STANDARD HVOF PROCESS COMPARED TO THE HVOF PROCESS FOR INTERNAL COATING WITH FINE POWDERS

G. Matthaeus, Dortmund / D; W. Brandl, Gelsenkirchen / D; I.-F. Secosan, Gelsenkirchen / D; G. Marginean, Gelsenkirchen / D; V. Chirila, Gelsenkirchen / D; D. Ackermann, Bottrop / D

The main argument against the use of the internal HVOF process is the high thermal stress to which the substrates are subjected during the coating process. Traditional HVOF guns operate with a flame stream energy level of 100 – 200 kW. Rendering HVOF technology usable for the application of internal coatings requires the reduction of the energy level of the flame stream to 20 kW, while safeguarding high particle velocity and sufficient temperature despite the reduced energy level. This requires an inter-coordinated process made up of HVOF gun, powder feeder, fuel control and powder, based on the use of fine powders with particle sizes of -25 +5µm, -15 +5µm and -10 +3µm.Thermico's ID CoolFlow M HVOF internal spraying gun comes equipped with a 5mm acceleration nozzle and radial powder feed. It is suitable for internal diameters of 80mm and above and eliminates the typical overheating problem.The ID CoolFlow M HVOF gun is suitable for internal coatings with Thermico 776 WC-CoCr powder, which comes in grain sizes of -15 +5µm and -30 +15µm. A comparison of both processes requires a number of specimen coatings with different parameters, which have to be compared to reference coatings. These reference coatings are produced using a Thermico CJS K4.2 - 776/G in combination with WC-CoCr 86 10 4 powder with a grain size of -30 +15µm, and a CJS K5.2 - 776 gun, using a finer powder with a grain size of of -15 +5µm. The base material consists of heat-treated steel rings with a hardness of 45 HRC, an internal diameter of 130 mm and a wall thickness of 10mm. Subsequently, the density, porosity and structure of the specimen is assessed, and they are checked metallographically and with a scanning electron microscope, including EDX analysis. The specimen's wear is monitored using the prototype of an internal coating test stand, developed by the Institute of Materials Science at the University of Applied Sciences Gelsenkirchen. It is essentially based on the principle pin-on-disc tribometer for rotative movements.

1 Introduction

The HVOF guns for internal spraying, ID CoolFlow and ID CoolFlow M, are based on CJS technology in combustion chamber design and feature all the advantages of a decoupled stream temperature and velocity control, allowing the processing of very fine powders without overheating them. When it comes to the construction of the gun, unlike in conventional straight expansion nozzles, a redirection of the stream takes place in the divergent part of the laval nozzle. The powder is fed in following the redirection of the stream in the straight part of the expansion nozzle.
The ID CoolFlow gun comes equipped with an 8mm acceleration nozzle and dual radial powder feed and is suitable for internal diameters greater than 200mm. The smaller ID CoolFlow M is equipped with a 5mm acceleration nozzle and basic radial powder feed and may be used for internal diameters greater than 110mm [1].

ID CoolFlow HVOF guns, powder feeders, fuel control and powder make up an inter-coordinated process based on the use of fine powders with particle sizes of -25 +5µm, -15 +5µm and -10 +3µm. These small particle sizes require the use of suitable powder feeders.

2 Equipment

2.1 Powder Feeder

A constant powder flow requires a special powder feeder. The powder feeder in **Fig. 1** is suitable for standard as well as extremely fine powders of <5µm. The weighing sytem registers the powder mass flow, which is then measured with great precision via a closed control circuit into the carrier gas in "Constant Powder Flow" mode.

Fig. 1. Thermico's CPF 2 Powder Feeder with balancer and heating package.

2.2 CJS HVOF Torch

The reference coatings in this project were produced using Thermico's Carbide Jet System (CJS) **Fig. 2**. Two different nozzle/combustion chamber configurations, the CJS K4.2 and CJS K5.2, are available for this gun. This HVOF gun is equipped with a dual radial powder injection at a 16° angle. The jet temperature is controlled by a kerosene-oxygen system, while the jet speed is controlled by a hydrogen-oxygen system. The guns are liquid-cooled to prevent heat accumulation. Both operate with a two-step hydrogen and kerosene combustion system. The K4.2 features a small combustion chamber in the second step, where less energy is required to create high particle temperatures. In contrast, the K5.2 has a large combustion chamber in the second step, where more energy is required to create high particle temperatures. Coarse particle fractions, especially tungsten carbide and chrome carbide alloys, can be applied using the K4.2. Applying super-fine powders demands a specifically designed combustion chamber such as the K 5.2, which has been developed for this purpose

Fig. 2. Thermico's CJS HVOF Gun.

2.3 ID CoolFlow Mono HVOF Gun

The ID CoolFlow Mono gun is a HP HVOF system for high pressure but cold internal HVOF spraying, **Fig. 3**. Operating at reduced power levels, the ID CoolFlow flame applies coatings at reduced substrate temperatures. It is equipped with a single radial powder injector and designed to spray internal diameters of at least 80mm.

