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

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## Abstract

Exposed to particle erosion environments, metal-sprayed coatings are damaged by micro-machining and ploughing at low impact angles. The generation and propagation of subsurface lateral cracks at high impacting angles damage single-phase ceramic coatings. Therefore, multicomponent coatings deposited by high-energy processes have been widely used to provide wear protection in most of the applications. As commercial arc-sprayed coatings have been used to a limited extent in applications involving erosion and abrasion wear, developing attractive wear resistant arc-sprayed coatings has been found necessary.

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. Typical 1 mm-thick coatings composed of ductile and hard phases with 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°, 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. Being thermally stable up to 850°C, arc-sprayed coatings produced with the new cored wire are attractive for applications in many industrial sectors involving high temperatures.

## 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-corrosion that industrial cost-effective solutions are rarely obtained. Micro-machining 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 displaced 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 pull out. In situations between those described above, there is controversy about the right 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 troublesome.

Carbide-metal coatings containing a high volume of touching 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. 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, most of the arc-sprayed coatings produced have been used to a limited extent in applications involving erosion and abrasion wear [1-7].

A new cored wire is proposed for producing hard arc-sprayed coatings to resist abrasion and particle erosion up to high temperature. This paper gives the comparative performance of coatings produced with the new cored wire with other sprayed coatings or structural materials when exposed to erosion, abrasion and slurry conditions. 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.

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## 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 (100m/s) particles impacting with low and high angles,
- 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 possess good resilience to resist particle impacts at 90°. The coating is composed of phases of which compositions and morphologies are obviously different from those found in the cored wire. It contains ductile and hard phases with a Knoop hardness reaching 1800 kg/mm$^2$. More details concerning the chemical composition of this cored wire will be given after the patent issue. Figure 1 shows that the microstructure of the Alpha-1800 arc-sprayed coating is composed of intimately intercalated hard and ductile sprayed lamellae.

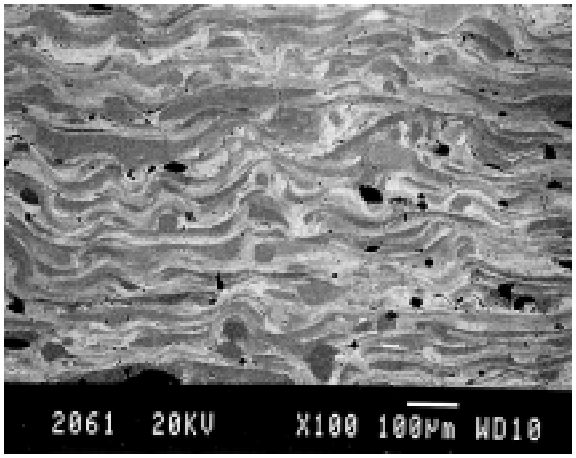

Fig.1 - Scanning electron micrograph cross-section of Alpha-1800 arc-sprayed coating (in dark: hard phases, in light: ductile phases).

## Experimental Procedure

**Arc sprayed coatings and materials**. The new cored wire, Alpha-1800, produced in 25-100 kg batches, was arc sprayed with air (pressure: 550 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. These are:

- 95MXC (Hobart Tafa Technologies, Concord, NH)
- austenitic stainless steel #1 and Tufton 500 (Mogul-Miller Thermal Inc., Appleton, WI),
- 440 C martensitic stainless steel (Aerospace Alloy, New York, NY),
- Armacor M, Armacor 16 and Duocor (Amorphous Technologies International, Laguna Niguel, CA),
- Colmonoy 88 (Wall Colmonoy, Madison Heights, MI),
- 97T (Metallisation Limited, Dudley, England).

The chemistry of these wires and their spray deposition parameters have been described earlier [8]. Commercial coatings were deposited on 100 by 100 by 3mm grit-blasted mild steel pieces to a thickness of about 500µm.

For comparison purpose, other sprayed coatings and structural materials were also erosion tested. These include:

- WC+10%Ni coatings (JP 5000 (HVOF), Tafa, Concord, NH),
- WC+12%Co coatings (Diamond Jet (HVOF), Sulzer Metco, NY),
- WC+NiCr Lasercarb (Technogenia S.A, Saint-Jorioz, France),
- Chromium carbide-iron submerged arc overlays,
- AISI 1045 and 1020 normalized steel,
- AISI 304 stainless steel.

