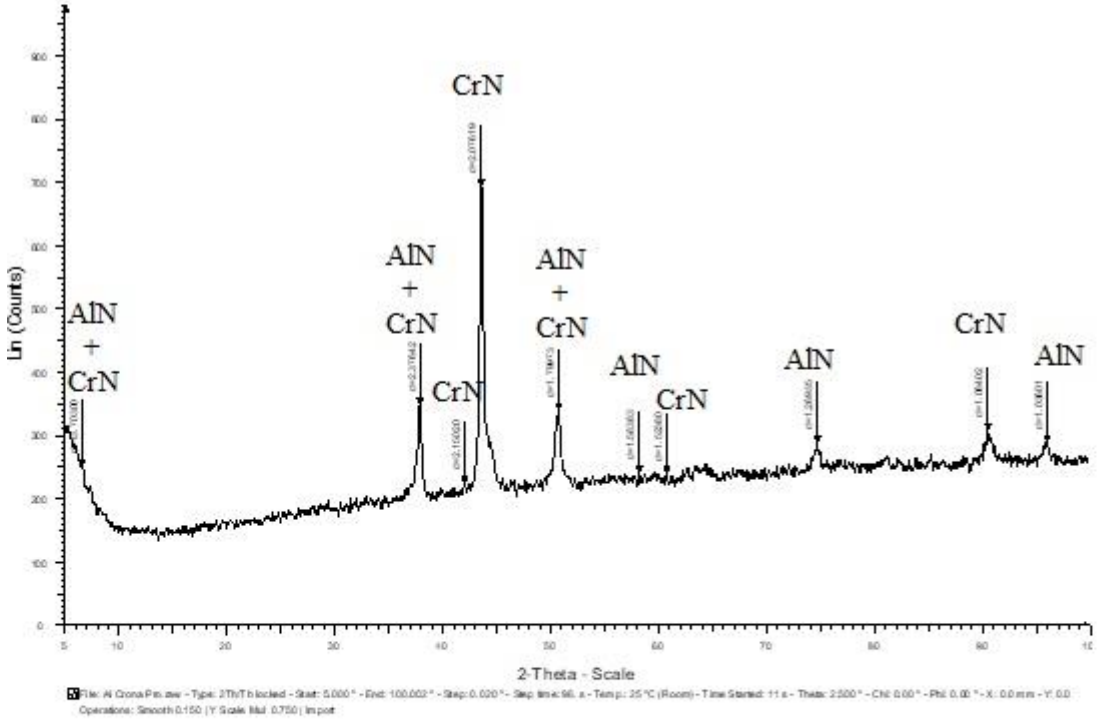
2.3 Characterisation of coatings

2.3.1 XRD Analysis

Successfully depositedcoatings were visually examined with the help of photographic camera and colours of coatings were recorded as well as visually analysed.Optical macrographs of coated specimens were taken with hep of Image analyser fitted with inverted microscope at magnification of 100X. The as coated specimens were examined through XRD (X-Ray Diffraction) to analyse the different elemental phases present on the surface of coated substrates. The patterns of XRD were obtained by a Bruker AXS D-8 Advance Diffractometer with Cu K (alpha) radiation and nickel filter at 30 mA under voltage of 40kV which is available at IIT, Roorkee. The specimens were scanned with a 2.2 kW Copper K (alpha) anode at a speed of 20 min^{-1} and at an angle ranging from 20°-120°. The‘d’ values were calculated from the XRD patterns with the help of attached EVA software.



1(a) Monolayer



1(b) Multilayer

Fig. 1: XRD patterns of substrate coated with Monolayer AlCrN and Multilayer AlCrN coating

2.3.2 SEM/EDAX Analysis

Surface morphology of the coated specimens were analysed with the help of SEM/EDAX (Scanning Electron Microscopy/Energy Dispersive X-Ray) equipment. It generates SEM micrographs along with the energy dispersive spectrum to check the elemental composition of two different coatings deposited on the substrates as shown in Figure 2(a) and Figure 2(b). It shows that coatings deposited on the substrates are uniform, homogeneous and surface of substrates are free from any kind of cracks.

