

Erosion and Abrasion Resistance of Boride and Carbide-Based Weld Overlays

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Abstract

WELD OVERLAYS, more specifically chromium carbide weld overlays, have been widely used as thick coatings to protect critical plant components from abrasion wear. These thick coatings have been also considered in applications involving severe erosion, their thickness being synonymous with long life protection. Recently, boride-based arc-sprayed coatings have been developed especially for erosion control. They have demonstrated their superiority in erosion resistance over various coatings including chromium carbide submerged arc overlays. This work was undertaken to produce dense boride-based coatings comparable in thickness with carbide-based overlays. A GMAW (Gas Metal Arc Welding) welding procedure was developed for depositing boride-based overlays from cored wires. A comparative evaluation of the hardness, erosive and abrasive wear resistance of these boride-based overlays with regards to chromium and tungsten carbide overlays was carried out. Abrasion and erosion wear testing demonstrated that boride-based overlays showed higher abrasion and erosion resistance than chromium and tungsten carbide-based overlays. Overlays with higher wear resistance can be obtained if appropriate welding procedure is used to decrease weld bead dilution and therefore increase coating hardness. Results also showed that boride-based coatings deposited by arc spraying possess higher erosion resistance than those produced by the welding process.

Introduction

Weld overlaying and arc spraying are the most attractive and easy-to-use techniques to apply wear resistant coatings on critical plant components. 1-mm thick arc-sprayed coatings are convenient for thin-wall large surfaces while thicker coatings deposited by welding processes are suitable to protect localised areas on rather thick substrates.

The wear protection afforded by these two types of coatings admittedly depends on the coating composition and the

deposition technique. Thick wear-resistant coatings meaningfully provide long life protection. Efforts have been devoted to produce thicker and more wear resistant coatings by depositing cored wires by arc spraying and welding techniques. Arc-sprayed coatings may contain borides and carbides while weld overlays are usually carbide-based materials.

In a previous work, hard boride-based arc-sprayed coatings have shown higher erosion and abrasion resistance than submerged arc chromium carbide overlays and other arc-sprayed coatings [1]. This work has been devoted to deposit boride-based overlays by welding and to compare their hardness, erosion and abrasion resistance to those produced by depositing cored wires containing chromium or tungsten carbide.

Experimental Procedure

Hardfacing materials. Two usual chromium carbide hardfacing wires proposed by many vendors were selected for the study. The first one (referred as to Fe-Cr-C) contains up to 3,5 wt% C and 22 wt% Cr. Other alloying elements such as Mn, Si, Mo and V are also present in this cored wire. The second wire (referred as to Fe-Cr-C-Nb) contains up to 2,8 wt% C, 13 wt% Cr and 5,2 wt% Nb. W, V, Mo, Si, Mn are also added within this cored wire. The third cored wire selected contains between 55 and 60 wt% WC. This material is referred as to WC-(Ni-Cr-Si-B).

The cored wires producing iron-boride and iron and chromium boride-based coatings are known as Alpha 1800 and Alpha Plus (SYNTHESARC Inc., Boucherville, Quebec, Canada). This family of cored wires is based on the use of hard boride phases instead of carbides commonly used in most of the commercialised coatings.

Weld surfacing. A Miller 456P GMAW (Gas Metal Arc Welding) (Praxair, Appleton, WI) welding source was used to deposit all the cored wires. The selected welding parameters for the different cored wires are summarized in Table 1.

Table 1: Welding parameters used for depositing cored wires.

	Fe-Cr-C	Fe-Cr-C-Nb	WC-(Ni-Cr-Si-B)	Alpha 1800	Alpha Plus
Polarity	DCEP *	DCEP	DCEP	DCEP	DCEP
Wire diameter (mm)	1,6	1,6	1,6	1,6	1,6
Gas	Ar (1)	Ar (1)	Ar (1)	Ar(2)	Ar(2)
Voltage (V)	25	25	25	23	25
Wire feed rate (mm/s)	63,5	63,5	63,5	69,9	84,7
Tip-to-work distance (mm)	19	19	19	19	19
Travel speed (mm/s)	2,12	2,12	2,12	2,12	2,12
Oscillation amplitude (mm)	31,75	31,75	31,75	31,75	31,75
Oscillation speed (Cycles/s)	0,67	0,67	0,67	0,67	0,67

* DCEP means direct current electrode positive.