HVOF coatings were manufactured following spray parameters recommended by the powder suppliers while other coatings or structural materials were obtained from suppliers or users. All types of coatings and reference specimens were diamond-ground to obtain flat surfaces prior to erosion and abrasion testing.

**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°C and 315°C using the gas-blast method with a laboratory 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 iron 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 1 summarizes the test parameters used in most erosion tests.

**Table 1 - Gas-blast erosion parameters**

| | |
|---|---|
| Erodent particles | Iron ore (-300 + 32 µm) |
| Particle flow rate | 0.044 (± 5%) g s$^{-1}$ |
| Mean velocity of particles | 97 (± 5%) m s$^{-1}$ |
| Erosion test duration | 300 s |
| Test temperatures | 25 (±5) and 315 (±15)°C |

Fig. 2 - Scanning electron micrograph of iron ore particles.

Particle erosion tests were also carried out on alpha-1800 arc-sprayed coatings at temperatures up to 650°C and compared with arc-sprayed Armacor M coatings, AISI 1020 and 304 steels. Before being submitted to the erosion test, specimens were heated up to the testing temperatures over a period of time of about 900 s. (15 minutes) The thermal stability of coatings was also evaluated by erosion testing at room temperature specimens that had been heat-treated at temperatures up to 1100°C for 1.8 x $10^4$ s (5 hours).

**Slurry erosion testing.** Slurry erosion tests were carried out using a slurry jet erosion device. Not being a standardized procedure, the test consists in circulating 7 liters of prepared slurry during 3600 s using an air-powered double-diaphragm slurry pump. The re-circulating slurry, consisting of filtered 15-20°C tap water with 10 wt % 212-300 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 surface specimens for each test. Selected coatings, including HVOF WC-Co coatings, were tested and compared to Alpha-1800 arc-sprayed coatings.

**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 testing method consists in 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 ended after 2000 revolutions. All coatings, except HVOF WC-Co coatings, were compared with Alpha-1800 arc-sprayed coatings.

**Erosion and abrasion evaluation.** Particle erosion was reported as volume loss per kilogram of erodent particles ($mm^3$/kg of iron ore) while slurry erosion and abrasion were reported as volume loss in $mm^3$. The volume loss measurements of damage resulting from wear were performed with an optical profilometer [10] having accuracy greater than 1%. Before measurements, samples were ultrasonically cleaned in iso-propanol and oven-dried at 100°C.

**Hardness measurements.** Diamond pyramid hardness (DPH) 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 7 measurements.

**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 glued studs at 150°C, tensile tests were carried out following the recommended procedure.

**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 of 3 x $10^3$s (50 min) of heating in air up to 800°C and cooling cycles of 600 s (10 min). The total exposure time to 800°C is $1.5x10^5$s (104 hours). The weight gains after temperature exposition were used to evaluate the relative resistance to cyclic oxidation of Alpha-1800 arc-sprayed coatings.

## Results and Discussion

**Particle erosion resistance of the Alpha-1800 arc-sprayed coating.** 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°C and 315°C as shown in Figures 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 temperature increase is generally more important at 25° than at 90°. The (Fe-Cr-C) overlay, however, lost 3 times more volume at 315°C than at 25°C at both impact angles.

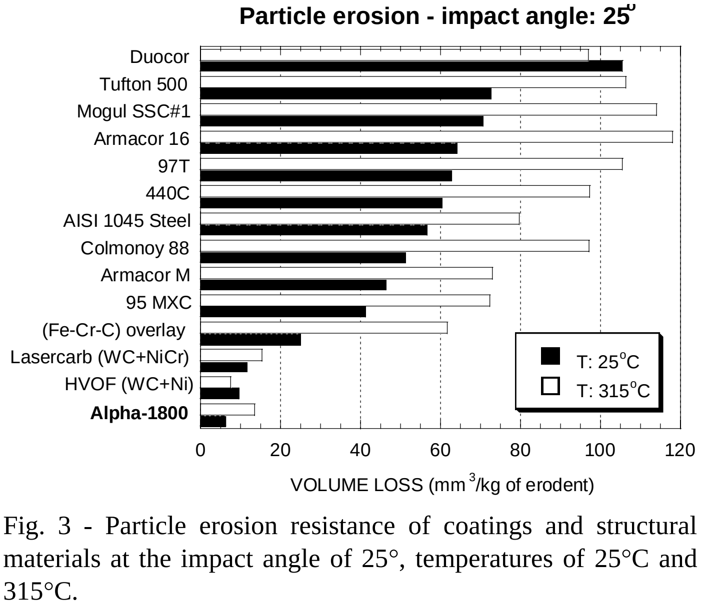

Fig. 3 - Particle erosion resistance of coatings and structural materials at the impact angle of 25°, temperatures of 25°C and 315°C.

