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Hard Arc-Sprayed Coating with Enhanced Erosion and Abrasion Wear Resistance

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A cored wire formulation, referred to as Alpha 1800, has been developed to produce tailored arc-sprayed coatings that are tough enough to resist particle impacts at 90° and sufficiently hard to deflect eroding particles at low impact angles. One millimeter thick coatings composed of ductile and hard phases with a Knoop hardness reaching 1800 kg/mm^2 were easily produced by arc spraying the cored wire with air. Coatings were (1) erosion tested at 25 °C and higher temperatures at impact angles of 25 and 90° in a gas-blast erosion rig, (2) slurry erosion tested at impact angles of 25 and 90°, and (3) abrasion wear tested using the ASTM G-65 test procedure.

Results show that coatings produced with the new cored wire are at least 5 times more erosion resistant and 10 times more abrasion resistant than coatings produced by arc spraying commercial cored wires. The performance of the new arc-sprayed coating can be compared with that of high-energy WC-based coatings. Maintaining their erosion resistance after being exposed to temperatures up to 850 °C and possessing good oxidation resistance, arc-sprayed coatings produced with the new cored wire are attractive for applications in many industrial sectors involving high temperatures.

Keywords abrasion, arc spraying, cored wire, erosion, high temperature, slurry erosion, sprayed coatings

1. Introduction

Erosion is produced by the impact of sharp particles on a surface. Solid particles transported in gas or liquid flows cause severe damage on industrial components and lead to expensive repair and part replacement. High temperature or corrosive fluids introduce such a pernicious combination of erosion and corrosion that industrial cost-effective solutions are rarely obtained. Micromachining and ploughing actions damage surfaces exposed to low-angle incident particles. This type of wear can be compared to abrasion when low velocity incident particles are traveling parallel to the exposed surface. Hard ceramic coatings have been considered sufficient to reduce scratching abrasion observed, for instance, in straight runs in pipelines. When the impact angle is large, the exposed surface should be able to withstand repeated deformation. Elastic materials such as metals are usually preferred to ceramics in which cracks rapidly propagate and lead to material pullout. In situations between those described above, there is controversy about the correct match of materials. Moreover, as the extent of damage produced by erosion considerably increases with the velocity and the size of incident particles, the selection of materials to resist particulate erosion in all situations becomes difficult.

Carbide-metal coatings of a continuous skeleton containing hard phases have been adopted to provide erosion and abrasion wear protection in numerous applications. The deposition of these coatings required the use of high-energy thermal spray processes, difficult to operate on site. A high coating thickness is achieved through good thermal stress management with efficient cooling devices.

Arc spraying, one of the simplest spraying techniques, has been restricted to the deposition of metals for applications involving mainly corrosion protection and part restoration. Although some cored wires have been proposed during the last decade, the erosion resistance of these arc-sprayed coatings has not surpassed that of structural materials nor of coatings produced by high-energy processes.[1–7]

A new cored wire is proposed for producing hard arc-sprayed coatings to resist abrasion and particle erosion. This paper gives its comparative performance in particle erosion, slurry erosion, and abrasion with other coatings or structural materials. Relevant information on spraying parameters that influence coating performance is highlighted. Finally, useful properties such as coating bond strength and thermal stability upon exposure to high temperature are outlined.

2. Development of Erosion-Resistant Arc-Sprayed Coatings

Research and development work on arc-sprayed coatings stemmed from the needs to develop coatings that

- resist the impact of large mineral particles or oxide scales,
- possess good erosion-oxidation characteristics up to high temperatures,
- resist the impact of high-velocity (100 m/s) particles impacting with low and high angles, and
- can be easily and safely arc sprayed with air on site and in shops.

A cored wire formulation has been developed to produce a tailored arc-sprayed coating that is sufficiently hard to deflect high-velocity erosive particles at low-impact angles and that possesses good resilience to particle impacts at 90°. The coating contains

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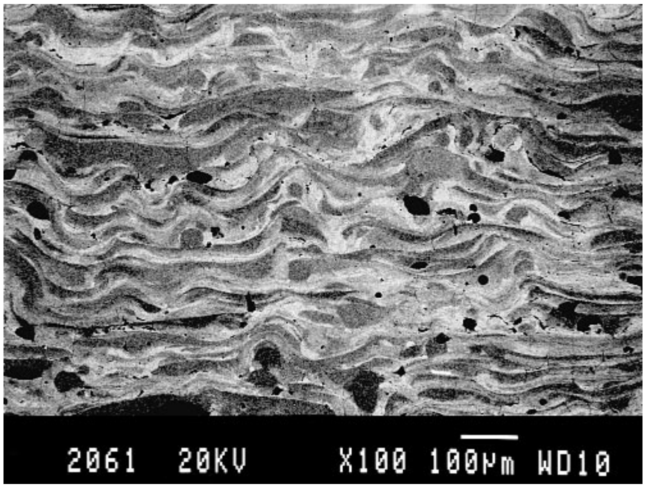

Fig. 1 Scanning electron micrograph cross section of Alpha 1800 arc-sprayed coating (in dark: hard phases, and in light: ductile phases)

