SLURRY AND DRY PARTICLE EROSION WEAR PROPERTIES OF WC-10CO4CR AND CR_3C_2-25NICR HARDMETAL COATINGS DEPOSITED BY HVOF AND HVAF SPRAY PROCESSES

V. Matikainen[1]*, S. Rubio Peregrina[1], N. Ojala[1], H. Koivuluoto[1], J. Schubert[2], Š. Houdková[2], P. Vuoristo[1]

[1]Materials Science and Environmental Engineering, Tampere University, FINLAND.
[2]VZÚ Plzeň, CZECH REPUBLIC

ABSTRACT

Thermally sprayed hardmetal coatings were produced to provide improved erosion wear compared to conventional cast GX4CrNi13-4 martensitic steel (CA6NM) used in hydro turbine components. Sprayed coatings and reference materials were tested with high-speed slurry pot tester using either fine or coarse quartz as the erosive media. Additional erosion tests were carried out with centrifugal dry erosion tester. Tungsten carbide based coatings provided the highest wear resistance due to the high hardness and even distribution of the fine carbide particles. The cast 13-4 steel samples experienced up to 180 times higher wear rates in fine quartz slurry and up to 36 times higher wear rates in coarse slurry compared to the sprayed coatings.

Keywords: Slurry erosion; Erosion; Thermal spray; Coating; Hardmetal

*Corresponding author: Ville Matikainen (ville.matikainen@tuni.fi)

INTRODUCTION

Erosion of machine components by hard particles entrained in gaseous or liquid flow is common issue e.g. in hydro power, mining and pulp&paper industries. Especially hydro turbines experience accelerated wear worldwide due to the hard mineral particles from the river sediment [1]. The erosive wear can be reduced by modifying the surface structures of the components or by adding an additional layer of material with high wear resistance. The latter alternative can be achieved by thermal spraying.

Thermal spraying is a widely used technique to produce hardmetal coatings based on tungsten and/or chromium carbides. High velocity oxygen-fuel (HVOF) and high velocity air-fuel (HVAF) spray processes are most commonly used to accelerate and heat-up the hardmetal powder to produce the overlay coatings. The powder consists of agglomerate particles that contain hard carbide particles bound together by a ductile metal matrix consisting of Ni or Co alloy. Typically, the particles reach velocities of 600-1000 m/s and temperatures of 1350-1900°C before they impact on the surface [2]. During the spray processing, the particles are in partially melted state as the metal matrix melts at lower temperature leaving the carbides in solid state. As a result, dense 50-500 µm coatings are produced layer-by-layer as the particles hit the surface, flatten and solidify.

The main difference between HVOF and HVAF spray processes is the compressed air used in the latter as the oxidizer instead of pure oxygen in the combustion. During the last decade, HVAF spray process has gained increasing amount of interest from thermal spray industry and researchers as an alternative to the widely used HVOF spray process. The main benefits include lower combustion temperature, higher particle velocity, higher spray rate and reduced carbide dissolution.

Several coatings with WC-10Co4Cr or Cr_3C_2-25NiCr composition were manufactured and tested in three different conditions with increasing erosion intensity/stress.

MATERIALS AND METHODS

Commercial agglomerated and sintered WC-10Co4Cr and Cr_3C_2-25NiCr powders were sprayed with gaseous-fuel HVOF (Diamond Jet Hybrid 2700: Oerlikon Metco, Switzerland), liquid-fuel HP/HVOF (JP5000: Praxair, USA) and modern HVAF (M3: Uniquecoat Technologies LLC, USA) spray processes on low-carbon steel substrates. Details of the spray powders are given in Table 1.

Table 1. Sample designation, spray process, commercial powder and nominal size distribution.

Sample	Process	Composition	Particle size
H1W2	HVAF	WC-10Co4Cr	-25+5
H2W2	HP/HVOF	WC-10Co4Cr	-36+15
H3W2	HVOF	WC-10Co4Cr	-36+15
H1C2	HVAF	Cr_3C_2-25NiCr	-30+10
H2C2	HP/HVOF	Cr_3C_2-25NiCr	-30+10
H3C2	HVOF	Cr_3C_2-25NiCr	-45+15

Slurry erosion tests were carried out with an in-house built high-speed slurry erosion tester in two conditions: i) water+33 wt.% 0.1-0.6 mm quartz and ii) water+33 wt.% 2-3 mm quartz. Samples were tested for four 20-minute cycles (4×20min) and the slurry was replaced after each cycle. Samples were rotated through all stations to ensure similar wear. Erosion tests in dry condition were done with a centrifugal erosion tester using same 0.1-0.6 mm quartz sand as in slurry erosion. Details of the wear tests are given in Table 2.

Table 2. Summary of the wear tests with increasing intensity.

	Wear test	Quartz size	Particle velocity
I	Slurry erosion	0.1-0.6 mm	16 m/s [a]
II	Slurry erosion	2-3 mm	16 m/s [a]
III	Dry erosion	0.1-0.6 mm	~80 m/s

[a] Velocity at the sample tip.

