IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876
Research paper **© 2012 IJFANS. All Rights Reserved**, **Volume 10, Iss 3 , 2021**

A Critical Review on High Temperature Oxidation Performance of Coatings on Steel Substrate

[1,]Md Sarfaraz Alam

[1]Department of Mechanical Engineering, Sershah Engineering College Sasaram, Bihar, India

---

Abstract

High temperature oxidation is a severe problem in high temperature application components such as Gas turbine blades, vanes, combustor cans, etc., in the power production industry. The main problem encountered in forming scales over the surface is that it further degrades. In recent decades, Cermet coatings have become very popular for many industrial applications due to their excellent physical, tribological, high temperature and mechanical properties. This review article suggests that by cermet coatings over the steel substrate may reduce the excessive formation and propagation of scale. Further, this can be used as a barrier to the diffusion/penetration of corrosive elements through coatings.The published work in the literature survey covers the period of past 20 years with main focus on the current trends.

Keywords:High temperature oxidation;Tribology;WearResistance;**Cermet*****Coatings.***

1. INTRODUCTION

New and improved materials are needed to meet the demands of growing industries as the sustainable development idea is put into practise. Superior surface qualities, such as high hardness, high erosion, high wear, high temperature oxidation, and hot corrosion resistance, are required for parts in modern industrial applications. Since alloys with these qualities are usually highly expensive, it would be beneficial to lower the cost of items that need them [1]. The surface layer of a less expensive substrate can be characterised in order to achieve this cost reduction. The advancement of engineering and technology depends on the creation of novel materials. The general purpose of surface modification is to provide ordinary materials enhanced qualities [2]. Surface functionalization is necessary for tribology and thermal barrier applications. The advancement of surface engineering is a result of this demand.

Surface modification involves adding lustre or protecting a substrate's surface against oxidation, corrosion, and wear. There are numerous methods for altering a material's surface. The use, cost, and environmental factors all play a role in the technique selection. The various surface modification techniques are Thermochemical Coatings (such as Carburizing, Nitriding, Cyaniding, etc.), Electroless deposition, Electrodeposition, Spray Coatings (such as Thermal Spray Coating, Flame Spray, Plasma Spray Coating, HVOF, etc.), Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD), Tungsten Inert Gas Cladding, Laser Cladding, etc. Surface Engineering is the collective name for these several approaches. Surface engineering approaches give the necessary substrate functional qualities such resistance to oxidation and corrosion as well as physical, thermal, chemical, electronic, electrical, magnetic, wear, and mechanical stresses. A wide variety of materials, including ceramics, metals, composites, and polymers, can be coated on one or more different substrate materials [3–9].

When metals, alloys, and coatings are exposed to air or oxygen, a special kind of corrosion degradation known as oxidation occurs. Oxidation can occur in other settings as well, such as those containing carbon dioxide and sulphur dioxide, which have less powerful oxidation potentials. The production of scales is a common symptom of deterioration. Apart from surface scale development, internal oxide production within the substrate can also coexist with the outer scale. The growth of the oxide scale is caused by oxidation. In the case of a thin, adhesive substrate that grows slowly, the produced oxide scale shields the substrate from additional oxidation. If the scale spalls often and the metal is constantly being consumed, finally the material fails.

2. RESEARCH PROGRESS IN HIGH TEMPERATURE OXIDATION

Huang et al. [10] examined the material's oxidation behaviour using a single-crystal Nickel based superalloy at temperatures between 900 and 1100 °C. The alloy exhibited a sub-parabolic rate law in oxidation study at 900 and 1000 °C, however a parabolic rate law was seen during exposures to 1100 °C, according to the data. On the dendritic and inter-dendritic areas of the superalloy, different scales formed after oxidation at 900 &1000 °C. The subsurface zone of the dendritic area had a substantial amount of internal nitride precipitates, whereas the subsurface zone of the inter-dendritic area showed no internal nitride.

Singh et al. [11] employed thermogravimetric techniques to investigate the cyclic oxidation behaviour of plasma-sprayed Ni-20Cr, NiCrAlY, Ni-3Al, and Stellite-6 coatings over the course of 50 cycles in a hostile condition of Na_2SO_4-60%V_2O_5. The Superni 600 superalloy was coated with these materials. Its oxide scale displayed considerable spallation, suggesting that the uncoated superalloy had oxidised rapidly. Reports state that spinels made of mixed oxides of nickel, chromium, cobalt, and nickel-aluminum were protective against hot corrosion and high temperatures, and these phases were mainly disclosed for the oxidised coatings.