Fig. 2 Scanning electron micrograph of iron ore particles

Table 1 Wires used for producing arc-sprayed coatings

Code	Coating type	Composition(a)	Supplier
W1	Austenitic stainless steel	0.1C, 18–20Cr, 8–12Ni, 2.0Mn, 0.7–1.0Si, Fe bal	Praxair Inc. (Appleton, WI)
W2	Martensitic stainless steel	16–18Cr, 0.95–1.2C, 1.0Mn, 1.0Si, 0.75Mo, Fe bal	Aerospace Alloy (New York, NY)
W3	Steel containing oxides	94.5Fe, 1.9Mn, 1.1O_2, 2.5 other (not specified)	Praxair Inc. (Appleton, WI)
CW1	Chromium-rich steel	…	Praxair Inc. (Concord, NH)
CW2	Nickel-based alloy containing fine boride and carbide particles	0.8C, 15Cr, 3B, 4Si, 3.5Fe, 17.3W, Ni bal	Wall Colmonoy (Madison Heights, MI)
CW3	Ferritic steel containing amorphous phases	1.7Si, 28.0Cr, 2.0Mn, 3.7B, Fe bal	Amorphous Technologies International (Laguna Niguel, CA)
CW4	Duplex steel containing amorphous phases	8.4Cu/Ni, 1.8Si, 21.0Cr, 6.5Ni, 1.0Mn, 2.5B, 0.2C, Fe bal.	Amorphous Technologies International
CW5	Ferritic stainless steel containing titanium and tungsten carbide particles	1.2Si, 14.0Cr, 4.5Ni, 0.6Mn, 1.9B, 26.0WC, 6.0TiC, Fe bal.	Amorphous Technologies International
CW6	WC-Co particles embedded in a hardened steel	…	Metallisation Limited (Dudley, England)

(a) Composition given by the supplier

Table 2 Other coatings and structural materials tested

Designation	Material	Process	Sample origin
HVOF (WC + Ni)	WC + 10% Ni	HVPOF (JP 5000) Praxair (Concord, NH)	Coatings sprayed in NRC Laboratory
HVOF (WC + Co)	WC + 12% Co	HVOF (Diamond Jet) Sulzer Metco (New York, NY)	Coatings sprayed in NRC Laboratory
Laser (WC + NiCr)	WC particles in a NiCr matrix	Laser deposition Technogenia S.A. (Saint-Jorioz, France)	Samples supplied by end users
Overlay (Fe-Cr-C)	Chromium carbides in a steel matrix	Submerged arc welding	Samples supplied by end users
AISI 1045 steel	n.a.	n.a.	Material provided from vendors
AISI 304 stainless Steel	n.a.	n.a.	Material provided from vendors

boride phases that are synthesized from the cored wire during arc spraying. It is composed of ductile and hard phases with a Knoop hardness reaching 1800 kg/mm^2. Figure 1 shows that the microstructure of the Alpha 1800 arc-sprayed coating is composed of intimately intercalated hard and ductile-sprayed lamellae.

3. Experimental Procedure

3.1 Sprayed Coatings and Materials

The new cored wire, referred to as Alpha 1800, produced in 25 to 100 kg batches, was arc sprayed with air (pressure: 550

Table 3 Gas-blast erosion parameters

Erodent particles	Iron ore (32–300 μm)
Particle flow rate	4.4×10^{-5} ($\pm$5%) kg/s
Mean velocity of particles	97 ($\pm$5%) m/s
Erosion test duration	300 s
Test temperatures	25 ($\pm$5) and 315 ($\pm$15) °C

kPa) using a Miller BP 400 arc spray system (Appleton, WI). Except for coating bond strength evaluation and in-field testing, the coating thickness was limited to 1 mm. Spray parameters that influence the erosion resistance of the Alpha 1800 coating will be highlighted: arc amperage and voltage, spray distance, traverse speed, and spray angle.

Nine commercial wires, including conventional and cored wires, were also arc sprayed with this spraying system. The designation of these wires is given in Table 1. The chemistry of these wires and their spray deposition parameters and the microstructures of coatings were described earlier.[8] These arc-sprayed coatings were deposited on 100 by 100 by 3 mm grit-blasted mild steel pieces to a thickness of about 500 μm. For comparison purposes, other coatings and structural materials were also erosion tested. These are listed in Table 2. HVOF coatings were manufactured with spray parameters recommended by the powder suppliers, while other coatings or structural materials were obtained from suppliers or users. All coatings and reference specimens were diamond-ground ($R_a \approx 2$ μm) to obtain flat surfaces prior to erosion and abrasion testing.

3.2 Erosion Testing

All coatings and reference specimens, except HVOF WC-Co coatings, were erosion tested at impact angles of 25 and 90° and temperatures of 25 and 315 °C using a laboratory gas-blast device.[8] The erodent particles were constituted of oven dried and sieved angular iron ore particles (Fig. 2) with a particle size distribution comprised between 32 and 300 μm. A laser anemometer was used to measure the speed of the iron ore particles at 10 mm from the alumina nozzle. As the nozzle internal diameter measures only 1.6 mm, the erosive particles strike the surface target in a very small area. The circumference of the impact area is formed by a circle, having a 3 mm diameter, at the impact angle of 90°, and an ellipse, having a small axis of 4 mm and a large axis of 8 mm, at the impinging angle of 25°. Table 3 summarizes the test parameters used in most erosion tests.

Particle erosion tests were also carried out on Alpha 1800 arc-sprayed coatings at temperatures up to 650 °C and compared with CW1 and CW3 arc-sprayed coatings, AISI 1020 and 304 steels. Before being submitted to the erosion test, specimens were heated to the test temperatures over a period of time of about 900 s (15 min). The structural stability of coatings was also evaluated by erosion testing at room temperature specimens that had been maintained at temperatures up to 1100 °C for 1.8×10^4 s (5 h).

