

Cost-efficient wear / corrosion protective coatings using High Velocity Oxy Fuel Wire Spraying

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1. Introduction

High velocity oxy fuel (HVOF) sprayed coatings feature high bond strength and low porosity. This spraying method uses powders as feedstock. From conventional flame spraying the benefits resulting from the application of wire feedstock like higher deposition rates and efficiency are well known. The wires have to provide a sufficient flexibility in order to allow a secure feeding. Not every alloy or wanted coating material meets this demand. Cored wires expand the spectrum of applicable materials. In most cases a high degree of alloying can be achieved during the spraying process. This allows the use of a velum material providing good flexibility to form coatings of high hardness and wear resistance. Up to now there has been no systematic research on the application of cored wires for the high velocity oxy fuel wire spraying process (HVCW). The supersonic gas velocities cause high particle velocities and thereby short times of interaction between the particle and the environment. Therefore oxidation can be reduced significantly.

There is need of wear and corrosion protective coatings for components in combustion and exhaust gas cleaning processes. For these applications long repair intervals and the possibility to repair on-site are of high interest to reduce the costs due to the loss of production [1]. Self-fluxing and cermet coatings have proven to be best suited for wear / corrosion protection at elevated temperatures [2-7]. The combination of hard carbides and suitable alloying materials for a nickel based velum in a cored wire allows the production of such coatings from the HVCW process.

2. Experimental procedure

The samples are sprayed with a Praxair HVCW system Type 216 using ethylene as fuel gas. The spraying gun is moved manually. The spraying parameters are kept constant at flow rates of 30 l/min C₂H₄, 100 l/min O₂, an air pressure of 5,500 hPa and a spraying distance of 150 mm. For the oscillating wear test and for the corrosion test disk shaped specimen (diameter: 40 mm; height: 10 mm) and for the Taber-Abraser wear test flat specimen (100 x 100 x 4 mm) from C 45 N are applied. All specimen are grit blasted

with corundum (angle of impact: about 75°; blasting pressure: 6,000 hPa) and cleaned in an ultrasonic ethanol bath prior to spraying.

The different combinations of applied velum and filler materials are listed in **table 1**. Iron and nickel based wires with and without reinforcing carbides were sprayed in order to determine the influence of the carbides on the performance of the coatings. The benefits of WC/W₂C, and other refractory carbides as reinforcing hard phases are studied. All wires sprayed have an outside diameter of 1.6 mm. For evaluation of the wear and corrosion resistance WC/Co/Cr 86/10/4 (Amdry 5843) coatings are sprayed by HVOF with a Perkin Elmer Metco Diamond Jet spraying system.

product name	velum	filler contents
AS – 815	Fe	B, C, Cr, Si
AS – 816	Fe	C, Cr, refractory carbides
AS – 751	Ni	B, WC/W ₂ C (10 – 50 µm)
AS – 751 RC	Ni	B, refractory carbides
AS – 753	Ni	B, C, Cr, Si
AS – 760	Ni	B, Cr, refractory carbides

Table 1: Applied combinations of velum and filler materials for spraying feedstock

The sprayed coatings are characterised by optical microscopy, SEM and EDX. The wear resistance is determined for two different types of wear mechanisms. On the one hand the Taber-Abraser wear test (abrasive wheels: Calibrade H-10; load per wheel: 10 N; rotating speed: 60 min⁻¹; duration: 10.000 cycles) for evaluation of the abrasive wear resistance and on the other hand an oscillating wear test (counter body: Al₂O₃ ball, diameter: 9 mm; load: 20 N; amplitude: 1 mm; frequency: 20 Hz, duration: 60 minutes) are applied. While the specimen are exposed to the Taber-Abraser test in the as-sprayed state, the oscillating wear test requires polished surfaces to allow secure determination of the wear depth. For the evaluation of the corrosion resistance the DIN 50018 test in sulphurous water steam environment (2,67 l SO₂ in a 400 l chamber) is applied. In addition to as-sprayed and machined specimen manufactured from all wires, remelted coatings from DURMAT AS 753 are tested. Finally the possibility of remelting manually by a C₂H₂/O₂ flame and in a vacuum furnace are studied and compared. In the vacuum furnace the specimen are heated up to 1075°C (20 °C/min) at a pressure of 10⁻⁶ hPa and cooled down (100 °C/min) in an argon stream.

