70(10A): 59-64; 2022. DOI: 10.18311/jmmf/2022/31051

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: www.informaticsjournals.com/index.php/jmmf

Microstructure Characteristics and Properties of NiCrMoFeCoAl-30% Cr_3C_2 HVOF Coating on T22 Boiler Tube Steel

Viresh G Patil[1*], B. Somasundaram[1], Sakthivel Kandaiah[2] and N Jagadeeswaran[1]

[1]*School of Mechanical Engineering, REVA University Bengaluru, India. E-mail: [*]patilviresh751@gmail.com / somasundarb@reva.edu.in*

[2]*Department of Chemistry, School of Applied Sciences, REVA University Bengaluru, India.*

Abstract

In the present investigation, the NiCrMoFeCoAl-30%Cr_3C_2 composite coating was deposited on T22 baresteel with the HVOF technique. Cr_3C_2-based coatings offer high hardness, and good corrosion resistance. High-velocity oxy-fuel spray techniques comprising suspension feedstock have been considered a particularly promising substitute for producing more homogeneous and denser Cr_3C_2 coatings with lower as-deposited higher hardness, surface roughness, and superior quality corrosion resistance. The specimen's microstructure has been characterized by SEM/EDS and XRD methods. The coating thickness, porosity, microhardness, and coating density have been assessed.

Keywords: *HVOF composite coating, SEM/EDStechnique. Microhardness, Porosity.*

1.0 Introduction

In high-temperature environments, HVOF coatings exhibit great durability, superior bond strength, and corrosion resistance properties [1-2]. The microhardness values are thus associated with the conditions heat treatment and porosity variability [3]. Thermal spraying is considered adequate to install a protective coating, without affecting any other material of the material [4-7]. HVOF cermets - Co, WC - CoCr, and Cr_3C_2 - NiCr systems are the most often covered by WC. In demanding operational situations, such as hostile environments, the covering of WC-Co and WC-CoCr exhibits better tribological structures [8-9]. Several investigations have been done on evaluating entire coating designs [10-14]. Cr_3C_2-based materials are often used to improve the complex application of high-temperature applications including abrasions, slides, soil erosion and stress [15-24]. Various studies have recommended that hot-rolled hot cermet with a high amount of fine-grained carbide can have better wear and tear [25]. For HVOF Cr_3C_2 – NiCr coating and Cr_3C_2 carbide particles, carbides $Cr_{23}C_6$ and Cr_7C_3 can also be shown, allowing the prescribed results concluding XRD analysis [26-27]. At present, they have a high melting point, Cr_3C_2-NiCr coating similarly extends to high resistance to oxidation corrosion [28-29]. The NiCr matrix allows for corrosion resistance, while the caride ceramic peak substantially influences wear resistance [30]. Different phases are further indicated as carbides in Cr_3C_2 powders. Due to their low altitude the temperature changes [31]. The Cr_3C_2-Ni20Cr coating is used for applications with high-temperature resistance up to 850°C [32].

In the present study, the microstructure of

*Corresponding author

Table 1: Chemical composition of T22 substrate steel

Fe	Ni	Cr	Ti	Al	Mo	Mn	Si	C
Bal.	-	2.55	-	-	1.10	0.52	0.43	0.14

Table 2: Chemical composition of the HVOF coatings (wt. %)

HVOF coatings	Ni	Cr	Mo	Fe	Co	Al	Cr_3C_2
NiCrMoFeCoAl-30%Cr_3C_2	39.9	15.4	2.1	4.9	4.2	3.5	30

NiCrMoFeCoAl-30% Cr_3C_2 coating was sprayed with both SEM and XRD methods. The coating was designed to test for hardness, porosity, and microhardness.

2.0 Development of Coating

2.1 Selection of Substrate Material

The chrome-moly metal designated as ASTMSA213-T22 was employed as the bare material for the present study. T22 substrate material is used for boiler power plants. Table 1 shows the chemical composition of T22 substrate steel. Specimen with standard dimensions of 25 mm × 25 mm × 5 mm are recommended, laid down using SiC abrasive sheets up to 180 grit and later blown with Al_2O_3 pre-spraying of HVOF to improve the adhesion of the underground steel coating.

