Recent Developments in Low-Energy Welding

Fig. 1 — LEW field repair of aluminum alloy wheels. (Photo courtesy of Huys Industries.)

See why the LEW process is carving out its own niche

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Low-energy welding (LEW) is unique in that the process welds without distorting the substrate, nor creating a heat-affected zone (HAZ) or any residual stresses and strains in the material (Ref. 1). Largely because of its incredibly fast cooling rates, in many cases LEW can weld dissimilar materials that other processes cannot weld easily or at all (Ref. 2). It is a quick, micro-arc, pulsed, capacitor discharge as well as an electronically controlled process that applies melted material to a nominally conductive surface (Ref. 3). As the name suggests, little energy is injected into the welds. The machines are portable, easy to use, cost effective in terms of both capital and operating costs, and environmentally friendly. The process uses little electricity and creates little waste (Ref. 4).

Sources of Growth in LEW

Automation

As you would expect from the characteristics, the LEW process is versatile. Previously named electric spark deposition (ESD) or pulsed electrode deposition (PED), the term LEW is generally preferred today because its power supplies have become more powerful, controllable, and programmable, and their applicators have become broader in the range of their mechanical functions (variably rotating, vibratory, and both rotational and vibrational). The automation of the process itself has grown with the needs and capabilities of metal printing and additive manufacturing (Ref. 5). Its fast cooling rate and low heat input reduces the potential for diffusion, facilitating the use of lower grade materials treated with LEW to meet the same performance requirements of more expensive alloys.

The LEW process deposits material by creating a momentary short circuit between a moving electrode made up of the filler or additive material, and the substrate. Because short circuiting heats only a very small volume of the substrate near the produced electric arc combined with the momentary nature of the electric arcing, the overall heat generated and transferred to the substrate is relatively minimal (Ref. 1). Moreover, the small melted volume resulting from such short circuiting can also be transferred out of the deposition area more quickly via conduction through the relatively large substrate. At the same time, the material transfer mechanism of the LEW process leads to a metallurgical bond between the deposited material and the substrate.

Thus the LEW process makes an attractive candidate for surface modification and for the restoration of high-value components (superalloys, hybrid-manufactured items, injection molds, and turbine blades). It provides a fine microstructure, permitting little diffusion, and reduces intermetallic compounds that allow for nonequilibrium metastable phases (Ref. 6). Inconels, cermets, refractory materials, heat-susceptible materials (precipitate-hardened elements, low-melting-temperature alloys), and residual stress-susceptible compounds such as thinner walled, lower weight, and precision components will benefit from these characteristics. Industries pushing to develop higher tolerances, complex alloy content, and advanced heat treatments, or making new materials susceptible to heat damage from traditional welding techniques also benefit from this process. Combined with its lower capital costs compared to some other advanced welding techniques, LEW's appeal is clear.

Additive Manufacturing

The rapid growth in additive manufacturing is another source for the growth. Surface defects can be removed, and the finish, hardness, corrosion resistance, and other characteristics can be improved. The popularity of LEW is increasing due to recent developments in digital and electronic power control; a wider range of applicators; improvements in control mechanisms such as force and voltage feedback; and advances in vision software. These developments allow for both a wider range of materials and thicknesses to be welded (for both coatings and repairs) due to the superior management of the intermittent contact and energy pulses of the process. Now the quality of the weldments, the rate of deposition, and the thickness of depositions achieved have increased significantly (Ref. 7).

In its early years, LEW was primarily used for repairs and coatings for high-value tools, dies, and carbides (Refs. 8, 9). Simple applications can often be performed in air, with no inert gases, requiring only household voltage (110V AC in North America). LEW is readily portable, easy to use, and is inexpensive compared to other welding processes. The portability of the LEW process makes it easy to do field repairs. Figure 1 shows an example of the repair of an aluminum alloy wheel with the LEW process while Fig. 2 shows the LEW repair of a titanium alloy golf club.