Ar (1): means Ar-25 wt% CO₂ Ar (2): means Ar-2 wt% O₂.

Welding operation was done using a weaving pattern and weld deposits are composed of one or two passes. 6.4 mm-thick degreased mild steel plates were used as base metal plates. A copper backing plate placed underneath base metal was acting as a heat sink.

Arc spraying. Alpha 1800 cored wire was arc sprayed with air using a Miller BP 400 Arc Spray System (Praxair, Appleton, WI) on 3.2 mm-thick grit blasted steel to form 1mm-thick boride-based coatings. Arc spraying parameters are shown in Table 2.

Table 2: Arc spraying parameters.

Arc voltage	35 Volts
Arc amperage	250 A
Spray distance	7.62 cm
Traverse speed	15 cm/s
Air pressure	550 kPa

Surface preparation. All types of coatings were diamond-ground to obtain flat surfaces (Ra ≈ 1 μm) prior to erosion and abrasion testing.

Erosion testing. All weld overlays were erosion tested using a gas-blast erosion rig, described earlier [1, 2]. Tests were carried out at two impact angles (25° and 90°) and for two temperatures (25°C and 315°C). In this test, high-speed erosive particles strike the sample surface in a very localised area. The impact area is less than 10 mm² for the 90° impact

angle and less than 30 mm² for the 25° impact angle. The main erosion test parameters are described in Table 3.

Table 3: Gas-blast erosion parameters.

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

Abrasion testing. Weld overlays abrasion wear resistance was measured in accordance with the Dry Sand/Rubber Wheel Abrasion Test (ASTM G65, procedure A). The testing consists in abrading a specimen with a grit of controlled size and composition. A force of 130N maintained the specimen against the rubber-coated wheel. Quartz sand (50/70 mesh) (300/212 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 6000 revolutions.

Erosion and abrasion evaluation. Particle erosion was reported as volume loss per kilogram of erodent particles (mm³/kg of iron ore) while abrasion was reported as a volume loss in mm³. The volume loss measurements of damage resulting from wear were performed with an optical profilometer having accuracy greater than 1% [3].

Hardness measurements. Rockwell C (HRC) macrohardness measurements were performed on all diamond ground weld overlays. Results reported are means of seven measurements.

Dilution measurements. Dilution was obtained by measuring the geometrical features of the weld deposit. Polished cross sections of weld deposits were photographed and images were analysed. The penetration area is the surface of the weld underneath the base plate surface while the reinforcement area is the surface of the weld above base plate surface. Dilution is defined as the ratio of the penetration area over the total weld surface (penetration area plus reinforcement area).

Results and Discussion

Particle erosion resistance of weld overlays. Erosion tests results at 25°C and 300°C are reported in Fig. 1 and 2. Both graphs have been drawn on the same scale in order to see how significant is the wear rate increase at high temperature. A rough comparison between Fig. 1 and Fig. 2 shows that carbide-based overlays are much more sensitive to a temperature rise than boride-based ones. Detrimental temperature effects are obviously observed for the carbide-based overlays at the impact angle of 25° [1].