3.3 Slurry Erosion Testing

Slurry erosion tests were carried out with a laboratory slurry jet erosion device. Not being a standardized procedure, the test consists of circulating 7 L of prepared slurry during 3600 s using an air-powered double-diaphragm slurry pump. The recirculating slurry, consisting of filtered 15 to 25 °C tap water with 10 wt.% 212 to 300 μm quartz sand particles, was pumped from a tank and forced to impinge on the test surface. The velocity of the slurry was measured to be 10 ms^{-1}. Specimens were maintained at 90 and 25° and exposed to the slurry jet for 3600 s. Slurry flow measurements determined that 82.9 kg of quartz sand impinged the surface specimens for each test. Selected coatings, including HVOF WC-Co coatings, were tested and compared to Alpha 1800 arc-sprayed coatings.

3.4 Abrasion Wear Testing

The abrasion wear resistance of coatings was measured in accordance with the dry sand/rubber wheel abrasion test (ASTM G65, procedure B).[9] The method consists of abrading a specimen with a grit of controlled size and composition. A force of 130 N maintained the specimen against the rubber-coated wheel. Quartz sand (50/70 mesh) (300 μm/212 μm) was introduced between the specimen and the wheel at a flow ranging between 4 and 6 g/s. The wheel rotates in the same direction as the flowing sand and the test is ended after 2000 revolutions.

3.5 Erosion and Abrasion Evaluation

Particle erosion was reported as measured volume loss per kilogram of erodent particles (mm^3/kg of iron ore), while slurry erosion and abrasion were reported as measured volume loss in cubic millimeters according to the standard procedure. The volume loss measurements of damage resulting from wear were performed with an optical profilometer, as described earlier.[10]

3.6 Hardness Measurements

Diamond pyramid hardness measurements were performed with a Knoop indentor on cross sections of coatings and conventional materials with a load of 25 g. Results are reported as means of ten measurements.

3.7 Coating Bond Strength

The adhesive bond strength of Alpha 1800 arc-sprayed coatings was measured according to the ASTM C-633-79 test procedure.[11] Alpha 1800 cored wire was sprayed directly on mild steel studs for a coating thickness lower than 2 mm and on 6.25 mm thick mild steel substrates for larger coating thicknesses. Grit-blasted coatings and opposing studs were glued together with an adhesive (EP-15 glue, Master Bond Inc., Hackensack, NJ). After curing at 150 °C, tensile tests were carried out following the recommended procedure.

3.8 Cyclic Oxidation

Oxidation tests were performed to a limited extent on Alpha 1800 arc-sprayed coatings and 1020 structural steel. Samples were submitted to 50 heating cycles (3×10^3 s (50 min)) in air up to 800 °C and cooling cycles of 600 s (10 min) at room temperature. The total exposure time to 800 °C is 1.5×10^5 s (104 h). The weight gains after temperature exposure were used to evaluate the relative resistance to cyclic oxidation of Alpha 1800 arc-sprayed coatings.

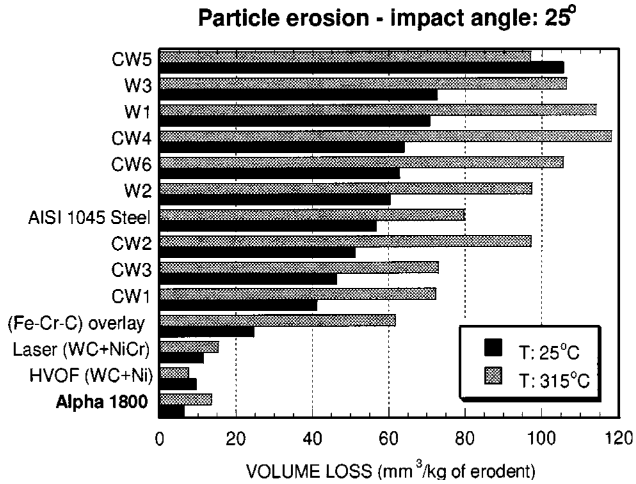

Fig. 3 Particle erosion resistance of coatings and structural materials at the impact angle of 25° and temperatures of 25 and 315 °C

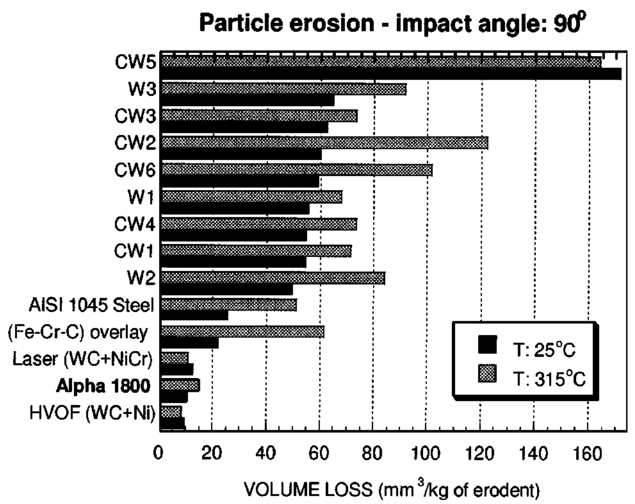

Fig. 4 Particle erosion resistance of coatings and structural materials at the impact angle of 90° and temperatures of 25 and 315 °C

4. Results and Discussion

4.1 Particle Erosion Resistance

The volume loss of Alpha 1800 arc-sprayed coating is considerably lower than that of all other arc-sprayed coatings at impact angles of 25 and 90° and temperatures of 25 and 315 °C, as shown in Figure 3 and 4. The volume loss of Alpha 1800 coating is at least 5 times lower than that of any arc-sprayed coating tested within this work. Sprayed coatings, submerged arc overlays, and structural materials generally lost more volume at 315 °C than at 25 °C. It should be observed that the volume loss due to a temperature increase of 290° is generally more important at 25 than at 90°. As the area exposed to impacting particles is larger at 25°, coatings and structural materials are more damaged by the erosion-oxidation mechanism. The (Fe-Cr-C) overlay lost 3 times more volume at 315 °C than at 25 °C at both impact angles. Loss of toughness due to carbide precipitation is most likely responsible for the higher volume loss at 315 °C. Materials containing a large amount of carbon such as (Fe-Cr-C) overlay are susceptible to embrittlement.