Many of these repairs can be done inexpensively and quickly, in the field, with little training or setup. Many armed forces have adopted LEW for such repairs, from rocket launcher slides on helicopters, to combat tanks and submarines (Ref. 10). The rapid rise in patent applications in the past few years for LEW-related processes reflects its increased use and expanding research in its capabilities.

New Applications in LEW Equipment

Digital and Online Control of LEW

What is new is an increase in programmable digital control and online monitoring of the LEW process itself (Ref. 5). The latest advanced LEW equipment has detailed controls of charging speed, discharge modes and real-time voltage, and frequency monitoring. There are speed and movement mode controls on the LEW applicators to suit different applications. Various power supply capabilities are

Fig. 2 — LEW repair of a titanium alloy golf club. (Photo courtesy of Huys Industries.)

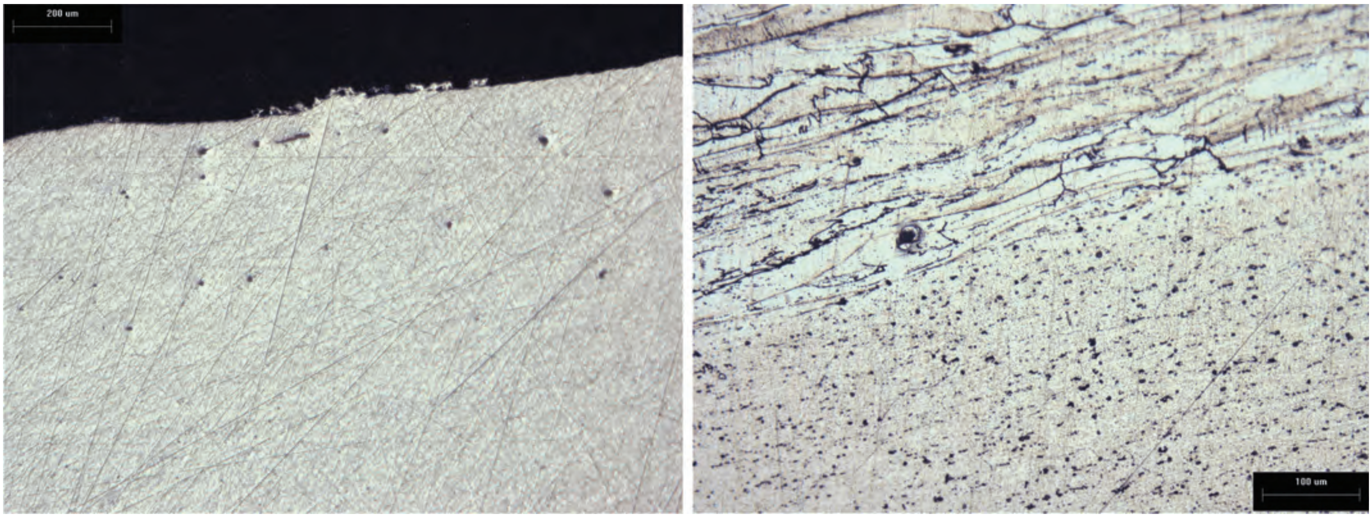


Fig. 3 — Optical image of a repaired 6061 aluminum sample with Al 6061 without etching (left) and with etching (right). (Photo courtesy of the University of Waterloo.)

also available for different material requirements.

Figure 3 shows an example of why LEW is easy and becoming popular. The etched micrograph in Fig. 3 illustrates that using a substitute alloy such as Al 4043 or Al 5356 is not necessary because a regular Al 6061 can be used with no discernible HAZ. No major defects are observed in the repaired area nor at the interface. Thus, the material can be repaired with its base material using LEW.

Glove Boxes

In addition, the use of glove boxes has been increasing for LEW. Glove boxes provide a stable and constant inert atmosphere with none of the turbulence that a rapidly moving stream of a shielding gas may have on the welding process in a manual application outside of a glove box. Modern glove boxes are also becoming more suited for comfort during manual welding, with variably tilting chambers. They are better prepared for automation or higher production rates, with items such as internal cooling for the trapped inert gas, rapidly pressurized and vacuum pass-through antechambers, water-cooled fixturing, and built-in cameras for quality control and production tracking. Figure 4 shows a tilting inert gas shielding glove box for LEW. The tilting design will help adjust the sample to suit different shaped components and better control of the LEW process.

