ISSN 2349-6193
Impact Factor (PIF): 2.805

IJESMR

International Journal OF Engineering Sciences & Management Research

EXPERIMENTAL INVESTIGATION OF NICKEL ALUMINIDE (NI3AL) NANOSTRUCTURED COATED ECONOMISER TUBE IN BOILER

*** Gokulakannan A, Karuppasamy K**
*PG Student ,Department of Mechanical Engineering, ANNA University Regional Campus, Tirunelveli, Tamilnadu, India
Assistant Professor, Department of Mechanical Engineering, ANNA University Regional Campus, Tirunelveli, Tamilnadu, India

DOI: 10.5281/zenodo.57204

KEYWORDS: Corrosion Resistant Coating, PVD, XRD, SEM and Microhardness.

ABSTRACT
Thermal Power Stations all over the world are facing the problem of boiler tube leakage frequently. The consequences of which affects the performance of power plant and huge amount of money loss. Hot corrosion and erosion are recognized as serious problems in coal based power generation plants in India. The maximum number of cause of failure in economizer unit is due to flue gas erosion. The corrosion resistant coatings used conventionally are having some limitations like degradation of the coatings and improper coatings which may lead to pitting corrosion. The nano composite corrosion resistant coating can overcome this problem.Corrosion prevention by the use of nanostructured coatings for separating material from the environment is gaining importance in surface engineering. In this present investigation have attempted to suggest a probable solution for reduction of erosion in economiser zone and its analysis using nano structured coating analysis. In Physical Vapour Deposition (PVD) coating method is used to coated the Economiser tube in boiler. The erosion – corrosion behavior of nanostructured coating on SA210GrA1 steel under actual boiler environment is evaluated. The Nickel Aluminide nanocomposites are characterized using XRD, SEM and EDX.

INTRODUCTION
The power plants are facing the problem of boiler tube leakage it is more critical when they are running on full load. It becomes one of the critical reasons among numerous reasons of the energy crisis. In most of the thermal power station, coal is burnt to convert water into steam which has been expanded through a turbine for the generation of electricity. Coal is a complex fuel that contains varying amount of sulphur and a substantial fraction of non-combustible mineral constituents, commonly called ash [1]. The coal used in Indian power stations contains ash (about 50%), consisting of abrasive mineral species (hard quartz up to15%) which cause erosion of tubes [1]. During the combustion of coal, the mineral matter is transformed into fly ash, which is deposited on heat transfer surfaces of boilers. Accumulation of these deposits on the boiler tubes inhibits the heat transfer which is known as slagging or fouling. The heat transfer tubes of the boilers used in thermal power plants are subjected to intolerable levels of surface degradation by means of the combined cause of erosion–corrosion mechanism, ensuing in the tube wall thinning and untimely failure [2]. Boiler tubes have limited life and can fail due to various failure mechanisms. Tube failures are classified as in-service failure in boilers. These failures can be grouped under six major causes:

- Stress rupture
- Fatigue
- Water side corrosion
- Erosion
- Fire side corrosion
- Lack of quality

Erosion is a process in which material is removed from the surface layers of an object impacted by a stream of abrasive particles. Factors influencing fly ash erosion in coal fired boilers are

- The velocity of flue gas
- The temperature of flue gas
- The mineral content in coal