The study conducted by Sidhu et al. [12] examined the wear behaviour and high-temperature oxidation of fly ash coating when sprayed using a shrouded plasma spray technique at 900°C. The development of $SiO_2$and Al_2O_3on the coating surface, according to their study, is what gave fly ash coating its superior oxidation resistance over mild steel substrate.

In ambient air at 1000 °C, Liu et al. [13] investigated the isothermal oxidation of laser-coated TiC/W_2C composite coatings on TiAl substrates. The TiC/W_2C composite coatings coated with lasers have low oxidation resistance and good resilience to wear.

The oxidation behaviour of cemented carbide (WC-10Co) between 450 and 700 °C was investigated by Shi et al. [14]. After 4 hours of air oxidation, the oxidation scale thickness varied from 39.1 μm to 2.12 mm, creating a porous oxide layer.

Liu et al. [15] investigated the oxidation behaviour of the Cobalt based superalloy DZ40M in the air at 900–1100 °C for up to 2000 hours. The results indicated that because of severe oxide scale cracking and spalling, this alloy may develop a protective oxide scale during isothermal oxidation at 900 and 1000 °C, but not at 1100 °C. While $CoCr_2O_4$ was mainly generated between 1050 and 1100 °C, the protective Cr_2O_3 oxide scale formed during the isothermal oxidation of DZ40M at 900 and 1000 °C. There was substantial spalling and cracking of the oxide scale.

Somasundaram et al. [16] reported that the growth of Al and Cr oxides on the coated surface led to coatings consisting of NiCrAlY and WC-Co exhibiting better oxidation resistance than substrates.

According to studies by Jagadeeswaran et al. [17], the Cr_3C_2/NiCrAlY coating sprayed by HVOF exhibited better oxidation behaviour at 800 °C than the Ti alloy.

Jafri et al. [18] investigated the high-temperature oxidation behaviour of four WC-Co HVOF thermal spray coatings. The three types of WC-Co materials are Ni coated micro structured WC-Co (Ni/mc-WC), nano-structured WC-Co (Ni/nc-WC), and micro-structured WC-Co (mc-WC). The results showed that Ni/mc WC had an improvement in oxidation resistance of 88.5% compared to mc-WC coating and Ni/nc-WC had an improvement of 89.3% compared to nc-WC coating after three hours at 800 °C. When Ni/nc-WC and Ni/mc-WC were oxidised at 800 °C, SEM analysis showed extremely thick and sticky oxide layers that were between 30 and 40 µm in thickness. On the surface of the mc-WC and nc-WC coatings, however, extremely porous oxide layers with thicknesses of 210 and 300 nm were created. The kinetics investigation's findings showed that the oxidation of the mc-WC and nc-WC coatings, respectively, follows the linear rule.

Erfanmanesh et al. [19] examined the oxidation behaviour of WC-Co and Ni/WC-Co coatings as well as the effects of applying an electroless Ni pre-coating over WC-12Co powder. They came to the conclusion that the time dependence of weight gain for WC-Co coating and Ni/WC-Co coating showed linear and nonlinear parabolic-like behaviours, respectively.

Mathapati et al. [20] effectively applied a WC-Co/ NiCrAlY/cenosphere coating on MDN 321 steel using a plasma spray method, with an average thickness of 150 µm. The coating demonstrates superior oxidation protection over the steel substrate, as seen by its reduced parabolic rate constant (Kp) at 600 °C compared to MDN 321 steel. The increased oxidation resistance of the coating is attributed to the production of Cr_2O_3, NiO, and Al_2O_3 oxides on its top layer. As a result of the generated oxides, oxygen cannot pass through the coating as an oxygen diffusion barrier.

Shoufa et al. [21] have developed WC-10Co cemented carbide. After being oxidised for two hours in air at 500 °C, they found that the weight gain per unit surface area was 0.09 mg/cm^2. As the temperature increased from 650 °C to 800 °C, it increased noticeably from 5.07 mg/cm^2 to 79.49 mg/cm^2. Concurrently with the increase in temperature, the thickness of the oxidation layer increased from 0.74 µm to 1.35 mm. The oxidation process is controlled by the reaction at the interface, which is why the mass gain curves at low temperatures (below 650 °C) exhibit linear law. At higher temperatures (800 °C), on the other hand, the reduced partial pressure of oxygen translated into a quasi-parabolic rule.