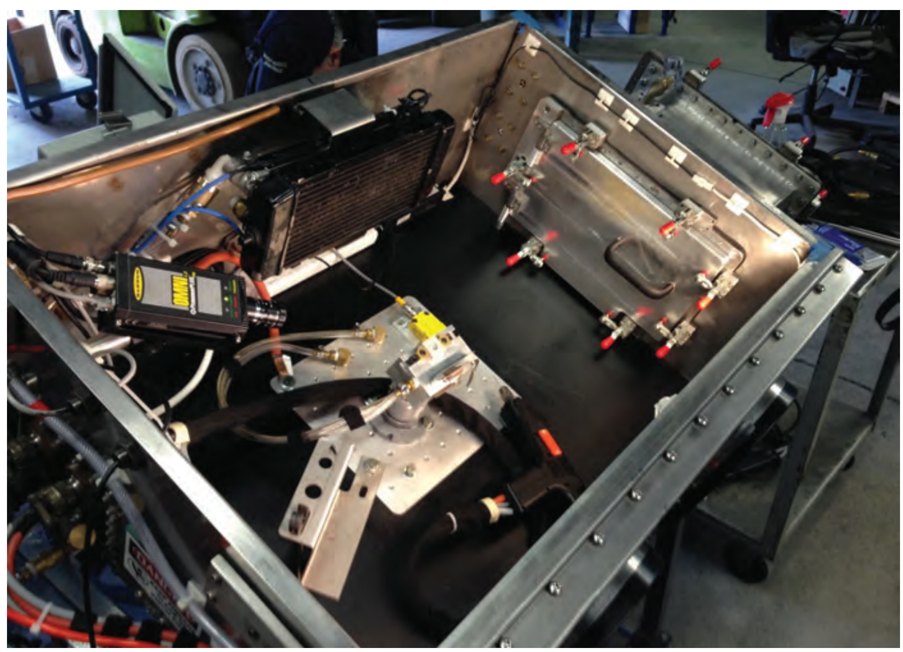


Fig. 4 — Tilting inert gas shielding glove box for LEW. (Photo courtesy of Huys Industries.)

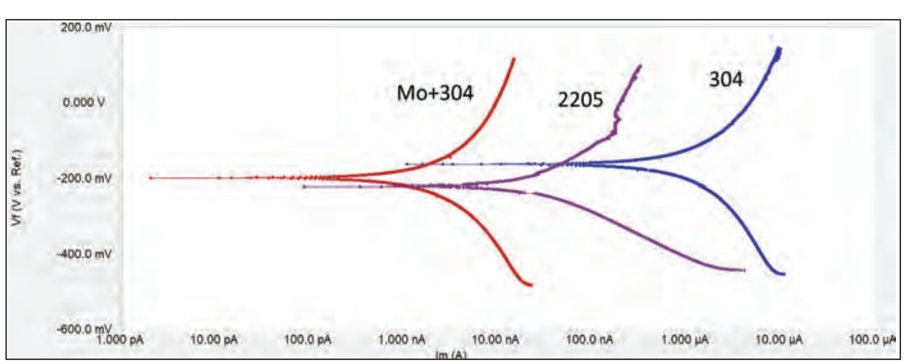
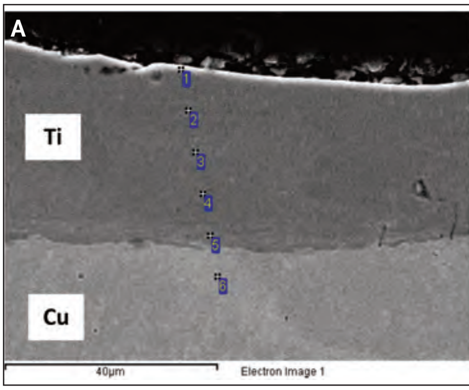