IJESMR
International Journal OF Engineering Sciences & Management Research

- The arrangement of pressure parts
- Deviation from design condition

High temperature surface oxidation and erosion by the impact of fly ash and unburnt carbon particles are the main problems in coal fired boilers. Therefore, the development of erosion resistant and high temperature oxidation protection systems in industrial boilers is a very important topic from both engineering and economic point of view [3]. Thermal spray coating of heat transfer tubes which are exposed to fireside of the coal fired boiler is one of the possible methods to reduce tube thinning. Numerous types of thermal spray coatings are commonly used in boilers including nickel−chrome,TAFA 95MXC, iron−chrome, and Inconel 625 [4]. In thermal spray industry, a considerable attempt has been taken towards the development of nanostructured coatings, although none of these materials have been developed to the level where they can be economically used in boilers. Two approaches have been commonly used to produce nanostructured coating: the first approach is to start with a heavily deformed mechanically milled micron-sized powder that has a nanoscale-structure and the second approach relies on direct spraying of nano-powder precursors on the substrate [4]. Preparation of nanostructured feedstock powders is the initial step for the synthesis of nanostructured coatings. A number of routes that are capable of producing nanostructured materials include mechanical alloying/milling, gas condensation, thermo-chemical technique, spray conversion processing, vapour deposition, sputtering, electro-deposition, crystallization of amorphous alloys and sol–gel processing techniques [5]. Of these methods, only mechanical milling and thermo-chemical techniques have been used to produce huge quantities of nanostructured materials for possible commercial applications [6]. Thermal spraying of mechanically milled feedstock powders has been used as a means to produce nanocrystalline coatings having superior properties compared to conventional coatings [7−15]. WU et al [16] studied the cycle oxidation resistance of high velocity oxy-fuel (HVOF) sprayed nanostructured Ni60−TiB2 composite coating at 800 °C with static air sprayed by high velocity oxygen fuel spray method. In the earlier study [16], the nanostructured composite coating exhibited better cycle oxidation resistance than the conventional composite coating. In the present work deals with the preparation of Nickel Aluminide (Ni_3Al) nano composites coatings using physical vapour deposition process on boiler tube(Economiser) and the coated samples were mechanically and metallurgically(XRD,SEM and EDX analysis) characterized for their stability against cyclic oxidation resistance and erosion resistance.(5)

MATERIALS AND METHODS

MATERIAL SELECTION

Required Properties of Coating Materials

- High corrosion and erosion resistant
- High wear resistant
- High thermal conductivity
- High hardness
- Good adhesion and low porosity

Table 2.1 Various Material properties of Ni_3Al

S.No.	Material Properties	Ni_3Al
1.	Density g/cm^2	**7.16**
2.	Thermal conductivity W/m K	**28.85**
3.	Young's modulus GPa	**178**
4.	Poisson's ratio	**0.3**
5.	Shear stress GPa	**73**
6.	Yield strength MPa	**500**

The Nickel Aluminide(Ni_3Al) powder employed were of research grade with a purity level of 99%.The material properties shown in Table 2.1.

PROCESSING OF THE COATINGS

Preparation of Substrates and Coating Materials Commercially available boiler tube material (SA210 GrA) were chosen as the substrate materials for the present work. The specimens are circular in shape having a dimension (ID 44.5 mm ,OD 54.1mm). Nickel and aluminium metal powders of commercial grades are used to produce nickel aluminide coating, which is formed at high temperature during physical vapour deposition. These two

ISSN 2349-6193
Impact Factor (PIF): 2.805

IJESMR

International Journal OF Engineering Sciences & Management Research

powders Ni : Al were thoroughly mixed in ratio 3:1 by weight. The particle size range the powders used in the study, are given in the table.2.2.

Table 2.2 Particle size range used for coating

Powder	Range
Aluminum	-106µm to +53µm
Nickel	-74 Aµm to +53 µm

The raw powders were characterized for their chemical purity by standard wet chemical analysis. They were found to contain only about 0.8% of the respective metal oxides and were thus more than 99% pure.

PHYSICAL VAPOUR DEPOSITION (PVD)

This process is carried out in an evacuated chamber. The target (substrate) and the coating material are kept facing each other. The coating material is heated using a heat source like electrical heater or electron beam, in low pressure. The coating material evaporates directly from solid state and deposits on the target. This is known as thermal evaporation. In physical vapour deposition (PVD) process (Fig.2.1), the coating is deposited in vacuum by condensation from a flux of neutral or ionized atoms of metals. There are also other PVD techniques(figure 2.1) available for deposition of hard coatings such that magnetron sputtering (or sputter ion plating), combined magnetron and cathodic arc vapour (plasma or arc ion plating) deposition and arc processes are most widely used techniques to deposit titanium-aluminium based coatings. This process is carried out in high vacuum at temperature between 150°Cand 500°C. The high purity solid coating material (metals such as titanium, chromium & aluminium is either evaporated by heat or by bombardment with ions (sputtering).

