www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610

Review on the Part of HV of Thermal Spray Coating in Protection to Corrosion

Prof. Nagaraja. C. Reddy

Assistant Professor
Department of Mechanical Engineering
Bangalore Institute of Technology
VV. Puram, K.R.Road
Bengaluru-560004, Karnataka, India
Mobile No 09449991551
Mail id: cnraaja@gmail.com

Prof. B.S. Ajay Kumar

Professor
Department of Mechanical Engineering
Bangalore Institute of Technology
VV. Puram, K.R.Road
Bengaluru-560004, Karnataka, India

Prof. H.N.Reddappa

Professor
Department of Mechanical Engineering
Bangalore Institute of Technology
VV. Puram, K.R.Road

www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610

Bengaluru-560004, Karnataka, India

ABSTRACT

Materials degradation due to corrosion is the major problem in power generation equipment, gas turbine, fluidized bed combustion, industrial waste incinerators etc. Some super alloys have been developed, but they are unable to have different properties to meet the demand of today's industry. Therefore, a composite system of a base material providing the necessary mechanical strength with a protective surface layer different in structure and/or chemical composition can be an optimum choice in combining material properties. Thermal spray coating of the components before they put into service by suitable surfacing alloy and with suitable coating method can increase the life of these components several fold. Choice of right coating method and alloy for a particular application is extremely important to get the desired service life. The corrosion of some materials and the role of HVOF thermal spray coatings to counteract the same have been reviewed, with an aim to understand the phenomena along with various applications.

Keywords: HVOF thermal spray coating, Corrosion, Coating alloys etc.

1. INTRODUCTION

The corrosion was first recognized as a serious problem in 1940's in connection with the degradation of fireside boiler tubes in coal-fired steam generating plants and later with the severe attack of gas turbine air-foil materials [1]. It is also a serious problem in power generation equipment, in gas turbines for ships and aircraft and in other energy conversion and chemical process systems example: in boilers, internal combustion engines, fluidized bed combustion and industrial waste incinerators [1-3]. Hot corrosion became a topic of importance and popular interest in the late 60's, when gas turbine engine of military aircraft suffered severe corrosion during the Vietnam conflict in operation over sea- water [4]. According to a recent study, the total annual estimated direct cost of metallic corrosion in the U.S. is staggering $276 billion-approximately 3.1% of the Nation's Gross Domestic Product (GDP). This cost is more than the annual cost of weather related disasters, which is just averaging $17 billion annually. However, unlike weather related disasters, corrosion can be controlled, but at a cost. The report further revealed that the 25% to 30% of annual corrosion costs in the U.S. could be saved if proper corrosion management practices were employed [5]. An estimated 40% of total US steel production goes to replacement of corroded parts and products. So far as India is concerned, the corrosion costs may touch Rs. 24000 crore (Rs. 240000 million). This cost is for the materials corrosion in building structures, bridges, chemical plants, offshore platforms, power plants, ships, pipe lines for transportation of hydrocarbon, electrical and electronics components [6].

Corrosion is an unintentional gradual degradation of a metal occurs because of chemical or electrochemical attack. As a result of corrosion the metal gets converted to its compounds such as oxide, chloride, nitride, sulfide etc. depending upon the environment. Corrosion may be classified as dry corrosion, wet corrosion and hot corrosion. Dry corrosion is a chemical process that usually involves a gas environment and a solid surface. High temperature air oxidation is a common example. Wet corrosion occurs in an aqueous medium with dissolved salts. Hot corrosion is an accelerated form of oxidation, which occurs when metals are heated in the temperature range 700^0-900^0C in the presence of sulphate deposits formed as a result of the reaction between sodium chloride and sulphur compounds in the gas phase around the metals [7, 8]. In the recent years, there has been an increased interest in surface engineering of components using advanced thermal spray processes for applications in aggressive environments. With the advent of the HVOF spray process, thermal sprayed coating (TSCs), which has limited usefulness as corrosion protection coatings due to the presence of interconnected porosity in the structure of coatings, have now gained popularity and are being studied extensively for their corrosion resistant properties [9].