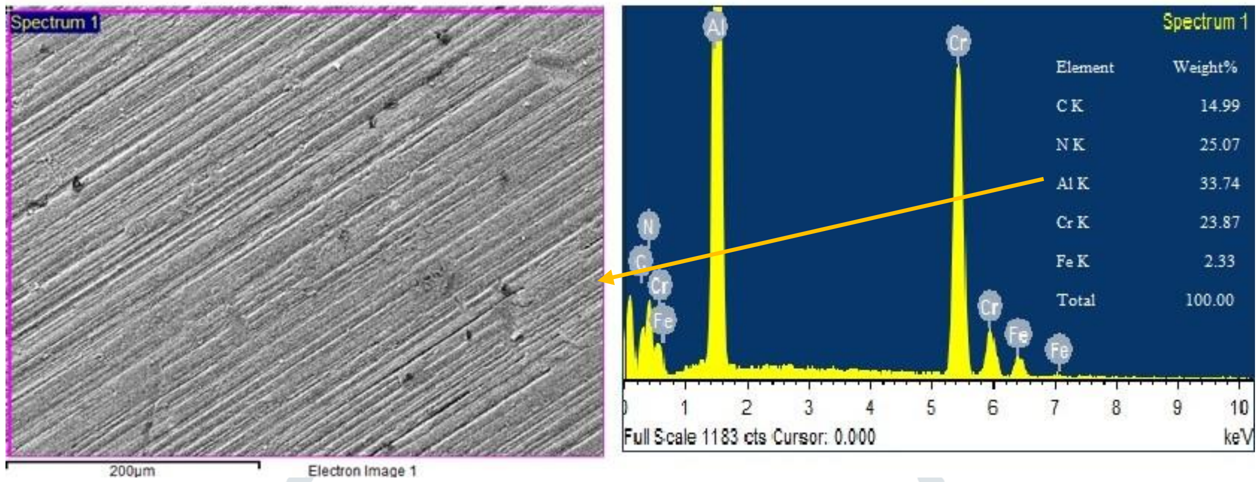


Fig. 2(a)

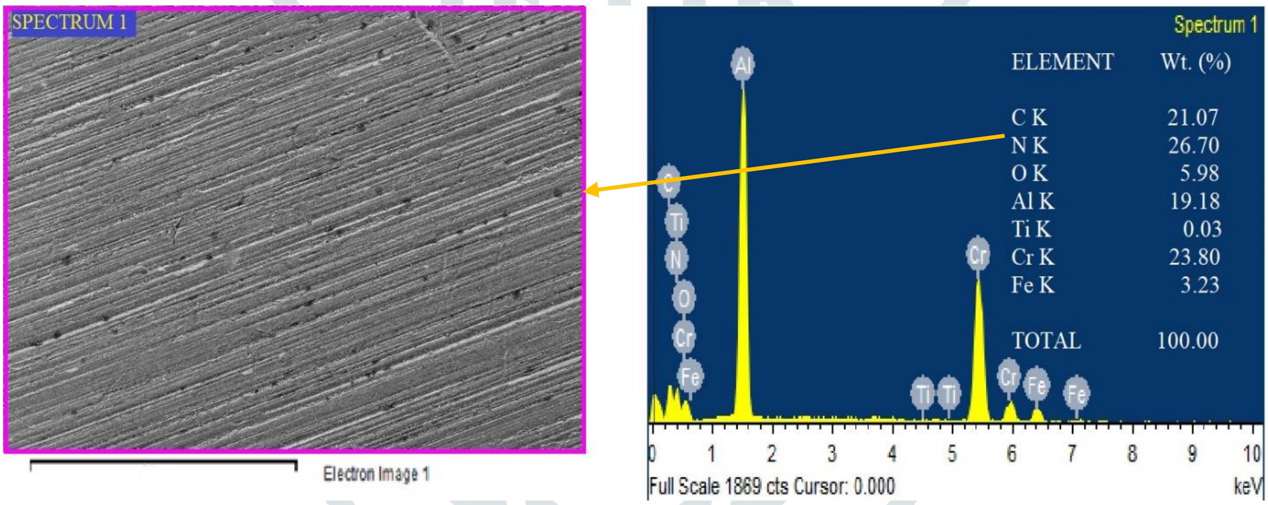


Fig. 2(b)

Fig. 2: Representation of elemental composition of AlCrN monolayer and multilayer nano-coatings

2.3.3 Surface Roughness

Mitutoyo SJ-410 equipment was used to measure the surface roughness (R_a) value of the coated and uncoated substrates. Surface roughness of uncoated specimens was recorded to be 0.016 µm and that of monolayer and multilayer coated specimens was recorded to be 0.149 µm and 0.080 µm respectively. Porosity of substrates were analysed with image analyser fitted with inverted microscope. Porosity of uncoated sample was found to be about 1% and that of monolayer and multilayer coated specimens was found to be less than 0.5 %.

