# Wires for arc- and high velocity flame spraying – wire design, materials and coating properties

J. Wilden[a)], A. Wank[a)], F. Schreiber[b)]

[a)] Chemnitz University of Technology, Germany
[b)] DURUM Verschleißschutz GmbH, Krefeld, Germany

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## Abstract

Cored wires show a high potential for production of protective coatings for combined corrosion and wear applications. Iron and nickel based grooved cored wires without and with different reinforcing carbide fillers have been sprayed by arc- and high velocity combustion wire (HVCW) spraying with a Praxair Type 216 gun. Depending on the wear mechanism coatings with a similar abrasive or oscillating wear resistance like HVOF WC/Co/Cr 86/10/4 have been produced. For effective protection against oscillating wear wires with a large diameter and therefore a high content of reinforcing carbide filler have to be applied. All nickel based coatings with chromium addition show an improved corrosion resistance compared to HVOF-sprayed WC/Co/Cr 86/10/4. For coatings from wires with NiCr 80/20 velum no effect of severe sulphurous corrosion in the DIN 50018 test is observed. HVCW-spraying is especially suitable, when only a low degree of interaction between velum and filler material is wanted as for cermet-like coatings. Conventional arc-spraying rather meets the demands of a high degree of interaction between velum and filler necessary for the production of pure metallic coatings like NiCrBSi. All manufactured coatings show good machinability.

## Introduction

Thermal spray processes using wire feedstock are superior to those using powder feedstock with respect to the energy consumption for the formation of molten particles, to deposition rate and to handling demands. As the particles atomized from the wire tip are completely molten, the deposition efficiency is in general higher. Additionally in most cases the wire feedstock is cheaper than the analogous powder. But not every alloy or coating material can be manufactured as a wire. For secure feeding the wire material has to provide a sufficient flexibility. Therefore a sufficient strength to prevent failure of the wire and ductility to prevent brittle fracture is necessary.

Cored wires expand the spectrum of producible coating materials. They allow the combination of a velum material providing good flexibility with any kind of filler material in powder state. There are two different directions of development for manufacturing coatings from cored wires. On the one hand a spraying process providing a high degree of interaction between the velum and filler material can be applied to alloy a ductile velum material forming hard (and brittle) alloys [1-3]. On the other hand a process, that allows only little interaction of velum and filler material, can be applied to manufacture cermet-like coatings. In order to achieve a good bonding between the hard phases – carbides, borides or nitrides - an improvement of the wetting behavior of the matrix material is beneficial. Both for iron and nickel based matrices the addition of boron (and silicon) can provide such improvement.

Arc-spraying has the highest process efficiency and deposition rates among thermal spray processes. 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 [4,5]. Arc-spraying provides relatively high process temperatures exceeding 5000 K in the arc and for the subsonic methods the time of interaction in-flight is sufficient to assure a high degree of alloying between feedstock components. Cheap raw materials are in the center of interest to use the complete potential to decrease coating costs.

High velocity combustion wire spraying processes (HVCW) combine the benefits of high velocity spraying methods with those using wire feedstock. The high particle velocities result in a high bond strength and low porosity. Because of the short times of interaction between the particle and the environment oxidation can be reduced significantly. The application of wire feedstock allows higher deposition rates and efficiency. Up to now there has been no systematic research on the application of cored wires for the high velocity combustion wire spraying process.

A further promising possibility to manufacture wires that form the coating material during the spraying process is to apply coated wires. A very cost-efficient technique is to coat a central wire with powders in an organic binder. These compound wires show a good flexibility, but a secure central position of the massive wire has to be achieved. Changes in the position of the central wire in the compound lead to discontinuous melting behavior during the spraying process. Furthermore the application of an organic binder leads to strong expansion of the compound wire inside the spraying gun during the process and can cause an interruption of the wire feeding. Finally the inclination between flame and wire in most spraying guns is too small to assure a complete melting of both the coating powder and the central wire. Radial feeding outside the spraying gun may be a more suitable way to apply wires with this type of design.

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 [6]. Self-fluxing and cermet coatings have proven to be best suited for severe wear / corrosion protection even at elevated temperatures [7-12]. Both for arc-spraying and HVCW mobile spraying systems with easy handling are available, that make the on-site production of these coatings possible applying cored wires.

## Experimental

Arc-spraying is carried out with a standard G30/2 system and a closed nozzle system LD/U2 from OSU Maschinenbau GmbH and HVCW with a Praxair system Type 216 using ethylene as fuel gas. The spraying guns are moved manually in both cases. The parameters applied for arc-spraying and HVCW are listed in **table 1** and **table 2** respectively. For the oscillating wear and the corrosion test disk shaped specimens (diameter: 40 mm; height: 10 mm) and for the Taber-Abraser wear test flat specimens (100 x 100 x 4 mm) of C 45 N are applied. All specimens 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.