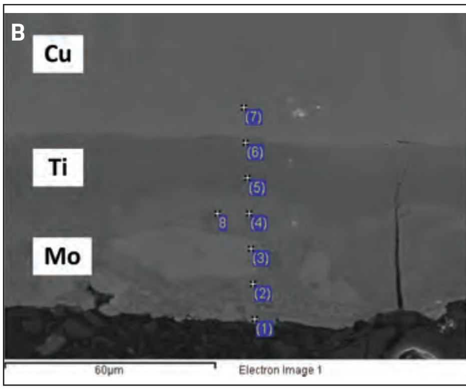
Fig. 5 — Tafel test results of Mo-coated 304 stainless steel. (Photo courtesy of the University of Waterloo.)

Table 1 — Corrosion Rate Results from Electro-Chemical Analysis (Courtesy of the University of Waterloo.)

Material	Corrosion Rate (mils per year)
Mo + 304 SS	0.042
2205 DSS	0.165
304 SS	14.89



Spectrum	Ti	Cu
1	86.67	13.33
2	87.61	12.39
3	81.20	18.80
4	80.42	19.58
5	1.28	98.72
6		100.00



Spectrum	Ti	Cu	Mo
(1)	30.20	26.33	43.48
(2)	50.22	21.80	27.98
(3)	26.89	14.43	58.68
(4)	52.83	27.17	20.00
(5)	76.18	12.79	11.03
(6)	64.17	34.37	1.46
(7)		100.00	

Fig. 6 — A — Ti coating on Cu substrate by LEW (top); B — Mo coating on Cu with Ti as the interlayer (bottom). (Photos courtesy of the University of Waterloo.)

Coatings and Interlayers

Another interesting application of LEW is applying inexpensive coatings to replace more expensive materials. Molybdenum (Mo), an important alloy element used to improve corrosion resistance, has been applied to many high corrosion-resistant steels. One such application is the use of the LEW process to apply a coating of Mo to 304 stainless steel in lieu of expensive high corrosion-resistant materials.

Figure 5 and Table 1 show the electro-chemical analysis results of Mo-coated 304 stainless steel (Ref. 11). Duplex stainless 2205 is considered a benchmark for commercial high corrosion-resistant material (Ref. 12). The Tafel test of DSS 2205 and 304 SS are also performed as the benchmark and baseline. The corrosion rates are calculated from the Tafel tests, as shown in Table 1. The Mo-coated 304 stainless steel exhibits excellent corrosion resistance to 5% NaCl solution. It corrodes 350 times slower than 304 SS, and four times slower than DSS 2205.

Some materials are immiscible or have very little solubility, which makes them difficult to be welded. An interlayer has been proved to be an effective way to solve this issue. LEW provides a new approach to join immiscible materials by applying an interlayer that is compatible with both materials. For example, according to the Cu-Mo phase diagram, Mo and Cu are immiscible materials. It is a great challenge to join Cu and Mo directly, while Ti has good weldability with both materials. LEW provides a new approach for applying Mo coating on Cu by depositing Ti as an interlayer. Figure 6A shows the SEM results of Ti coating on Cu substrate. The composition of Ti is relatively uniform across the coating layer, and no major defects were found in the Ti coating. Figure 6B shows Mo coating was successfully deposited on a Ti interlayer with the LEW process.

Summary

Welding with low relative energy reduces the heat-affected zone as well as thermal stresses and distortion, allowing dissimilar and high alloy content material to be metallurgically welded with limited diffusion and ultrafine, strong microstructures.

The LEW process can be used both in simple, noncomplex, portable, and inexpensive applications as well as in highly sophisticated automatic and robotic applications with exotic materials.

The low penetration achieved with this process means the surface can be alloyed to have local properties, and its fast cooling rates and low heat input reduces the potential for diffusion, facilitating the use of lower grade materials treated with LEW to meet the same performance requirements as more expensive alloys. Used for joining, repairs, and coatings for oxidation, corrosion, and wear resistance; for changing a substrate's hardness, electrical conductivity, and thermal properties; for surface texturing, alloying, and flame retardation; and, increasingly, for automated metal build-up and printing, the LEW process is carving out its own niche. WJ

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