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Arc-spraying of reinforced self-fluxing coatings

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1. Introduction

Arc-spraying has the highest process efficiency and deposition rates among the methods of thermal spraying. While earlier investigations mainly focussed on the development of HVOF processes, nowadays arc-spraying has met high interest again, because of the potential to decrease the coating costs by replacing other spraying methods. There are two major research aims concerning the arc-spraying process. On the one hand processes with a controlled atmosphere (low pressure or inert gas atmosphere) are developed. On the other hand the particle velocity is increased by applying supersonic nozzles [1,2].

But arc-spraying is restricted to electrically conductive wires. Additionally the wires have to provide a sufficient flexibility in order to allow a safe feeding. Not every alloy meets this demand. The application of cored wires expands the spectrum of applicable materials. They allow to combine non-conductive powders as filler material with a metallic conductive velum. Using hard carbides as filler material cermet-like coatings can be produced. In most cases a high degree of blending can be achieved during the spraying process. This allows the alloying of a velum material providing good flexibility to form a brittle and / or hard alloy [3-5]. Cheap raw materials are in the centre of interest to use the complete potential to decrease coating costs.

2. Experimental procedure

The samples were sprayed with a standard G30/2 system and a closed nozzle system LD/U2 from OSU Maschinenbau GmbH. The spraying gun was moved manually. The parameters applied are listed in **table 1**. 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 were applied. All specimen were grit blasted with corundum (angle of impact: about 75°; blasting pressure: 6,000 hPa) and cleaned in ethanol in an ultrasonic bath prior to spraying.

Different combinations of velum and filler materials were applied. The main objective was to produce cermets with WC/W_2C hard phases in a corrosion resistant self-fluxing matrix material. Variations of the diameter of the carbide particles and the chromium content in the matrix composition were investigated. Additionally self-fluxing NiCrBSi without reinforcing carbides were sprayed in order to determine the influence of the carbides on the performance of the coatings. Furthermore the benefits of other refractory carbides as reinforcing hard phases were studied. The applied combinations of velum and filler materials are listed in **table 2**. All wires sprayed had an outside diameter of 1.6 mm. For evaluation of the wear and corrosion resistance WC/CoCr 86/10 4 (AMDRY 5843) were sprayed by HVOF with a Perkin Elmer Metco Diamond Jet spraying system.

voltage	23-30 V
wire feed rate	5 – 9 m/min
atomising gas pressure	1,750 – 3,500 hPa
spraying distance	100 – 200 mm

Table 1: Applied process parameters

wire	velum	filler contents
AS – 751 c	Ni	B, WC/W_2C (30 – 100 µm)
AS – 751 s	Ni	B, WC/W_2C (10 – 50 µm)
AS – 761	NiCr 80 / 20	B, WC/W_2C (10 – 50 µm)
AS – 760	Ni	B, C, refractory carbides
AS – 753	Ni	B, Si, Cr

Table 2: Applied combinations of velum and filler materials for spraying feedstock

The sprayed coatings were characterised by optical microscopy, SEM, EDX, microhardness (HV 0,05) and surface roughness tests. The wear resistance was 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: Al_2O_3 ball, diameter: 9 mm; load: 20 N; amplitude: 1 mm; frequency: 20 Hz, duration: 60 minutes) were applied. While the specimen were 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 SO_2 in a 400 l chamber) was applied. Finally the possibility of manual remelting with a C_2H_2/O_2 flame was studied.

3. Results

The wires showed good sprayability with a continuous melt off behaviour. Only in the case of the wire filled with coarse WC/W_2C some discontinuities were observed. In **figure 1** a cross section of a cored wire and the tip of a wire after the spraying process are shown. Inside the velum the carbides are completely embedded in a metallic matrix. This suggests that the carbide particles are wetted by the molten velum material at the wire tip before the melt is atomised. This contradicts statements, that the filler material is sucked out of grooved cored wires during the spraying process resulting in a heterogeneous distribution of the carbide particles in the coatings.

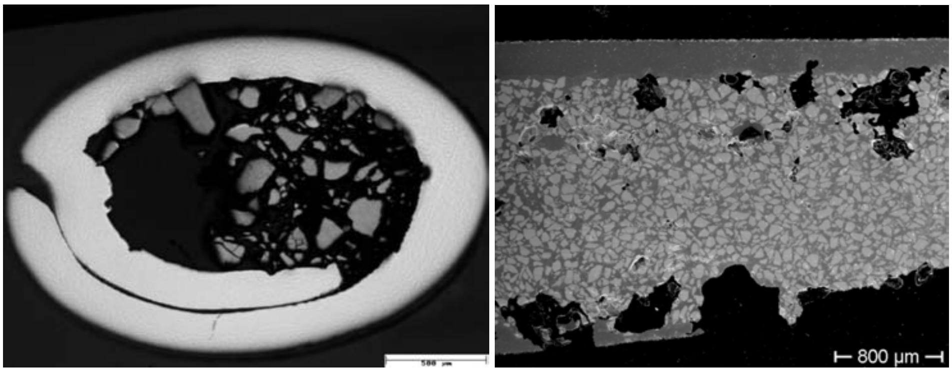

Figure 1: Inclinated cross section of a cored wire (left) and wire tip after spraying (right)