2.2 Coating Deposition Process

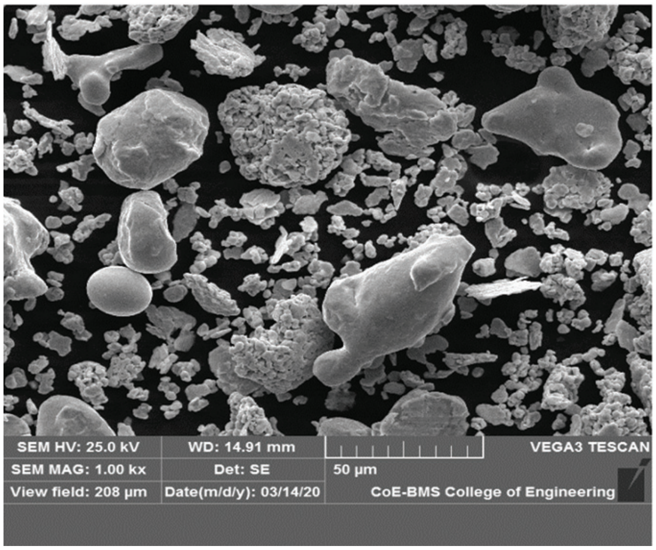

Figure 1: SEM micrograph of feedstock NiCrMoFeCoAl-30%Cr_3C_2 powder

HVOF spraying was done using HIPOJET 2700 machines. NiCrMoFeCoAl-30%Cr_3C_2 powder coated with particle size -45 + 15 µm wide and has a circular morphology. Figure 1 shows a SEM image of feedstock powder. All process parameters and spraying distance were maintained consistently during the coating development, and the powder was deposited all over the surface of the bare alloy. Table 2 shows the chemical composition of the coating powder.

2.3 Characterization Techniques

PAN alyticical diffractometer tool was used to perform XRD tests (X with CuKa radiation & Ni filter at 30 mA under 40 kV power). Samples were scanned at 2θ ranges of 100 to 800. Samples were included in SEM studies to identify the morphology status of the bare and coated sample. After initial description, c/s details were identified, samples were cut in a cross section and cold coated with acrylic resin to measure the magnitude of microhardness, porosity and the thickness of the coating in transoptic powder by mirror polishing were performed. Micro-Vickers robust machines help test the hardness of a 300g load-bearing cover for a 10 s duration according to the ASTM E384 standard. Metaplus image analysis software helps test the coated layer's cohesiveness based on the ASTM B276 standard. A transparent micrograph (Olympus BX53M Upright Metallurgical Microscope) assists in analyzing the small cover formation, density, and porosity of the composite samples. The amount of coating is determined. Samples were tested using XRD, SEM, and EDS techniques for surface definition, coating morphology, and its fragmented analysis, and basic coating formulations.

3.0 Results and Discussion

3.1 Characterization for As-deposited Coating

Coating thickness size is 195mm. The average porosity value of HVOF sprayed by NiCrMoFeCoAl-30%Cr_3C_2 coating

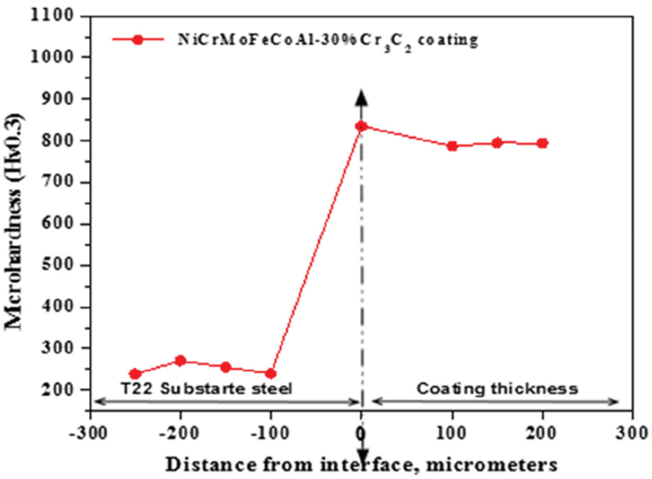

Figure 2: Variation in cross-sectional micro-hardness for a HVOF coated steel sample