2. HIGH VELOCITY OXY FUEL (HVOF) THERMAL SPRAYING PROCESS

HVOF systems are relatively new innovations from the thermal spray industries, developed in the past few years. It is a flame deposition technique, where powder material is melted by the use of combustion of oxygen and a fuel gas and is propelled at a high velocity by the use of compressed air, towards the surface. In the combustion zone, the powder material enters the flame, where it becomes molten or semi-molten, depending on the melting temperature and the feed rate of the material. The flame temperature for the HVOF process is between 2300 – 3000 ^{0}C.The molten or semi-molten particles are then propelled out of the gun nozzle at supersonic velocities of over 1350 m/s towards the substrate [10]. HVOF spray processes differ from conventional flame spray as combustion is internal to the nozzle and the gases are, initially at much higher pressure than those in the atmospheric burning of the flame spray. These high pressures allow the HVOF process to spray at supersonic rates with improved powder particle heating and melting characteristics. The combustion gases are expanding through a nozzle system and the injected powder particles gain significantly higher velocity due to the high gas velocities.

2.1 HVOF AND OTHER COATING PROCESSES

www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610

HVOF process has the following advantages over other processes [10-13].

- High-density coating.
- Low porosity coating.
- High hardness coating.
- High bond strength of the coating.
- Thick coating.
- Fine finishing capability.
- Lower oxide content of the coating.
- More uniform and efficient particle heating due to the high turbulence experienced by the particles within the combustion chamber.
- Much shorter exposure time in flight due to the high particle velocities.
- Lower surface oxidation due to short particle exposure time compared to other thermal spraying techniques.
- Compared with the D-gun, the combustion process in HVOF thermal spraying is a continuous one.

Due to the high particles velocity and moderate temperatures, HVOF processes are preferably used for coating materials that tend to decompose at higher temperatures. This is the main reason for their application of deposition of hard metals/cemented carbides such as WC/Co and Cr_3C_2-NiCr, since these have high density and extreme wear resistance. Also the FeNiCo-alloys inconel (NiCrFe), Triballoy (CoMoCr), Hastalloy (NiCrMo) and self fluxing Ni-based alloys can be efficiently deposited. Low melting point ceramics such as alumina and alumina-titania are also applied via some HVOF process for abrasion wear and dielectric applications. One of the major applications is in the replacement of hard chrome plating [9].

Zhao et al [12] reported the influence of the spraying processes (i.e. Atmospheric Plasma Spraying, Shrouded Plasma Spraying and High Velocity Oxy Fuel) on the properties of 316L stainless steel coatings. The coatings were studies in term of their microstructure, oxidation and corrosion behaviour in 0.1 N H_2SO_4 and 0.1 N $C_2H_8O_7.H_2O$ acid solutions. The HVOF coatings were reported to be dense, harder, more oxidation and corrosion resistant than the other coatings. Sundararanjan et al [14] evaluated the steam oxidation resistance of Ni-20Cr metallic coatings on 9Cr-1Mo type steel at different steam temperatures in the range of 600-750^{0}C. Authors used high velocity oxy-fuel (HVOF) as well as air plasma spray to deposit the coatings. They concluded that denser and less porous HVOF coating yielded a better steam oxidation resistance than the APS coating for longer test duration.

