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A Review of Electrically-Assisted Manufacturing

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The mechanical properties of metals change temporarily or permanently under application of electric currents under deformation. This phenomenon is often referred to as electroplasticity. The electroplasticity of metals and their alloys has been investigated under various loading conditions including tensile, compressive, bending, and hardness tests. Electrically-assisted manufacturing (EAM) utilizes this electroplasticity in manufacturing processes. Due to its technical advantages such as enhanced formability and reduced springback, EAM is energy efficient with reduced process time. Recent developments in EAM include various bulk deformation and sheet metal forming processes. This paper summarizes previously reported electroplastic behaviors of various metals or metal alloys and recent EAM processes. In addition, contemporary EAM patents are briefly reviewed.

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1. Introduction

Electrically-assisted manufacturing (EAM) is a new concept for manufacturing processes that utilize the electroplasticity of metals and their alloys. EAM is one of hybrid manufacturing processes aiming to improve productivity, efficiency, and quality.[1-10] Various EAM studies have shown that the material properties of a metal can be modified simply by applying electricity to the metal during deformation. The classical works and studies by Troitskii,[11] Okazaki,[12] and Conrad[13] provide good background information regarding the effect of electricity on the material properties of metals.

As recently reported by Ross et al.[14] and Perkins et al.,[15] the presence of a continuous electric current during plastic deformation of a metal may significantly reduce the flow stress of the metal. Under compression, the formability of a metal is significantly enhanced with application of a continuous electric current.[15] Studies have shown that the disadvantage of the reduced maximum elongation of metals under tension with a continuous electric current[14] can be overcome by applying an electric current periodically (a pulsed electric current) instead of continuously.[16-19]

By properly utilizing the electroplastic behaviors of metals, EAM is expected to reduce the process time and manufacturing cost in various conventional manufacturing processes such as sheet metal forming or die forging. Since EAM is expected to be carried out at relatively lower temperatures compared to hot working, the common problems of hot working such as thermal stress, warp, and low controllability of tolerance can be minimized. Therefore, EAM is a cost-effective and energy-saving manufacturing process that also enhances the quality of products.

This review summarizes the previously reported electroplastic behaviors of various metals or their alloys in EAMs processes. Also, contemporary EAM patents are briefly reviewed.

2. History of Electroplasticity

In the 1960s, Troitskii[11] reported a phenomenon in which applying an electric current during deformation reduced the flow stress and increased the elongation of metals. In 1970s, Troitskii et al.[20] also argued that the phenomenon could be induced by the effect of drifting electrons (electron wind) on dislocations and showed that flow stress could be reduced by using high-pulsed currents. After the work of Troitskii, the influences of continuous or pulsed electric current on mechanical properties such as flow stress, stress relaxation, creep, dislocation generation, mobility, brittle fracture, fatigue, and formability of various metals[13,21-23] have been investigated. The

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magnitude of drifting electron-dislocation interaction under a pulsed electric current was determined in theory,[20] while Okazaki et al.[24] focused on the effects of crystal structure, impurities, skin effect, pinch effect, and resistance heating on the reduction of stress. Conrad et al.[25] studied the effect of a pulsed electric current on the mechanical behavior of metals.

The athermal effects of an electric current on the mechanical properties of metals under deformation are often referred to as electroplasticity. It has been reported that the electroplasticity of a metal affects the recrystallization,[26-28] surface hardness,[29] ductility and strength,[30,31] elongation,[19,32] and residual stress.[33] Obviously, the process parameters of the electric current such as the use of a pulsed current and the current density based on the cross-sectional area perpendicular to the direction of the electric current are crucial factors[19,34-36] in the optimization of forming processes utilizing electroplasticity.[37]

It is natural that electric currents applied to a metal increase the temperature of the metal due to Joule heating, regardless of the magnitude of the temperature increase. The thermal (Joule heating) and athermal (electroplasticity) effects of a continuous electric current were studied by comparing the results of electrically-assisted forming by applying electric currents to metals during deformation with the results of conventional oven heating[15] or hot working[38] at temperatures equal to or higher than the temperature applied during the electrically-assisted forming. According to Perkins et al.,[15] even at lower temperatures, the stress reduction during the electrically-assisted compression of aluminum, copper, iron, and titanium-based alloys was clearly higher than that of conventional compression at elevated temperatures. Also, according to Dzialo et al.,[38] the temperature increase obtained during electrically assisted compression of copper alloys was lower than that during a hot working process at the same reduction of stress. Ross et al.[39] suggested isolatable effects due to electricity such as Joule heating, kinetic energy (pushing dislocations), and retained stress-strain energy, while reporting that a higher resistivity of material induced a greater electroplastic effect. Salandro et al.[40,41] assumed that the electric current during deformation produced only heating and deformation energy. He suggested a quantified electroplastic effect coefficient to separate the effects of the electric current into thermal and athermal effects. Moreover, it has been suggested that the threshold values of current density exist to induce an appreciable electroplastic effect on materials.[42,43] Perkins et al.[15] reported that the threshold was not obtained for the copper-based alloy evaluated in their study.

