Comparison of Deposits of Wires Applied by Welding, Thermal Spraying, and Spray and Fuse

Mechanical properties of deposits for three different alloys were evaluated

BY ROBERT H. UNGER, RICHARD D. COOK, AND WILLIAM C. MOSIER

Welding and thermal spraying are both widely used to provide surface enhancement to metallic substrates. Wear resistance, corrosion resistance, surface finish and thermal or electrical conductivity are all examples of surface properties that can be substantially altered by applying a weld or thermal spray coating. Often, thermal spray deposits are subsequently fused to further enhance the deposit characteristics.

This article examines critical properties of three wires that are applied by these processes, to provide increased wear and corrosion resistance for severe wear applications.

Methods of Deposition

The samples for testing were prepared using the following deposition techniques:

Gas Metal Arc Welding — This method was used to apply the welded deposits. Described simply, the process consists of striking an arc between a consumable electrode of the feedstock material and the substrate, while using a shielding gas — Fig. 1. The weld metal fuses with the substrate, creating a very dense, metallurgically bonded deposit.

Wire Arc Spray — This is the most widely used method of applying wire deposits by thermal spraying. Two feedstock wires are isolated and brought to an intersecting point, where voltage is applied across the wires establishing an arc that melts the tips of the wires. An atomizing gas, normally air, is directed across the arc zone. The atomized particles are accelerated and propelled onto the substrate to build up a coating deposit. The surface deposit is mechanically bonded and will typically contain a degree of oxide and porosity.

Spray and Fuse — It is common to fuse thermal spray coatings after deposition to eliminate porosity in the deposit and improve bond strength and impact resistance. This involves heating the coating to its fusing temperature by use of a torch, oven, laser, or other technique. The wire arc sprayed deposits were fused in this study by using a rosebud torch with a neutral flame (Fig. 2) to approximately 2400°F (1300°C).

Deposition Process Advantages

While each deposition process has its unique advantages and limitations (Table 1), all are widely used in a number of successful applications. Weld surfaced has a metallurgical bond that makes it particularly effective for high-impact applications such as crushing or digging in the mining, oil field, cement, and power generation industries. Weld surfacing also has virtually no porosity, which makes it very effective in wet corrosion applications, such as chemical storage tanks, pulp and paper processing, and petrochemical applications.

Wire arc spray deposits have a mechanical bond and arc less successful under impact. The porosity of the coatings makes it more necessary for wet corrosion applications. But, the high speed and ease of application make it ideal for on-site work, such as boiler tubes in the power generation industry. And, as it puts...
very little heat into the substrate, it is often the process of choice for applying metal coatings to thin or nonmetallic substrates, where distortion or even melting of the substrate is a concern. The lack of any dilution (mixing of coating and substrate) make thin coatings down to 1–2 mils possible, without sacrificing the properties of the coating.

Fusing of the arc spray coatings is an added step in the process, but, it can often “bridge the gap” between arc spray and welding, by eliminating the porosity of the arc spray coatings and improving the bond from mechanical to metallurgical. While fusing has been primarily used in the past for powder flame spraying NiCrBSi materials, it is now being evaluated for several severe applications using arc spray deposition.

**Materials Tested**

Three materials were chosen for testing.
- PMct 273, FeCrBSi amorphous alloy
- PMET 860BC, Alloy 625 with boron carbide
- PolyTung NiCrBWC

All three materials have shown success in high-wear applications in both welded and sprayed form.

The materials are manufactured using a special cored wire technology. This consists of starting with a metal strip, which is first formed into a channel. Powder is fed into the strip channel to achieve the desired final composition. The strip/powder is then passed through dies to close the seam and reduce the wire to the final diameter. Cored wire technology allows unique compositions, many of which could not be made by normal wire drawing techniques, to be formulated and manufactured quickly and economically.

**Evaluation Tests Performed**

The following tests were performed on all materials — Fig. 3:
- Metallurgy (photomicrographs at 200 X)
- Microhardness — Vickers (ASTM E384)
- Abrasion test (ASTM G65, 6000 cycles)

**Evaluation Test Results**

**Metallography — 200-X photomicrographs** were prepared for all samples. The results are shown in Figs. 4–6.

The arc sprayed deposits exhibit the lamellar structure common to thermal spray. A small degree of porosity and oxide can also be noted, as well as the presence of discreet unmelted tungsten carbide particles in the PolyTung NiCrBWC material (Fig. 6) and a large degree of amorphous structure in the PMET 273 — Fig. 4.