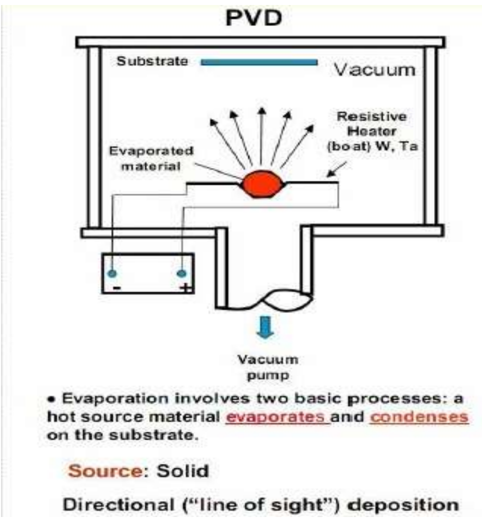

Figure 2.1 PVD Technique

By using this deposition technique, thin films of different metals are deposited on different surfaces. This technique involves condensation from the vapor phase. There are three main steps involved in this process.

- By the sublimation of evaporating of a material corresponding vapor phase.
- Transportation of the material to the substrate from source.
- Formation of the thin film and particle by nucleation and growth.The sourcecan beavaporated by using electron beams,thermal energy,sputtering technique,cathode arc plasma.

RESULTS AND DISCUSSION

XRD PHASE COMPOSITION ANALYSIS

The structural features of nickel aluminide is studied from XRD data. XRD of Nickel aluminide nano composites are shown in Fig.The nickel aluminide composite powders used for making preforms were

IJESMR
International Journal OF Engineering Sciences & Management Research

subjected to X-Ray Diffraction analysis. The XRD patterns were obtained at ambient temperature by step scanning on an X-ray powder diffractometer (Bruker Eco D8 Advance X Ray Diffractometer) using a monochromatic CuKα radiation (λ= 1.54056 Ao) in the range of 2θ= 0°–90°with a step size of 0.050.
XRD of nickel aluminide nano composites is shown in Figure 3.1. .The XRD patterns reveal well developed reflections of nickel aluminide nanocomposites . Strong Bragg reflections were seen in the XRD which correspond to the reflection of nickel aluminide composite.The XRD patterns of the samples exhibit the characteristic peak at 2θ=38.5°, which corresponds to the plane of Cu. They also exhibit peak at 2θ=44.5°indexed as planes.The X-ray diffractograms are taken on the raw material and on some selected coatings using a BRUKER ECO D8 ADVANCE X Ray Diffractometer. The XRD results are shown in figures 3.1.

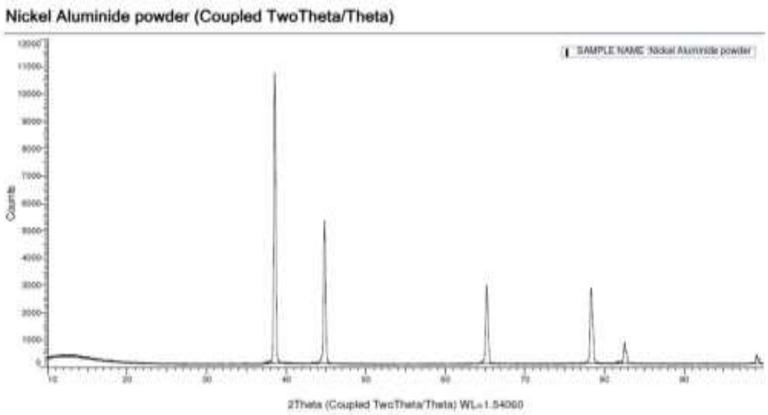

Figure 3.1 X Ray Diffractogram of Nickel-Aluminide powder

SCANNING ELECTRON MICROSCOPIC ANALYSIS
The cross sectional morphology of the without and with nanostructured coatings was examined using SEM and is shown in Figs. respectively. The magnified SEM morphology for the without and with nanostructured coatings is shown in Figure 3.2&figure 3.3.The dense and uniform microstructure was observed in the nanostructured coatings, compared to the without coating. From the figure it is clear that,the mild steel(boiler tube) substrate has been covered with the nanostructured nickel aluminide particles. The particle size found over the specimen were approximately in the range of about 100-250 *nm*. Figure 3.3 shows good dispersion throughout the cross section when compared to without coating thickness.
Figure 3.2 and 3.3 shows the SEM images of without coated and with coated samples respectively. The grain size of the with coated sample was smaller than without coated sample.In without coating the crystals of different size were oriented randomly and there was no size uniformity (Figure 3.2). But in with coated sample more uniform crystals were observed (Figure 3.3).