For WC/W_2C filled wires deposition rates up to 8 kg/h and deposition efficiencies of 60% are achieved, while for the carbide free wire the deposition rates amount to 7.5 kg/h with a deposition efficiency of 65%. In general high atomising pressures lead to finer lamellae and higher density of the coatings. While there is an increase of the deposition efficiency with rising atomising pressure, the efficiency decreases for WC/W_2C reinforced coatings, when a threshold of 2,500 hPa is exceeded. High atomising pressures lead to finer and faster sprayed particles. Therefore more and more carbide particles reach the surface with too less surrounding molten matrix material and with too high kinetic energy and act as abrasives. Furthermore the atomising pressure influences the surface roughness. The higher the atomising pressure the lower the surface roughness. The influence is especially significant for coatings from carbide filled wires. An increase of the atomising pressure from 1,750 hPa to 3,000 hPa leads to a bisection of R_a (from 45,7 µm to 25,2 µm) for wires filled with fine WC/W_2C particles, while the change is not that significant for carbide free coatings (from 24,4 µm to 20,2 µm) Depending on the process parameters vertical cracks with a maximum length of about 100 µm were observed in the coatings. Usually these cracks are only found in the metallic matrix.

With WC/W_2C filled wires coatings with a porosity less than 5% and for the carbide free wire even less than 3% can be achieved (**figure 2**). For all applied wires there is a complete bonding between the substrate and the coating. The carbide content in the coatings amounts to about 20 Vol.-% for coarse and to about 30 Vol.-% for fine WC/W_2C. While fine WC/W_2C particles show a homogeneous distribution in the coatings, coarse particles are concentrated at some locations. This may be correlated to the discontinuous spraying process.

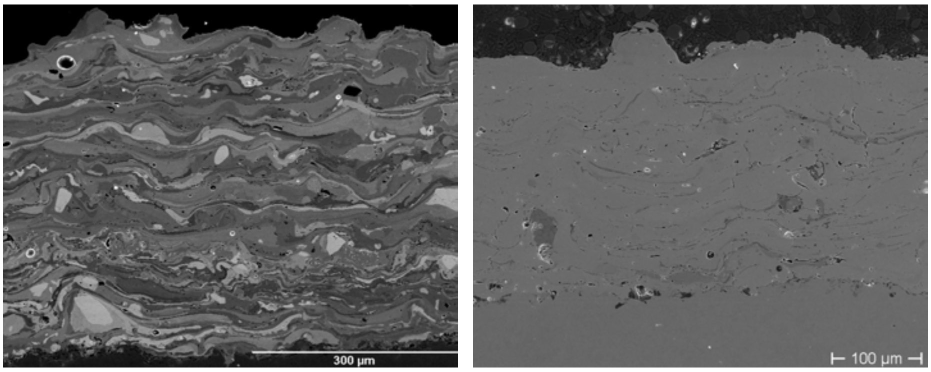

Figure 2: SEM pictures from cross sections of coatings reinforced with fine WC/W_2C particles (left) and carbide free self-fluxing coatings (right)

The microhardness of the self-fluxing coatings without carbide reinforcement amounts to 749 HV 0,05. Depending on the process parameters the matrix of the WC/W_2C reinforced coatings shows a similar microhardness (up to 741 HV 0,05), while the microhardness of the carbides (about 2050 HV 0,05) is not dependent on the process parameters, as only a small amount is molten and solved in the matrix metal.

When the coatings are exposed to the Taber-Abraser test, they undergo a high wear in the beginning, that is due to the elimination of roughness peaks. The smoother the surface becomes, the lower is the wear rate. 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**. The coatings without reinforcing carbides stand wear stress four times longer than mild steel. The wear resistance of the coatings reinforced with coarse WC/W_2C show a similar performance. Their wear resistance is restricted by the heterogeneous carbide distribution. Reinforcement by finer WC/W_2C obtain an about 15% better wear resistance. Especially the coatings produced with high atomising pressures show good wear behaviour. The wear resistance of HVOF sprayed WC/CoCr 86/10 4 is only 3 times higher than that of the arc-sprayed coatings reinforced with refractory carbides.