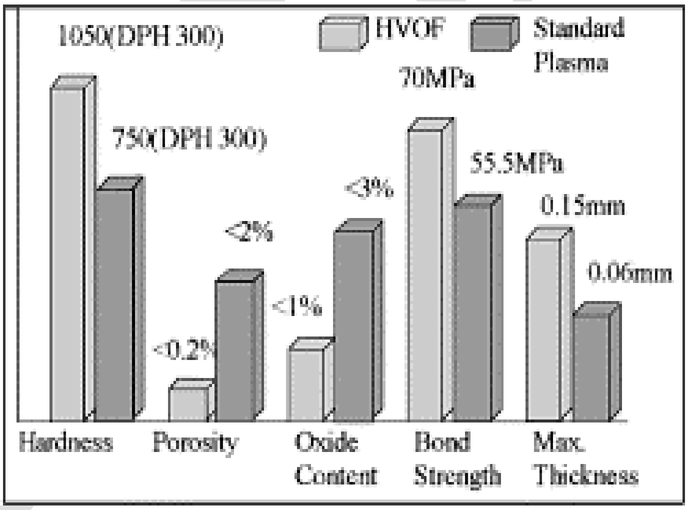

Figure 1. Characteristics of HVOF and standard plasma process coatings

2.2. ROLE OF HVOF COATING IN CORROSION PROTECTION

High Velocity Oxy Fuel coatings are being used on many industrial components to prevent surface degradation by elevated temperature corrosion. High temperature corrosion and wear of heat exchanger tubes and other structural materials in coal-fired boiler are recognized as being the main cause of downtime at power-generating plants, which could account for 50-75% of their total arrest time. High temperature oxidation and erosion by the impact of fly ashes and unburned carbon particles are main problems to be solved in these applications, especially those regions where component surface temperature is above 600^{0}C (873 K). Therefore, the development of high temperature oxidation protection systems in industrial boilers is a very important topic from both engineering and an economic perspective [14]. Hot corrosion observed in boiler, incinerators, diesel engines, mufflers of internal combustion engines and gas turbines. The hot corrosion process is markedly dependent on parameters such as alloy composition, gas composition, deposit composition, and temperature [3]. The HVOF spraying system enables the metal and alloys with the high melting point up to about 2000˚ C to be deposited on the target surface. These features are suitable for an application to the corrosion resistant coating.

2.3 NICKEL CHROMIUM COATINGS

Modern thermal spray processes such as high velocity oxyfuel (HVOF) and plasma spraying are often applied to deposit high-chromium, nickel coatings onto the outer surface of various parts of the boilers, e.g. tubes to prevent the penetration of hot gases [17]. Nickel-chromium alloys have been used as coatings to deal with oxidation environments at high temperature. When nickel is alloyed with chromium, this element oxidizes to Cr_2O_3 at rates which could make it suitable for use upto about 1200^{0}C, although in practice use is limited to temperature below about 800^0C [16]. Uusitalo et al [18-19] performed the high temperature corrosion tests, on ferritic and austenitic boiler steels, five Ni-Cr high velocity oxy-fuel (HVOF) coatings, laser-melted HVOF coating, and diffusion chromized steel, in oxidizing atmosphere containing 500 ppm HCl, 600 ppm H_2 S, 20% H_2 O, 5% CO, and Ar as a balance at temperature of 550^0C. They concluded that homogeneous and dense coatings with high chromium content performed well and protected the substrate material. Corrosive species were able to penetrate through some of the HVOF coatings and attack the substrate via interconnected network of voids and oxides at splat boundaries. In different study reported by same authors [20], in oxidising atmosphere of 500 vppm HCl, 3% O_2, 14% CO_2, 20% H_2O and Argon as balance, the Fe_3Al, Ni-57CrMoSiB and Ni-21Cr-9MoFe coatings were proved to be poor in resisting the high temperature oxidation. The substrates were observed to be attacked by corrosive species through the voids and oxides. It has further been observed that Laser-melted Ni-57Cr HVOF coating did not suffer any corrosion. The coating was partially covered with oxides formed during the laser treatment. Oxides have further increased the corrosion resistance of the coating. Further, laser melting homogenizing the structure of the HVOF coating. Authors [21] further investigated the high temperature behaviour of the same coatings in the presence of a salt environment of 40% Na_2SO_4-40% K_2SO_4-10NaCl-10KCl in two environments viz. oxidising environment of N_2-20H_2O-14CO_2-3O_2-500 vppm HCl, reducing environment of N_2-20H_2O-5CO-0.06H_2S-500 vppm HCl. They found that the corrosion was more severe in oxidising environments as compared to the corrosion in reducing environment. The protective oxide layer was formed only in case of Ni-57CrMoSiB coating. Whereas in reducing conditions materials with high chromium content were found to be able to form a protective layer containing chromium, sulphur, and sodium. The corrosion resistance of this layer increased with increasing chromium content. Further it was concluded that the corrosion resistance of nickel-based, high chromium coating materials was satisfactory in the test conditions.

The formation of protective oxide scale of Cr_2O_3 was observed on the HVOF NiCr coated surfaces by Sundararanjan et al [14]. The diffusion of nickel from the coatings to the substrate and the diffusion of iron from the substrate to the coatings for longer exposures to steam oxidation were also noticed. The rate of diffusion of Ni and Fe were found to be almost similar. The diffusion increased with increase in the temperature and duration Sundararanjan et al [22]. The diffusion of iron caused formation of Fe_2O_3 scale, which was suggested to be the reason for non-protectiveness of coatings for longer exposure times. The chromium did not participate in the diffusion process in either side expect their enrichment at the surface as oxide. This oxide is attributed for the protection against the scale growth. Additionally, in case of APS coating, the scale initiation was also observed at the interface between the coating and the substrate, which propagated with testing temperature and duration. Whereas in case of Ni-50Cr coatings, the formation of Fe_2O_3 scale was noticed in case of APS coatings only [23]. In another study they reported the behaviour of Mn and Si present in the spray powder. In the 80Ni-20Cr coating, Mn segregation and Si enrichment at the coating surface was noticed during steam oxidation at 750^0C/1000 h. 50Ni-50Cr specimens steam oxidized at 750^0C/1000h showed less segregation of the elements to the coating surface. This is attributed to the protective chromium oxide layer formation on the surface, which restricts the diffusion process [24].