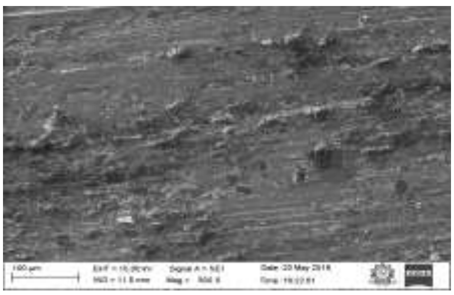
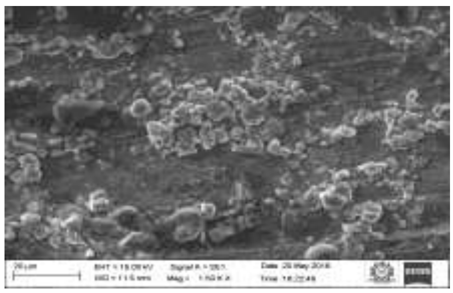

Figure 5.2 SEM image for without coating

ISSN 2349-6193
Impact Factor (PIF): 2.805

IJESMR
International Journal OF Engineering Sciences & Management Research

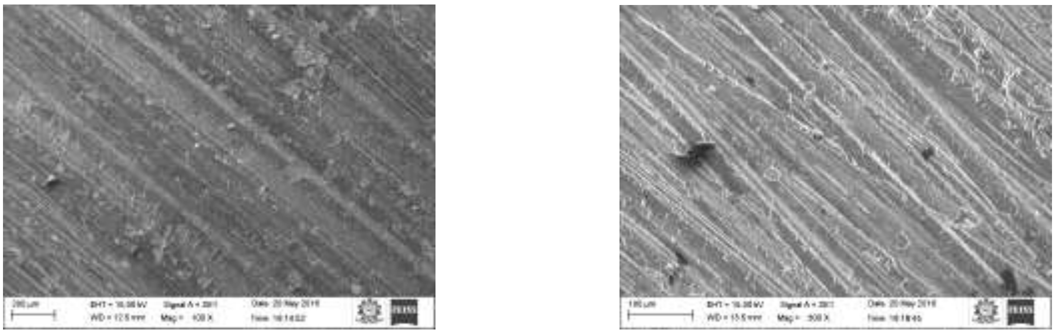

Figure 5.3 SEM image for with coating

ENERGY-DISPERSIVE X-RAY SPECTROMETRY

The chemical composition of nanoparticles was measured by energy dispersive X-ray spectrometry (EDX) in a transmission electron microscope. Spectra were acquired for a live time of 100s. A nominal electron beam probe diameter of 3 nm was used to analyze small volumes of single nanoparticles. A larger probe size (10 - 30 nm) was used to analyze clusters of nanoparticles.A standardless analysis of the measured spectrum was done by the Cliff-Lorimer technique(without correcting for absorption and fluorescence) using the software Bruker System SIX software, version 1.6 (from THERMO Electron Corporation). The elements in the spectrum are identified according to their characteristic X-ray energy. Different elements were identified from their characteristic energy using the automatic peak search function of the software. In two of the samples(without and with coated samples), the characteristic radiation of was detected(Figures 3.4 and 3.5).

