Improving and Repairing Surface Material Characteristics with ESD

This inexpensive, clean, and portable process is capable of producing high-quality depositions

BY NIGEL SCOTCHMER AND BARIŞ GÖKÇE

Electrospark deposition (ESD) is a process where a metal or cermet electrode is transferred with a short-duration spark to a substrate (Ref. 1). The use of ESD to repair or to improve surface characteristics is inexpensive, flexible, easy, and versatile. Repairing rather than replacing components is beneficial for the environment as it reduces waste and introduces cost savings because repairs are less expensive than a new component. Indeed, the use of ESD supports the ideals of the circular economy, where overall efficiency and effectiveness is improved by reusing systems to reduce global waste.

ESD provides a high-quality deposition with a small heat-affected zone (HAZ) and a low quantity of defects. It also achieves a good metallurgical bond. Compared to laser cladding, for example, ESD permits faster cooling rates and considerably less heat buildup in the component being repaired or coated. This permits alloys that are processed using ESD to have a finer subgrain microstructure with the potential for improved material characteristics (Ref. 2).

This article provides illustrations of the points above, from basic, inexpensive repairs or surface modification to the more complex surface enhancements for items such as additively manufactured components.

Wide Application Areas

Perhaps the most common use for ESD is the application of carbides to metals to prolong life, reduce wear, and regain dimensional tolerances. Examples such as pulleys, shears, blades, chainsaws, bearings, jaws, gun barrels, and gripping surfaces can be significantly improved with ease. In Fig. 1A and B, we see an example of an ESD-treated chock in a large steel mill to which a tungsten carbide coating was added for strength and wear resistance. Figure 2A and B shows the treatments of a chainsaw blade and lawn mower blade likewise coated. The low heat input of ESD can permit frequent resharpening of the blades as the temper of the underlying steel is not affected, exponentially reducing costs and further lengthening service life.

Many such coatings are performed in air with no shielding gas. Manual ESD machines are readily portable and require local, standard voltage like 110 or 220 V. Not only can many coatings and repairs be done in situ, on location, in the farmer's field, on an installed machine in a factory, or even in a battlefield repair depot, but the welding equipment is also simple.

A side effect of the relative low heat input into the welding process is the ability of the ESD process to join dissimilar materials more easily than some other welding processes. For instance, hard carbides can be applied to soft contact tips, swan necks, and nozzles in gas metal arc welding, which can significantly improve the life of the copper in hot applications. One such example is the ESD addition of

Fig. 1 — A — Steel mill chock bearing; B — close-up of chock bearing. (Courtesy of Arcelor Mittal.)

carbide around the hole of a contact tip. Contact tips wear as the welding wire moves through the central hole. Because of the low heat input from the ESD process, high-temperature hard alloys and cermets can be welded to low-temperature soft alloys with relative ease. In the case of the contact tip, this can reduce wear damage of the central hole — Fig. 3.

As the wire traverses and exits from the contact tip, friction occurs due to the high temperature and wire speed. This friction causes the copper-based contact tip to wear and the tip bore to open, causing slip wear. The wire can expand the hole diameter toward one side depending upon the angle of the torch or robot arm. However, coated with ceramic TiC, contact tip life can be increased as the slip wear is reduced as the hole diameter grows from the edge of the tip surface, which is now coated with a hard carbide as a thermal and wear barrier (Refs. 3–6).

In the case of resistance welding, the application of titanium carbide to a copper-chromium-zirconium electrode can not only delay deformation from the heat and force applied during welding but also delay the alloying of the copper with the zinc coating of many steel alloys used in automotive applications. Silver coatings on copper can similarly be applied for application in high-voltage electrical contacts. ESD coating of silver alloys, instead of silver electroplating, on copper can reduce the area coated with silver, further reducing costs. High conductivity is achieved, which reduces arcing and permits the use of less silver.