Regarding the mechanism of electroplasticity, hypotheses relating electrons and dislocations have been widely accepted.[20,21,44,45] Kravchenko[44] suggested a theoretical explanation based on the interactions between electrons and dislocation movements (so called electron wind). He concluded that, if the velocity of drifting electrons exceeds the dislocation velocity, the force of the electrons on the dislocation becomes sufficient to accelerate the dislocation. Fiks[46] suggested an electron wind model to calculate the diffusion of dislocation flow due to electric currents. He claimed that the effective dislocation charge, which is dragged by electrons, can be considerably large and becomes more apparent at a lower temperature since the mean free paths of electrons become longer. The drag force of electron–dislocation interactions was assumed to be proportional to the difference between the velocity of the drifting electrons and the dislocation velocity.[21]

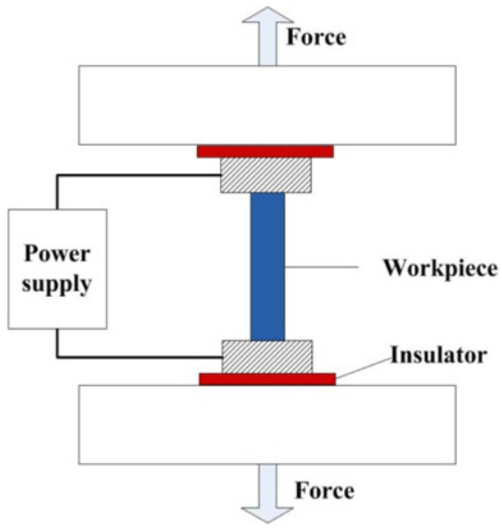

Fig. 1 A schematic of the experimental setup for electrically-assisted tensile testing (modified and redrawn from Ref. 14)

Li et al.[47] studied the electroplastic effect on the microscopic scale based on the classical free-electron theory. Their results are consistent with Conrad's theory for the influence of a high pulsed current density on the flow stress of metals.[42,43] Li et al.[48] also argued that the motion of electrons should be described by quantum laws, and the Schrödinger equation of ions and electrons needs to be solved in order to understand the electron state in metals.

On the other hand, the thermal effect of electric current has also been considered. Goldman et al.[49] claimed that the interactions between electrons and dislocations are negligible at temperatures above 20K. Moreover, at 4.2K, there is no electroplastic effect on lead in the superconducting state, which cannot generate Joule heating due to a zero resistivity. Cao and co-workers[50] reported that the stress reduction became negligible when the specimen was cooled by forced air during tensile testing with continuous electric currents and suggested that the role of Joule heating on the metal's plastic behavior should be reevaluated. In addition, Magargee et al.[51] suggested the notion of current density sensitivity, which is a new parameter to determine the temperature increase with respect to current density.

3. Material Properties in Electroplasticity

The effects of electric current on the material properties of metals have primarily been evaluated based on tensile, compressive, bending, and hardness tests, as tabulated in Table 1. The results generally show decreases in flow stress, energy for plastic deformation, and springback.

3.1 Tensile Test

A general schematic of the electrically-assisted tensile test is shown in Fig. 1. For tensile loading, enhanced formability and reduced flow stress are usually achieved by applying a pulsed electric current during deformation.[52]

For example, the poor formability of ultra-high strength steel sheets,

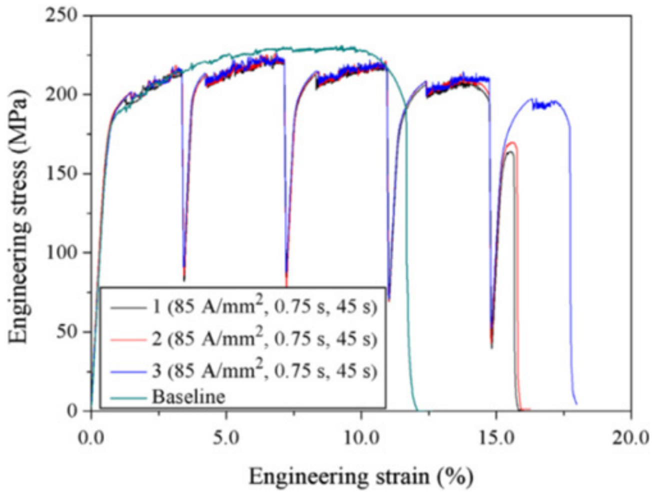

Fig. 2 Experiment results of 5052-H32 aluminum alloys under a pulsed electric current[18]