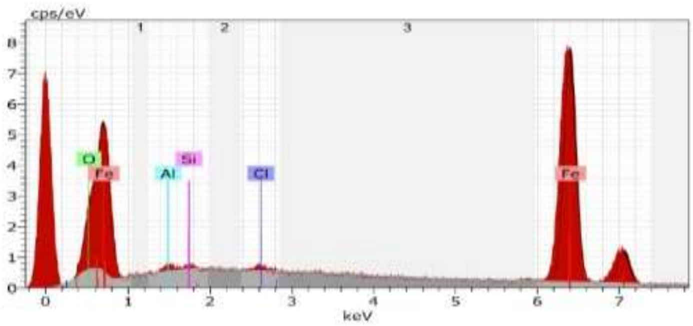

Figure 3.4 EDX images for without coating

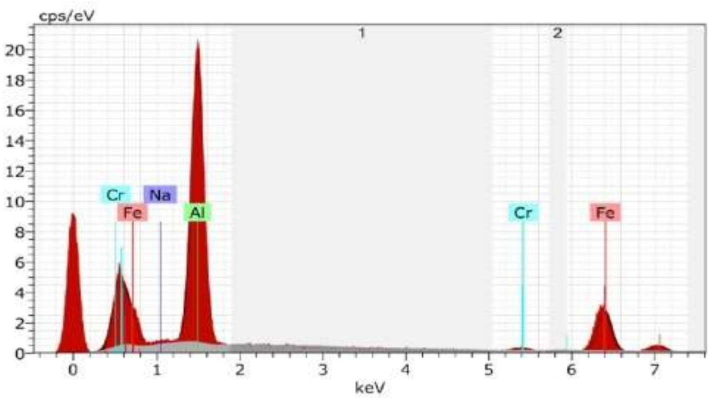

Figure 3.5 EDX images for with coating

ISSN 2349-6193
Impact Factor (PIF): 2.805

IJESMR

International Journal OF Engineering Sciences & Management Research

COATING MICROHARDNESS ANALYSIS

Micro-hardness measurement was done on the optically distinguishable phases on the coating cross-section (on the interface as well as on the substrate), with a Wilson Microhardness Tester(Wolpert Group-German) using HV1 Kg load on polished cross section of the samples.

Table 3.1 Without and With Coating micro hardness levels

S.No.	Without Coating	With Coating
1	267	318
2	269	321
3	268	319

The results are summarized in Table 3.1. In Ni_3Al coatings three different range of hardness values are observed. The variation of hardness values may be due to the formation of different phases i.e. aluminides during coating deposition and existence of different alumina phases i.e. α- and γ-alumina etc.
The microhardness values are shown in table 3.1.Microhardness values ofNickel aluminide coated sample was 319 against 268 of without coating.

CONCLUSIONS

The conclusions drawn from the present work are as follows:

- The suitable material for nano coating was selected.
- Mixture of commercial grade nickel and aluminum powder is coatable on metal substrates by physical vapour deposition technique. These coatings possess desirable coating characteristics such as good adhesion strength, hardness etc.
- During physical vapour deposition, formation of aluminide phases of nickel is observed.
- Maximum deposition efficiency of ~ 57% is obtained for Ni-Al coatings on boiler tube substrates.
- Operating power level of the physical vapour deposition influences the coating adhesion strength, deposition efficiency and coating hardness to a great extent. The coating morphology is also largely affected by the torch input power.
- Occurrence of phase transformations and formation of aluminide phases such as Ni3Al during physical vapourdeposition is evident. The different aluminide phases observed in XRD studies corroborate to the observation of different hardness values of different optically distinguished phases.

SEM images indicated the good dispersion throughout the cross section when compared to without coating thickness.

REFERENCES

1. Valero A, Cortes C. Ash fouling in coal-fired utility boilers:Monitoring and optimization of on-load cleaning [J]. Prog Energy Combust Sci, 1996, 22: 189−200.
2. Sidhu T S, Prakash S, Agrawal R D, Ramesh B.Erosion–corrosion behaviour of Ni-based superalloy Superni-75 in the real service environment of the boiler [J]. Sadhana, 2009, 34(2):299−307.
3. Higuera hidalgo V, Belzunce verela J, Carriles menendez A, Poveda martinez S. High temperature erosion wear of flame and plasma-sprayed nickel−chromium coatings under simulated coal-fired boiler atmospheres [J]. Wear, 2001, 247:214−222.
4. Branagan D J, Breitsameter M, Meacham B E,Belashchenko V. High-performance nanoscale composite coatings for boiler applications [J]. Journal of Thermal Spray Technology, 2005, 14(2): 196−204.
5. Suryanarayana C. Nanocrystalline materials [J]. International Materials Reviews, 1995, 40: 41−64.
6. Navas C, Colaco R, de Damborenea J, Vilar R. Abrasive wear behaviour of laser clad and flame sprayed-melted NiCrBSi coatings [J]. Surface and Coatings Technology, 2006, 200: 6854−6862.
7. He J H, Ice M, Lavernia E J. Synthesis of nanostructured Cr3C2-25(Ni20Cr) coatings [J]. Metallurgical and Materials Transactions A, 2000, 31: 555−564.