2.3.4 Thermal Analysis

Uncoated and coated specimens were tested using DSC (Differential Scanning Calorimeter) to analyse the thermal properties. Each substrate was tested for about 1 hour 5 mins which includes heating and cooling cycle of 32.5 minutes each. Heat vs temperature graph as shown in Fig 3 shows that monolayer (Alcona Pro) coated sample absorb more amount of heat energy as compared to uncoated and multilayer (Altensa) coated samples. It can be concluded from that monolayer (Alcrona Pro) coated samples are thermally more stable than the other samples.

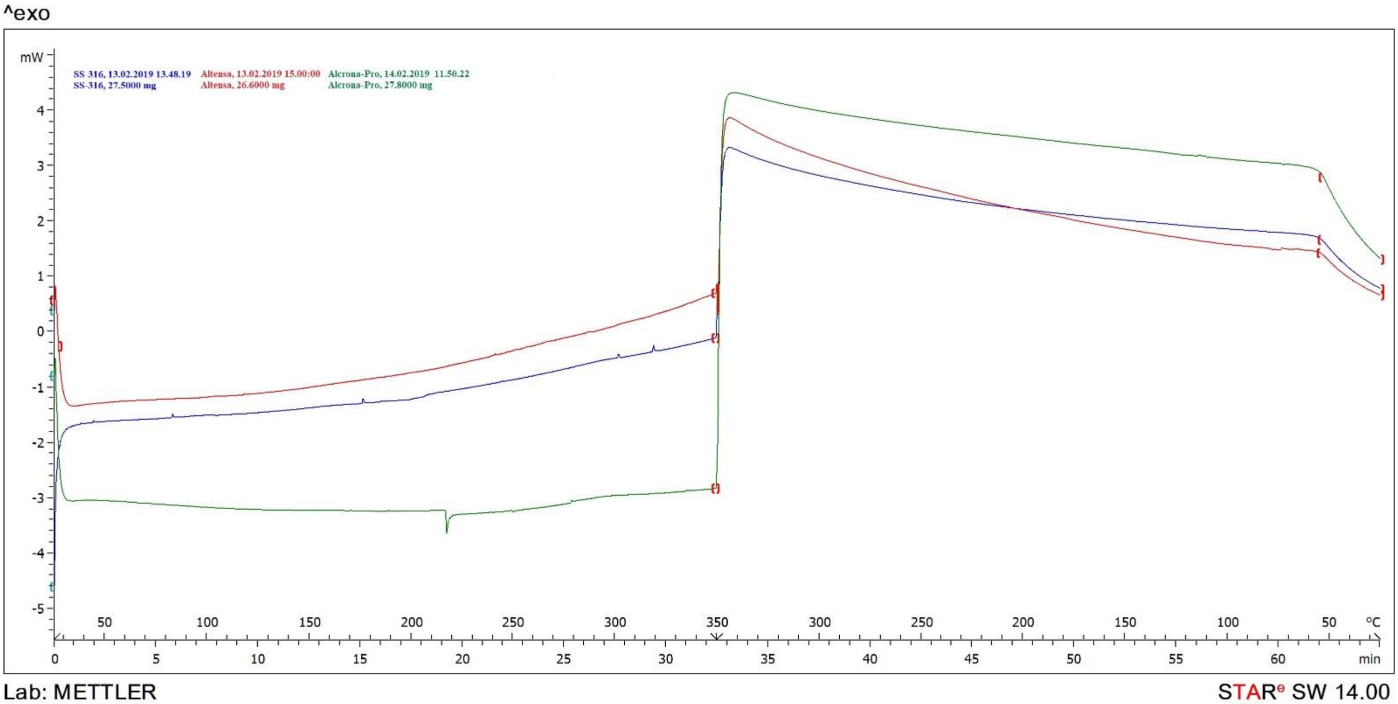


Fig. 3**:** Thermal Analysis of Uncoated and as coated substrates

2.4 Selection of Erodent and Impact Angle

In boilers of thermal plants lot of fly ash is produced on burning of coal which mainly consists of large amount of silica and alumina particles along with ferrous oxide particles. These particles are responsible for the erosion of material of the components of the boilers. Since most of the researchers have used silica as the erodent particles to improve the functioning of components against erosive wear so Alumina (Al_2O_3) particles have been selected to impinge on the substrate surface in stimulated boiler environment.

The erosive wear of the components basically causes two different kinds of failures namely brittle and ductile. The erodent particles generally strike the surface at angles. This striking angle generally varies from 0-90º. The chances of brittle type of failure increases with increase in the striking angle of erodent particles and chances of ductile failure is maximum between angles of 20-º. So for this research work two angle i.e. 30º and 90º has been selected to impinge the particles on the substrate surface at a flow rate of 3g/min.

The erosive test on the uncoated as well as coated substrates was performed on Ducom Air Jet Erosion Tester at Guru Nanak Dev Engineering College, Ludhiana. Figure 3 shows the schematic diagram of air jet erosion tester rig. Conditions of boilers were stimulated in the tester by setting the temperature of the temperature of sample at 400°C and temperature of air was set to be at 800°C. Each sample was tested for 3 hours by striking the erodent particles at two different 30º and 90º at a flow rate of 3g/min. All process parameters are given in Table 3.