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

**table 1:** Arc-spraying parameters

| | |
|---|---|
| ethylene ($C_2H_4$) | 30 l/min |
| oxygen ($O_2$) | 100 l/min |
| air pressure | 5,500 hPa |
| spraying distance | 150 mm |

**table 2:** HVCW parameters

**Table 3** shows a list of the applied combinations of velum and filler materials as well as their official product name from the wire feedstock supplier DURUM Verschleißschutz GmbH. Iron and nickel based wires with and without reinforcing carbides are sprayed in order to determine the influence of carbide reinforcement on the performance of the coatings. The benefits of eutectic tungsten carbide $WC/W_2C$ (FTC) and other refractory carbides as reinforcing hard phases concerning wear protection and of different chemical matrix compositions concerning the corrosion protection are studied. The sprayed wires are grooved cored wires and have an outside diameter of 1.6 mm. An inclined cross section of the wire DURMAT AS 751 s is shown in **figure 1**. For comparison of the results WC/Co/Cr 86/10/4 (Amdry 5843) coatings are sprayed by HVOF with a Perkin Elmer Metco Diamond Jet spraying system.

| **product** | **velum** | **filler** |
|---|---|---|
| DURMAT AS 815 | Fe | B, C, Cr, Si |
| DURMAT AS 816 | Fe | B, C, Cr, FeCr, Nb |
| DURMAT AS 751 c | Ni | B, FTC (60 – 160 $\mu$m) |
| DURMAT AS 751 s | Ni | B, FTC (10 – 50 $\mu$m) |
| DURMAT AS 761 | NiCr 80/20 | B, FTC (10 – 50 $\mu$m) |
| DURMAT AS 751 RC | Ni | B, refractory carbides |
| DURMAT AS 753 | Ni | B, C, Si, Cr, Fe |
| DURMAT AS 760 | Ni | B, Cr, refractory carbides |

**table 3:** Applied combinations of velum and filler materials in spraying feedstock

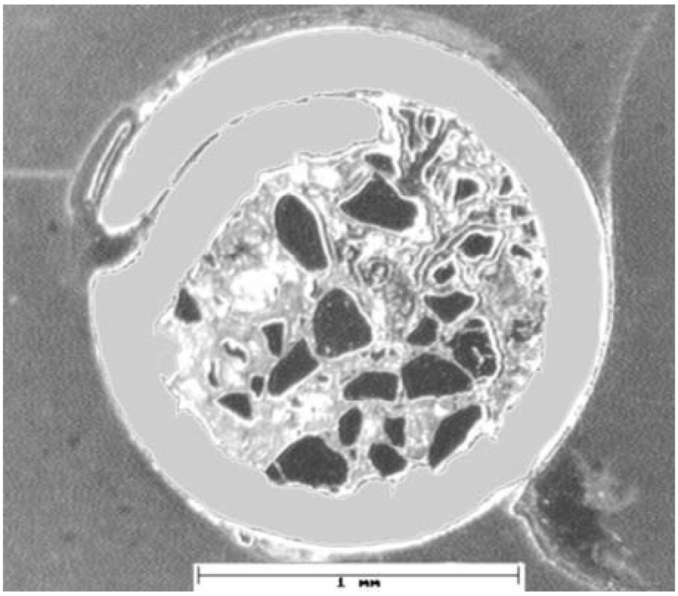

**figure 1:** Inclined cross section of a cored wire (DURMAT AS 751 s)

The sprayed coatings are characterized with regard to the coating morphology and their bonding to the substrate by optical microscopy and SEM. EDX is applied to determine the chemical composition of the coatings phases. Additionally microhardness (HV 0.05) and surface roughness tests are carried out. The possibility of remelting either manually by a

$C_2H_2/O_2$ 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. 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; rotat. 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) are applied. While the specimens 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 $SO_2$ in a 400 l chamber) is applied. In addition to as-sprayed and machined specimens manufactured from all wires, remelted coatings from DURMAT AS 753 are tested.

## Results

### Process and metallographical characterization

*Arc-spraying*

Except for the wire DURMAT AS 751 c all wires showed good sprayability with a continuous melt off behavior. The coarse $WC/W_2C$ filler material affects the spraying process by leading to frequent breakdown of the arc. In **figure 2** the tip of a wire DURMAT AS 751 s after the arc-spraying process is shown. The carbides are completely embedded in a metallic matrix with a velum of still not molten nickel surrounding the compound. This suggests that the carbide particles are wetted by a mixture of molten velum and filler material at the wire tip prior to the atomization of the melt. 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.

For wires filled with fine $WC/W_2C$ (DURMAT AS 751 s) deposition rates up to 8 kg/h and deposition efficiencies of 60% are achieved, while for the carbide free wires DURMAT AS 815 and DURMAT AS 753 the deposition rates amount up to 7.5 kg/h with a deposition efficiency of 65%. For wires with a high carbide filler content the maximum deposition efficiency can be determined at atomizing pressures of 2,500 hPa, while the efficiency rises for wires without reinforcement continuously with increasing atomizing pressure (**figure 3**). When a critical atomizing pressure is exceeded the carbide particles impact on the surface with too less surrounding molten matrix material and with too high kinetic energy and act as abrasives.

In general high atomizing pressures lead to finer lamellae and higher density of the coatings, because finer particles are formed from the melt at the wire tip and accelerated to higher velocities. For the same reason rising atomizing pressures cause a decrease of the surface roughness. The influence is especially significant for coatings from wires with carbide filler. An increase of the atomizing gas pressure from 1,750 to 3,000 hPa leads to a decrease of $R_a$ from 45,7 to 25,2 $\mu$m for wires filled with fine eutectic tungsten carbide particles. For carbide free coatings from the wire DURMAT AS 753 the change is not that significant ($R_a$: 24,4 $\mu$m for a pressure of 1,750 hPa and 20,2 $\mu$m for 3,000 hPa). For some process parameters vertical cracks with a maximum length of about 100 $\mu$m can be observed in the coatings. Apart from a few exceptions these cracks are only found in the metallic matrix.