Fig. 3. Thermico's ID CoolFlow Mono HVOF Gun.

3 Experimental

3.1 Material

WC-CoCr 86 10 4 powder is the feedstock for Thermico's 776/F powder, **Fig. 4**. In order to obtain fine powder with a grain size of -15 +5 µm, the commercially available feedstock powder was sieved using a wind sieving device.

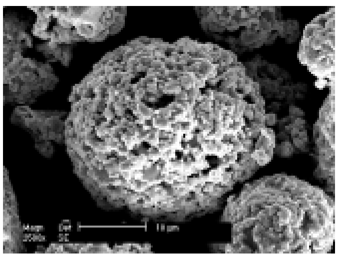

Fig. 4. Powder morphology of Thermico's 776/F powder.

The coatings were sprayed on the internal surface of the substrate which consists of heat-treated steel rings with a hardness of 45 HRC, an internal diameter of 130 mm and a wall thickness of 10mm. The substrate was degreased, roughened and cleaned prior to the coating process. For this procedure, the substrate was placed in a sandblasting cabin and treated with -60 +20µm grain size alumina particles and an operating pressure of 6 bars at a distance of approximately 200 - 250mm.

3.2 Processing

After preparing the substrate for the coating process, it was placed in a special test set-up consisting of two aluminium tubes with a length of 220mm, an internal diameter of 150mm and a wall thickness of 15mm. The substrate ring was placed in between these two tubes and fixed to both by set scews. This alignment was fastened on a turntable which rotates at a constant revolution speed of 180 rpm. To spray the reference coatings with the CJS guns, the top tube is left out. To ensure evacuation of the backscattered particles and the hot flue gases, the turntable is equipped with an internal extraction system **Fig. 5**.
During and after the HVOF process, the substrate was cooled by an air nozzle and the temperature monitored by an infrared temperature sensor.

Fig. 5. Special test set-up for internal coatings with Themico's ID CoolFlow Mono Gun.

The two reference coatings were sprayed at the parameters summarised in **Table 1/2**

Table 1. HVOF thermal spraying process parameters CJS 4.2 (reference parameter)

Parameter	Value
Kerosene flow rate [l/h]	8
Hydrogen flow rate [l/min]	49
Oxygen flow rate [m^3/h]	45
Powder propellant gas [l/min]	6.2
Vibrator pressure [bar]	2
Carrier rate [min^{-1}]	2
Spraying distance [mm]	300
Spraying angle [°]	105
Rotation speed table [min^{-1}]	180
Gun overruns	40

Table 2 HVOF thermal spraying process parameters CJS 5.2 (reference parameter)

Parameter	Value
Kerosene flow rate [l/h]	16
Hydrogen flow rate [l/min]	40
Oxygen flow rate [m^3/h]	45
Powder propellant gas [l/min]	6.2
Vibrator pressure [bar]	2
Carrier rate [min^{-1}]	2
Spraying distance [mm]	300
Spraying angle [°]	105
Rotation speed table [min^{-1}]	180
Gun overruns	40

As part of this test series, different parameters, such as spraying distance, kerosene flow rate and oxygen flow rate, were varied according to **Table 3-6**

Table 3 HVOF thermal spraying process parameters ID CoolFlow Mono 1 (standard parameter)

Parameter	Value
Kerosene flow rate [l/h]	3
Hydrogen flow rate [l/min]	49
Oxygen flow rate [m^3/h]	15
Powder propellant gas [l/min]	12.8
Vibrator pressure [bar]	3
Carrier rate [min^{-1}]	3
Spraying distance [mm]	55
Spraying angle [°]	105
Rotation speed table [min^{-1}]	180
Gun overruns	60

Table 4 HVOF thermal spraying process parameters ID CoolFlow Mono 2 (short-distance parameter)

Parameter	Value
Kerosene flow rate [l/h]	3
Hydrogen flow rate [l/min]	49
Oxygen flow rate [m^3/h]	15
Powder propellant gas [l/min]	12.8
Vibrator pressure [bar]	3
Carrier rate [min^{-1}]	3
Spraying distance [mm]	35
Spraying angle [°]	105
Rotation speed table [min^{-1}]	180
Gun overruns	60

Table 5 HVOF thermal spraying process parameters ID CoolFlow Mono 3 (low-hardness parameter)

Parameter	Value
Kerosene flow rate [l/h]	2
Hydrogen flow rate [l/min]	65
Oxygen flow rate [m^3/h]	12
Powder propellant gas [l/min]	12.8
Vibrator pressure [bar]	3
Carrier rate [min^{-1}]	3
Spraying distance [mm]	55
Spraying angle [°]	105
Rotation speed table [min^{-1}]	180
Gun overruns	60

Table 6 HVOF thermal spraying process parameters ID CoolFlow Mono 4 (no exhaustion parameter)