3. Results

The wires show a good sprayability with a continuous melt off behaviour and a sharp jet. On the right hand side in **figure 1** a picture of the spraying process applying a DURMAT

AS 751 wire by Praxair HVCW gun Type 216 is shown. A macroscopic picture of a cross section of this cored wire is shown on the left hand side of **figure 1**.

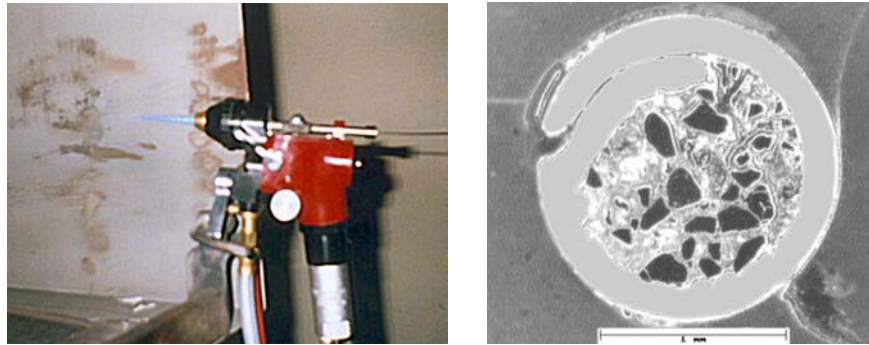


Figure 1: Spraying of an AS 751 wire (left) and cross section of a cored wire (right)

The surface of the sprayed coatings is smooth with R_a less than $20\ \mu\text{m}$ for carbide reinforced coatings and less than $10\ \mu\text{m}$ for coatings without carbide filler. Porosities less than 5% for coatings with reinforcing carbides and for the carbide free coatings even less than 3% can be achieved. For all applied wires there is a complete bonding between the substrate and the coating. The carbide content in the coatings amounts to about 5 Vol.-% in the case of the iron based cored wire DURMAT AS 816 and to about 20 Vol.-% in the case of the DURMAT AS 751 RC (**figure 2**). The reinforcing carbide particles are homogeneously distributed in the coatings and show a good metallurgical bonding to the matrix material due to a small molten interface. Therefore the carbides cannot be abraded easily from the coating surface, which would lead to more severe wear stress on the coating surface. Some coatings show interlamellar cracks with a length of up to $200\ \mu\text{m}$. These cracks can be avoided by optimising the process parameters with respect to thermally induced residual stresses.

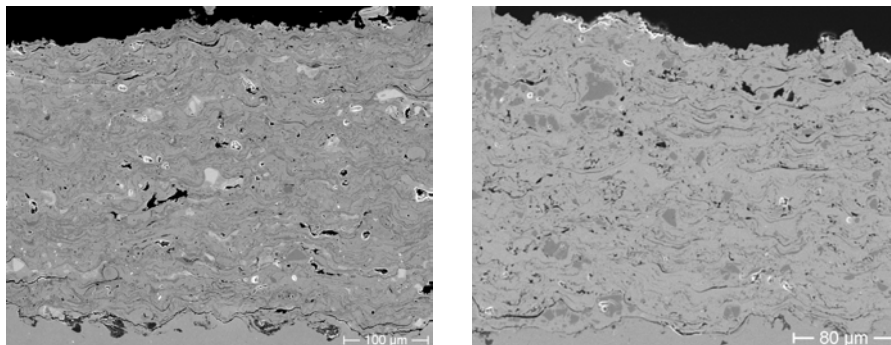


Figure 2: SEM pictures from cross sections of an iron based coating reinforced with NbC (left) and a nickel basis coating reinforced with refractory carbides (right)

When the coatings are exposed to the Taber-Abraser test, the weight loss in the beginning is fairly high, which is due to the elimination of roughness peaks. The smoother the surface becomes, the lower the wear rate is. When a smooth surface is achieved, the gradient of the wear curve becomes constant and allows the determination of a linear wear rate. A comparison of the determined linear wear rates is shown in **figure 3**.

