Automation in Low-Energy Welding

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Automated LEW head setup. (Image courtesy of Huys Industries.)

Use of low-energy welding technology has expanded to meet the needs of applications using complex and sensitive alloys

Advances in material science and manufacturing, along with the explosion of 3D metal printing, are producing more efficient, lighter weight, and effective products than ever before.

Every year, the electronics, aerospace, and automotive industries push the boundaries of engineering with smaller, lighter, and stronger structures featuring new alloys and the increasingly popular magnesium, aluminum, titanium, and nickel high-strength alloys (Refs. 1, 2).

Working with these materials comes at a steep cost, as they are often heat, wear, and chemically sensitive to many of the traditional manufacturing processes. The popularity of these materials has been developed in tandem with precision manufacturing and joining processes, such as solid-state, electron-beam, and laser processes (Ref. 3).

These new parts provide a significant increase to the efficiency of a design, but remain highly susceptible to corrosion, erosion, heat effects, and gouging. As maintenance for these parts is required, the original joining equipment is often inflexible and unable to meet the dynamic needs of a repair. The traditional metal repair techniques such as gas tungsten arc, gas metal arc, and other welding technologies can be inadequate — often irreversibly damaging these parts (Ref. 1).

Low-Energy Welding

Where lightweight, high-strength alloys are concerned, a low-energy input can be key. Low-energy welding (LEW) technologies have been found to be affective in the repair and deposition of magnesium, aluminum, titanium, and nickel alloys, as there is little or no effect to the original part.

What is Low-Energy Welding?

Low-energy welding technology has developed from the earlier electrospark deposition (ESD) process. This micro-arc welding process uses high current and very short duration pulses, with comparatively longer cooling times, to deposit a small amount of an electrode material onto the substrate (Refs. 4, 5).

Deposition occurs when the charged electrode makes localized and intermittent contact with the substrate. The short circuit rapidly discharges the built-up voltage, ionizing the gases in the gap between the electrode and the substrate. A small arc carries the high-current pulse, while the high heat and pressure cleans and melts the surface of the substrate and a small amount of the electrode material.

Figure 1 shows a magnified high-speed image that captures the arc when the electrode contacts the substrate (Ref. 4).

Strong metallurgical bonds and the cathodic etching of the substrate to remove surface contaminants and oxides characterize the process. A high cooling rate prevents the formation of brittle intermetallic compounds and the diffusion structures that are common in joining high-alloy-content metals and dissimilar alloys. The short-duration arc and mass transfer can provide a near zero heat effect to the original part surface and microstructure, with the LEW process often creating coatings and depositions with imperceptible heat-affected zones (HAZ) and no residual stresses (Ref. 4).

Figure 2A, B shows cross sections of images featuring steel-to-steel LEW depositions. These images, unetched and etched, respectively, illustrate the good metallurgical bond, minimal HAZ, and fine microstructure of the deposited coating.

The process allows for the localized bonding of high-ceramic-content cermet materials to metals with drastically different melting temperatures, chemical properties, and thermal expansion coefficients. Localized buildup and repair of heat-susceptible, high-strength alloys such as magnesiums, titaniums, nickels, and aluminums are now possible. The preferred alloys of these materials are prone to HAZ defects such as the segregation of alloying elements, residual stress cracking, solidification cracking, increased grain size, and others (Refs. 5 and 8). These defects typically made certain alloys of these materials un-weldable in structural and those applications prone to fatigue.