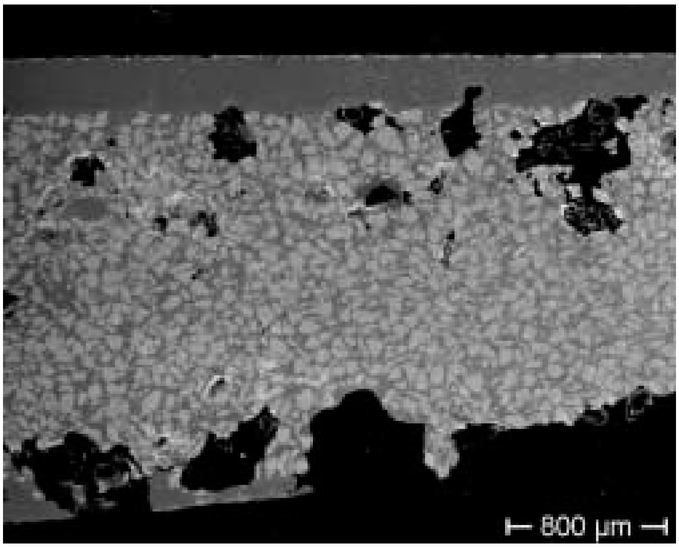

**figure 2:** Tip of the wire DURMAT AS 751 s after arc-spraying

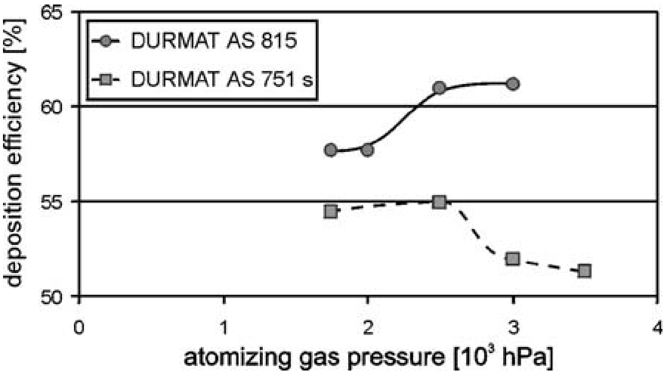

**figure 3:** Deposition efficiency depending on the atomizing gas pressure

Coatings with remarkably low porosity can be manufactured. Porosities less than 5% for wires filled with fine eutectic tungsten carbides and even less than 3% for the carbide free wire DURMAT AS 753 are possible (**figure 4**). 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 $WC/W_2C$. The carbide particle distribution in the coatings is homogeneous, when the applied particles are fine (**figure 5**). The concentration of coarse particles at some locations can be correlated to the discontinuous spraying process mentioned above.

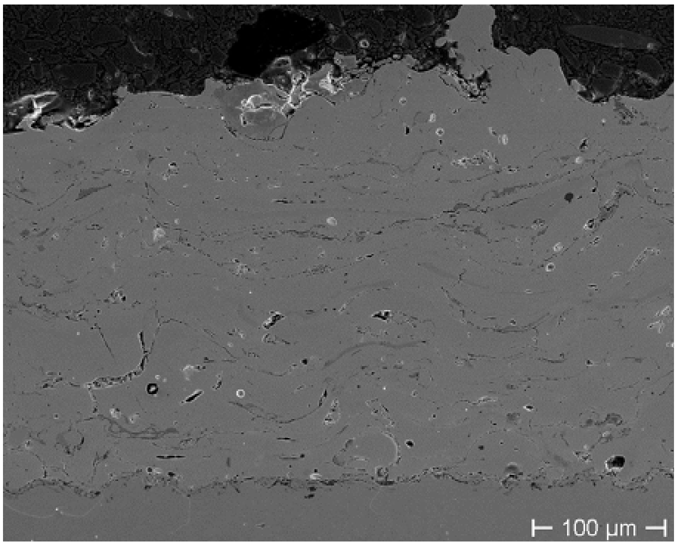

**figure 4:** SEM picture of a cross section of an arc-sprayed coating from DURMAT AS 753

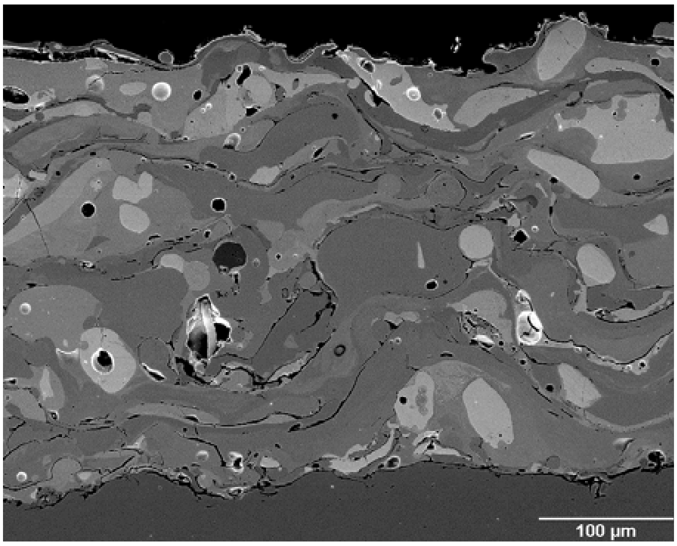

**figure 5:** SEM picture of a cross section of an arc-sprayed coating from DURMAT AS 751 s

The reinforcing carbide particles are completely embedded inside the metallic matrix, which is beneficial for abrasive wear resistance, because the particles cannot be removed out of the compound as easy as in the case of simple mechanical inclusion without metallurgical bond. For low voltages and high spraying distances a considerable amount of boron remains not molten inside the coating. A sufficient heat transfer from the arc to the wire tip is necessary to assure, that the boron can alloy the matrix melt and improve the wettability. Small spraying distances lead to a higher heat transfer from the arc to the coating surface and therefore to a higher degree of boron solution in the matrix.