Parameter	Value
Kerosene flow rate [l/h]	3
Hydrogen flow rate [l/min]	65
Oxygen flow rate [m^3/h]	15
Powder propellant gas [l/min]	12.8
Vibrator pressure [bar]	3
Carrier rate [min^{-1}]	3
Spraying distance [mm]	55
Spraying angle [°]	105
Rotation speed table [min^{-1}]	180
Gun overruns	15

4 Results and Discussion

4.1 Coating Characterization

Powder morphology and particle size were examined using a scanning electron microscope with secondary and backscattered electron imaging (SEM and BSE, respectively). The samples for the SEM and BSE observation were prepared from a transverse section using standard metallographic techniques. The cross section of the coatings was examined using a scanning electron microscope as well as a light microscope. In addition, characterizations in terms of porosity and hardness of the coatings were performed by DHS image database software.
The microscope images of the polished cross section of the two reference coatings applied with the CJS 5.2 and CJS 4.2 are illustrated in **Fig. 6.** The thickness of the applied coatings amounts to approximately 150 µm for all samples in this test series.

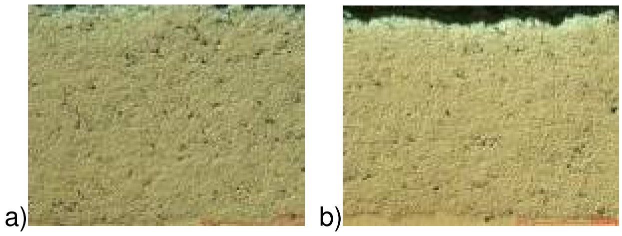

Fig. 6. Microscope images of reference coatings, applied with WC-CoCr 86 10 4: a) CJS 4.2, b) CJS 5.2

The samples of the CJS 4.2 and CJS 5.2 feature a porosity of below 1%. The hardness was measured and amounts to 925.59 HV 0.3 with a standard deviation of 200 HV for the CJS 4.2 and 1097.75 ± 118 HV 0.3 for the CJS 5.2 sample. These figures show that higher flow kerosene rates lead to more homogenous and improved coatings because of the higher thermal energy level applied to the coating [3].
Additional microscope images of the ID CoolFlow Mono test coatings are illustrated in **Fig. 7.** The changes in parameters according to **Tables 3-6** were made to illustrate changes in hardness and porosity.

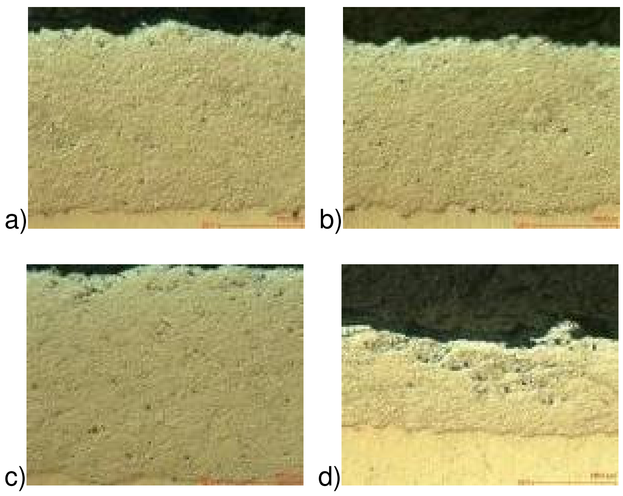

Fig. 7. Microscope images of the of the ID CoolFlow test coatings: a) standard parameter, b) short-distance parameter, c) soft-surface parameter, d) no-exhaustion parameter

The differences in hardness and porosity between the standard parameter and the short-distance parameter samples are insignificant, both featuring a hardness of 1155.75 ± 134 HV 0.3 and 1158.9 ± 143 HV 0.3, respectively.
A lower kerosene and oxygen flow rate causes, as expected, coatings with a lower degree of hardness. All coatings except the ID CoolFlow Mono 4 feature a homogenous morphology and very fine structure with a porosity of below 1%.
The coating applied without offtake shows a clearly higher porosity in the second half of the coating than all other coatings, but an increased hardness of 1250.68 ± 119 HV 0.3. The higher porosity is due to a lack of flue gas evacuation during the spraying process, which also causes a higher substrate temperature and increased hardness. When the powder-melting ratio is depressed, various large particles rebound off the substrate surface and the coatings tend to feature a higher porosity.

4.2 Conclusion

Thermico's new ID CoolFlow Mono allows the application of high-hardness and low-porosity internal coatings. The variation in oxygen, kerosene flow rate, spraying distance and exhaustion show in which way these factors influence the surface in terms of hardness and porosity. This step was rendered possbile using an inter-coordinated process made up of HVOF gun, powder feeder, fuel control and fine powder with a grain size of -15 +5 µm. Further improvements in hardness and porsity can be achieved by reducing the powder's grain size.

5 Literature

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[3] Reiners G., Kreye H., Schwetzke R.: Properties and characterization of thermal spray coatings, ITSC 1998, International Thermal Spray Conference and Exposition, Thermal Spray, Meeting the Challenges of the 21th Century, Nice, Ff, May 25-29, 1998.