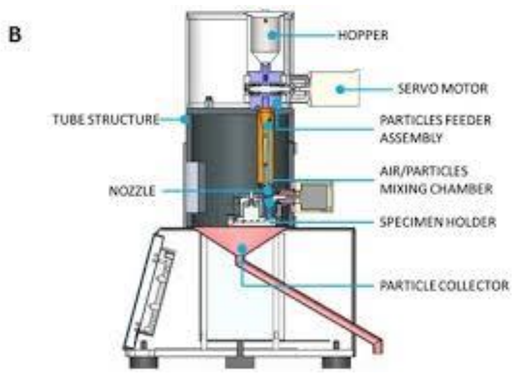


Fig. 4: Schematic of Air jet erosion tester

Table 3 Erosive Test Parameters

Erodent	Alumina(Al_2O_3)
Size Of Particle(µm)	50
Erodent Flow Rate(g/min)	2&3
Impact Angle(°)	30&90
Temperature of air(°C)	800
Specimen temperatre(°C)	400
Time (h)	3h per sample

III. Results and Discussion

3.1 Visual Examination

On examining the coated substrates under the inverted microscope it was observed with the help of macrographs that monolayer coatings looks dark greyish in appearance and multilayer coatings look light greyish in appearance. After performing the erosive test on the coated as well as uncoated substrates it was observed that craters were formed on the surface of the substrates. Depthness of craters were found to be more in case of uncoated substrates due to absence of any protective layer on it. Craters of monolayer coated substrates were shallower as compared to uncoated substrates and craters of multilayer coated specimens were further shallower than monolayer substrates.

Interestingly shape of craters depends upon the angle of impingement of the erodent particles. When the erodent particles were impinged at 90º,craters formed were round in shape and this shape changes to elliptical when particles were impinged at 30º. It was noticed that craters formed on coated specimens were rough as compared to those of uncoated specimens because of the coating present on the surface of the substrate.

3.2 SEM/EDAX of worn out samples

All worn out samples were examined through SEM/EDAX analysis and macrographs of each specimen was obtained. The macrographs of worn out uncoated SS316 specimens at both impingement angles shows that cracks were formed and even erodent gets embedded on surface. The macrographs suggests that material removal occurs because of the ploughing action of erodent particles impacted at different angles. Impingement of particles causes ploughing action which removes the material from the surface. The particles of erodent when strike the surface of components and pushes the material and erodent particles gets embedded into the surface which causes formation of craters.