The oscillating wear test shows the benefits of carbide reinforcement (**figure 4**). The higher the amount of hard phases in the coatings, the lower the wear depths. The coatings without carbide reinforcement showed no improvement against this type of wear compared to the mild steel substrate. For WC/W_2C reinforced coatings an improvement by the factor 8 was achieved. The coatings containing about 15 Vol.-% refractory carbides and the coatings with NiCr 80/20 matrix withstand oscillating wear 3.5 times better than mild steel. Al_2O_3/TiO_2 coatings are useless for applications with oscillating wear stress, as a 200 µm thick coating is completely abraded within 5 minutes. By conventional wire flame spraying coatings with a WC/W_2C content of about 40 Vol.-% were produced applying wires with a diameter of 2.8 mm, which allowed a higher content of carbides in the feedstock. Though these coatings showed a high porosity (about 20 Vol.-%) the wear resistance in the oscillating wear test surpass that of the arc-sprayed coatings.

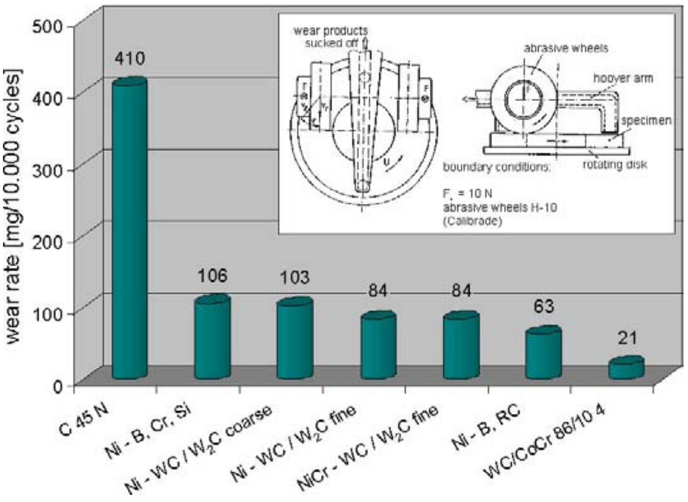

Figure 3: Comparison of linear wear rates in the Taber-Abraser test

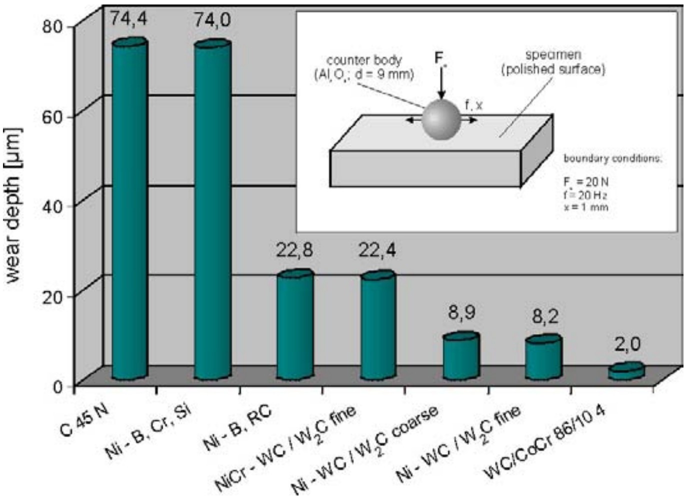

Figure 4: Comparison of wear depths after the oscillating wear test

The arc-sprayed coatings with a high chromium content in the matrix showed good corrosion resistance in the DIN 50018 test. Both NiCrBSi and NiCr – WC/W_2C coatings - as spayed, machined or remelted in the case of NiCrBSi - showed no visible formation of corrosion products within 80 hours of testing. But all other coatings, including WC/CoCr 86/10 4, formed 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/CoCr 86/10 4 coatings.

The carbide free coatings can be remelted manually using a C_2H_2/O_2 flame. This results in a smooth surface and a homogeneous distribution of hard phases in the coating.

The remelted coatings show a fairly high porosity of about 5 Vol.-%. An optimisation of the remelting process, e.g. carrying out the process in a vacuum furnace, will decrease the porosity significantly.

4. Discussion and perspectives

Because of the high efficiency of arc-spraying and the relatively cheap raw materials arc-sprayed WC/W_2C reinforced self-fluxing coatings show a great potential to reduce coating costs for wear protection applications. Significant benefits of the carbide reinforcement regarding wear resistance have been proven both in the Taber-Abraser and in the oscillating wear test. The corrosion resistance of coatings with a sufficient chromium content in the metal matrix exceed that of nowadays HVOF sprayed WC/CoCr coatings. The coatings show good machinability, when using c-BN grinding disks. No pores can be detected on the surface visually.

Following work has to be done to optimise the deposition efficiency. Additionally wires with a diameter of 3.2 mm will be applied in order to increase the carbide content in the feedstock and succeeding in the coatings. Furthermore the bonding strength will be determined quantitatively. 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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