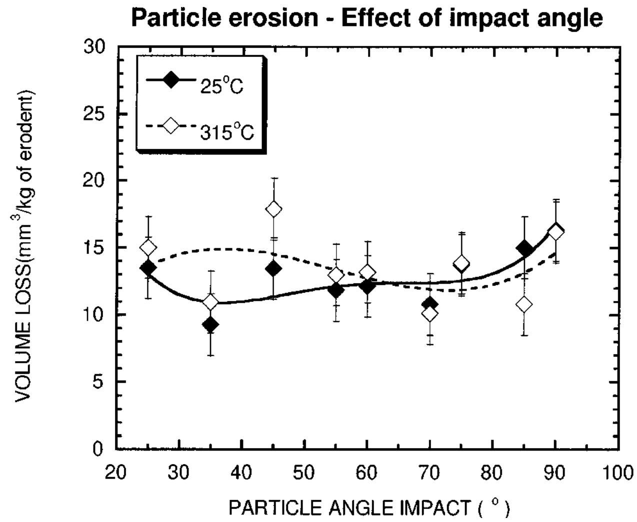

Fig. 5 Influence of particle impact angle on the erosion resistance at 25 and 315 °C. Error bars correspond to the standard deviations measured at the impact angle of 90°

For both impact angles and temperatures, the particle erosion resistance of Alpha 1800 arc-sprayed coating can be compared with high-energy HVOF (WC-Ni) and laser (WC-NiCr) coatings. The volume loss of Alpha 1800 arc-sprayed coating is the lowest volume loss observed at the impact angle of 25° and the temperature of 25 °C. Its volume loss at 90° is almost equal to that of HVOF WC-Ni coatings. For the other conditions, HVOF WC-Ni coatings showed better erosion resistance (Fig. 3 and 4).

4.2 Influence of the Impact Angle on the Particle Erosion Resistance of the Alpha 1800 Arc-Sprayed Coating

Like all sprayed coatings, Alpha 1800 possesses a microstructure composed of oriented splat lamellae. Therefore, its erosion resistance should be influenced by the impact angle of erosive particles. Figure 5 illustrates the variation in volume loss measured for particle impact angles ranging between 25 and 90° at temperatures of 25 and 315 °C. Maximal volume losses are observed at 45 and 90°. However, it is difficult to conclude that there is an actual variation of volume loss with the impact angle due to the size of the standard deviation.

4.3 Slurry Erosion Resistance

As shown in Fig. 6, the slurry erosion volume loss of Alpha 1800 arc-sprayed coating is lower than that of all arc-sprayed coatings tested. At both impinging angles, the volume loss of the Alpha 1800 arc-sprayed coating is 3.5 times lower than that of the CW2 coating. HVOF (WC-Co) coatings presented the best slurry erosion resistance observed. At the impinging angle of 90°, the volume loss of the Alpha 1800 arc-sprayed coating is very close to that of the HVOF (WC-Co) coating.

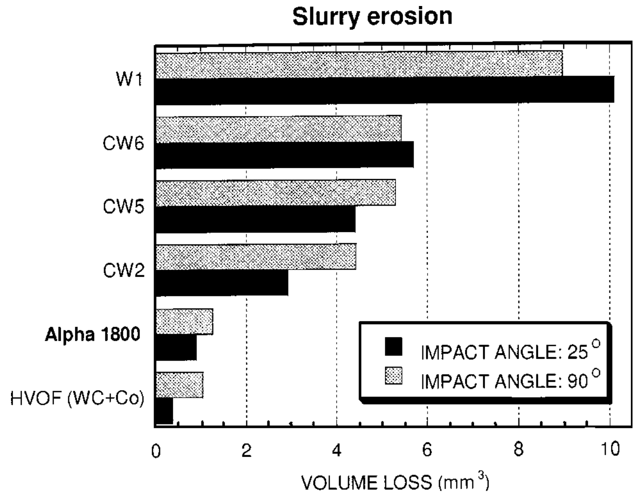

Fig. 6 Slurry erosion resistance of Alpha 1800 arc-sprayed and selected coatings

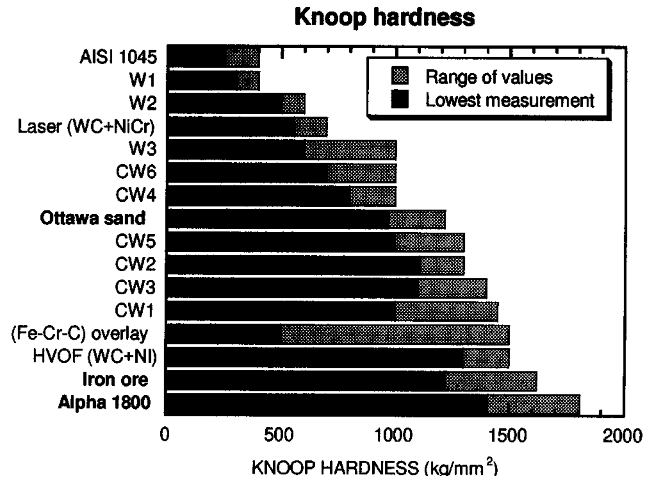

Fig. 8 Knoop hardness of coatings, structural materials, and erosive particles (iron ore and Ottawa sand)