Yttria-stabilized zirconia (YSZ)@Ni core-shell powders combined with NiCoCrAlY alloy powders are laser cladded to create the composite coating on GH4169 alloy by Zheng et al. [22]. First-principle calculations and experimental studies are used to study the coatings' cyclic oxidation behaviour, particularly the growth of the oxide layer. According to the findings, the coated GH4169 alloy has a higher level of corrosion resistance than the untreated GH4169 alloy. A planar YSZ interlayer, an inner layer made of Cr_2O_3 created during laser cladding, and an outer layer made of cellular dendrites make up the three layers of the coating.

The planar yttria-stabilized zirconia interlayer becomes thinner and the cellular dendritic outer layer thickens with increasing oxidation time after oxidation at 1000 and 1050C. An Al2O3 layer develops between the planar interlayer and the Cr2O3 inner layer. Specifically, the weak interface strength of Al2O3/Cr2O3 caused cracks to form at the interface, ultimately leading to the breakdown of the composite coating.

The microstructure and oxidation behaviour of CoNiCrAlY coatings made using the APS, HVOF, and CGDS deposition processes are compared and examined by Richer et al. [23]. Utilising SEM and XRD investigations, the microstructural characteristics of the coatings were described. Following coating samples, isothermal heat treatments were applied at 1000 °C. While oxide scale compositions were ascertained using SEM, XRD, and EDS studies, oxide growth rates were established through a series of mass gain measurements.The study's findings indicate that while the APS coating has a high amount of apparent flaws and oxide content, the as-sprayed CGDS and HVOF coatings have similar microstructures. Because of their low porosity and oxide content, oxidation trials showed minimal rates of oxide development for both the CGDS and HVOF coatings. After 100 hours of oxidation, the oxide scale on the CGDS and HVOF coatings was primarily made of alumina and did not contain any harmful, quickly expanding mixed oxides. Nonetheless, the HVOF coating was also found to have scattered NiO and Cr_2O_3.

4. SUMMARY AND OUTLOOK

This article examines the most recent research and breakthroughs in the field of high temperature oxidation performance on various coatings on steel substrates. The coatings on steel substrate exhibited greater oxidation and hot corrosion resistance due to the protective WO_3/Cr_2O_3, etc.phases.Thedevelopedphasesserve as mechanism of transportation across this scale. These are typically slow growth in nature. Thus, oxide retards/prevents the inward diffusion of gaseous/vapour impurities and the outward diffusion of other alloy elements.

REFERENCES

[1] Spain, E., Avelar-Batista, J.C., Letch, M., Housden, J. and Lerga, B., 2005. Characterisation and applications of Cr–Al–N coatings. *Surface and Coatings Technology*, *200*(5-6), pp.1507-1513.

[2] Calabrese, L. and Proverbio, E., 2020. Special Issue "Recent Developments on Functional Coatings for Industrial Applications". *Coatings*, *10*(11), p.1017.

[3] Tuominen, J., Kaubisch, M., Thieme, S., Näkki, J., Nowotny, S. and Vuoristo, P., 2019. "Laser strip cladding for large area metal deposition". *Additive Manufacturing*, *27*, pp.208-216.

[4] Mozgovoy, S., Alik, L., Hardell, J. and Prakash, B., 2019. "Material transfer during high temperature sliding of Al-Si coated 22MnB5 steel against PVD coatings with and without aluminium". *Wear*, *426*, pp.401-411.

[5] Fernandes, J.D., Pazin, W.M., Aroca, R.F., Junior, W.D.M., Teixeira, S.R. and Constantino, C.J.L., 2019. "Photoluminescent properties in perylene PVD films: Influence of molecular aggregates and supramolecular arrangement". *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *211*, pp.221-226.

[6] Luo, S., Zheng, L., Luo, H. and Luo, C., 2019. "A ceramic coating on carbon steel and its superhydrophobicity". *Applied Surface Science*, *486*, pp.371-375.

[7] Guo, L., Dai, Q., Huang, W. and Wang, X., 2019. "Composite Ni/UHMWPE coatings and their tribological performances". *Applied Surface Science*, *481*, pp.414-420.