RESULTS AND DISCUSSION

Slurry erosion with fine quartz size effectively attacked the soft metal matrix between the hard carbides. This was especially significant in the case of Cr_3C_2-25NiCr coatings, which have larger carbide particles and larger areas of matrix between the carbides. Despite the higher wear rates of the Cr_3C_2-25NiCr coatings, they also provided substantial improvement in wear resistance compared to the cast 13-4 steel, which experienced 25 mm^3 volume loss. With coarser quartz size the wear was dominated by ploughing and material removal of the extruded coating material. The difference between the hardmetal coatings and the reference 13-4 was decreased as the material loss of the reference was 141 mm^3.

Similar performance of the coatings was observed in dry erosion, but now the increase in wear resistance compared to the reference 13-4 steel was significantly reduced. Only WC-10Co4Cr coatings were able to provide significant improvement in wear resistance. Maximum erosion rate was observed at 60° impact angle.

The wear performance of the sprayed hardmetal coatings was primarily affected by the feedstock material composition resulting in highest wear resistance with WC-10Co4Cr coatings (in Fig. 1). However, within the same composition it can be noticed that the spray process plays an important role. This stems from the differences in material processing

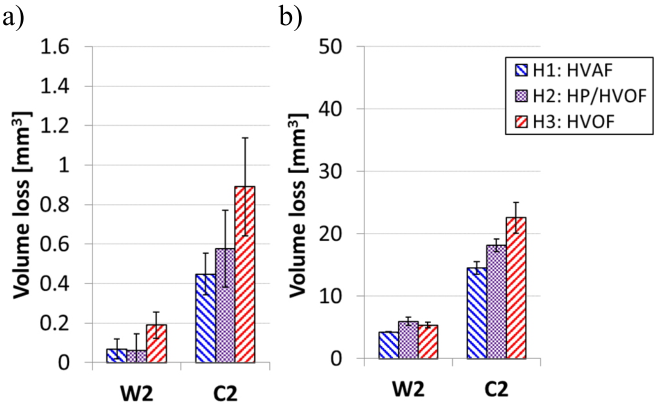

Figure 1. Volume loss of the coatings after a) slurry erosion test with fine quartz and b) with coarse quartz.

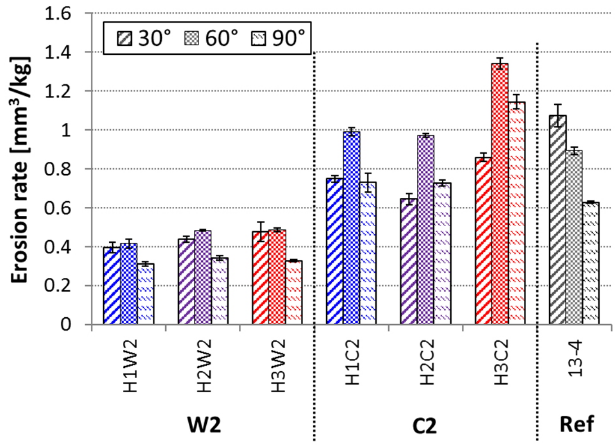

Figure 2. Erosion rate of WC-10Co4Cr coatings (W2), Cr_3C_2-25NiCr coatings (C2) and reference samples after dry erosion tests at 30°, 60° and 90° impact angles

between the three spray processes. HVOF spray process provides the highest particle melting while the particle velocity remains low (~600 m/s). The liquid-fueled high-pressure HVOF (HP/HVOF) produces higher particle velocities (~700 m/s) and more controlled particle heating compared to HVOF. The HVAF spray process, on the other hand, produces highest particle velocities (850-1000 m/s) and significantly lower particle temperatures compared to the HVOF and HP/HVOF processes. Increased kinetic energy component of the particles produces denser coatings with less defects. Lower particle temperature also allows the use of fine particle size distributions without over melting the material, which further decreases the size of the existing defects in the sprayed coating. As a result, the coatings are more compacted and homogeneous, and provide higher wear resistance.

CONCLUSIONS

- WC-10Co4Cr coatings sprayed with HVAF spray process provided the highest increase in wear resistance (up to 180 times higher) compared to reference materials.
- Increasing intensity of erosion, i.e. increasing particle size or increasing particle velocity, decreases the difference between the performance of hardmetal coatings and the cast 13-4 steel.
- Slurry erosion of hardmetal coatings takes place as selective erosion of soft metal matrix with fine erosive media.

REFERENCES

[1] U. Dorji and R. Ghomashchi, “Hydro Turbine Failure Mechanisms : An Overview”, Eng. Fail. Anal., vol. 44, pp. 136–147, 2014. https://doi.org/10.1016/j.engfailanal.2014.04.013

[2] V. Matikainen, H. Koivuluoto, P. Vuoristo, J. Schubert and S. Houdková, ” Effect of Nozzle Geometry on the Microstructure and Properties of HVAF-Sprayed WC-10Co4Cr and Cr_3C_2-25NiCr Coatings”, J. Therm. Spray Tech., 2018, (accepted). https://doi.org/10.1007/s11666-018-0717-z

[3] N. Ojala, K. Valtonen, P. Kivikytö-Reponen, P. Vuorinen, V.-T. Kuokkala,

"High speed slurry-pot erosion wear testing with large abrasive particles", Finnish J. Tribol., vol. 33, pp. 36–44, 2015.
https://journal.fi/tribologia/article/view/69243

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help of Mr. Mikko Kylmälahti in the spraying of the coatings. MSc Matikainen gratefully acknowledges the financial support from Finnish Cultural Foundation and International Thermal Spray Association (ITSA).