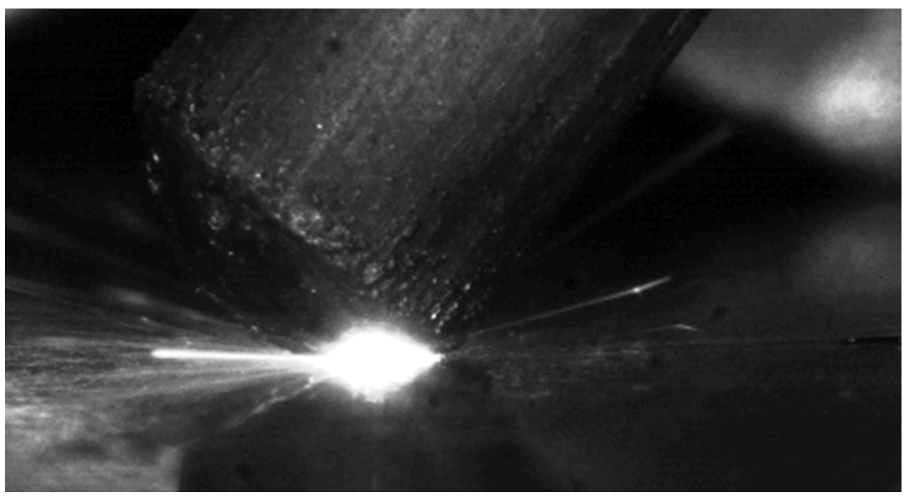

Fig. 1 — High-speed image of arc evolution. Shown is a steel electrode and steel substrate (Ref. 4).

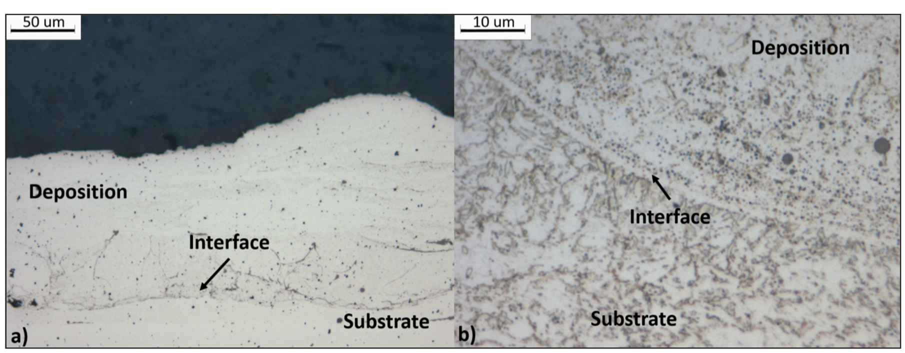

Fig. 2 — Cross section of LEW deposition (steel on steel): A — Unetched lower magnification image; B — etched cross section highlighting the deposition interface (Ref. 4).

The LEW technology is used traditionally for mold repair and coating high-ceramic cermet materials. Now with advanced and digital power supplies, the applications expand to the repair of sensitive materials; cladding; localized alloying; and surface modification for wear, corrosion, roughness and hardness properties (Refs. 6, 7).

Figure 3 shows the unetched and etched images, respectively, of an Inconel® 718 defect repaired using the LEW process. Note that in the unetched image, the repair is almost imperceptible to the substrate material.

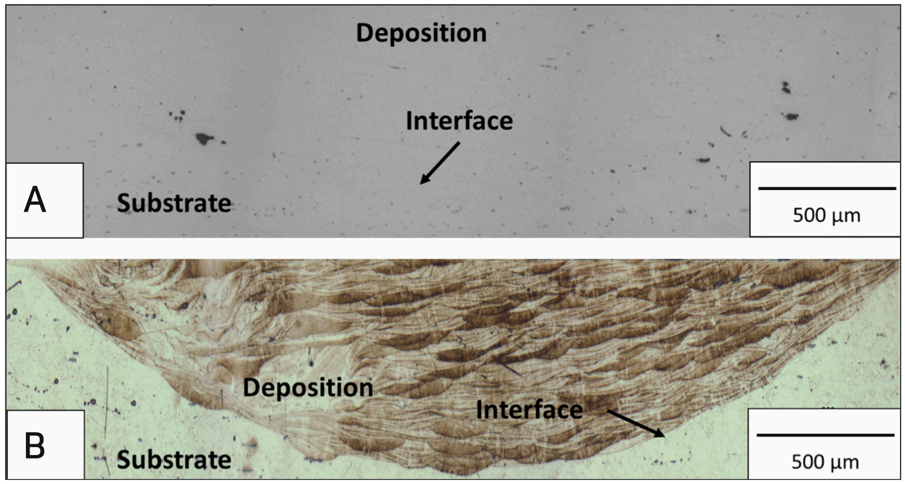

Fig. 3 — Cross section of LEW Inconel® 718 repair. A — Before etching; B — after etching. (Image courtesy of the University of Waterloo.)

Controlling the LEW Process

There are numerous critical parameters that have a significant and immediate impact on the LEW process. Advanced LEW power supplies continue to offer the user fine adjustment and control over, and increasing the width of the welding window. Improvements in the power supply waveforms, parameter range, and output pulse speeds drive the innovations in LEW equipment. The major parameters that control the equipment performance are the pulse capacitance, voltage, and frequency (Ref. 4).