[8] Szaraniec, B., Pielichowska, K., Pac, E. and Menaszek, E., 2018. "Multifunctional polymer coatings for titanium implants". *Materials Science and Engineering: C*, *93*, pp.950-957.

[9] Kaur, H., Sharma, J., Jindal, D., Arya, R.K., Ahuja, S.K. and Arya, S.B., 2018. "Crosslinked polymer doped binary coatings for corrosion protection". *Progress in Organic Coatings*, *125*, pp.32-39.

[10] Huang, L., Sun, X.F., Guan, H.R. and Hu, Z.Q., 2006. "Oxidation behavior of a

single-crystal Ni-base superalloy in air at 900, 1000 and 1100° C”. *Oxidation of metals*, *65*, pp.207-222.

[11] Singh, H., Puri, D., Prakash, S. and Srinivas, M., 2006. “Characterisation of high temperature oxide scales for plasma sprayed NiCrAlY coated Ni- and Fe- based superalloys”. *Anti-Corrosion Methods and Materials*, *53*(5), pp.283-295.

[12] Sidhu, B.S., Singh, H., Puri, D. and Prakash, S., 2007. “Wear and oxidation behaviour of shrouded plasma sprayed fly ash coatings”. *Tribology international*, *40*(5), pp.800-808.

[13] Liu, X.B. and Yu, R.L., 2007. “Microstructure and high-temperature wear and oxidation resistance of laser clad γ/W2C/TiC composite coatings on γ-TiAl intermetallic alloy”. *Journal of alloys and compounds*, *439*(1-2), pp.279-286.

[14] Shi, X., Yang, H., Shao, G., Duan, X. and Wang, S., 2008. “Oxidation of ultrafine-cemented carbide prepared from nanocrystalline WC–10Co composite powder”. *ceramics international*, *34*(8), pp.2043-2049.

[15] Liu, P., 2009. “High Temperature Oxidation Behavior of Low Pressure Gas Phase Deposited Aluminide Coatings on Co-Base Superalloy DZ40M”. *Journal of Chinese Society for Corrosion and protection*, *19*(3), pp.144-150.

[16] Somasundaram, B., Kadoli, R. and Ramesh, M.R., 2014. “Evaluation of cyclic oxidation and hot corrosion behavior of HVOF-sprayed WC-Co/NiCrAlY coating”. *Journal of thermal spray technology*, *23*, pp.1000-1008.

[17] Jegadeeswaran, N., Ramesh, M.R. and Bhat, K.U., 2014. “Oxidation resistance HVOF sprayed coating 25%(Cr3C2-25 (Ni20Cr))+ 75% NiCrAlY on titanium alloy”. *Procedia materials science*, *5*, pp.11-20.

[18] Jafari, M., Enayati, M.H., Salehi, M., Nahvi, S.M., Han, J.C. and Park, C.G., 2016. “High temperature oxidation behavior of micro/nanostructured WC-Co coatings deposited from Ni-coated powders using high velocity oxygen fuel spraying”. *Surface and Coatings Technology*, *302*, pp.426-437.

[19] Erfanmanesh, M., Abdollah-Pour, H., Mohammadian-Semnani, H. and Shoja-Razavi, R., 2018. “Kinetics and oxidation behavior of laser clad WC-Co and Ni/WC-Co coatings”. *Ceramics International*, *44*(11), pp.12805-12814.

[20] Mathapati, M. and Doddamani, M., 2018, April. “Cyclic oxidation behavior of plasma sprayed NiCrAlY/WC-Co/cenosphere coating”. In *AIP Conference Proceedings* (Vol. 1943, No. 1). AIP Publishing.

[21] Shoufa, L., 2018. “Oxidation behavior of WC–Co cemented carbide in elevated temperature”. *Materials Research Express*, *5*(9), p.095801.

[22] Zheng, H.Z., Zhou, P.F., Li, G.F. and Peng, P., 2020. Cyclic oxidation behavior of NiCoCrAlY/YSZ@ Ni composite coatings fabricated by laser cladding. *Journal of Iron and Steel Research International*, *27*, pp.1226-1235.

[23] Richer, P., Yandouzi, M., Beauvais, L. and Jodoin, B., 2010. Oxidation behaviour of CoNiCrAlY bond coats produced by plasma, HVOF and cold gas dynamic spraying. *Surface and Coatings Technology*, *204*(24), pp.3962-3974.