For self-fluxing NiCrBSi coatings without carbide reinforcement (DURMAT AS 753) the average microhardness amounts to 749 HV 0.05. For carbide reinforced coatings it is not sensible to indicate an integral average microhardness, as the measured values differ significantly depending on, whether the place of indentation affects the matrix or a carbide particle. For different process parameters the microhardness of the matrix of coatings from DURMAT AS 751 s varies between 499 and 741 HV 0.05, while the microhardness of the eutectic tungsten carbides (about 2000 HV 0.05) does not depend on the process parameters. The variations are due to different amounts of molten carbides solved in the nickel matrix, which causes an increase of the hardness, and different porosities. The scattering of the microhardness values of the matrix of iron based coatings is less compared to that of the nickel based coatings. The average matrix hardness of coatings produced from the wire DURMAT AS 816 is 706 HV 0.05 and the standard deviation is 111 HV 0.05. The low deviation is mainly due to the low carbide filler content of (about 5 wt.-%).

*HVCW-spraying*

All applied cored wires show a good sprayability with a continuous melt off behavior. Because of the experiences with coarse eutectic tungsten carbides in arc-spraying the DURMAT AS 751 c is not sprayed. The particle jet is sharp, symmetrical and stable.

According to the higher particle velocities and thereby the higher degree of particle flattening after impact the surfaces of the HVCW sprayed coatings are smoother compared to arc-sprayed coatings. For carbide reinforced coatings $R_a$ less than 20 $\mu$m and for coatings without carbide filler less than 10 $\mu$m are achieved.

The porosity of the produced coatings is similar to that of arc-sprayed coatings. Coatings with reinforcing carbides show less than 5% porosity and the carbide free coatings even less than 3%. The short process times lead to a suppression of alloying. Therefore a considerable amount of e.g. carbon filler material is not solved in the metallic matrix, but remains as inclusion inside the coating (black phase in **figure 6**). The carbon content is a crucial point for the properties of iron based matrices, as the formation of different phases strongly depends on the carbon content. Furthermore graphite inclusions will strongly influence the wear behavior of the coatings. On the one hand graphite itself features a low wear resistance, on the other hand it is known to cause a significant decrease of friction in many applications.

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 7**) or DURMAT AS 751 s. There is a homogeneous distribution of the reinforcing carbide particles in the coatings with a good metallurgical bonding to the matrix material, which is due to a small molten interface. Accordingly 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 $\mu$m. These cracks can be avoided by optimizing the process parameters with respect to thermally induced residual stresses.