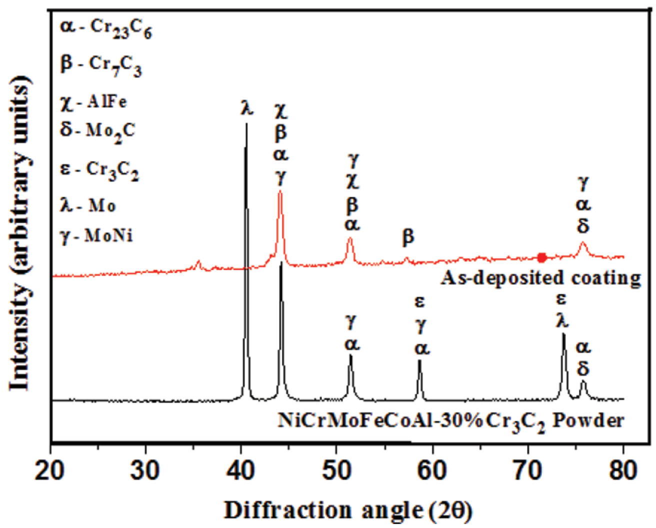

Figure 3: XRD spectra of as-sprayed NiCrMoFeCoAl-30% Cr_3C_2 coating and feedstock powder

was found to be less than 1.5%. The microhardness of the coating is shown in Figure 2. An estimated value of 270.4 HV0.3 is obtained by T22 substrate steel, the thickness of NiCrMoFeCoAl-30% Cr_3C_2 coating to T22 substrate steel is located at 854$HV_{0.3}$. It is evident that when microhardness rises, the coating's thickness rises as well. The thickness of the coating increases with decreasing porosity, due to the thick coating of the HVOF spraying method, perhaps the porosity will decrease. The microhardness of the HVOF coating is observed to change in the c/s due to homogeneities in the covering microstructure. The coating density is 7.65 Kg/m^3. Variations in porosity, microhardness, and intensity of HVOF as deposits included are reported in Table 3.

3.2 XRD Analysis of the As-deposited Coating

The XRD diffractogram for the composite powder and as-deposited into the T22 steel is displayed in Fig.3. The XRD analysis of NiCrMoFeCoAl-30%Cr_3C_2 coated and powdered component contains the $Cr_{23}C_6$ phase as a subgroup with other major Cr_7C_3 phases, and AlFe can be detected. HVOF coating showed almost the same phases as measured by the combined powder.

3.3 Surface Morphology of the As-deposited Coating

The SEM image of NiCrMoFeCoAl-30%Cr_3C_2 coating is shown in Fig.4. HVOF coating have been found to have particles connected with a splat-like morphology with a similar microstructure. EDS analysis of NiCrMoFeCoAl-30%Cr_3C_2 composite coating, EDS 1 site specifies the presence of Ni & Cr objects in large quantities and a small number of Co, Fe, Mo, and Al objects were found. The presence of Cr, Ni has high concentrations and a minor amount of Fe, Mo and Co was observed in selected area 1. The closest is the formation of sprayed powder. The emergence of a minor number of Mo& Fe elements on the surface of clothing, which determines the distribution of these substances from voids to wear as stated in the EDS analysis.

3.4. Cross-sectional Analysis of the as-sprayed Coating

The BSEI showing the morphology of the c/s of coating and EDS compliant analysis of HVOF-induced NiCrMoFeCoAl-30%Cr_3C_2 coating is displayed in Figure 5. The HVOF as-sprayed coating has been described, Ni and Cr

Table 3: Variation of porosity, microhardness, and thickness of coated steel

HVOF coating	Porosity (%)	Vickers Microhardness, VHN ($HV_{0.3}$)	Density (Kg/m^3)	Coating thickness (mm)
NiCrMoFeCoAl-30%Cr_3C_2	1.33	854	7.65	195