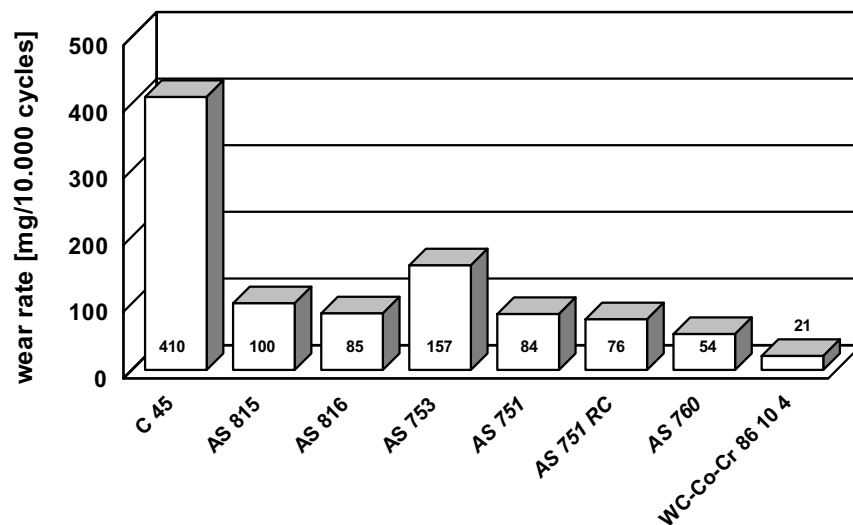


Figure 3: Comparison of linear wear rates in the Taber-Abraser test

The DURMAT AS 753 and AS 815 coatings without reinforcing carbides stand this kind of wear stress three and four times longer than mild steel respectively. The rather low wear resistance of the coatings from AS 753 is due to an insufficient degree of blending during the spraying process. The coatings from the wire DURMAT AS 760 show the highest wear resistance of all HVCW sprayed coatings and stand the Taber-Abraser wear test by factor 8 longer than mild steel. The wear resistance of HVOF sprayed WC/Co/Cr 86/10/4 is 2.5 times higher than that of the HVCW-sprayed coatings.

The oscillating wear test shows the benefits of carbide reinforcement (**figure 4**). The higher the content of carbides in the coatings, the lower the wear depths. The coatings without carbide reinforcement and low carbide content show no significant improvement against this type of wear compared to the mild steel substrate. By conventional wire flame spraying of DURMAT AS 751 with a diameter of 2.8 mm, which allow a higher carbide content in the feedstock, coatings with a WC/W₂C content of about 40 Vol.-% can be produced. Though these coatings show a high porosity (about 20 Vol.-%) the wear resistance in the oscillating wear test surpass that of all HVCW coatings.

The free chromium content in the matrix of coatings from the wires DURMAT AS 753 (13 At.-%) and DURMAT AS 760 (10 At.-%) is sufficient to obtain a good corrosion resistance in the DIN 50018 test. Both coatings - as sprayed, machined or remelted in the

case of AS 753 - show no visible formation of corrosion products within 80 hours of testing. But all other coatings, including WC/Co/Cr 86/10/4, form corrosion products covering the complete surface within 8 h of testing. This suggests, that the arc-sprayed coatings with sufficient chromium content in a nickel based matrix are suitable for combined protection against wear and severe corrosion in contrast to HVOF sprayed WC/Co/Cr 86/10/4 coatings.

