Critical Factors Affecting the Quality of Electro-spark Deposits on Nickel-base Superalloys

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Electro-spark deposition (ESD) is a pulsed micro-welding process that is used to repair or modify the surface of metals. One main application of electro-spark deposition is repairing turbine blades. Laser processing and gas tungsten arc welding are commonly used for turbine repair. However, these processes can cause a range of metallurgical issues in the repaired component. These include microcracking in the heat-affected zone[1] as well as local loss of properties. ESD occurs at rapid cooling rates, mitigating a number of these metallurgical concerns. This paper covers some key processing issues known to affect deposition rates and resulting surface quality, including changes to the electric circuitry (that affect pulse shape) and quality of the shielding used.

The ESD Process

Electro-spark deposition effectively adds layers of material to a substrate as a series of "splats." These splats are small volumes of liquid metal that are transferred from a rotating consumable electrode during short duration current pulses. The current pulses themselves are created by repeated discharges from a capacitor-based power supply. The spark is created from a high-speed short circuit that releases the stored energy within the capacitor.

The volume of metal transferred to the substrate is small (on the order of tens of microns in diameter) and cools extremely rapidly on contact. Observed cooling rates are orders of magnitude higher than other joining processes. Some estimates of cooling rates for other repair processes are provided in Figure 1. Here it can be seen that cooling rates for ESD are roughly three orders of magnitude higher than for gas tungsten arc welding, and two greater than laser welding. Such rapid cooling rates allow repairs to be made on a range of material substrates with little or no secondary processing.

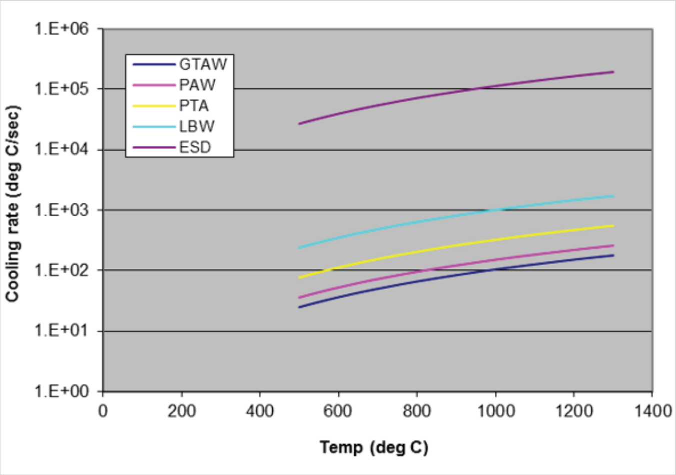

Figure 1: Calculated cooling rates for conventional repair technologies[2]

System Variations for Trials

Previous work with capacitor discharge welding has shown that a reverse-biased diode across the system output could provide a secondary path for reversed current flow (in underdamped circuits). This secondary path results in an extension of the current waveform. Current waveforms with and without a diode are presented in Figures 2 and 3. The waveform in Figure 2 (with the diode) clearly shows an extension of the flowing current out to several hundred micro-seconds. Conversely, the waveform without the diode (Figure 3) represents a typical half cycle of current flow. Deposition trials were further conducted both in a glove box (to produce an argon filled environment) as well as outside using local shielding.

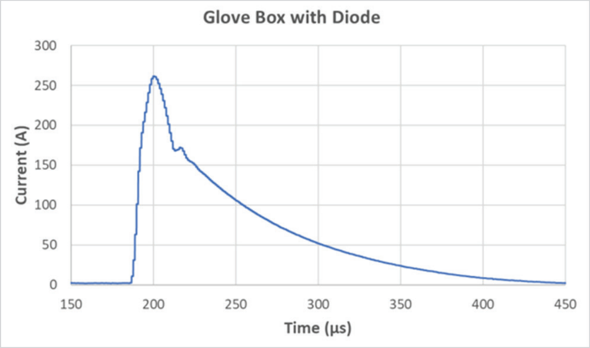

Figure 2: Characteristic current waveform during ESD employing a reverse biased diode on the power supply output

Figure 3: Characteristic current waveform during ESD without a reverse biased diode on the power supply output

Best practices identified include application of the diode as well as glove box-based shielding. Resulting deposits demonstrated better deposit quality in terms of no inclusion of contaminants. Micrographs showing the resulting surface as well as a cross section of the deposit are provided in Figures 4 and 5, respectively. The extended tail of the current waveform (associated with the reverse-biased diode) stabilizes the temperature of the electrode, as well as the resulting deposition process. Use of the glove box minimized the potential for any oxidation of the transferred splat volumes, improving internal deposit quality.

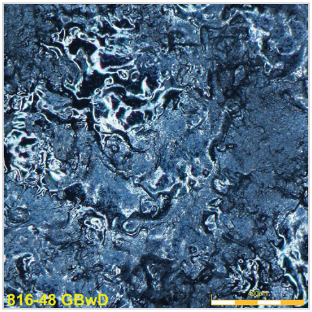

Figure 4: Splat morphology of a deposit made using a biasing diode and glove box shielding

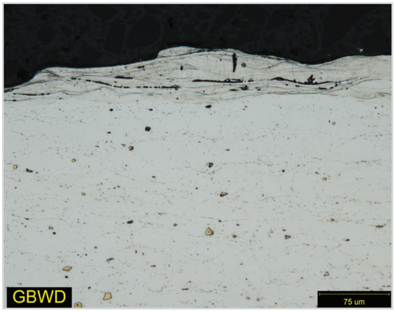

Figure 5: Microstructure of a deposit made using a biasing diode and glove box shielding

Conclusions

In this study, an Inconel 625 electrode was used on a substrate composed of the same material to create a protective coating through the layering of deposits. Two different welding environments were tested, and the use of a diode was examined to understand how deposition rates were affected. In addition, metallographic interpretation was used to examine the surface quality and internal weld integrity. The following conclusions have been made based on the results from the conducted trials:

- *Atmosphere is critical because it affects the degrees of oxidation which in turn affects our ability to get decent surface quality*
- *Electrode temperature stability leads to higher deposition rates*
- *Changes in environment lead to more drastic changes in surface quality when compared to the effect of the inclusion of a diode*

To learn more about electrospark deposition, please contact **lamanuel@ewi.org**.

REFERENCES

[1] Brown, E.Allen, et al. "A Parametric Study of Improving Tool Life by Electrospark Deposition." Wear, vol. 138, no. 1-2, 1990, pp. 137–151., doi:10.1016/0043-1648(90)90173-8Gould, J. E. and Kapustka, R. N. 2012. Application of novel repair methods to advanced materials. Proceedings – IIW International Conference on Welding for Repair and Life Extension of Plants and Infrastructure, 65th IIW Annual Assembly. IIW, Paris, FRANCE.

[2] Kondensatorentladungsschweißen – Grundlagen, Verfahren und Technik. Merkblatt DVS 2911. DVS Verband, 2016.

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