When the macrographs of AlCrN based monolayer substrates were examined it was found that coating at the centre of crater formed is eroded because of impingement of erodent particles at different angles. Also it was observed that few traces of coatings were present on the sides of craters. These craters were formed due to impacting of particles at different angles for 3 hours.

On obtaining macrographs of AlCrN based multilayer coated specimens it was found that erodent particles causing cracks. It also shows the presence of particles of erodent on the surface. It has been found that very little amount of coating is present at the centre of craters which means it has protected the substrate from the erodent. Further EDAX analysis confirms that AlCrN multilayer coatings performs better than the AlCrN monolayer coatings irrespective of impingement angle. The results of SEM/EDAX are show in Future 5and Figure 6 respectively.

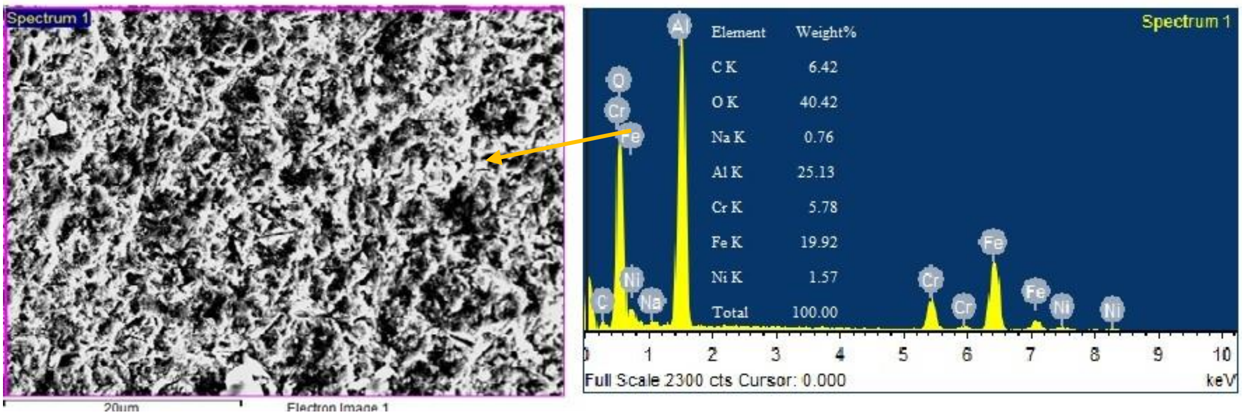


Fig. 5(a)

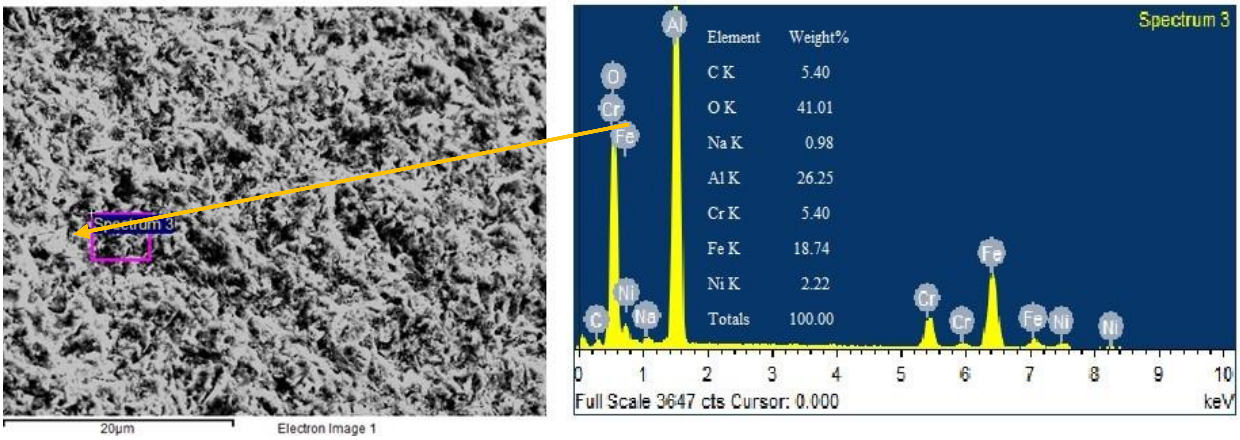


Fig. 5(b)