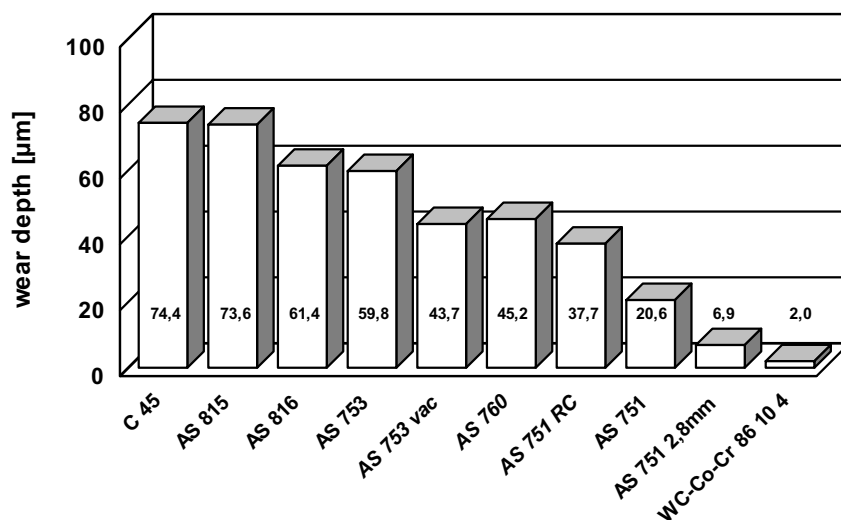


Figure 4: Comparison of wear depths after the oscillating wear test

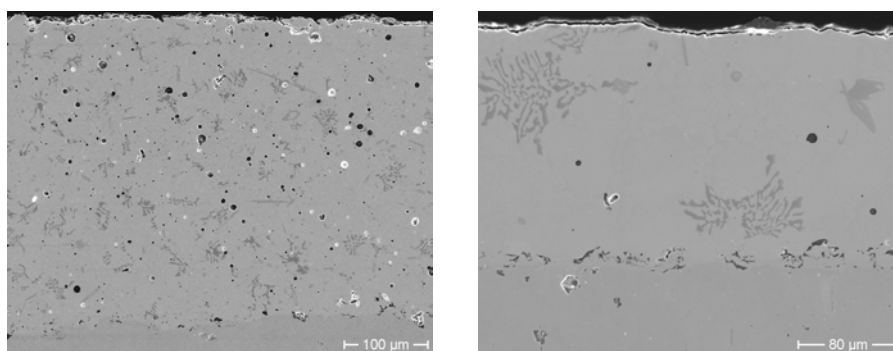


Figure 5: SEM pictures of manually (left) and in a vacuum furnace (right) remelted coatings from DURMAT AS 753

The coatings from the wire DURMAT AS 753 can be remelted both manually using a $\text{C}_2\text{H}_2/\text{O}_2$ flame and in a vacuum furnace. This results in a smooth surface and a homogeneous distribution of hard chromium carbide and boride phases in the coatings.

The manually remelted coatings show a porosity of about 3 Vol.-% while the coatings remelted in the vacuum furnace are free from pores (**figure 5**). The remelting of the coatings has a beneficial effect on the oscillating wear resistance resulting in a decrease of the wear depth of 30 %.

4. Discussion and perspectives

Cored wires have successfully been applied to produce self-fluxing and cermet-like coatings. Depending on the wear mechanism coatings with a wear resistance nearly as good as that of conventional HVOF WC/Co/Cr 86/10/4 coatings can be manufactured. When a sufficient free chromium content in the matrix is realised, the coatings from nickel based wires show a better performance under severe sulphurous corrosion conditions. The dominant factor for improvement of the resistance against oscillating wear is the carbide content, which can be increased significantly by applying wires with a larger diameter and thereby a higher filler content. The coatings show good machinability, when using c-BN grinding disks. No pores can be detected on the surface visually. HVCW sprayed NiCrBSi coatings can be remelted either manually in a C₂H₂/O₂ flame or in a vacuum furnace. Latter results in pore free coatings with a smooth surface and an increased oscillating wear resistance. All in all HVCW has been proved to be suitable to manufacture comparatively cheap coatings from cored wires with a high potential for combined wear / corrosion protection.

Following work will be done with further reinforcing hard phases. Furthermore wires with a diameter of 3.2 mm will be applied. Additionally investigations on the optimisation of the deposition efficiency will be made. Finally a comparison between arc-sprayed, conventional and high velocity wire flame sprayed coatings will be done with regard to coating properties and coating costs.

5. References

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