Huys Industries, Weston, Canada, has come up with a process using patent-pending dual grounding, where two workpiece connections, attached on either side of two thin sheets being joined, use different circuit paths interchangeably for the current pulses. This can assist in the joining of sheets by alternating circuits on either side of the joint being welded (Ref. 7).

Along the same lines, minor water leaks in resistance welding shanks can be repaired. Frequent electrode replacement can cause wear on the taper of the gun arm that holds the electrodes. Cooling water may leak through this wear. As the shank or gun arm can be an expensive replacement, it can be cost effective to repair a worn gun arm taper by applying aluminum or copper, and then milling to the original dimensions with a tool like the Ta-

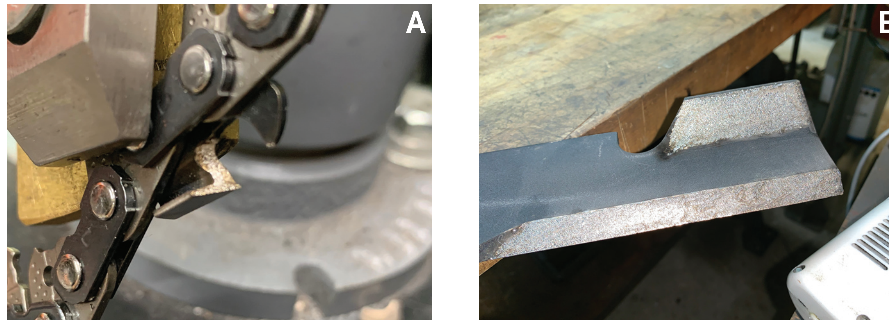

Fig. 2 — A — Coated chainsaw blade; B — coated cutting edge and deflector for lawn mower blades. (Courtesy of Pierce Design Tool.)

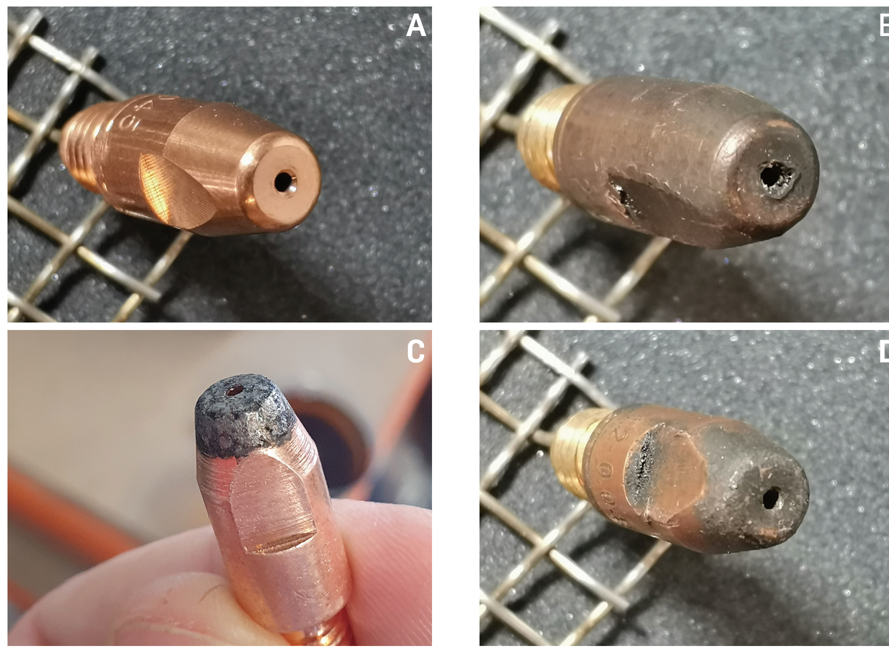

Fig. 3 — A — Uncoated contact tip; B — worn uncoated contact tip; C — coated contact tip; D — worn coated contact tip. (Courtesy of SAKA LPG Tank, Konya, Turkey.)