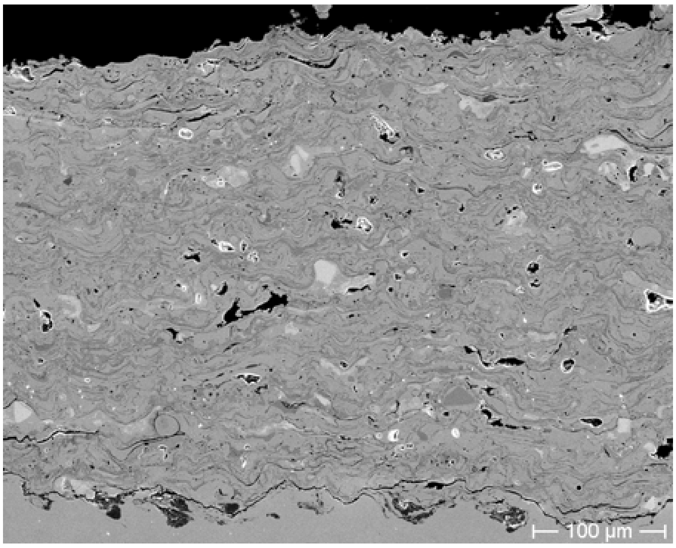

**figure 6:** SEM picture of a cross section of an HVCW sprayed coating from DURMAT AS 816

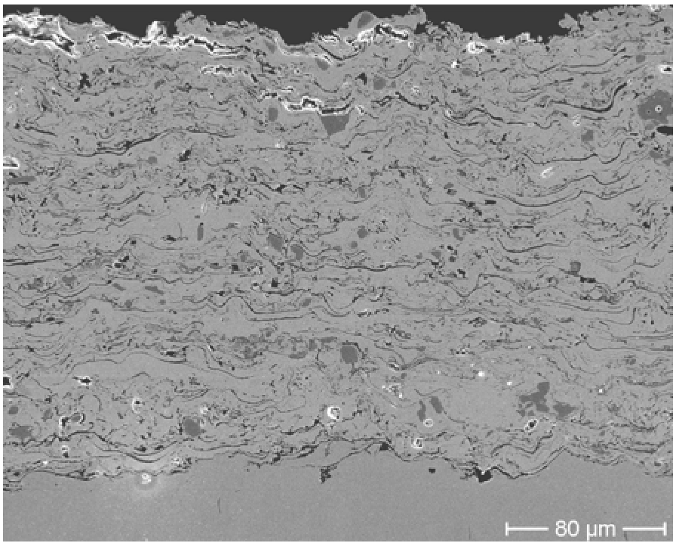

**figure 7:** SEM picture of a cross section of a HVCW-sprayed coating from DURMAT AS 751 RC

### Remelting behavior

The NiCrBSi coatings produced from the wire DURMAT AS 753 can be remelted either manually using an acetylene/oxygen flame or in a vacuum furnace. Both results in smooth surfaces and a homogeneous distribution of hard chromium carbide and chromium boride phases in the coatings. No significant differences in the remelting behavior can be observed between arc- and HVCW-sprayed coatings, as the porosity in the as-sprayed state is comparable for both spraying methods. The manually remelted NiCrBSi coatings (**figure 8**) show a porosity of about 3 vol.-% while those remelted in the vacuum furnace are free from pores (**figure 9**). The low pressure in vacuum remelting processes is an effective driving power to remove gases included and/or solved in the coatings because of the high gradient in partial gas pressures between the gases in the coating and in the furnace environment. For both spraying and remelting methods there is a complete metallurgical bonding between coating and substrate material. While the coating surfaces are clean and shiny after remelting in the vacuum furnace, the surfaces of manually remelted coatings are covered with dark oxides. The oxide layer can easily be removed by a wire brush.

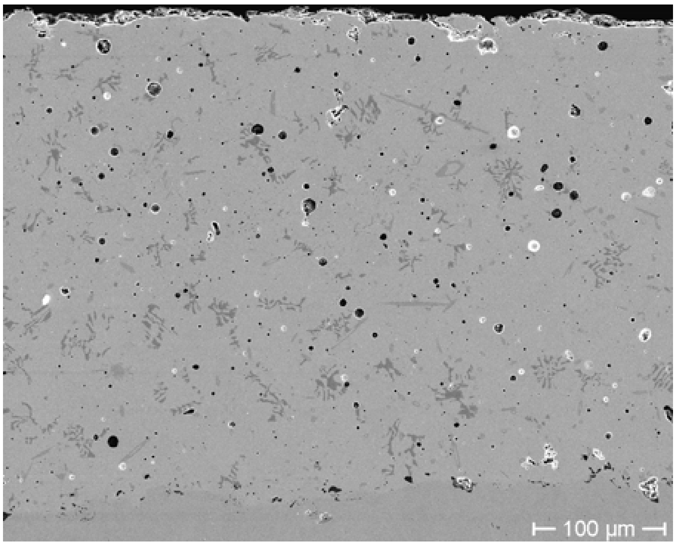

**figure 8:** SEM picture of a cross section of a manually remelted HVCW-sprayed NiCrBSi coating

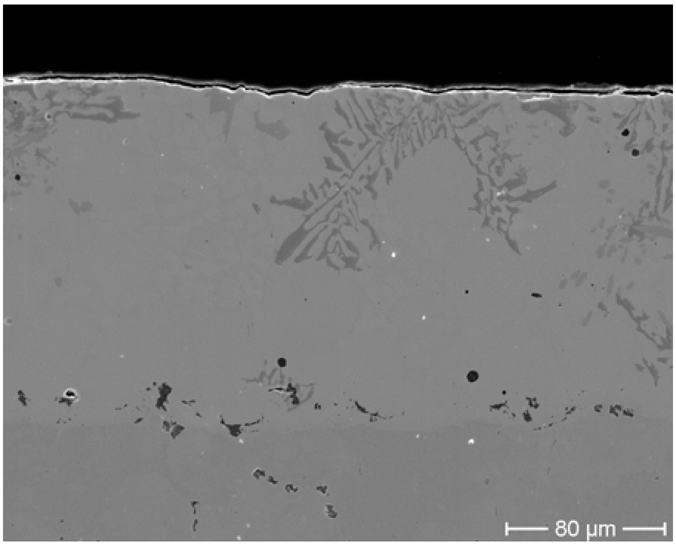

**figure 9:** SEM picture of a cross section of a HVCW-sprayed NiCrBSi coating remelted in a vacuum furnace (pressure: $10^{-6}$ Pa, heating rate: 20 °C/min, max. temperature: 1,075 °C, duration: 10 min., quenching rate: 100 °C/min)

**Wear resistance**

*Taber-Abraser wear test*

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. With increasing test time and therefore smaller surface roughness a decrease of the wear rate is observed. As the surface roughness of the carbide reinforced coatings is higher compared to the pure metallic coatings, the starting weight loss is especially steep. For the same reason the non-linearity of the weight loss is more significant for the arc-sprayed than for the HVCW- or HVOF-sprayed coatings. 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 of the arc-sprayed coatings is shown in **figure 10** and of the flame-sprayed coatings in **figure 11**.