Total of eight different chromium containing HVOF sprayed coatings with varying proportions of alloying elements such as Ni, Mo, Si, Fe, Co, W, B and C have been studies by

Chidambaram et al [9] in hydrochloric acid medium. The electrochemical behaviour of each coating has been compared with that of bulk AISI 316. The HVOF sprayed AISI 316 coating reportedly offer a lower corrosion resistance compared to bulk AISI 316. High nickel and chromium containing coatings offer corrosion resistance comparable to bulk AISI316.

Yamada et al [25] carried out studies to evaluate the high-temperature corrosion resistance of Ni-20Cr, Ni-50Cr and Cr coated boiler tubes in actual refuse incineration plant as well as in laboratory tests. It was observed that detonation sprayed Ni-50Cr coating exhibited the highest corrosion resistance in laboratory test at 873K among the detonation gun sprayed, plasma sprayed and HVOF sprayed coatings. Hodgkiess et al [26] studied the erosion–corrosion behaviour of a thermally sprayed Ni–Cr–Si–B–C cermet coating in saline solution in the presence and absence of solid particles. They found that cermet coating undergo less weight loss than the stainless steel in solid/liquid conditions but vice-versa during solid-free impingement and this was attributed to the relative influences of erosion and corrosion. Zhao et al [27] studied the corrosion mechanism of HVOF deposited NiCrBSi coatings by immersing the specimens in 3.5% NaCl with pH adjusted to 3 by addition of acetic acid. The technique such as scanning electron microscope, electron probe microanalysis, spectral analysis and X-ray diffraction were employed to study the mechanistic process of corrosion of the coating surface. They conclude that the corrosion first occurred on the surface of the coating around the particles that had not melted during spraying and the defects such as pores, inclusions and microcracks, and then developed along the paths formed by pores, microcrackes, and lamella structure. The main failure mechanism of the coating is exfoliation or laminar peeling off. Optimization of spraying process parameters and remelting of the coating was suggested for further improvement in corrosion resistance.

2.4 COBALT BASED COATINGS

Studies on oxidation and hot corrosion resistance of Stellite-6 coatings on boiler steels were conducted by Singh [28] in simulated as well as in actual boiler conditions. Coatings were found to be effective in all the environments. The auther opined that the formation of $CoCr_2O_4$ spinel in all the environments might have contributed to requisite resistance, which was believed to block the diffusion activities through the CoO by suppressing the further formation of CoO agreeing to the views of Luthra [29]. Figure 2.15 shows probable oxidation mechanism for Stellite-6 coated GrA1 boiler steel exposed to air at 900^0C for 50 cycles as proposed by Singh [28]. Guilemany et al [30] studied the microstructures developed at the interface of a HVOF sprayed WC-CO coating onto a copper substrate with smooth and grit blasted surface. Author concluded that with polished surface thin melted layer and poor adherence is obtained. However with the grit blasted copper surfaces a thicker melted layer and good adherence was obtained. Cha and Wolpert [31] conducted high-temperature erosion and corrosion of thermally spray, Ni-based materials like Colmonoy 62 (NiCrFeBSi) and NiCrBSi/WC and Co-based material T800 fabricated by thermal spray processes like HVOF, Flame sprayed and sintered (FS/sinter) and air plasma spray (APS). The corrosion studies in the environment containing HCl, H_2O, O_2 and N_2 at a temperature of 500 ^{0}C indicated that the Colmonoy 62 applied by HVOF or by APS show the same corrosion rates. NiCrBSi/WC coating formed by FS/sinter proved to be a fair combination of erosion and corrosion resistance.