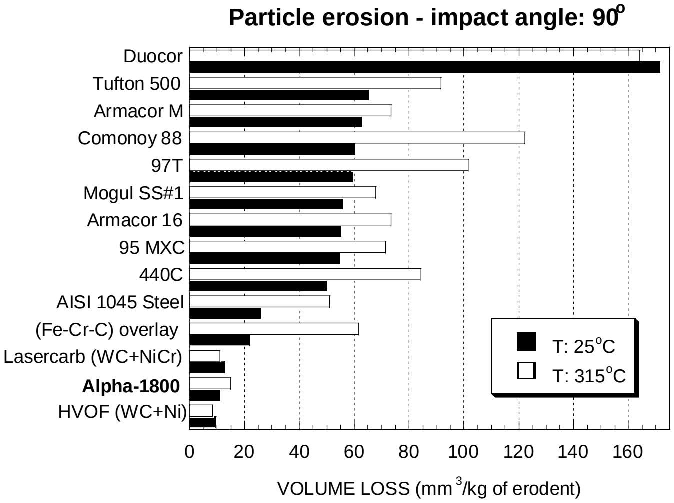

Fig. 4 - Particle erosion resistance of coatings and structural materials at the impact angle of 90°, temperatures of 25°C and 315°C

For both impact angles and temperatures, the particle erosion resistance of Alpha-1800 arc-sprayed coating can be compared with expensive HVOF (WC-Ni) and Lasercarb (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).

**Influence of the impact angle on the particle erosion resistance of the Alpha-1800 arc-sprayed coating.** Most of the sprayed coatings possess a microstructure composed of oriented splat lamellae. Therefore, the erosion resistance of Alpha-1800 arc-sprayed coatings could 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°C 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. However, higher volume loss was observed at the impact angle of 90°.

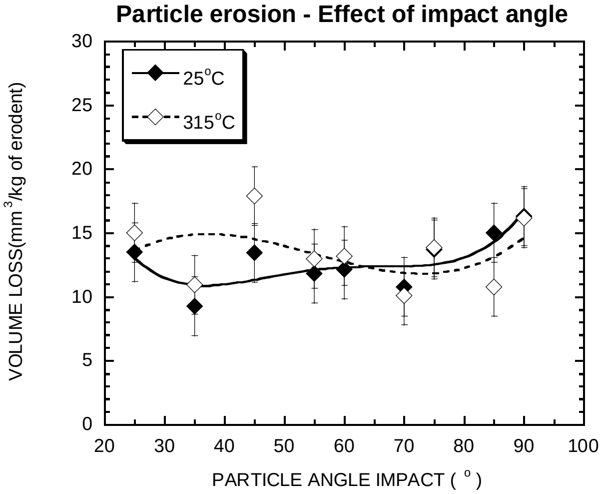

Fig. 5 - Influence of particle impact angle on the erosion resistance at 25°C and 315°C. Error bars correspond to the standard deviations measured at the impact angle of 90°.

**Slurry erosion resistance of the Alpha-1800 arc-sprayed coating.** As shown in Figure 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 Colmonoy 88. HVOF (WC-Co) coatings presented the best slurry erosion resistance observed. At the impinging angle of 90°, the volume loss of Alpha-1800 arc-sprayed coating is very close to that of the HVOF (WC-Co) coating.

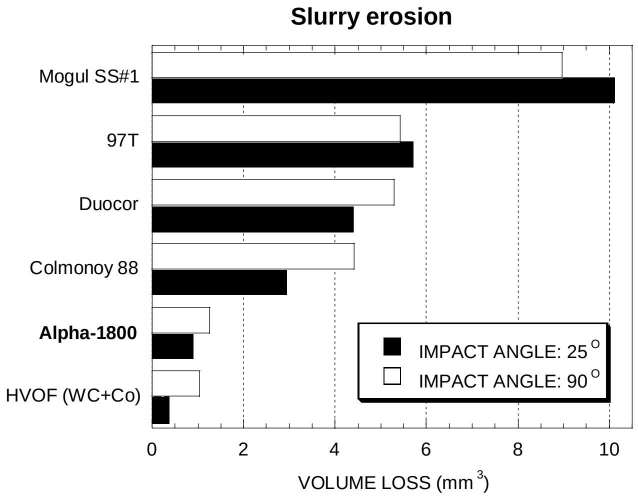

Fig. 6 - Slurry erosion resistance of Alpha-1800 arc-sprayed and selected coatings.