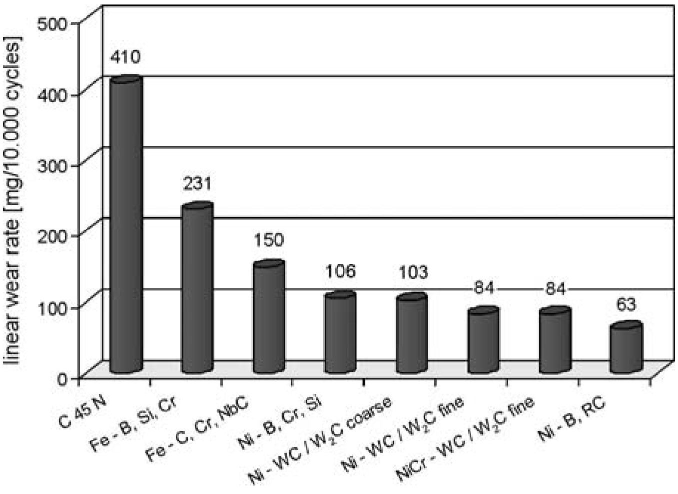

**figure 10:** Linear wear rates of arc-sprayed coatings in the Taber-Abraser test

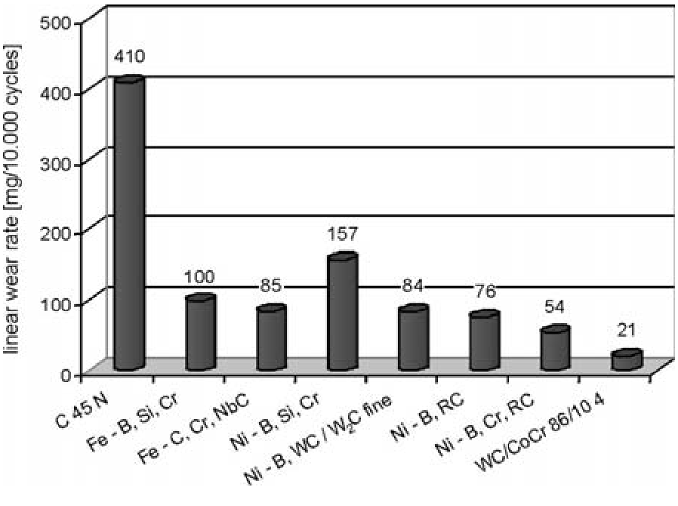

**figure 11:** Linear wear rates of HVCW-sprayed coatings in the Taber-Abraser test

For all wires a significant improvement of the wear resistance against abrasive wear in the Taber-Abraser test in comparison to the mild steel substrate is achieved. But the relative performance of the coatings depending on the spraying method is in some cases very different. While the abrasive wear resistance of the FeCrBSi (DURMAT AS 815) coatings is higher, when HVCW is applied, it is vice versa in the case of the NiCrBSi (DURMAT AS 753) coatings. For both wires a large amount of filler material was not molten during HVCW-spraying and therefore the composition distribution is not as homogeneous as by arc-spraying. The HVCW-sprayed FeCrBSi coatings show about 3 vol.-% of graphite inclusion. This graphite may act as a solid lubricant lowering the friction between abrasive wheel and coating surface and thereby resulting in a lower weight loss. The HVCW-sprayed NiCrBSi coatings contain a lot of not molten boron and other filler contents, which affect the wear resistance negatively in comparison to the homogeneous coatings manufactured by arc-spraying.

While the wear resistance of the carbide reinforced coatings with nickel based matrix is comparable for both spraying techniques, there is a significant improvement of the wear resistance of the iron based DURMAT AS 816 coatings, when HVCW-spraying is applied. This may again be due to the graphite, that is not solved completely in the iron matrix in the case of HVCW-spraying.

In general the application of the refractory carbide mixture results in a better resistance against abrasive wear than eutectic tungsten carbide. Though the content of eutectic tungsten carbide in the coatings is higher than that of the refractory carbides, the linear wear rate is higher. But it has to be considered, that eutectic tungsten carbides are heavy and therefore the volume loss – the value of interest - is less compared to coatings reinforced with a refractory carbide mixture, when the same weight loss is measured.

For arc-sprayed eutectic tungsten carbide reinforced coatings no influence of the matrix composition can be observed. The linear wear rate of coatings from the wire with pure nickel velum (DURMAT AS 751 s) and with NiCr 80/20 velum (DURMAT AS 761) is identical. In contrast for HVCW-sprayed refractory carbide reinforced coatings there is a remarkable improvement of the abrasive wear resistance, when the nickel matrix contains chromium. Coatings from the wire DURMAT AS 760 contain 10 at.-% chromium and 7 at.-% silicon, but only 5 vol.-% of refractory carbides, while coatings from DURMAT AS 751 RC contain only nickel and 20 vol.-% of refractory carbides. In spite of the lower carbide content the coatings from DURMAT AS 760 show a 30% less weight loss compared to DURMAT AS 751 RC coatings.

The arc-sprayed coatings with coarse eutectic tungsten carbides show a higher linear wear rate than the coatings reinforced with fine carbides. This is due to the heterogeneous distribution of the coarse carbides in the coatings. The areas without carbides can easily be abraded causing an overall higher weight loss.

The resistance against abrasive wear of conventional WC/Co/Cr 86/10/4 coatings produced by HVOF is only 2.5

times higher than that of HVCW-sprayed refractory carbide reinforced coatings from the wire DURMAT AS 760.

*Oscillating wear test*

For applications with oscillating wear stress pure ceramic coatings like APS-sprayed $Al_2O_3/TiO_2$ or $Cr_2O_3$ are useless. 200 $\mu$m thick $Al_2O_3/TiO_2$ coatings are completely abraded within 5 minutes under the applied conditions, because these materials cannot stand high load at a single spot. Suitable materials have to provide a sufficient ductility, but carbide reinforcement of metallic matrices results in significant improvements. The wear depths resulting from the oscillating wear test are shown in **figure 12** for the arc-sprayed coatings and in **figure 13** for the flame-sprayed coatings.