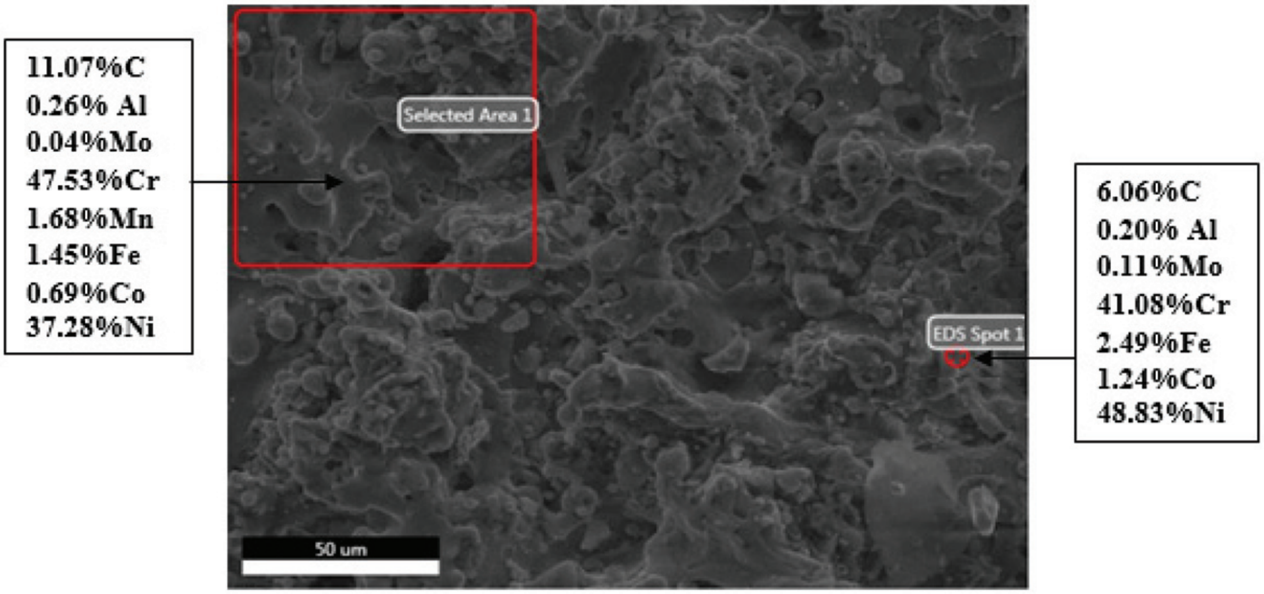

Figure 4: SEM and EDS examination of as-deposited NiCrMoFeCoAl-30%Cr_3C_2 coating.