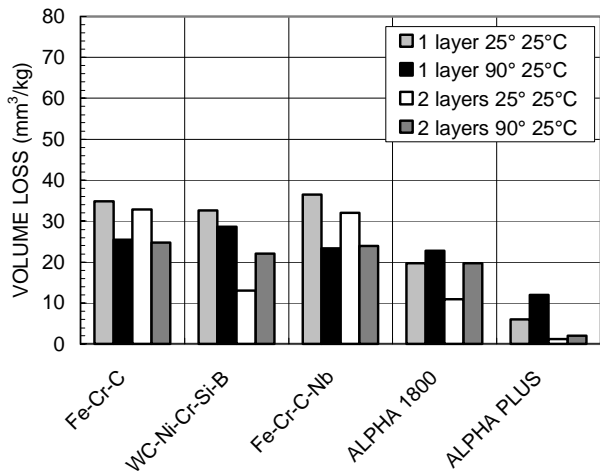


Figure 1: Erosion resistance of weld overlays at 25°C for impact angles of 25° and 90°.

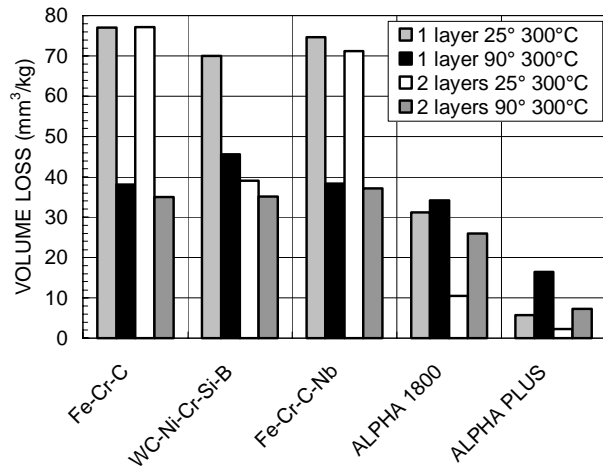


Figure 2: Erosion resistance of weld overlays at 300°C for impact angles of 25° and 90°.

Boride-based overlays present a better erosion resistance at the low impact angle of 25° whereas carbide-based ones possess a better erosion resistance at the high impact angle of 90°. In one- or two-layer deposit, all carbide-based materials show better erosion resistance at high impact angle with exception of the two-layer WC-(Ni-Cr-Si-B) overlay that presents better erosion resistance at room temperature at the impact of 25°.

A lower erosion resistance at low impact angle could indicate that overlays do not contain large amounts of hard phases. This can result from dilution when a single pass overlay is carried out. Overlays richer in hard phases can be obtained by adding a second pass. As shown in Fig. 1 and 2, the erosion resistance at 25° of chromium carbide-based is not increased with an additional layer. WC-(Ni-Cr-Si-B) overlay which contains boron and boride-based overlays benefit from a

second layer at room temperature. At 300°C, these overlays markedly keep the beneficial advantage of a second layer. Alpha Plus is by far the most erosion resistant overlay at both impact angles and temperatures.

Weld overlay abrasion resistance. Volume losses due to abrasion are reported in Fig. 3 for all overlays deposited in single or twin layers. It should be pointed out that the procedure A of the ASTM G-65 abrasion test is not adapted for volume loss higher than 100 mm³, the Fe-Cr-C overlay exceeding largely this prescribed limitation. Nevertheless, the procedure A was used with this material for comparison purpose.

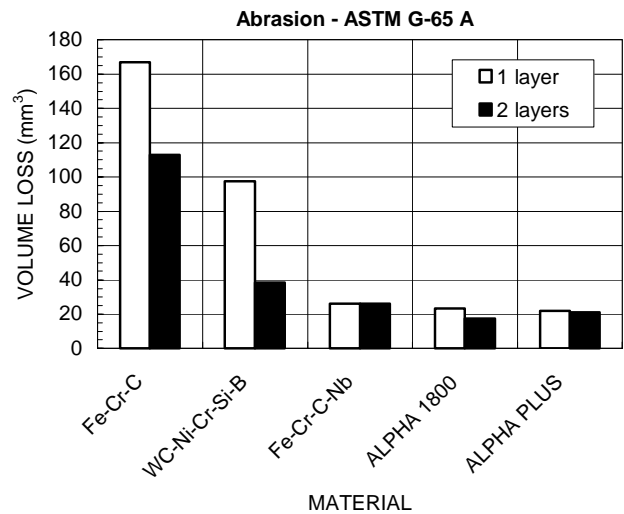


Figure 3: Abrasion resistance of weld overlays.