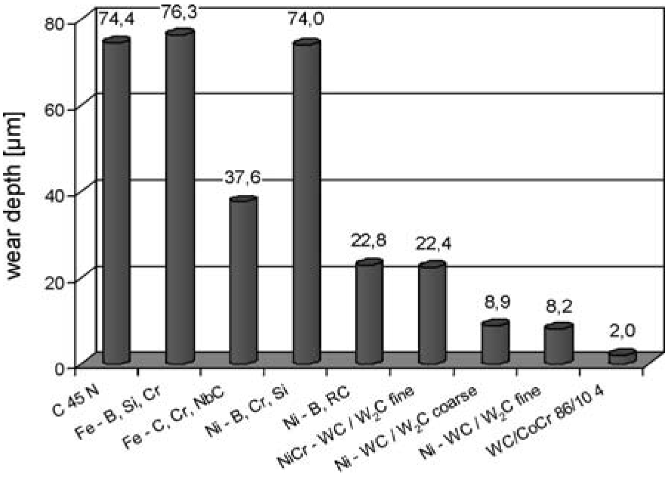

**figure 12:** Wear depths of arc-sprayed coatings after the oscillating wear test

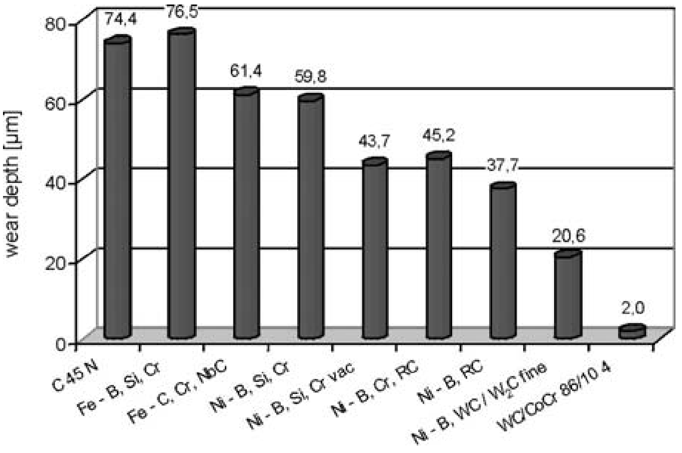

**figure 13:** Wear depths of HVCW-sprayed coatings after the oscillating wear test

Independent from the spraying method the coatings without carbide reinforcement show no improvement against oscillating wear compared to the mild steel substrate. The higher the amount of hard phases in the coatings, the lower the wear depths. Coatings produced from wires with a low content of carbide filler like DURMAT AS 760 (refractory carbide content in the coatings 5 vol.-%) or DURMAT AS 816 (NbC content in the coatings 5 vol.-%) can improve the oscillating wear resistance only by factor 2 compared to the mild steel substrate. The wear depth in arc-sprayed coatings from DURMAT AS 816 is only half that of HVCW-sprayed ones. This may be due the graphite in the HVCW-sprayed coatings. Graphite below the surface – the region of highest Hertzian stress - cannot transfer high shear stresses to material below and leads to failure because of insufficient sustain strength.

In opposition to the Taber-Abraser wear test arc-sprayed NiCrBSi coatings show a worse resistance against oscillating wear than HVCW-sprayed. Some not molten filler material in the HVCW-sprayed coatings has a high hardness and therefore acts as a reinforcing phase leading to improved wear behavior. After remelting in a vacuum furnace the oscillating wear resistance increases significantly, leading to a 30% lower wear depth compared to HVCW-sprayed coatings in the as-sprayed state. This is due to a homogeneous distribution of chromium carbides and borides in the remelted coatings.

In general wires with a high content of reinforcing carbides result in coatings with higher oscillating wear resistance, when arc-spraying is applied. The dependence of the wear resistance on the coatings metallurgy and on the energetic boundary conditions has to be studied in detail to allow an optimization of the interacting wire (composition) and energy source (process parameters). In contrast to the Taber-Abraser wear test the coatings reinforced with eutectic tungsten carbide show a higher resistance compared to the refractory carbide mixture. This can be related to higher carbide contents in the case of coatings with eutectic tungsten carbide. While the carbide content in HVCW-sprayed coatings from DURMAT AS 751 s is 20 vol.-%, arc-sprayed coatings contain 30 vol.-% eutectic tungsten carbides. The latter coatings achieve an improvement by the factor 8 compared to the mild steel substrate.

The oscillating wear resistance of coatings with $WC/W_2C$ reinforcement show a higher resistance, when the pure nickel velum is applied. In comparison the wear depth in coatings with NiCr 80/20 matrix is 2.5 times deeper. This may be due to the higher ductility of the chromium free matrix.

### Corrosion resistance

First a qualitative evaluation of the resistance against sulphurous corrosion is done by visual inspection of the surfaces after certain times of exposure. All coatings, except those from the wires DURMAT AS 761, DURMAT AS 753, and DURMAT AS 760 form corrosion products covering the complete surface within 8 h of testing. This is also observed for HVOF WC/Co/Cr 86/10/4. A dependence on the spraying method or the surface state is not observed. The specimen with corrosion products all over the surface are not tested for longer periods.