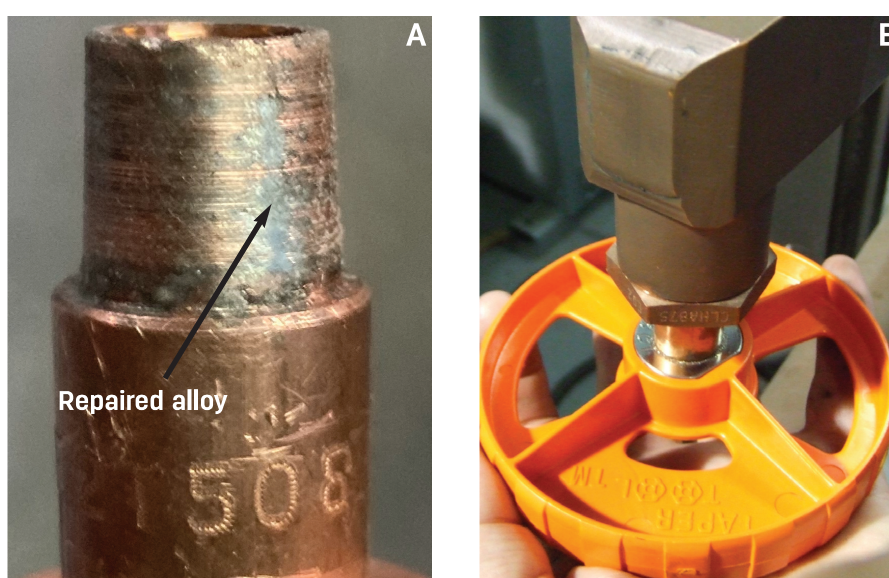

Fig. 4 — A — A repaired electrode shank; B — the Taper Tool. (Courtesy of Huys Industries.)

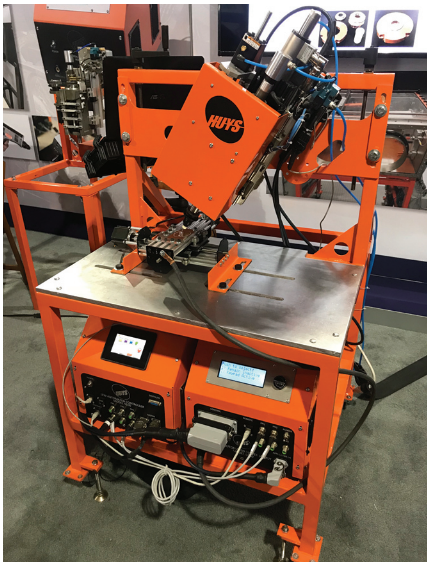

Fig. 5 — Moveable and automated ESD unit. (Courtesy of the National Research Council.)

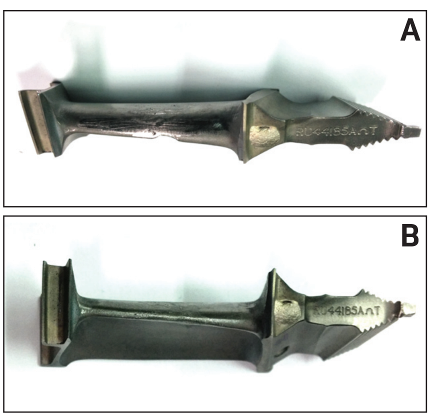

Fig. 6 — A turbine blade: A — Damaged; B — repaired. (Courtesy of Rolls Royce.)