**Abrasion resistance of the Alpha-1800 arc-sprayed coating**. As shown in Figure 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. Ranking between HVOF WC-Ni and Lasercarb WC-NiCr coatings, the abrasion volume loss of Alpha-1800 arc-sprayed coating is 2 times less than those of (Fe-Cr-C) submerged arc overlays and 24 times less than that of AISI 1045 steel.

**Hardness of Alpha-1800 arc-sprayed coating.** The hardness of materials being usually associated with erosion or abrasion resistance, the Knoop hardness of materials is given for information in Figure 8. It is generally admitted than soft materials possess resilience to resist 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.

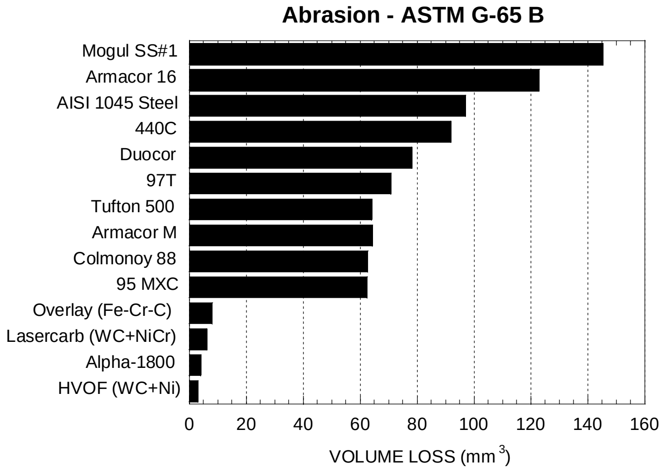

Fig. 7.- Abrasion resistance of coatings and structural materials.

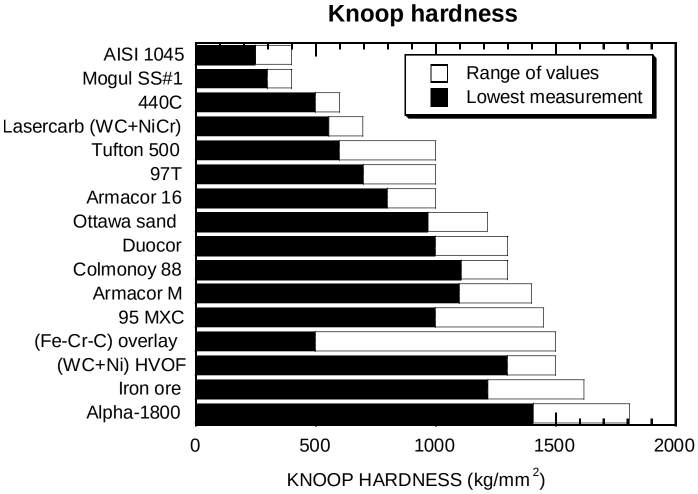

Fig. 8 - Knoop hardness of coatings, structural materials and erosive particles (iron ore, Ottawa sand).

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

**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 are illustrated in Figures 9 and 10 for AISI 1020 and 304 steels, Armacor M and Alpha-1800 arc-sprayed coatings. As shown in Figure 9, the volume loss of the Alpha-1800 arc-sprayed coating at the impact angle of 90° remains below that of AISI 1020 and 304 steels for the temperature range considered. On the contrary, the volume loss due to erosion of Armacor M arc-sprayed coating is at least two times higher than those of 1020 and 304 steels. At the impact angle of 25°, as shown in Figure 10, Armacor M 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.