A chromium content of 13 at.-% in an iron matrix (DURMAT AS 815) is not sufficient to stand the sulphurous attack in this test. The chromium content in the nickel matrix of coatings from the wires DURMAT AS 760 (10 at.-%) and DURMAT AS 753 (13 at.-%) is also not sufficient to obtain complete resistiveness in the DIN 50018 test. After 80 h of testing there is no formation of corrosion products visible, but metallographical studies show the occurrence of pitting corrosion. For the remelted coatings less formation of pits is observed. No corrosive attack on coatings produced from the wire DURMAT AS 761 (20 at.-% chromium in the nickel matrix) can be detected (**figure 14**). This suggests, that the chromium content in a nickel based matrix is crucial for protection against combined wear and severe sulphurous corrosion. Conventional HVOF sprayed WC/Co/Cr 86/10/4 coatings are not suitable for applications including severe sulphurous corrosion (**figure 15**).

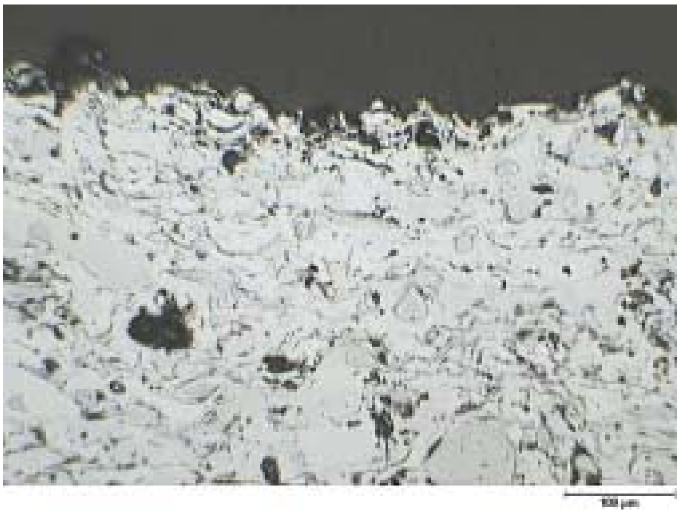

**figure 14:** Cross section of an arc-sprayed DURMAT AS 761 coating after the corrosion test

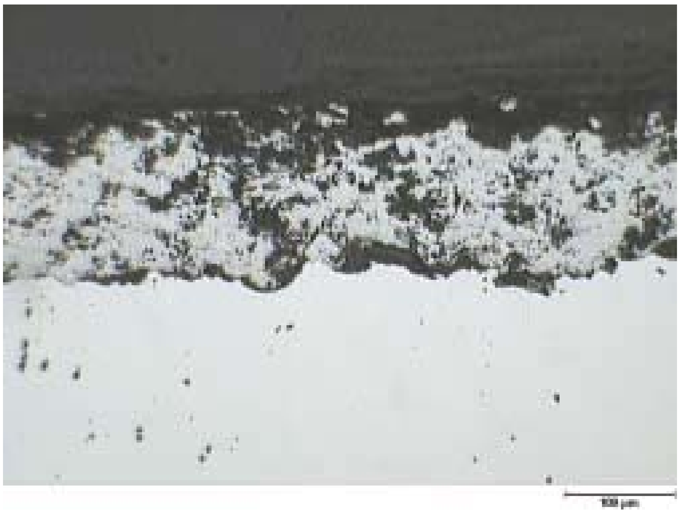

**figure 15:** Cross section of a WC/Co/Cr 86/10/4 coating sprayed by HVOF after the corrosion test

## Conclusions and Perspectives

Cored wires have successfully been applied to produce self-fluxing and cermet-like coatings by arc- and HVCW-spraying. Both for abrasive and oscillating wear adapted coatings with a wear resistance nearly as good as that of conventional HVOF WC/Co/Cr 86/10/4 coatings have been manufactured. When a sufficient free chromium content in a nickel matrix is realized, both arc- and HVCW-sprayed coatings show a better performance under severe sulphurous corrosion conditions than HVOF WC/Co/Cr 86/10/4. For severe sulphurous corrosion protection of surfaces undergoing abrasive or oscillating wear stress coatings from DURMAT AS 761 are recommendable. As the dominant factor for improvement of the resistance against oscillating wear is the carbide content, coatings for this application should be produced from wires with a large diameter (e.g. 3.2 mm) and thereby with a high carbide filler content.

The coatings show good machinability, when using c-BN or diamond grinding disks. No pores can be detected on the surface visually. The application of SiC grinding disks results in black greasing stripes.

Both arc- and HVCW-sprayed NiCrBSi coatings can be remelted either manually by an acetylene/oxygen flame or in a vacuum furnace. Latter results in pore free coatings with a smooth surface, a homogeneous distribution of chromium carbides and borides and an increased oscillating wear resistance.

Arc-spraying is suitable for production of coatings, that require a high degree of alloying between velum and filler material during the spraying process. HVCW is more beneficial for coatings, that require only a small surface area of the filler material molten and wetted by the metallic matrix. This spraying process has proofed to cause only little influence on the chemical composition of the filler material. But the process has to be optimized carefully in order to achieve a high amount of reinforcing filler material incorporated inside the coatings.

The experimental results show the excellent potential of arc-spraying and HVCW-spraying of cored wires for wear and corrosion protection. Further work has to be done on the metallurgical differences of these processes to optimize the wire layout with respect to the coating application.

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