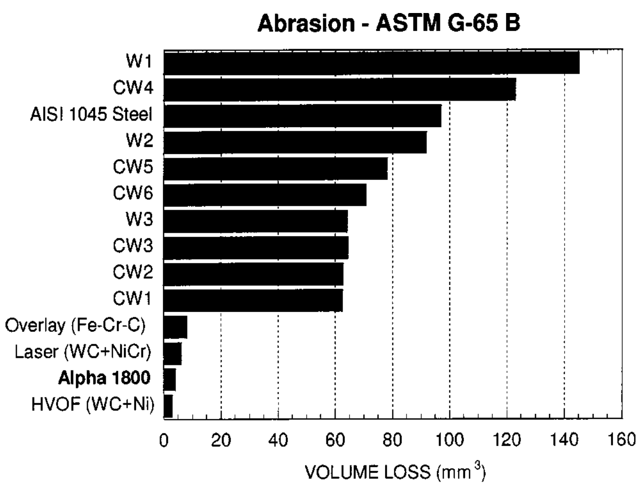

Fig. 7 Abrasion resistance of coatings and structural materials

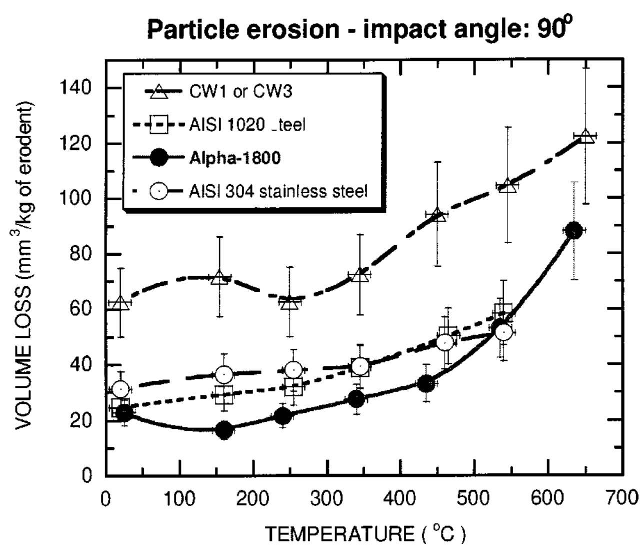

Fig. 9 Particle erosion resistance at 90° of Alpha 1800 and Armacor M arc-sprayed coatings, AISI 1020, and 304 steels with temperature. Error bars correspond to standard deviations

4.4 Abrasion Resistance

As shown in Fig. 7, the volume loss due to abrasion of the Alpha 1800 arc-sprayed coating is 15 times less than that of any arc-sprayed coating or structural material. Alpha 1800 ranks between HVOF (WC-Ni) and laser (WC-NiCr) coatings.

4.5 Hardness

Because the hardness of materials is usually associated with erosion or abrasion resistance, the Knoop hardness of materials is given for information in Fig. 8. It is generally admitted that soft materials possess resilience to particle impact at 90° and hard materials have ceramic phases making them able to deflect low-angle impacting particles. This general trend can be observed while comparing hardness measurements with erosion volume loss results.

The significance of hardness with regard to the wear behavior observed cannot be drawn directly. Admittedly, all materials tested contain hard and soft phases that indentation testing cannot take into account because of the size of these phases. However, as shown in Fig. 8, HVOF (WC + Ni) and Alpha 1800 coatings that are able to resist the impact of hard angular iron ore particles present the highest hardness.

4.6 Particle Erosion Resistance of the Alpha 1800 Arc-Sprayed Coating up to 650 °C

Particle erosion tests were carried out at higher temperatures to determine the extent of protection afforded by the Alpha 1800 arc-sprayed coating. The erosion volume loss at the impact angles of 25 and 90° for temperatures up to 650 °C is illustrated in Fig. 9 and 10 for AISI 1020 and 304 steels, CW3, and Alpha 1800 arc-sprayed coatings. As shown in Fig. 9, the volume loss of the Alpha 1800 arc-sprayed coating at the impact angle of 90° remains

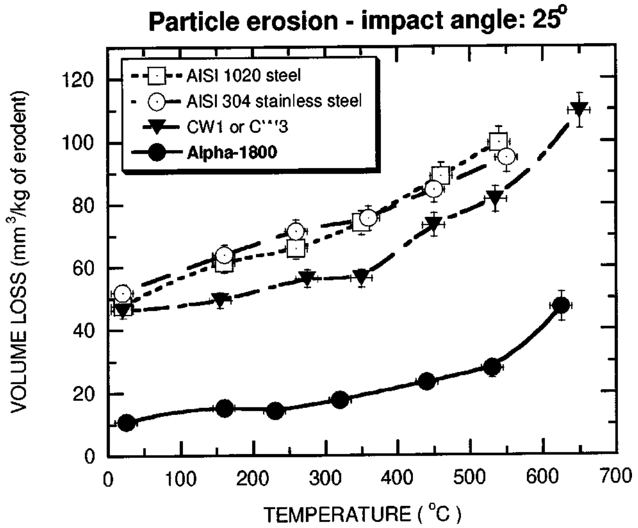

Fig. 10 Particle erosion resistance at 25° of Alpha 1800 and Armacor M arc-sprayed coatings, AISI 1020, and 304 steels with temperature. Error bars correspond to standard deviations