As observed in Fig. 3, two-layer overlays are better abrasion resistant than single-layer weld overlay. This increase in wear resistance could result from the enrichment in hard phases afforded by a second pass. However, the influence of this second layer is not very marked for all overlays. As shown in Fig. 3, the abrasion resistance of WC-(Ni-Cr-Si-B) and Fe-Cr-C nearly increases twofold after the addition of a second pass. Most likely, WC-(Ni-Cr-Si-B) and Fe-Cr-C cored wires contain lesser hard phases than the others. The dilution of the first pass with the base metal has a negative influence on their abrasion resistance. It should be noticed that boride-based overlays present better abrasion resistance even deposited in one layer. A reduction of wear comprised between 18 and 33% can be obtained with boride-based overlays over Fe-Cr-C-Nb overlays.

Weld overlay hardness. Hardness measurements are often used as a means to foresee both the erosion and abrasion resistance of materials. HRC (hardness on Rockwell C scale) hardness measurements are reported in Fig. 4. A comparison of this figure with Fig. 3 indicates that the abrasion resistance

of overlays cannot be directly related to their hardness, although the hardest overlay is the most erosion resistant.

Table 4: Alpha Plus two-layer weld overlay properties.

State of 1 st layer	Abrasion (Volume loss) (mm ³)	Hardness (HRC)
Cold	21.6	67.9
Hot	20.7	69.1

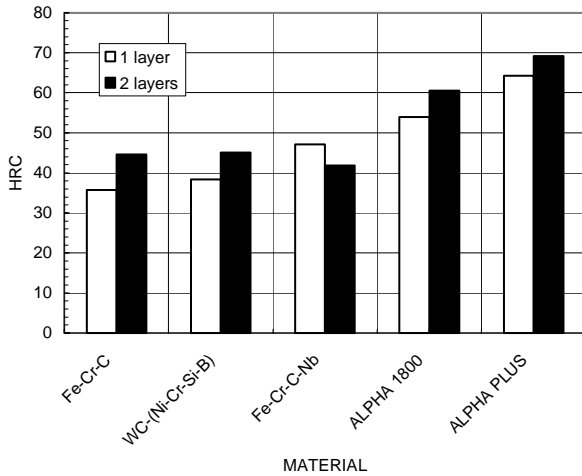


Figure 4: Hardness of weld overlays.

Influence of cooling rate. It is interesting to notice that all weld overlays become harder after a second pass except the Fe-Cr-C-Nb material. Although this two-layer deposit is less diluted than a one-layer overlay, it is softer. This softening effect most likely results from the cooling rate of overlays. The first hardfaced layer is still hot when the second layer is deposited. It has been previously observed that the cooling rate has a marked influence on both hardness and wear resistance of Fe-Cr-C materials [4]. The microstructure of Fe-Cr-C-Nb overlays can be also related to the cooling rate. The volume content and the size of primary carbides as well as the matrix nature (austenite, pearlite, martensite) depends upon the cooling rate. Admittedly these features determine mechanical properties of overlays.

The cooling rate should influence all two-layer weld overlays. Except the Fe-Cr-C-Nb overlays, all two-layer overlays present higher hardness and abrasion resistance. To elucidate the influence of the temperature of the first layer, a second boride-based layer (Alpha Plus) was deposited on both hot and cold previously deposited first layer using the same welding parameters. Properties of these two-layer overlays are presented in Table 4.

As observed in Table 4, welding a second Alpha Plus layer on a still hot first layer enhances slightly the abrasion resistance, the hardness being not significantly affected. Applying a second layer on a hot first layer lowers the weld bead cooling rate, which likely modifies the grain size, shape and orientation.