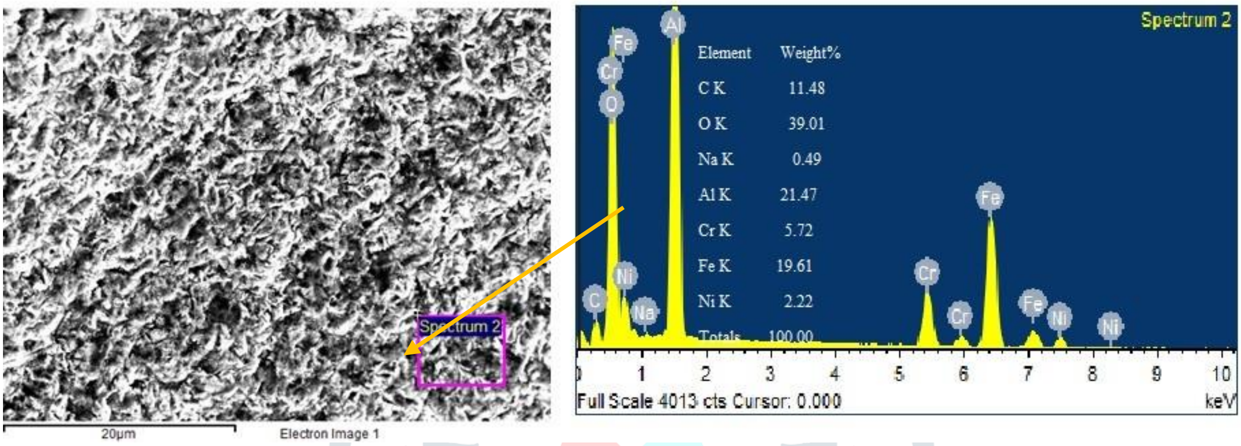


Fig. 5(c)

Fig. 5: SEM/EDAX analysis of samples eroded at 90° and 3 g/min
(a) Uncoated (b) monolayer (c) multilayer

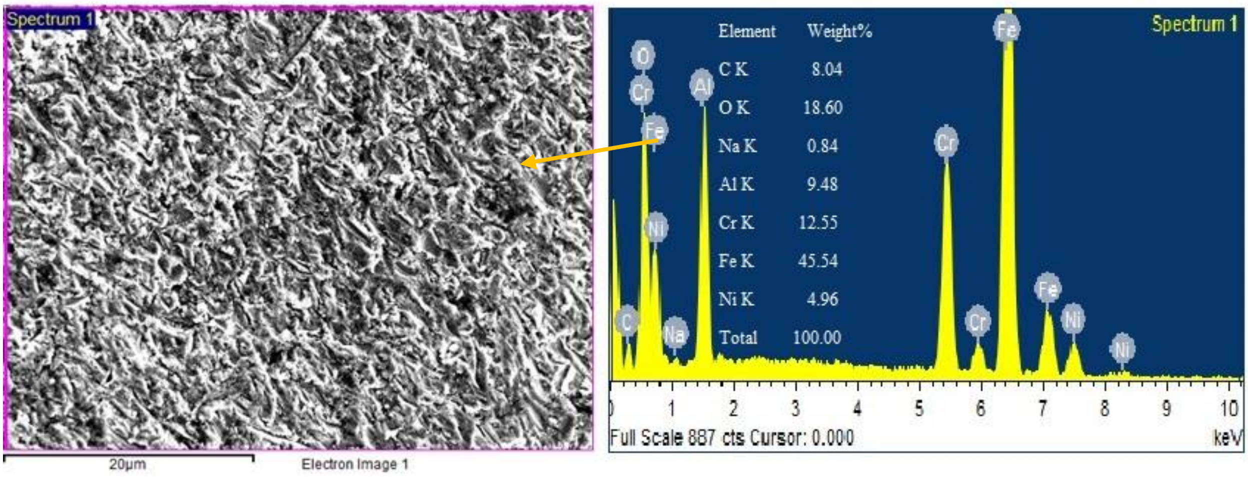


Fig. 6(a)