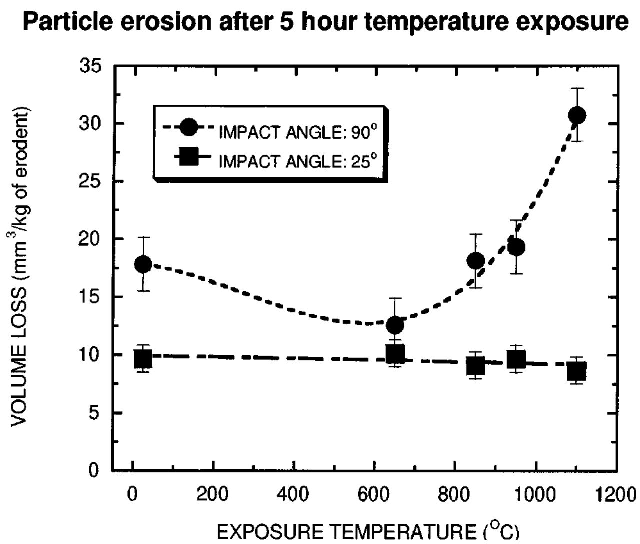

Fig. 11 Erosion volume loss of Alpha 1800 arc-sprayed coatings due to particle impact at angles of 25 and 90° (temperature: 25 °C) as a function of aging temperature for an exposure time of 1.8×10^4 s (5 h). Error bars correspond to standard deviations

below that of AISI 1020 and 304 steels for the temperature range considered. The volume loss due to erosion of CW3 arc-sprayed coating is at least 2 times higher than that of 1020 steel and 304 stainless steel. At the impact angle of 25°, as shown in Fig. 10, the CW3 arc-sprayed coating loses slightly less volume than solid steels. The volume loss of the Alpha 1800 arc-sprayed coating remained very low within the temperature range considered.

4.7 Structural Stability and Cyclic Oxidation of Alpha 1800 Arc-Sprayed Coatings

Though Alpha 1800 arc-sprayed coatings possess an excellent erosion resistance up to 650 °C, it could be of interest to

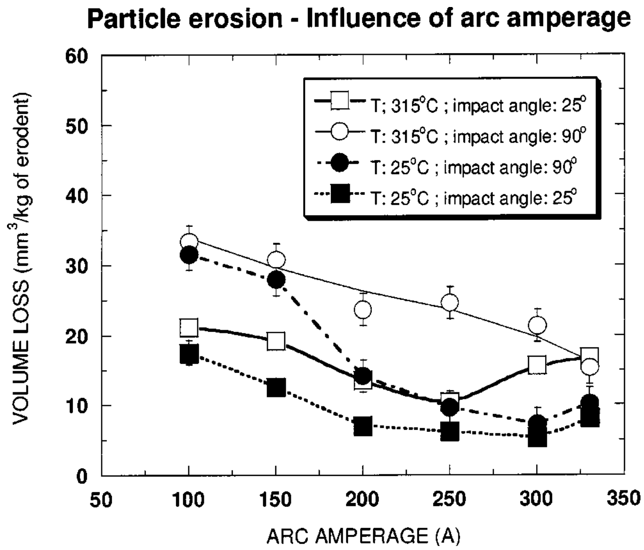

Fig. 12 The influence of arc amperage on the erosion resistance of Alpha 1800 arc-sprayed coatings. Spray distance: 7.62 cm, traverse speed: 15 cm/s, and arc voltage: 31 V. Error bars correspond to standard deviations

determine if the erosion resistance is maintained after exposure to higher temperatures. Phase transformations upon heating or cooling could affect the physical properties of coatings. Erosion tests, therefore, were carried out at room temperature on coatings maintained for different periods of time at temperatures higher than 650 °C. As shown in Fig. 11, the particle erosion resistance at the impact angle of 25° remained constant for soaking temperatures up to 1100 °C. However, the erosion resistance at 90° is largely influenced by prior heating. The volume loss is first reduced by 30% up to 650 °C due most likely to stress relief. Similar improvement in erosion resistance at the impact angle of 90° was also observed at 300 °C after a soaking period of 60 days. Thereafter, the volume loss increases to reach, for a soaking temperature of 850 °C, the volume loss of coatings tested at room temperature. For higher soaking temperatures, the volume loss at 90° increases due to microstructure changes. Particle erosion resistance at 90° is then more sensitive to phase rearrangement. In contrast, the erosion resistance at low angles is related to the amount of hard phases present within coatings.

Oxidation tests carried out at 800 °C indicated that Alpha 1800 arc-sprayed coatings gained 8 times less weight than AISI 1020 steel.

4.8 Influence of Spray Parameters on the Particle Erosion Resistance of Alpha 1800 Arc-Sprayed Coatings

Influence of Arc Amperage. Because it is synthesized during the deposition, the Alpha 1800 coating should be carefully sprayed to ensure better wear protection. Among all parameters considered, the arc amperage was found to be the most relevant. As shown in Fig. 12, both the volume losses at 25 and 90° decrease as the arc amperage increases. Spraying Alpha 1800 cored wire with arc current values comprised between 250 and 350 A, therefore, would produce coatings that are erosion resis-