2.5 NICKEL ALUMINIDE COATINGS

www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
IJRREM
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610

According to Schneibel and Becher [32] and Velon and Olefjord [33] nickel aluminide intermetallics are not only oxidation and corrosion resistant, but also thermodynamically compatible with a wide range of ceramics. Ni_3Al exhibit a very good high temperature strength and oxidation resistance. Moreover its mechanical properties and good creep resistance make it attractive for several industrial applications. The studies on the oxidation behaviour of the intermetallic compound Ni_3Al can be dated back to 1974. The research on this material has been conducted more intensively since the last decade or so because Ni_3Al base alloys had been found to be promising structural materials for high temperature applications [34]. The coatings Ni_3Al were reported to be effective in decreasing the corrosion rate in air as well as in molten salt during hot corrosion run by Sidhu & Prakash [35] at 900^0C. The microstructure and corrosion properties of nanocrystalline Fe–40Al coatings deposited by HVOF thermal spraying of milled powder have been investigated by Ji et al [36]. They reported that the coatings have complex microstructure consisting essentially of a mixture of well-flattened splats and non-fully melted powder particles within which an equiaxed nanometer-scale structure is retained. Amorphous Al_2O_3 and nanocrystalline Fe-rich oxides together with Fe_3Al were present at intersplat boundaries. They further reported that the feedstock powder size has a strong effect on the coating hardness and corrosion. High deformation and low temperature upon impingement of sprayed particles are required, for making a denser and less oxidized coating. Kawakita et al [37] developed the dense corrosion resistant coatings by using an improved HVOF spraying process with attachment of inert gas shroud mechanism. The coating of HastelloyC nickel base alloy by this process had zero through porosity and 0.2 mass% of oxygen content, leading to be comparable to the bulk material of HastelloyC in term of corrosion resistance. Authors reported that the post heat treatment of coating improved the adhesiveness, because of the diffusion of some elements at

www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610

the interface between the coating and the substrate made the interface junction ambiguous. The post polishing treatment increased the corrosion resistance of the coatings mainly because of the removal of the surface layer with a lot of pores appropriate for the starting point of crevice corrosion.

2.6 MCrAlY COATINGS

Toma et al [38] conducted short-time oxidation experiments on vacuum plasma sprayed (VPS) and HVOF-sprayed MCrAlY coatings and observed that the formation of metastable alumina led to a fast oxidation rate in the transient stage in case on VPS coating. This effect also influenced the oxidation rate in steady-state stage. Formation of α-Al_2O_3 as only phase in the oxide scale of the HVOF coating after a short oxidation time (~2.5 hours) determined the slow oxide growth. Authors suggested that the fine oxide dispersion formed in HVOF-sprayed MCrAlY coatings had a beneficial effect on the high-temperature oxidation behaviour of the coatings.

Isothermal and cyclic oxidation of freestanding HVOF sprayed Ni-20Cr-10Al-1Y thick coatings was investigated by Serghini and Dallaire [39] at 1200^0C. The coatings were found to be dense and remained crack free after thermal treatments. They further observed that the protective oxide layer formed did not flake off upon cyclic oxidation and suggested the use of coatings as anti-oxidant barriers in both isothermal and cyclic oxidation. Interdiffusion between the coating and substrate with a slight increase in chromium concentration at the interface was also noticed. The element distribution within the oxide layer was found to follow the order: Al-(oxide)/Y-(oxide)/Cr-(oxide)/Ni-(oxide)/NiCrAlY from the outermost oxide layer to the bulk of the coating

2.7 NICKEL TITANIUM COATINGS

This is one of the most interesting intermetallic as it has two different crystal structures, one is B2 (CsCl) structure i.e. high temperature austenitic phase while another is monoclinic B-19' structure that is low temperature martensite. This type of crystal structure gives this intermetallic excellent high temperature mechanical property such as oxidation resistance up to 900°C and good creep resistance up to a temperature of 1000°C. When we see the binary phase diagram of Ni-Ti system(as shown in Fig. 2), there are couple of stable intermetallic compound phases namely, $NiTi_2$ and Ni_3Ti.Out of these intermetallic compounds, Ni_3Ti has been tried and used in high temperature applications mainly because of is tetragonal structure and its high melting point of 1380°C. This intermetallic has a topologically close packed structure due to which it displays high microstructural, chemical and thermal stabilities. Along with this they generally show high strength at higher temperatures and reasonable deformability at lower temperatures. When compared with the other intermetallic phase Ni_3Al, Ni_3Ti has higher stability above 750°C and can retain strength at higher operating temperatures. This intermetallic can be obtained by mechanical alloying of pure Ni and Ti powders in 50:50 or 40:60 at.%. For example Karolus and Panek[40] developed NiTi alloy by mechanical alloying of Ni and Ti in different stoichiometric ratio to obtain $Ti_{66.7}Ni_{33.3}$, $Ni_{50}Ti_{50}$ and $Ni_{75}Ti_{25}$ (at.%) composition. The milling was carried out in a planetary ball mill inside the hardened steel vial under the argon atmosphere. The ball to powder ratio of 10:1 and 500 rpm were the ball milling parameters. The heat treatment of ball milled $Ti_{66.7}Ni_{33.3}$ and $Ni_{50}Ti_{50}$powders showed the formation of Ni_3Ti and Ni_2Ti intermetallic compounds. Further the XRD spectra taken on $Ni_{75}Ti_{25}$ powders showed that as the mechanical alloying of these powders progressed, creation of Ni(Ti) solid