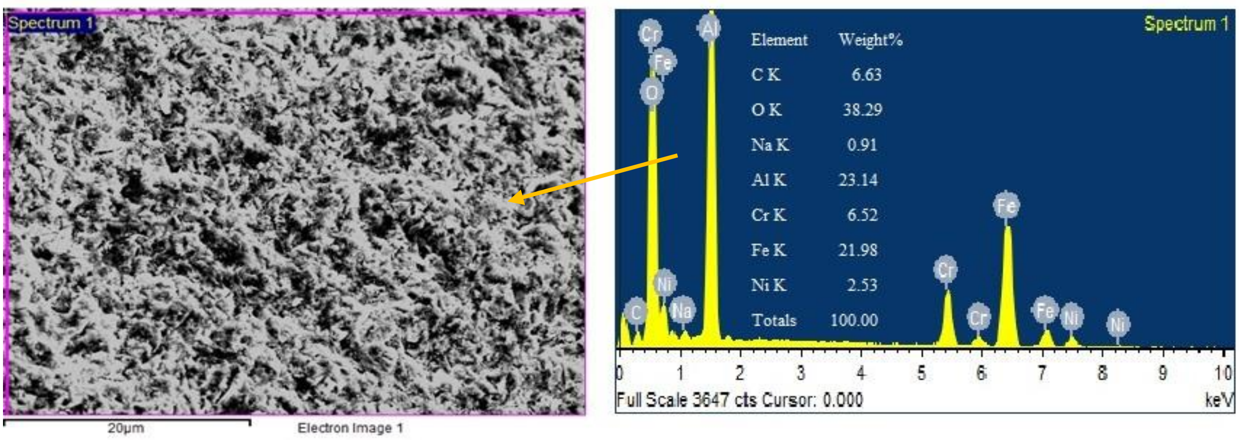


Fig. 6(b)

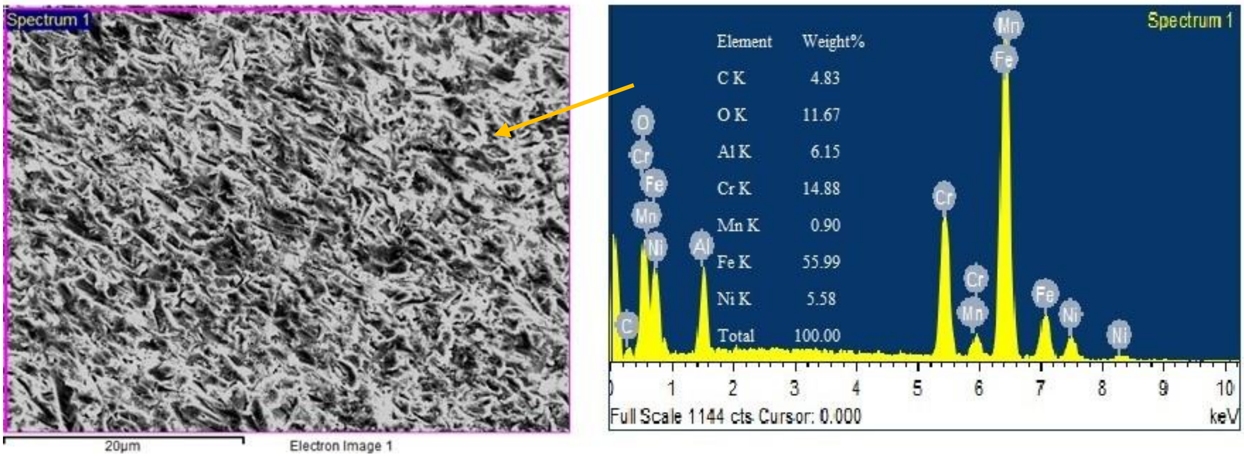


Fig. 6(c)

Fig. 6**:** SEM/EDAX analysis of samples eroded at 30° and 3 g/min
(a)Uncoated (b) monolayer (c) multilayer

3.3 Weight loss of worn out samples

When the samples were eroded in the air jet erosion tester by continuously impinging the erodent particles on the surface of the coated as well as uncoated substrates it leads to erosion from surface of samples. Fig 7 shows the weight loss of uncoated as well as coated samples at different impingement angle. It was observed that maximum weight loss occurs in case of uncoated substrates irrespective of the angle at which erodent particles were impinged. It is evident from the weight loss chart that maximum erosion occurs at 30º which is the reason of maximum failure of components due to ductile fracture of the surfaces.