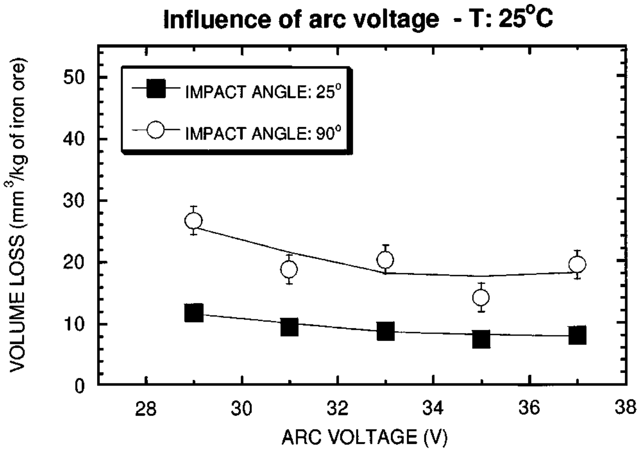

Fig. 13 The influence of arc voltage on the erosion resistance of Alpha 1800 arc-sprayed coatings. Arc amperage: 200 A, spray distance: 7.62 cm, and traverse speed: 15 cm/s. Error bars correspond to standard deviations

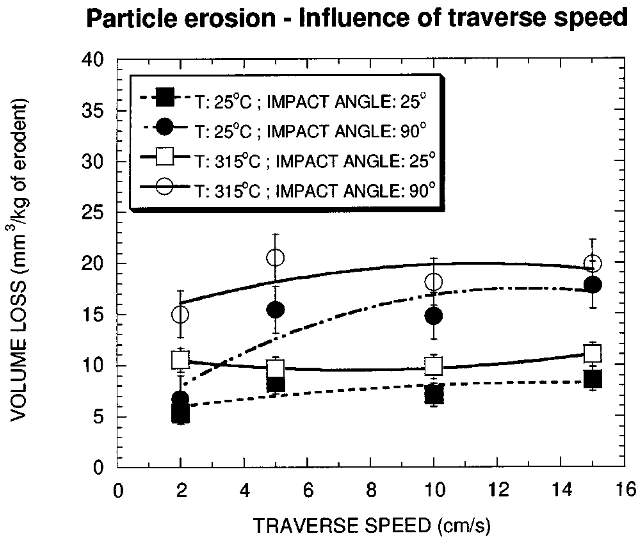

Fig. 15 Influence of the traverse speed on the particle erosion resistance of Alpha 1800 coatings at 25 and 315 °C. Arc voltage: 31 V, arc amperage: 200 A, and spray distance: 7.62 cm

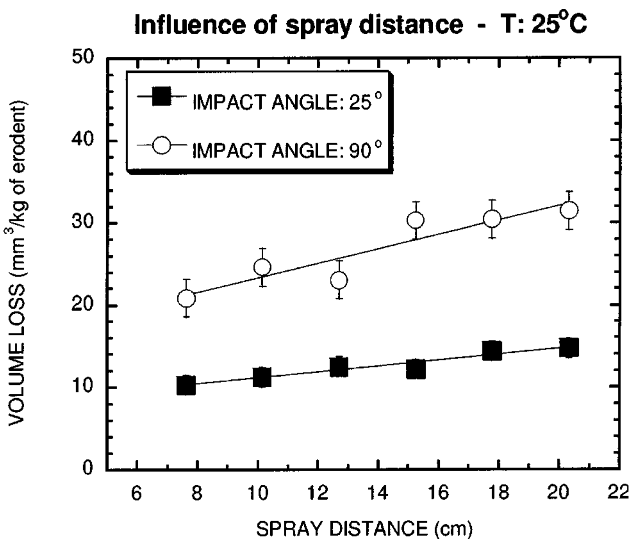

Fig. 14 Influence of the spray distance on the particle erosion resistance of Alpha 1800 coatings at room temperature. Arc voltage: 31 V, arc amperage: 200 A, and traverse speed: 15 cm/s

tant at both low- and high-impact angles. For erosion at higher temperatures, the same trend is observed.

Influence of Arc Voltage. At a fixed arc amperage of 200 A, the arc voltage has a slight influence on the erosion volume loss of Alpha 1800 sprayed coatings. As observed in Fig. 13, the variation in volume loss is small so that an arc voltage comprised between 31 and 36 V would produce coatings with equivalent erosion resistance. The trend illustrated for tests carried out at 25° is also valid at 315 °C.

Influence of Spray Distance. The erosion resistance of Alpha 1800 arc-sprayed coatings is also related to the spraying distance, as shown in Fig. 14. For both impact angles, the volume loss increases by 40% when the spray distance is increased from 7.62 cm (3 in.) to 20 cm (8 in.). Therefore, a spray distance of 8 cm (3 in.) is preferred. Higher heat transfer during coating buildup is achieved with a reduced spray distance and a low traverse speed.

Influence of Traverse Speed. Traverse speeds comprised between 5 cm/s (118 in./min) and 15 cm/s (355 in./min) do not affect the erosive wear properties of the Alpha 1800 coating, as shown in Fig. 15. However, traverse speeds lower than 5 cm/s (118 in./min) could result in erosion resistance improvement. A traverse speed of 2 cm/s (47 in./min) improves the erosion wear resistance, particularly at 90°. A significant reduction in volume loss is observed at both testing temperatures. It should be noted that a first pass sprayed with 2 cm/s raises the surface temperature to 185 °C, while for a traverse speed of 15 cm/s, the temperature reaches only 73 °C. The erosion resistance enhancement, particularly at high-impact angle, most likely results from stress relief due to temperature increase. Obviously, the coating temperature increase during the deposition depends on the size of parts and the gun movements. It should be considered that spraying by hand, where the traverse speed ranges between 5 and 15 cm/s, would produce relatively uniform coating wear properties. Spraying at speeds lower than 5 cm/s is not recommended. Coating thickness per pass as high as 0.98 mm (0.0386 in.) obtained with a traverse speed of 2 cm/s does not permit achievement of good overlapping passes.