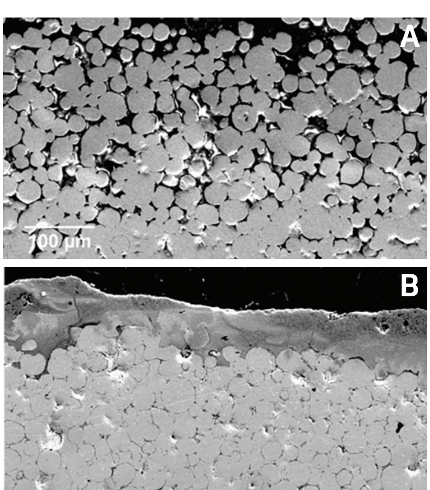

Fig. 7 — A — As-finished AM component; B — same part postprocessed with ESD.

per Tool™. In Fig. 4, we can see Al 4043 has been applied to the electrode shank, and then the surplus material has been removed with a handheld tool. The ability to easily repair a gun arm, in situ, with a portable ESD machine not only can prolong the service life of a component but can significantly reduce spare parts inventory and the logistical tracking, time, and cost of offsite repairs. In a large factory with hundreds of robots, this can be a game changer.

More Complex Applications

ESD can be used as an interlayer in welding dissimilar materials using various welding processes. One such application is in the resistance spot welding of aluminum to steel, where poor welds are achieved because of the formation of brittle intermetallic compounds. It has been shown that a magnesium alloy can be applied as an interlayer prior to spot welding of the parts and can almost double the shear strength of a welded joint (Ref. 8). The ability to quickly apply this coating locally without shielding gas makes it a cost-effective technique for industry when dissimilar aluminum-to-steel welds are needed.

More sophisticated applicators and power supplies permit a wider range of coatings, thicknesses, coating speeds, and achieved material characteristics to satisfy more demanding applications. Different types of applicators are useful for different kinds of applications and coatings. For instance, water-cooled applicators are used in continuous coatings of large parts to reduce the heat of the electrode, and vibrating applicators can be used for the application of larger carbide splats for larger wear-resistant components or if a rougher texture (for gripping, for instance) is sought. In these cases, electrodes up to ¼ in. or 6 mm in diameter, or larger, are employed, and a square inch of carbide coating (645 mm^2) can be deposited in a few minutes or less, depending upon the power available.

In cases where a finer deposition is required, narrower electrodes are used with lower voltages and capacitance, and applicators that permit both vibration and rotation are often utilized with an increased speed and amplitude. Depending upon the hardness of the material, effective peening by vibration can be achieved during the deposition of splats. At the same time, the electrode is still being rotated. When the firing and charging rates of the capacitors are increased, smaller splats with finer characteristics can be deposited. Finer control of the voltage and capacitance by a digital power supply can further improve the quality of the deposition. In addition, some power supplies permit the switching from alternating current to direct current while welding, providing additional flexibility and optional surface preparation and cleaning while coating. These options, combined with the secondary operations of peening and grinding, if required, reduce the peaks-and-valleys characteristic of ESD while permitting significantly greater thicknesses and dissimilar composite materials to be applied.

These additional parameter controls to the ESD process facilitate the coatings and repairs of the most demanding applications, where porosity, dendritic growth, and a negligible HAZ are needed. Automation can be adopted (Fig. 5), and bespoke metal alloys can be created for unique requirements of exotic and expensive materials. ESD as a low-heat-input repair process can address thinner features that are more susceptible to heat buildup. The ease of maintaining a lawn mower's blade sharpness for twice as long with tungsten carbide from ESD, even after many repeated sharpenings, can be applied to jet engines and turbine blades with automation and finer machine controls to offset human variability. Thus, even thin-wall repairs become candidates for ESD — Fig. 6. Gloveboxes are often employed for more air-sensitive coatings.

Additionally, the higher surface roughness and higher frequency of near-surface porosities in additively manufactured (AM) parts are detrimental to part performance, which makes surface modification by ESD in a post-processing function useful in high-performance parts. Of course, the low heat input of ESD readily enhances damaged or critical regions of conventional and AM parts without affecting the underlying part. Figure 7 illustrates how strength, fatigue life, and even appearance can be improved with postprocessing of AM components with ESD (Ref. 9).