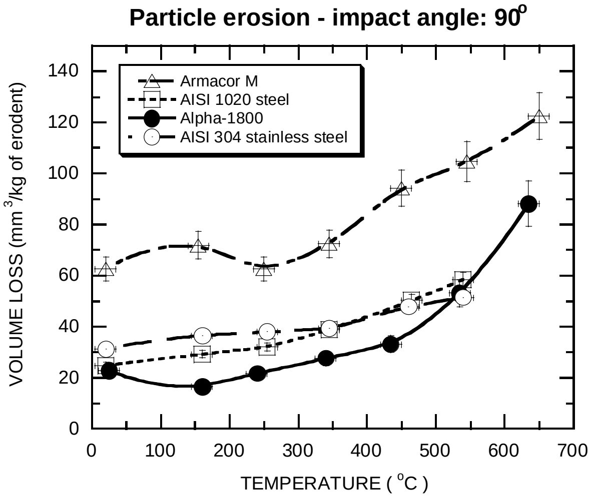

Fig. 9 - Particle erosion resistance at 90° of Alpha-1800 and Armacor M arc-sprayed coatings, AISI 1020 and 304 steels with temperature. Error bars correspond to standard deviations.

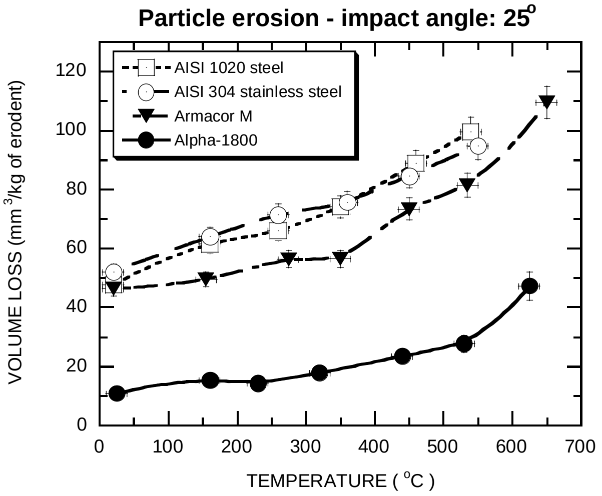

Fig. 10 - Particle erosion resistance at 25° of Alpha-1800 and Armacor M arc-sprayed coatings, AISI 1020 and 304 steels with temperature. Error bars correspond to standard deviations.

**Thermal stability 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 determine their thermal stability at higher temperatures. Phase transformations upon heating or cooling can affect their physical properties. Erosion tests were therefore carried out at room temperature on coatings maintained for different periods of time at temperatures higher than 650°C. As shown in Figure 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 temperature. The volume loss is first reduced by 30% at 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 at 850°C the volume loss obtained on coatings not heat-treated. For higher temperatures, the volume loss at 90° increases almost exponentially due to microstructure changes. As observed, particle erosion resistance at 90° is then more sensitive to phase re-arrangement. In contrast, the erosion resistance at low angles is related to amount of hard phases present within coatings.

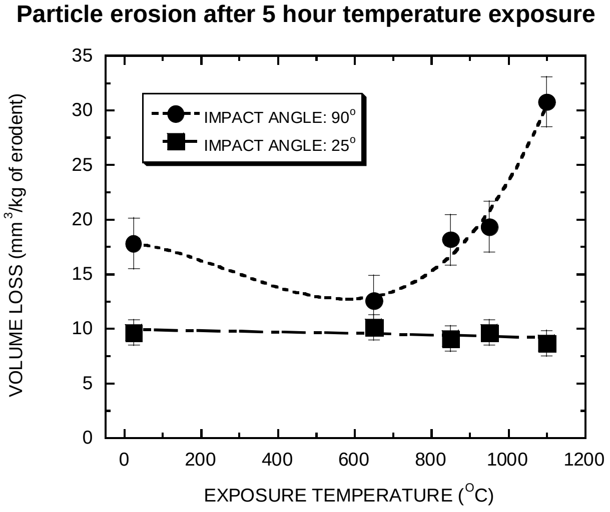

Fig. 11 - Erosion volume loss of Alpha-1800 arc-sprayed coatings due to particle impact at angles of 25° and 90° (Temperature: 25°C) as a function of ageing temperature for an exposure time of 1.8 x $10^4$ s. (5 hours). Error bars correspond to standard deviations.

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

**Influence of spray parameters on the particle erosion resistance of Alpha-1800 arc-sprayed coatings.**

*Arc Amperage.* Being 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 the most relevant one. As shown in Figure 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 would therefore produce coatings erosion resistant at both low and high impact angles. For erosion at higher temperatures, the same trend is observed.