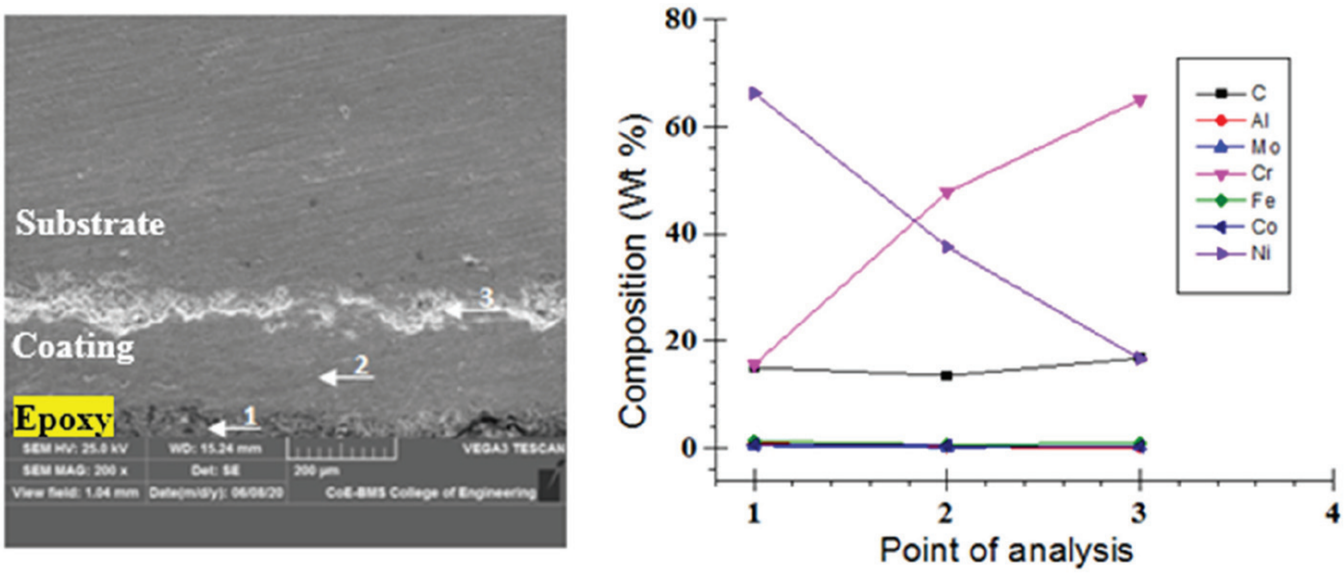

Figure 5: SEM/EDS point analysis (wt.%) across the cross-section of the as-sprayed coating

are present in the region of the outer layer scale in rich concentrations and a minor amount of Al, Co, and Mo in point 1. From point 2, the EDS investigations pectacles the existence of Ni, Mo, C, and Cr objects. The existence of Fe Cr, Ni, and C are evident in point 3.

4.0 Conclusions

1. It has been possible to obtain a NiCrMoFeCoAl-30%Cr_3C_2 coating with a coating thickness size of 195µm and an average microhardness of coating in the range of 835-860 $HV_{0.3}$.

1. In the NiCrMoFeCoAl-30%Cr_3C_2 coating region did not produce the voids. The typical deviation value was small, explaining the homogenous structure with 1.7% low porosity.