Figure 8 illustrates how selective ESD postprocessing of the regions most susceptible to fatigue failure, while also protecting from corrosion

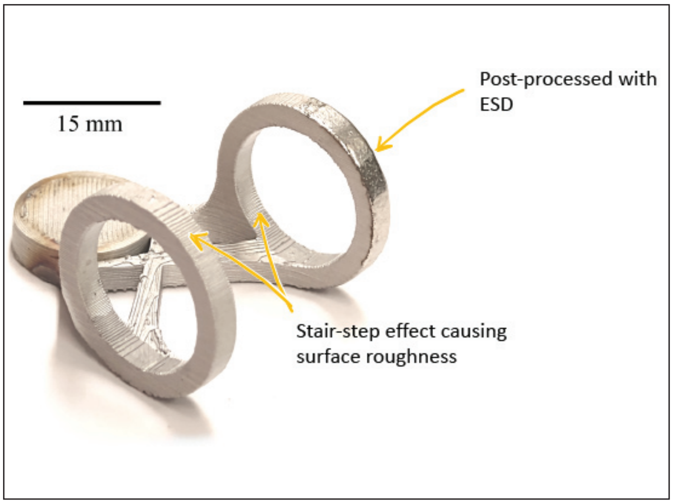

Fig. 8 — AM component, postprocessed on the right-hand side with ESD (Ref. 9).

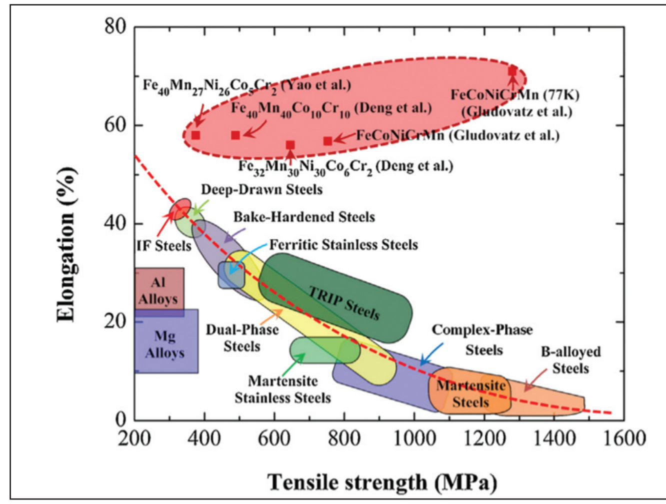

Fig. 9 — Strength vs. ductility for some HEAs vs. other conventional alloys (Ref. 10).

or wear (depending on the coating material choice), can improve material properties by removing stair-step effects (Ref. 9).

Obvious candidates for ESD that are emerging are high-entropy alloys (HEAs). HEAs are multicomponent alloys that can maintain high strength at higher temperatures than traditional superalloys. They can be corrosion and radiation-damage resistant as well as have very high fracture toughness, cryogenic strength, superparamagnetism, and superconductivity (Ref. 10). Applications are diverse and include rocket nozzles and nuclear construction. ESD, with its low heat input, can minimize the phase separation, precipitation, and segregation, and maintain the atomic-level mixing of the multicomponents that are the defining characteristics of HEAs, thus maintaining the sought-for material properties. See Fig. 9 for some comparative properties of HEAs to common steels.

Conclusion

Whether it is a simple application of carbide to a horseshoe by a blacksmith, or the rebuilding of a high-pressure turbine blade in an automated machine, the use of ESD is increasing in an age that seeks sustainability and cost effectiveness. The ESD welding process avoids creating HAZs, forms strong metallurgical bonds with minimal dilution, and avoids changing the metallurgy of the part being coated or repaired. The process allows for conductive metals and even dissimilar materials (from brittle, high-temperature cermets to soft, low-temperature metals) to be welded. It is ideal for surface modification and the repair of expensive conventional and AM components, maintaining or even improving mechanical properties and material characteristics. ESD is an inexpensive, clean, simple, and portable process capable of high-quality depositions. WJ

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