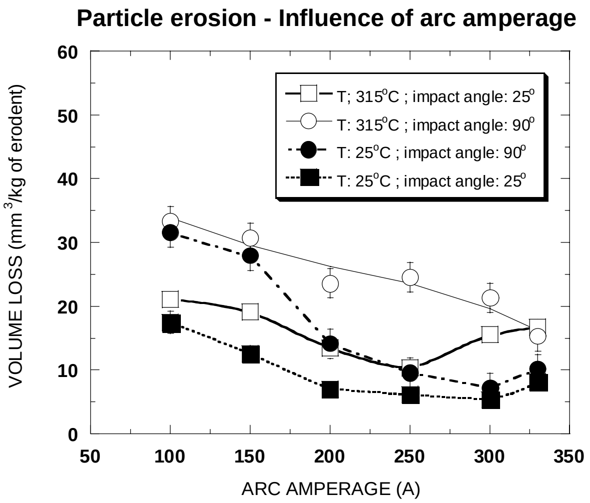

Fig. 12 - The influence of arc amperage on the erosion resistance of Alpha-1800 arc-sprayed coatings. Spray distance: 7.62 cm, traverse speed: 15 cm/s, arc voltage: 31 V. Error bars correspond to standard deviations.

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

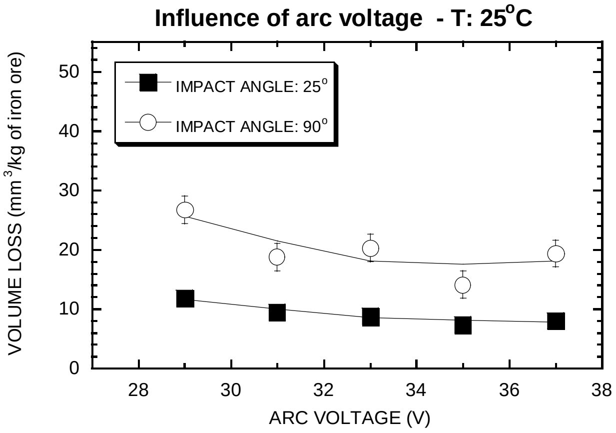

Fig. 13 - The influence of arc voltage on the erosion resistance of Alpha-1800 arc-sprayed coatings. Arc amperage: 200 A, spray distance: 7.62 cm, traverse speed: 15 cm/s. Error bars correspond to standard deviations.

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

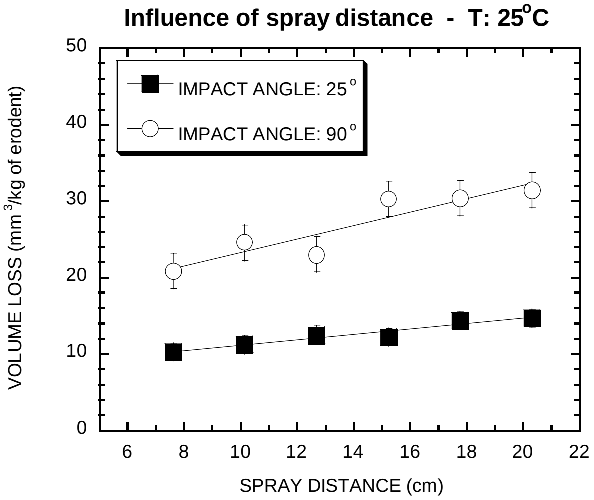

Fig. 14 - Influence of the spray distance on the particle erosion resistance of Alpha-1800 coatings at room temperature. Arc voltage: 31 V, arc amperage: 200 A, traverse speed of 15 cm/s.

*Traverse speed.* Traverse speeds comprised between 5 cm/s (118 inches/min) and 15 cm/s (355 inches/min) do not affect the erosive wear properties of the Alpha-1800 coating as shown in Figure 15. However, traverse speeds lower than 5 cm/s (118 inches/min) could result in erosion resistance improvement. A traverse speed of 2 cm/s (47 inches/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 with traverse speed of 15 cm/s, the temperature reaches only 73°C. The erosion resistance enhancement, particularly at high impact angle most likely result from stress relief due to temperature increase. Obviously, 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 traverse speed can range between 5 cm/s and 15 cm/s would product 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 inch) obtained with a traverse speed of 2 cm/s do not permit to achieve good overlapping passes.