The equipment further provides options in the applicators in methods or relative motion, with combinations of rotating and vibrating, with various speeds and amplitudes to best suit the application. The operator provides the largest variability to the process, with the application force, travel speed, deposition direction, electrode angle, and continuous deposition time all having a significant wide effective range as well as a significant impact on the quality of the depositions (Ref. 6).

Fine tuning the many parameters is key to realizing the desired effect of the deposition, be it to affect the surface roughness, deposition rate, or microstructural properties. Generalizing, inherent in the process is the fact that the lower the welding input energy of welding is, while still facilitating deposition, the better the results (Refs. 4 and 6).

This variability in physical parameters, and the prevalence for lower output power providing better deposition results, drives the argument for automated systems.

More sophisticated power supplies, applicators, and accessories, paired with an automated system, finally allows for the pinpointing of the exact electrical and physical parameters required to make high-quality and repeatable depositions. This is key for making low-defect, high-quality repairs, coatings, and surface treatments required for use in the aerospace industry.

Automated System

Automated systems require flexibility, as the controls and parameters unique to LEW must be integrated with any robot, machine tool, or computer numerical control (CNC) system already in place or available. This generally allows for the automation system being considered to treat the LEW unit as a spindle, with a fixed tool center point, while the automated LEW control system monitors and provides for all of the other necessary adjustments. Standard digital IO communications allow for easy integration with any motion or programmable logic controller. Higher level protocol, such as Modbus TCP, can be used for communications between the automated head controller and the LEW power supply, and can be integrated with third-party controllers of the robotic and CNC equipment. See the lead photo for an image of the automated LEW system during operation.

Figure 4 shows an image of the LEW automated unit assembly. The unit is comprised of a moving gantry supported by a linear motor to provide the position, force, circuit, and electrode consumption compensation. The gantry contains the rotating and vibrating motors for relative motion, shielding gas control and valves, LEW current transfer brushes and slip ring, as well as the electrode spindle. A spring and the force sensor compensate for rapid changes in the coating surface and maintain the low contact force required for the LEW process.

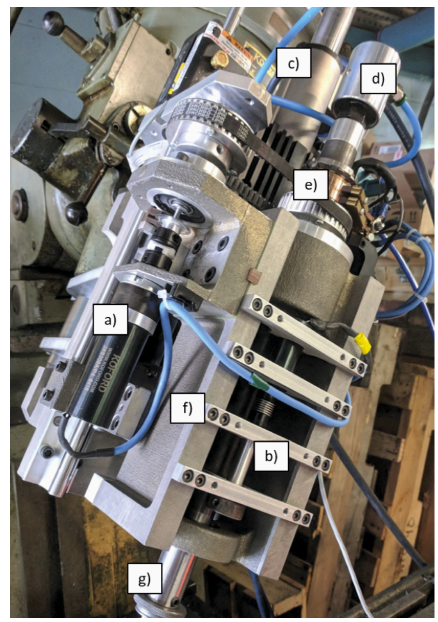

Fig. 4 — LEW automated unit assembly: A — Rotating relative motion motor; B — vibrating relative motion motor and eccentric weight; C — linear motor electrode consumption and force compensation; D — integrated shielding gas control; E — LEW current transfer brushes; F — sliding unit assembly; G — spring and force compensated LEW spindle. (Image courtesy of Huys Industries.)

The system slowly feeds the electrode forward to compensate for the additive consumption of the electrode