Influence of Spray Angle. Normally sprayed, the Alpha 1800 coating was found to be almost insensitive to the particle impact angle (Fig. 5). However, being an in-line-of-sight process, arc spraying produces coatings composed of preferably oriented splat lamellae. While coating complex parts or spraying by hand, arc spraying at an angle is inevitable. Therefore, it is of interest to determine to what extent the orientation of spray lamellae would affect the erosion resistance. Figure 16 shows the variation in volume loss for spray angles ranking between 45 and 90°. Surprisingly, the spray angle does not affect significantly the particle erosion resistance measured at both impinging angles and temperatures of 25 and 315 °C. The slight fall in ero-

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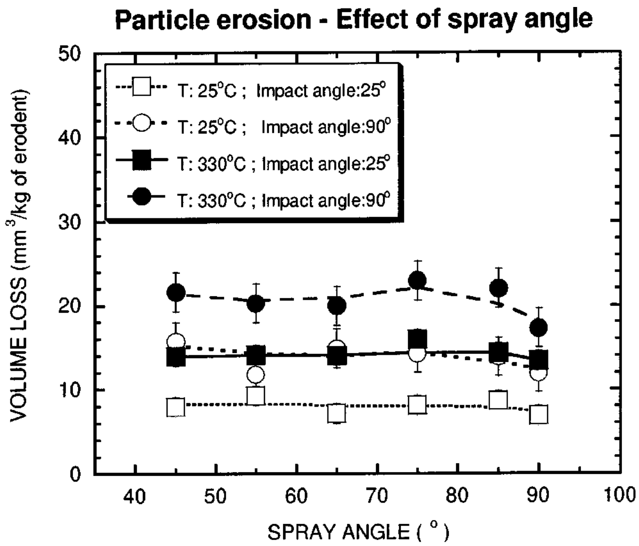

Fig. 16 Influence of the spray angle on the erosion volume loss of Alpha 1800 coating for impact angles of 25 and 90° and temperatures of 25 and 315 °C

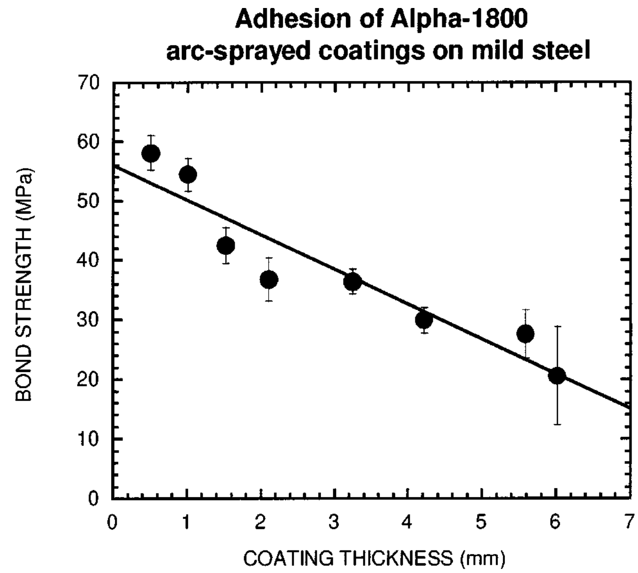

Fig. 17 Bond strength of Alpha 1800 arc-sprayed coatings as a function of coating thickness

sion volume loss at the spray angle of 90° would indicate that spraying normal to the surface is preferable.

4.9 Bond Strength of the Alpha 1800 Arc-Sprayed Coating

The extent of protection against wear depends on the ability of thick coatings to remain stuck on substrates. The coating bond strength is, therefore, an attribute as important as its wear characteristics if prolonged use is considered. The Alpha 1800 arc-sprayed coatings possess, as shown in Fig. 17, excellent bond strength for a 1 mm thickness. The adherence remains good up to 6 mm, the largest thickness being evaluated within this work. It should be mentioned that the rupture observed after tensile tests has never occurred at the coating-substrate interface.

5. Field Testing

The Alpha 1800 cored wire was sprayed by hand on site and with robots in the shop on fan components: removable leading edges, bolt covers, blades, deflectors, and large inlet entrance cone ducts. These pieces suffered extensive erosion wear damage and needed to be coated to reduce downtime and repair. Coatings, 1.25 to 1.5 mm thick, arc sprayed on fan components have been tested in service since October 1996 in the pelletizing plant of Quebec Cartier Mining Company (CMQC), located in Port-Cartier, Quebec. The early version of Alpha 1800 was arc sprayed by hand on site on the bolt covers of a fan operating at 275 °C. On the last periodic inspection (February 1999), no coating damage was noticed. Based on comments of CMQC maintenance personnel and laboratory testing, the Alpha 1800 arc-sprayed coating exceeds the predicted lifetime. The coating has improved the lifetime of components by a factor greater than 6 over steels or (Fe-Cr-C) submerged arc overlays widely used as fan materials.

6. Conclusions

Thick coatings can be manufactured by arc spraying Alpha 1800 cored wires. These arc-sprayed coatings possess particle erosion; slurry erosion, and abrasion wear resistances that considerably surpass those of structural materials and commercialized arc-sprayed coatings. Depending on the testing conditions, the erosion resistance of the Alpha 1800 coating equals or exceeds that of the finest coatings produced by high-energy processes. High-temperature tests showed that the Alpha 1800 coatings have excellent erosion resistance up to 650 °C at both impact angles of 25 and 90°. Their phase stability and oxidation resistance up to 800 °C ensure their use as protective coatings up to this temperature. Having been tested in industrial fans for 3 years, the coatings have shown no sign of failure. Easily deposited by hand or robots, the Alpha 1800 arc-sprayed coating is expected to find applications in numerous industrial sectors.

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