IJESMR
International Journal OF Engineering Sciences & Management Research

8. Tellkamp V L, Lau M L, Fabel A, Lavernia E J. Thermal spraying of nanocrystalline Inconel 718 [J]. Nanostructured Materials,1997, 9: 489−492.
9. Lau M L, Jiang h G, Nuchter W, Lavernia E J. Thermal spraying nanocrystaline Ni coatings [J]. Phys Status Solidi A, 1998,166: 257−268.
10. Lau M L, Strock E, Fabel A, Lavernia C J, Lavernia E J. Synthesis and characterization of nanocrystalline Co−Cr coatings by plasma spraying [J]. Nanostructured Materials, 1998, 10: 723−730.
11. He J H, Ice M, Dallek S, Lavernia E J. Synthesis of nanostructured WC-12pct Co coating using mechanical milling and high velocity oxygen fuel thermal spraying [J]. Metallurgical and Materials Transactions A, 2000, 31: 541−553.
12. Stewart D A, Shipway P H, Mccartney D G. Microstructural evolution in thermally sprayed WC−Co coatings: Comparison between nanocomposite and conventional starting powders [J]. Acta Mater, 2000, 48: 1593−1604.
13. Grosdidier T, Tidu A, Liao H L. Nanocrystalline Fe40Al coating processed by thermal spraying of milled powder [J]. Scripta Mater, 2001, 44: 387−393.
14. Ajdelsztajn L, Picas J A, Kim G E, Bastian F L, Schoenung J, Provenzano V. Oxidation behaviour of HVOF sprayed nanocrystalline NiCrAlY powder [J]. Mater Sci Eng A, 2002,338: 33−43.
15. Lau M L, He J, Schweinfest R, Ruhle M, Levi C G, Lavernia EJ. Synthesis and characterization of nanocrystalline Cu−Al coatings [J]. Mater Sci Eng A, 2003, 347: 231−242.
16. Wu Y S, Qiu W Q, Yu H Y, Zhong X C, Liu Z W, Zeng D C, Li S Z. Cycle oxidation behavior of nanostructured Ni60–TiB2 composite coating sprayed by HVOF technique [J]. Applied Surface Science, 2011, 257: 10224−10232.
17. da Cunha C A, de Lima N B, Martinelli J R, de Almeida bressiani A H, Fernando padial A G, Ramanathan L V.Microstructure and mechanical properties of thermal sprayed nanostructured Cr3C2−Ni20Cr coating [J]. Journal of Materials Research, 2008, 11(2): 137−143.
18. Rana N, Mahapatra M M, Jayaganthan R, Prakash S. Deposition of nanocrystalline coatings by modified LVOF thermal spray method [J]. Journal of Alloys and Compounds, 2014, 615: 779−783.
19. Yaghtin A H, Javadpour S, Shariat M H. Hot corrosion of nanostructured CoNiCrAlYSi coatings deposited by high velocity oxy fuel process [J]. Journal of Alloys and Compounds, 2014, 584:303−307
20. Mazaheri Y, Karimzadeh F, Enayati M H. Development of Al356−Al2O3 nanocomposite coatings by high velocity oxy-fuel technique [J]. Journal of Mater Sci Technology, 2013, 29(9): 813−820.
21. Enayati m H, Karimzadeh F, Jafari M, Markazi A, Tahvilian A. Microstructural and wear characteristics of HVOF-sprayed nanocrystalline NiAl coating [J]. Wear, 2014, 309:192−199.