www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610

solution proceeds and once the 90 hours ball milling was completed the creation of Ni_3Ti phase was observed. However heating of $Ni_{75}Ti_{25}$ powders lead to partial decomposition of Ni(Ti) solid solution in to Ni_3Ti phase.

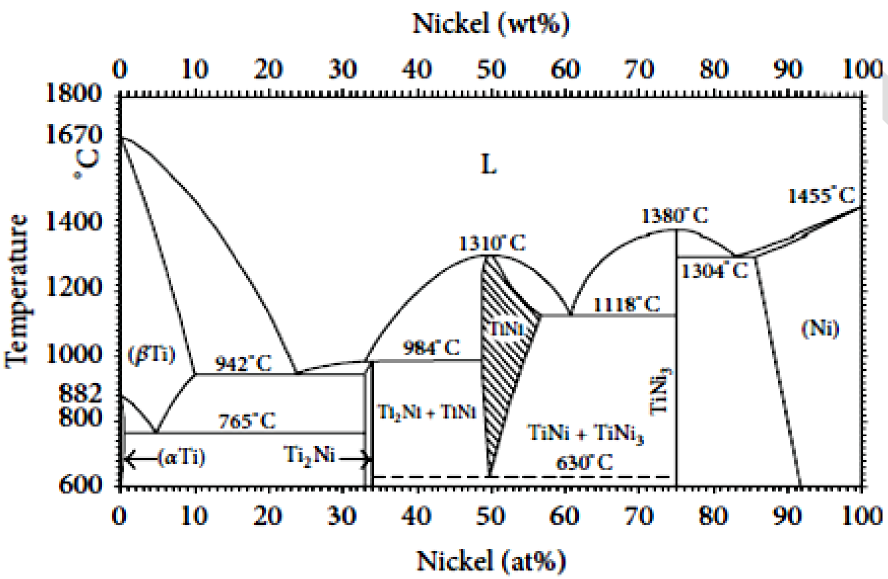

Fig.2. Ni-Ti system's Binary phase diagram

3. CONCLUSIONS

HVOF sprayed coatings can play a vital role in the protection of materials from the phenomena of corrosion, ultimately replacement and downtime costs and excellent way to enhance surface of materials. The effect of HVOF spraying on component life/performance will depend upon the spraying material/alloys and the various process parameters. A good amount of work has been done to investigate the performance of coating. However further investigations are required to optimize the various process parameters of HVOF sprayed coatings and in many industrials problems.

4. REFERENCES

[1] R. A. Rapp, and Y. S. Zhang, "Hot Corrosion of Materials: Fundamental Studies," JOM, 46 (12) (1994), 47-55.

[2] R. A. Rapp**,** Corrosion Science, "Hot Corrosion of Materials: A Fluxing Mechanism," 44 (2) (2002), 209-221.

[3] F. S. Pettit, and C. S. Giggins, "Hot Corrosion, Ch. 12," in 'Superalloys II,' Eds. Sims, C. T., Stollof, N. S. and Hagel, W. C., Pub. Wiley Pub., N. Y. (1987).

[4] R. A. Rapp, "Chemistry and Electrochemistry of the Hot Corrosion of Metals," Corros., 42 (10) (1986), 568-577.

[5] G. H. Koch, M. P. H. Brongers, N. G. Thompson, Y. P. Virmani, and J. H. Payer, "Historic Congressional Study: Corrosion Costs and Preventive Strategies in the United States," Supplement to Mater. Perfor., July (2002), 1-11.