References

1. Yin B, Liu G, Zhou H, Chen J and Yan F 2010 Sliding wear behaviour of HVOF-sprayed Cr_3C_2–NiCr/CeO_2 composite coatings at elevated temperature up to 800°C Tribol. *Lett*., 37 463-475.
2. Liam Reddy, Philip Shipway, Colin Davis and Tanyir Hussain 2017 HVOF and Laser-Cladded Fe-Cr-B Coating in Simulated Biomass Combustion: Microstructure and Fireside Corrosion Oxid. *Met*. 87 825-835.
3. C.K. Lin, C.C. Berndt, Proceedings of the 1993 National Thermal Spray Conference, Anaheim, CA, 7–11 June, 1993, p. 561.
4. Bala, N., Singh, H. and Prakash, S., 2009. High-temperature oxidation studies of cold-sprayed Ni–20Cr and Ni–50Cr coatings on SAE 213-T22 boiler steel. *Applied Surface Science*, 255(15), pp.6862-6869.
5. W. Tillmann, E. Vogli, I. Baumann, G. Kopp, C. Weihs, *J. Therm. Spray Technol*. 19 (1-2) (2010) 392.
6. A. Rico, J. Gómez-García, C.J. Múnez, P. Poza, V. Utrilla, *Surf. Coat. Technol*. 203 (2009) 2307.
7. Roy, M., Pauschitz, A., Polak, R. and Franek, F., 2006. Comparative evaluation of ambient temperature friction behaviour of thermal sprayed Cr_3C_2–25 (Ni20Cr) coatings with conventional and nano-crystalline grains. *Tribology International*, 39(1), pp.29-38.
8. Guilemany J M, Miguel J M, Vizcaino S, Lorenzana C, Delgado J, and Sanchez J, *Surf Coat Technol* 157 (2002) 207.
9. Seong B G, Hwang S Y, and Kim K Y, *Surf Coat Technol* 126 (2000) 256.
10. S. Al-Mutairi, M. Hashmi, B. Yilbas, and J. Stokes, Microstructural Characterization of HVOF/Plasma Thermal Spray of Micro/Nano WC-12% Co Powders, *Surf. Coat. Technol.*, 2015, 264, p.175-186
11. B. Song, Z. Pala, K. Voisey, and T. Hussain, Gas and Liquid- Fuelled HVOF Spraying of Ni50Cr Coating: Microstructure and High Temperature Oxidation, *Surf. Coat. Technol*., 2017, 318, p.224-232
12. J. Cabral Miramontes, G.K. Pedraza Basulto, C. GaonaTiburcio, P.D.C. Zambrano Robledo, C.A. Poblano Salas, and F. AlmerayaCaldero´n, Coatings Characterization of Ni-Based Alloy Applied by HVOF, *Aircr. Eng. Aerosp. Technol.*, 2018, 90(2), p.336-343
13. S. Saladi, P. Ramana, and P.B. Tailor, Evaluation of Microstructural Features of HVOF Sprayed Ni-20Al Coatings, *Trans. Indian Inst. Met*., 2018, 71(10), p.2387-2394
14. S. Tailor, A. Modi, and S. Modi, Thermally Sprayed Thin Copper Coatings by W-HVOF, *J. Therm. Spray Technol*., 2019, 28(1-2), p 273-282.
15. Y. Fukuda, H. Yamasaki, M. Kawahara, H. Kimura, Proceedings of International Symposium on Advanced Thermal Spray Technology and Applied Coating, Japan High Temperature Society, Osaka, 1988, p.49.
16. H. Fukutome, H. Shimizu, N. Yamashita, Y. Shimizu, in: A. Ohmori (Ed.), Proceedings of 14th International Thermal Spray Conference, Japan High Temperature Society, Osaka, 1995, p.21.
17. B.Q. Wang, G.Q. Geng, A.V. Levy, E.R. Buchanan, in: C.C. Berndt (Ed.), Proceedings of the International Thermal Spray Conference and Exposition, ASM International, Materials Park, OH-USA, 1992, p. 735.
18. P. Sahoo, R. Raghuraman, in: C.C. Berndt, T.F. Bernecki (Eds.), Thermal Spray Coatings: Research, Design and Applications, *ASM International, Materials Park*, Ohio, USA, 1993, p. 405.
19. Wang, B.Q. and Luer, K., 1994. The erosion-oxidation behaviour of HVOF Cr_3C_2-NiCr cermet coating. *Wear*, 174(1-2), pp.177-185.
20. E. Lugscheider, P. Remer, C. Herbst, K. Yushchenko, et al., in: A. Ohmori (Ed.), Proceedings of 14th International Thermal Spray Conference, Japan High Temperature Society, Osaka, 1995, p. 235.
21. B.Q. Wang, in: T.S. Sudarshan, K.A. Khor, M. Jeandin (Eds.), Surface Modification Technology X, The Institute of Materials, London, 1996, p. 265.
22. I. Fagoaga, J.L. Viviente, P. Gavin, J.N. Bronte, J. Garcia, J.A. Tagle, Thin Solid Films 317 (1998) 259.
23. Mann, B.S. and Prakash, B., 2000. High temperature friction and wear characteristics of various coating materials for steam valve spindle application. Wear, 240(1-2), pp.223-230.
24. Wang, B.Q. and Shui, Z.R., 2002. The hot erosion behaviour of HVOF chromium carbide-metal cermet coatings sprayed with different powders. *Wear*, 253(5-6), pp.550-557.
25. C.-J. Li, Y.-Y. Wang, G.-J. Yang, A. Ohmori, K.A. Khor, *Mater. Sci. Technol*. 20 (2004) 1087.
26. D.C. Crawmer, J.D. Krebsbach, W.L. Riggs, in: C.C. Berndt (Ed.), Proceedings of the International Thermal

Spray Conference and Exposition, ASM International, Materials Park, Ohio, 1992, p. 127.

27. L. Russo, M. Dorfmann, in: A. Ohmori (Ed.), Thermal Spraying, Current Status and Future Trends, *Japan High Temperature Society, Osaka*, 1995, p. 681.

28. J. Gang-Chang, L. Chang-Jiu, W. Yu-Yue,L.Wen-Ya, Microstructural characterization and abrasive wear performance of HVOF sprayed Cr_3C_2–NiCr coating, Surf.Coat. Technol. 200(2006)6749–6757.

29. C.J. Li,G.C.Ji,Y.Y. Wang, K. Sonoya,The dominant mechanism of carbon loss during HVOF spraying of Cr_3C_2-NiCr,Thin Solid Films 419 (2002) 137–143.

30. J. Rapouch, Degradation of Cr_3C_2-NiCr coating prepared by the HVOF technique, Kovove Mater.57 (2013)82–86.

31. Handbook, A.S.M., 1992. Alloy phase diagrams, vol 03. ASM International, Materials Park, p 556 and 1107.

32. Hillery, R.V., 1986. Coatings for performance retention. *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, 4(6), pp.2624-2628.