*Spray angle.* Normally sprayed, the Alpha-1800 coating was found almost insensitive to the particle impact angle (Fig. 5). However, being a 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. It is, therefore, 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°C and 315°C. The slight fall in erosion volume loss at the spray angle of 90° would indicate that spraying normal to the surface is preferable.

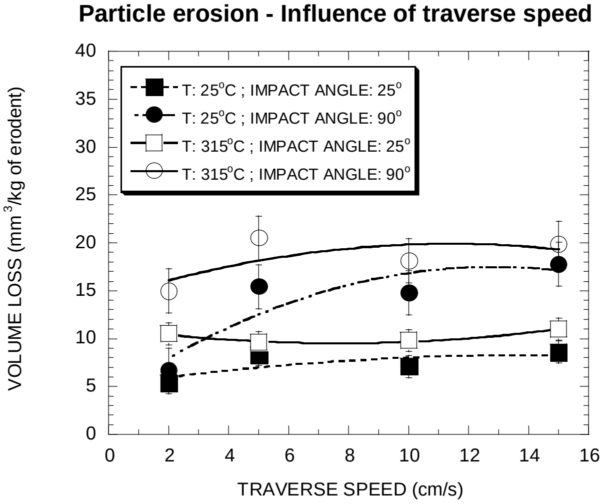

Fig. 15 - Influence of the traverse speed on the particle erosion resistance of Alpha-1800 coatings at 25°C and 315°C. Arc voltage: 31 V, arc amperage: 200 A, spray distance: 7.62 cm.

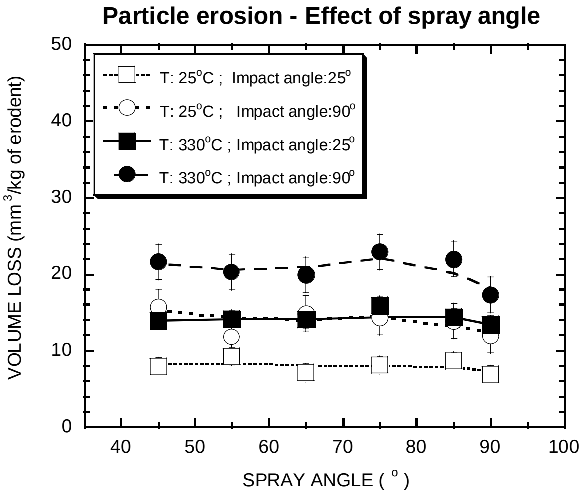

Fig. 16 - Influence of the spray angle on the erosion volume loss of Alpha-1800 coating for impact angles of 25° and 90° and temperatures of 25°C and 315°C.

**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, a coating attribute as important as its wear characteristics if prolonged use is considered. The alpha-1800 arc-sprayed coating possess, as shown in Figure 17, excellent bond strength for a 1mm 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 have never occurred at the coating-substrate interface. The reported figures would correspond to the cohesive strength observed for different coating thicknesses.

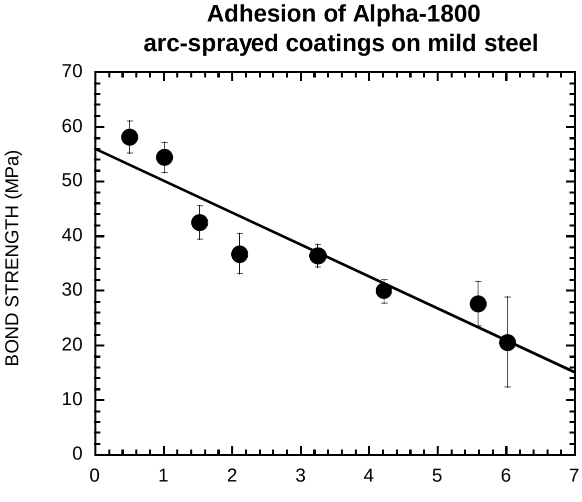

Fig. 17 - Bond strength of Alpha-1800 arc-sprayed coatings as a function of coating thickness.

**Field-testing**. The Alpha-1800 cored wire was sprayed by hand on site and with robots in 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, 1.25-1.5 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 bolt-covers of a fan operating at 275°C. On the last periodic inspection (February 1999), no coating damage could be noticed. Based on comments of CMQC maintenance personnel and laboratory testing, the Alpha-1800 arc-sprayed coating exceeds the predicted lifetime. The coating have 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.

## Conclusion

Thick coatings can be manufactured by arc spraying with air 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 would 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.

## Acknowledgments

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