Relationship between hardness and erosion resistance. Hard materials are expected to be erosion resistant at low impinging angles. The relationship between hardness and erosion resistance at low impact angles is displayed in Fig. 5. As observed in this figure, the erosion resistance at the impact angle of 25° tends to increase with overlay hardness. Generally, overlays composed of two layers are harder and more erosion resistant at low impact angles, except the Fe-Cr-C-Nb overlays. Adding a second overlay layer reduces the overall weld bead dilution. Small increase in hardness results in large improvement in erosion resistance of overlays containing boron while the erosion resistance of chromium carbide-based overlays is almost not affected by a variation in overlay hardness.

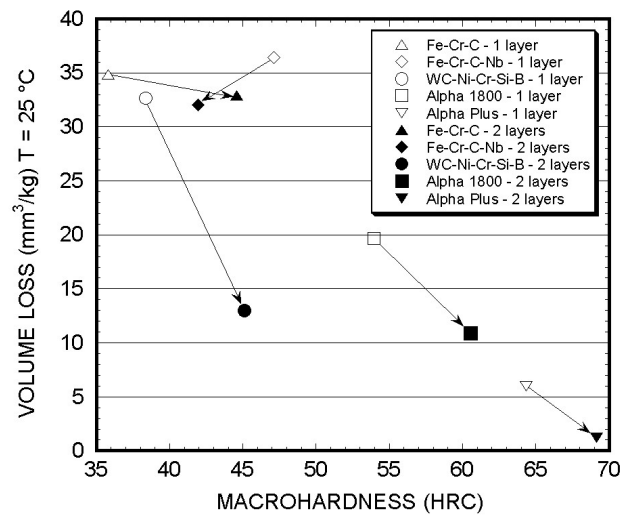


Figure 5: Relationship between the eroded volume at the impact angle of 25° and macrohardness of weld overlay layers. One-layer overlay and two-layer overlay are linked by an arrow.

The low global dilution resulting from the addition of a second overlay layer is most likely responsible from the increase in erosion resistance at the impact angle of 25°, the volume fraction of hard phases being higher. Reduced hardness after a second pass is due to a reduced cooling rate. The hardness of chromium carbide overlays is very sensitive to cooling rate particularly the metal matrix that could contain less martensite [4] and therefore it is softer. The hardness of a material should

be therefore cautiously considered as an indicator of the performance of a coating.

Importance of dilution. As mentioned earlier, the weld bead dilution affects directly the volume fraction of hard phases in overlays and therefore, the wear properties of overlays. Weld bead dilution depends upon many factors such as the welding technique, welding parameters, type of consumable, base plate material, thickness and surface condition. Voltage, current, stickout, weaving, electrode size, polarity, protection gas are among the most important welding parameters that influence the bead dilution. The bead dilution of a single layer overlay deposited on a 6.4 mm-thick base steel plate is around 30%. The global dilution is reduced to 15% with an additional layer of overlay. An ideal global dilution would be approximately 8 % [5] to benefit from a reliable metallurgical bond without losing too much wear resistance. Using thicker base plates, grit-blasted surface and water-cooled heat sink could help reaching a low dilution by decreasing weld penetration. Therefore, increased wear resistance would result.

Minimizing the weld bead dilution on industrial sites can be unachievable. Thus, the present work has not been concerned with optimizing the weld dilution but rather to obtain reliable well spread beads.

If the wear resistance was of prime importance, regardless of the cost, weld bead dilution must be reduced below the level currently achieved. Depositing an arc-sprayed coating of the same composition as the overlay prior welding is a convenient and efficient way to reduce the weld bead dilution as shown in Table 5 with boride-based coatings.

Table 5: Weld bead dilution of Alpha 1800 overlays.

TYPE OF OVERLAY	Bead dilution (%)
1 layer on steel base metal	30
2 layers on steel base metal	15
1 layer on 600 μm-thick arc-sprayed coating	15
1 layer on 1.25 mm-thick arc-sprayed coating	<10

The abrasion resistance of these overlays with reduced dilution is twofold increased and the erosion resistance is two to fivefold increased depending upon the impact angle and testing temperature. This technique can also be used with other boride-based overlay such as Alpha Plus.