[6] N. Gupta, "Technical Talk on Cathodic Protection," IIM Metal News, 16 (1) (2003), 38.

[7] P. Hancock, "Vanadic and Chloride Attack of Superalloys," *Mater. Sci. Technol.*, 3 (1987), 536-544.

[8] N. Eliaz, G. Shemesh, and R.M. Latanision, "Hot Corrosion in Gas Turbine Components," Eng. Fail. Anal., 9 (2002), 31-43.

[9] D. Chidambaram, C.R. Clayton, M.R. Dorfman, "Evaluation of the electrochemical behavior of HVOF-sprayed alloy coatings" Surface and Coatings Technology, xx (2003), xxx–xxx.

[10] J.M. Miguel, J.M. Guilemany, B.G. Mellor, and Y.M. Xu, "Acoustic emission study on WC-Co thermal sprayed coatings" Materials Science and Engineering A, 352 (2003A), 55-63.

[11] B.S. Mann, and V. Arya, "Abrasive and erosive wear characteristics of plasma nitriding and HVOF coatings: their application in hydro turbines" Wear, 249 (2001), 354–360.

[12] L. Zhao, E. Lugscheider, "Influence of the spraying processes on the properties of 316L stainless steel coatings" Surface and Coating Technology, 162 (2002 B), 6-10.

[13] C.H. Lee, and K.O. Min, "Effects of heat treatment on the microstructure and properties of HVOF-sprayed Ni-Cr-W-Mo-B alloy coatings" Surface and Coatings Technology, 132 (2000), 49-57.

[14] T. Sundararajan, S. Kuroda, T. Itagaki, and F. Abe, "Steam Oxidation Resistance of Ni-Cr Thermal Spray Coatings on 9Cr-1Mo Steel. Part 1: 80Ni-20Cr," ISIJ Int., 43 (1) (2003A), 95-103.

[15] M.M. helali, M.S.J. Hashmi, Proc. of the 10th Confernce of the Irish Manufacturing Committee (IMC 10) Galway, Ireland, 1992, p. 377.

[16] V. H. Hidalgo, J. B. Varela, A. C. Menéndeza, and S. P. Martýnez, "High temperature erosion wear of flame and plasma-sprayed nickel–chromium coatings under simulated coal-fired boiler atmospheres", Wear, 247 (2001), 214–222.

[17] J. Tuominen, P. Vuoristo, T. Mantyla, S. Ahmaniemi, J. Vihinen, and P.H. Andersson, "Corrosion Behavior of HVOF-Sprayed and Nd-YAG Laser-Remelted High-Chromium, Nickel-Chromium Coatings," J. Therm. Spray Technol., 11 (2) (2002), 233-243.

[18] M.A. Uusitalo, P.M.J. Vuoristo, T.A. Mantyla, "High temperature corrosion of coatings and boiler steels in reducing chlorine-containing atmosphere," Surface and Coatings Technology, 161 (2002A) 275-285.

[19] M.A. Uusitalo, P.M.J. Vuoristo, T.A. Mantyla, "Elevated temperature erosion-corrosion of thermal sprayed coatings in chlorine containting environments" Wear, 252 (2002B), 586-594.

[20] M.A. Uusitalo, P.M.J. Vuoristo, T.A. Mantyla, "High Temperature Corrosion of Coatings and Boiler Steels in Oxidizing Chlorine-containing Atmosphere," Mater. Sci. Eng. A 346 (2003), 168-177.

[21] Uusitalo, M.A., Vuoristo, P.M.J. and Mantyla, T.A., "High Temperature Corrosion of Coatings and Boiler Steels below Chlorine-containing Salt Deposits," Corros. Sci., 46 (6) (2004), 1311-1331.

[22] T. Sundararajan, S. Kuroda, T. Itagaki, and F. Abe, "Steam Oxidation Resistance of HVOF Thermal Sprayed Ni-Cr Coatings," Thermal Spray 2003: Advancing the Science & Applying the Technology, (Ed.) C, Moreau and B. Marpie, (2003B), 495-502.

[23] T. Sundararajan, S. Kuroda, T. Itagaki, and F. Abe, "Steam Oxidation Resistance of Ni-Cr Thermal Spray Coatings on 9Cr-1Mo Steel. Part 2: 50Ni-50Cr," ISIJ Int., 43 (1) (2003C), 104-111.