While among coated substrates multilayer coating i.e. Altensa comes out to be best in prevention of surface from erosive wear in both cases i.e. at 30° as well as at 90°. AlCrN based multilayer coatings i.e. Altensa comes out to be hardest coating due to presence of oxides on surface of coatings. These oxides are the major reason which make difficult for erodent particles to remove the material from the surface of the substrates.

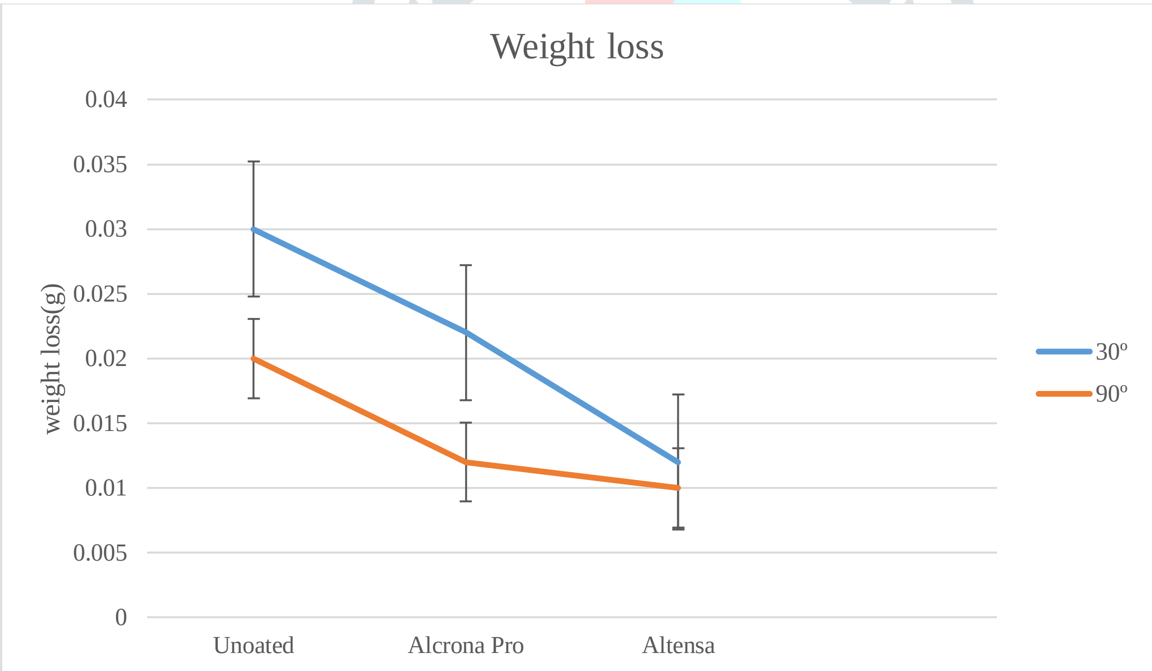


Fig. 7: Comparison of weight loss at different angles

IV. CONCLUSION

This phrase represents the conclusions made after the experimentation on coated and uncoated samples. AlCrN based monolayer and multilayer coatings were successfully deposited on the SS-316 substrates and their erosive rate w.r.t weight loss was recorded and their observations are recorded as follows:

- AlCrN based monolayer coatings deposited on the SS-316 substrates were found to dark grey in appearance and AlCrN based multilayer coatings were found to be light grey in appearance.
- Porosity of coated samples was found to be less than 1% which shows that coatings were evenly and uniformly deposited on the substrates ultimately leading to less erosive wear.

- Hardness of multilayer coatings was found to 3400 HV and that of monolayer coatings was found to be 3200 HV whereas thickness of coatings was found to be order 4-12 µm.
- As wear loss is inversely proportional to roughness of surfaces, values of surface roughness of monolayer coatings (R_a= 0.149µm) and multilayer coatings (R_a= 0.080 µm) suggests that multilayer coatings will have less wear rate.
- Experimentation results of erosive wear test were recorded and it is concluded that wear loss was maximum at 30° angle of impingement with 3 g/min flow rate.

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