Wear resistance of Alpha 1800 arc-sprayed coatings and Alpha 1800 weld overlays. Weld surfacing and arc spraying are two deposition techniques possessing their own advantages and drawbacks. Weld surfacing gives dense coatings free of oxide inclusion and forming a metallurgical bond with the substrate. Arc spraying offers a better deposition rate and a greater flexibility than weld surfacing. Arc-sprayed coatings can indeed be deposited in all positions, on virtually any kind

of metallic surfaces. Moreover, arc spraying is not concerned by dilution and substrate thickness.

Arc spraying or weld surfacing can be selected depending on the application and the thickness required. The wear resistance of boride-based coatings produced with these techniques is compared in Table 6 and Fig. 6.

The abrasion resistance of Alpha 1800 arc-sprayed coatings is better than of one-layer Alpha 1800 weld overlay and nearly equivalent to that of two layer Alpha 1800 weld overlay as reported in Table 6.

Table 6: Abrasion resistance of Alpha 1800 coatings.

COATING MATERIAL	Abrasion ASTM G65-A (Volume loss) (mm ³)
Alpha 1800 weld overlay- one layer	23.3
Alpha 1800 weld overlay - two layers	17.3
Alpha 1800 arc-sprayed	18.3

The particle erosion resistance of Alpha 1800 arc-sprayed and weld overlaid coatings is shown in Fig. 6. The erosion resistance of Alpha 1800 arc-sprayed coatings is lower than that of Alpha 1800 overlays except at 300°C and impact angle of 25° where the two-layer overlay present the highest erosion resistance.

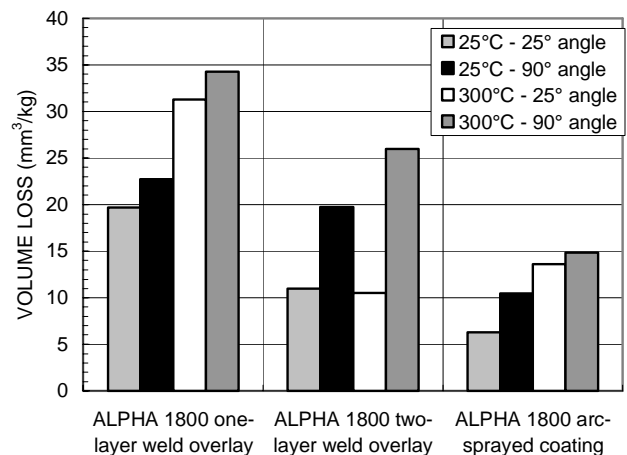


Figure 6: Erosion wear resistance of boride-based coatings.

The weld bead dilution in one-layer Alpha 1800 overlay is responsible for lower abrasion and erosion resistance. The microstructure differences in Alpha 1800 arc-sprayed and overlaid coatings and the differences in cooling rate would explain their different wear behavior. A microstructure analysis should be required to enlighten these differences. It is however noteworthy to observe that arc-sprayed coatings,

considered as fragile because of their lamellar microstructure, present amazing wear resistance in the tested conditions.

Summary and Conclusion

Alpha 1800 and Alpha Plus cored wire can be successfully deposited with the standard GMAW process to form thick boride-based coatings. Compared to carbide-based overlays boride-based overlays present superior abrasion and particle erosion resistance. These overlays are also the hardest coatings.

The deposition of a second layer of overlay decreases the overall weld bead dilution and it increases the erosion resistance of boron containing materials such as Alpha Plus, Alpha 1800 and WC-Ni-Cr-Si-B, especially at low impinging angle. Increase in hardness obtained with a second pass of overlay does not mean increase in erosion resistance particularly for carbide-based materials for which properties largely depend on cooling rate.

Although boride-based overlays are the most abrasion resistant, arc-sprayed boride-based coatings (Alpha 1800) present enviable erosion resistance. If thick coatings were required to guarantee component extended life, boride-based overlays would be therefore recommended.

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