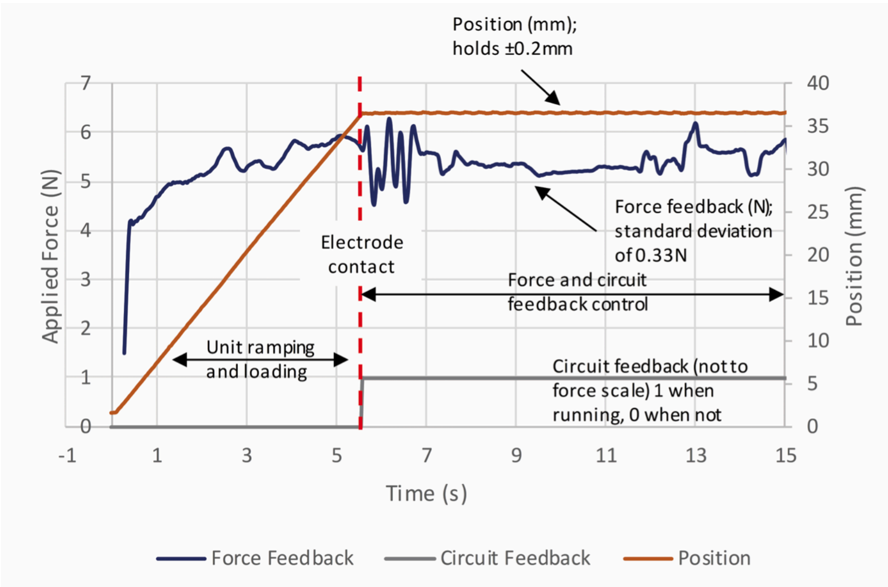

Fig. 5 — Force, circuit feedback, and position data from the LEW automated system during operations. (Image courtesy of Huys Industries.)

Fig. 6 — Force and position data during the automated system calibration process. (Image courtesy of Huys Industries.)

itself. The LEW process, and the relative motion while welding, makes it difficult to have a constant electrode feed. Systems incorporate rotating and vibrating relative motions for the electrode in various combinations and different speeds for different materials and applications. This relative motion assists in the effective deposition of different material combinations and electrode diameters.

Figure 5 charts the feedback signals for the automated system, which controls the position and applied force on the electrode. The circuit feedback sends a high signal when the LEW system is discharging. The closed loop force feedback contends with the consumption of the electrode, the inconsistencies in the substrate surface, the arc forces, and forces from the LEW process's relative motion.

The electrode consumption compensation is achieved by maintaining the low constant force required to facilitate the LEW process. Too high a force and the power supply will short circuit and no arc will be formed; and, if there is too low a force, or no contact, then the arc will also not form (Refs. 4, 5). The electrode compensation and proper applied force can be achieved through a dual closed-loop feedback hierarchy that considers the change in load on the electrode through a load cell and a signal to indicate the discharge of the LEW power supply circuit.

Functions are included to self-calibrate for the changing loading on the machine from operating at different angles. Touch point functions allow the user to set and monitor the consumption of the electrode as well as set safe limits for minimum remaining electrode lengths.

Figure 6 shows the force and position data during the calibration procedure, where the unit moves back and forth to measure the no load weight of the unit. Due to the moving mass of the unit gantry, a large opposing force is required to change directions. The force feedback during motion illustrates the noise level while constantly feeding forward.

Automated LEW System Research

Automated systems can control and record the optimum parameters and operating conditions for LEW applications. Varying the applied force, mechanical dampers, and springs, different closed-loop feedback algorithms and additional LEW arc feedback parameters could be the key to, as of yet, difficult LEW applications. As an emerging technology, there is still much to learn and improve.

For instance, the control and variance of lateral movement speed and direction in conjunction with different directions, types, amplitudes, and speeds of the rotating and vibrating relative motions while altering power pulses and frequency is in its infancy. Different deposition patterns, such as linear passes, spirals, or small circular patterns, electrode angles, and diameters can all affect deposition speed and quality. The effects of the different LEW power supply parameters can be quantified and optimized for different material combinations and applications.

Summary

The use of low-energy welding technology is expanding to meet the needs of applications using increasingly complex and sensitive alloys. This technology — once used only for localized repairs and cermet coatings — is being developed with increasingly advanced controls, customized inert atmosphere solutions, and more complicated applications.

With a focus on low heat input and solid-state processes, LEW is slated to have a place in the repair and coatings of advanced new materials. The benefits of LEW are best realized when paired with automation. The ability to process larger parts, with complicated geometries, for longer periods of time, minimizes the previous limitation of the LEW process where consistency and speed were limiting factors. Fixing, controlling, and monitoring all of the LEW parameters means improved repeatability and reliability in the deposition quality.

The advances and the increasing adoption of automation in manufacturing will increase the need for LEW in the modification of surface materials and their repair where new evolving materials and cost-effective strategies can maintain the material properties required. High-tech, aerospace, and advanced manufacturing companies now exploring the use of high-strength, lightweight materials can leverage this equipment to fill in the gaps for repairs, coatings, and surface treatments. WJ

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