The welded deposits show a much denser, homogeneous structure and lack of oxide. The presence of evenly dispersed

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**Table 1 — Comparison of Welding vs. Arc Spraying**

<table>
<thead>
<tr>
<th></th>
<th>Arc Spraying</th>
<th>Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallurgical bond</td>
<td>Mechanical bond</td>
<td>Metallurgical bond</td>
</tr>
<tr>
<td>Dilution at weld/substrate interface</td>
<td>No dilution at deposit/substrate interface</td>
<td>Dilation at weld/substrate interface</td>
</tr>
<tr>
<td>Weld metal is 100% dense</td>
<td>Coating is 95–98% dense</td>
<td>Weld metal is 100% dense</td>
</tr>
<tr>
<td>No porosity</td>
<td>May be some through porosity</td>
<td>No porosity</td>
</tr>
<tr>
<td>Weld deposit typically 0.125 in/pass</td>
<td>Usually no distortion of the substrate</td>
<td>Can be considerable distortion of the substrate</td>
</tr>
<tr>
<td>Can be considerable distortion of the substrate</td>
<td>Coating contains considerable oxides (5–10%)</td>
<td>Weld metal contains no oxides</td>
</tr>
<tr>
<td>Weld metal good under impact</td>
<td>Coatings not good under impact</td>
<td>Weld metal good under impact</td>
</tr>
</tbody>
</table>

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**Table 2 — ASTM C633 Adhesive Bond Strength Results**

<table>
<thead>
<tr>
<th></th>
<th>PMET 860BC Sprayed</th>
<th>PMET 860BC Sprayed and Fused</th>
<th>PMET 860BC Welded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Strength (ksi)</td>
<td>8.4</td>
<td>&gt;12.0</td>
<td>&gt;12.0</td>
</tr>
</tbody>
</table>

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**Fig. 2 — Spray and fuse.**

- Adhesive bond strength test (ASTM C633)
Fig. 3 — Test coupons of all materials.

Fig. 4 — PMET 273 amorphous alloy (200X).

Fig. 5 — 860BC Alloy 625 with boron carbide (200X).

Fig. 6 — NiCrBWC (200X).

boron carbides, chrome borides, and chrome carbides can be seen in the alloys, as well as some unmelted tungsten carbide particles in the PolyTung NiCrBWC material — Fig. 4.

The spray and fuse deposits clearly show that all three materials transformed in structure from the as-sprayed condition to look much more similar to the welded deposits in all respects — Figs. 4–6. The diamond-shaped indentations from the microhardness tests can be seen on several coupons.

Microhardness Vickers — All materials were tested for microhardness Vickers, ASTM E384 — Fig. 7. The as-sprayed deposits were universally the hardest form, showing very hard test results of 1010–1037 Vickers. When fused, the coatings became considerably softer (675–695 Vickers). The welded deposits displayed the least hardness (430–608 Vickers).
**Abrasion Test** — All materials were subjected to the ASTM G65 abrasion test at 6000 cycles. This test is an aggressive wear test, which uses a rubber wheel applied against the test material with a given force. Sand is introduced between the wheel and the coupon at a controlled rate, to serve as the abrasive media — Fig. 8.

Results for mild steel, hard chromium plating, and tool steel were added for comparison. All the sprayed, welded, and sprayed and fuse samples proved to be substantially (30–80%) more wear-resistant than hard chrome plating or tool steel — Fig. 9. The welded coupons proved the most wear-resistant. Fusing increased the wear-resistance of the sprayed coupons in all instances.

Interestingly, the sprayed coupons became softer when fused, but improved in wear-resistance, most likely an indication of improved integrity of the deposit as a result of the fusing operation.

**Adhesive Bond Strength Tests** — All materials were tested for bond strength, using the ASTM G633 adhesive bond test. All bond results were excellent, a minimum of 7200 lb/in.² and in most cases, exceeding the strength of the adhesive, > 12,000 lb/in.² (Table 2). The fusing operation increased the bond strength of the sprayed deposits in all instances.

**Applications**

Several high-wear applications are currently using these materials successfully or have been identified as targets for further testing and study. These include:
- Boiler tubes (Fig. 10)
- Coal-fired power generation
- Waste-to-energy power generation
- Black liquor recovery in the paper industry
- BOF hoods in the steel industry
- Rolls in the steel industry
- Fans in the power generation industry

**Conclusions**

- All three arc sprayed deposits can be successfully fused.
- The deposits are harder as sprayed, but more wear resistant when subsequently fused.
- The welded samples proved the most wear-resistant.
- Fusing the coatings also increased the density and bond strength of the coatings.
- Applications include boiler tubes, rolls and fans in the power generation, steel, and pulp and paper industries.

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