[24] T. Sundararajan, S. Kuroda, T. Itagaki, and F. Abe, "Behaviour of Mn and Si in the Spray Powder during Steam Oxidation of Ni-Cr Thermal Spray Coatings," ISIJ Int., 44 (1) (2004), 139-144.

[25] K. Yamada, Y. Tomono, J. Morimoto, Y. Sasaki, and A. Ohmori, "Hot Corrosion Behavior of Boiler Tube Materials in Refuse Incineration Environment," Vacuum, 65 (3-4) (2002), 533-540.

[26] T. Hodgkiess, A. Neville, and S. Shresth, "Electrochemical and mechanical interactions during erosion–corrosion of a high-velocity oxy-fuel coating and a stainless steel" Wear, 233–235 (1999), 623–634.

[27] W.M. Zhao, Y. Wang, L.X. Dong, K.Y. Wu, J. Xue, "Corrosion mechanism of NiCrBSi coatings deposited by HVOF" Surface and Coatings Technology. (2004), In press

[28] B.S. Singh, "Studies on the Role of Coatings in Improving Resistance to Hot Corrosion and Degradation," Ph.D. Thesis, Met. & Mat. Eng. Dept., Indian Institute of Technology Roorkee, Roorkee (2003).

[29] K. L. Luthra, "Kinetics of the Low Temperature Hot Corrosion of Co-Cr-Al Alloys," J. Electrochem. Soc., 132 (6) (1985), 1293-1298.

[30] J.M. Guilemany, J. Nutting, V.V. Sobolev, Z. Dong, J.M. Paco, J.A. Calero, J. Fernandez, "Interface Structures of high velocity oxy fuel sprayed WC-Co coating on a copper substrate" Materials Science and Engineering A, 232 (1997), 119-128.

[31] S. C. Cha, and P. Wolpert, "High-Temperature Erosion and Corrosion Measurement of Thermally Sprayed Materials," Adv. Eng. Mater., 5 (4) (2003), 213-217.

[32] J. H. Schneibel, and P. F. Becher, "Iron and Nickel Aluminide Composites," J. Chinese Institute of Engrs., 22 (1) (1999), 1-12.

[33] A. Velon, and I. Olefjord, "Oxidation Behaviour of Ni3Al and Fe3Al: 1. XPS Calibrations of Pure Compounds and Quantification of the Results," Oxid. Met., 56 (5-6) (2001), 415-424.

[34] Z. Liu, and W. Gao, "Oxidation Behaviour of Cast Ni3Al Alloys and Microcrystalline Ni3Al + 5% Cr Coatings with and without Y Doping," Oxid. Met., 55 (5-6) (2001), 481-504.

[35] B.S. Sidhu, and S. Prakash, "Evaluation of the Corrosion Behaviour of Plasma-Sprayed Ni3Al Coatings on Steel in Oxidation and Molten Salt Environment at 9000C," Surf. Coat. Technol., 166 (1) (2003), 89-100.

[36] G. Ji, O. Elkedimc, and T. Grosdidiera, "Deposition and corrosion resistance of HVOF sprayed nanocrystalline iron aluminide coatings",,Surface & Coatings Technology, (2004), in press.

[37] J. Kawakita, S. Kurida, T. Fukushima, and T. Kodama, "Development of dense corrosion resistant coatings by an improved HVOF spraying process," ASM International, Materails Park, Ohio, USA: Thermal Spray (2003) 353-359.

[38] D. Toma, W. Brandl, and G. Marginean, "Wear and corrosion behaviour of thermally sprayed cermet Coatings" Surface and Coatings Technology, 138 (2001), 149-158.

[39] S. Serghini, and S. Dallaire, "Cyclic and Isothermal Oxidation at 1200°C of HVOF NiCrAlY Sprayed Coatings," Proc. International Thermal Spray Conference, May 8-11, Montreal, Quebec, Canada, (2000), 1005-1009.

[40] M. Karolus, J. Panek, Nanostructured NiTi alloys obtained by mechanical synthesis and heat treatment, J. Alloys Compd 658 (2016) 709-715.

www.ijrrem.in Impact Factor: 2.9463
INTERNATIONAL JOURNAL OF RESEARCH REVIEW IN ENGINEERING AND MANAGEMENT (IJRREM)
Tamilnadu-636121, India
Indexed by
Scribd Impact Factor: 4.7317, Academia Impact Factor: 1.1610