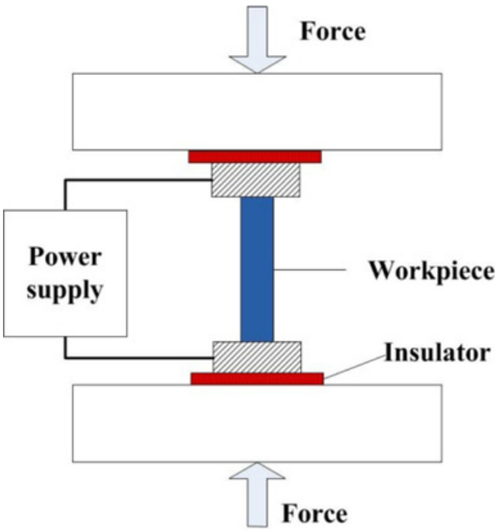

Fig. 3 A schematic of the experimental setup for the EA compression test (modified and redrawn from Ref. 63)

dual-phase steel sheets, and a magnesium AZ31B alloy was dramatically improved under pulsed electric currents in tensile testing.[53-56] The plastic deformation of 70/30 brass was enhanced for both fine and coarse grain specimens when a continuous electric current was applied in uniaxial tension testing.[57]

The tensile properties under a pulsed electric current were also investigated for 5052 and 5083 aluminum alloys,[19] 304 stainless steel,[58] and a Ti-6Al-4V alloy[37,59] at high deformation rates. It was also confirmed that titanium alloys[60,61] (VT1-0, VT6, $Ti_{49.3}Ni_{50.7}$), a ZA22 alloy,[62] and a 5052-H32 aluminum alloy[18] showed electroplastic behavior during tensile deformation with pulsed electric currents (Fig. 2).

On the other hand, Mai et al.[58] investigated the Joule heating effect on the strain of stainless steel. The plastic deformation increased when the resistivity increased due to Joule heating. However, at the same temperature, stress reduction was observed when the current density was increased from 5 A/mm^2 to 10 A/mm^2. For similar temperature profiles, Fan et al.[57] compared the results of oven-heated tensile and electrically-assisted tensile tests. The ultimate tensile strength obtained in the

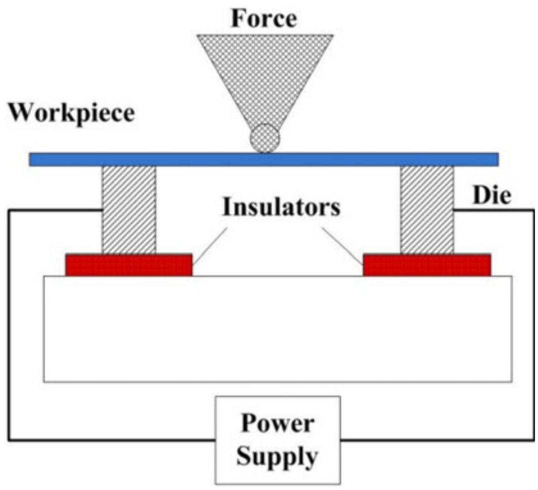

Fig. 4 A schematic of the experimental setup for the EA bending test (modified and redrawn from Ref. 40)

electrically-assisted tensile test was around 17% lower than that of the oven-heated tensile test. Moreover, Fan et al.[57] also argued that local heating at grain boundaries can be attributed to plastic deformation due to easy movement of grain boundaries by heating.

3.2 Compression Test

The schematic of the electrically-assisted compression test is shown in Fig. 3. Perkins et al.[15] reported the results for various materials investigated in electrically-assisted compression tests such as 304 stainless steel, 360 brass, and 6061 T6511 aluminum alloys. The contribution of electroplasticity of these materials decreased the total required energy versus current density. Dzialo et al.[38] determined that the temperature also affected the stress reduction. However, the heating itself was not the only reason for the observed effects. Moreover, the threshold current density significantly affected stress reduction in the compression of a Cu 260 alloy.

In addition, Siopis et al.[64] reported that larger grain sizes of copper in the compression test were less affected by electroplasticity than were fine grain sizes due to the small surface area of the grain boundaries. Higher continuous electric currents were necessary to aid the motion of dislocations at the boundaries. Hence, with increasing grain size, the threshold current density increased and the stress reduction decreased. However, the electroplasticity also affected the grain size due to accelerated recrystallization.[27]

3.3 Bending Test

In the bending process, springback results in less accuracy in manufacturing. Springback can be decreased through the use of an annealing process.[65,66] However, electroplasticity can easily reduce or eliminate springback. Moreover, the quality of the surface can be largely improved. A schematic of the electrically-assisted bending test is shown in Fig. 4.

Salandro et al.[40] reported that stress reduction, which was increased up to 77%, depended on the pulsed electric current. The required energy was also reduced. An analytical model in which it is assumed that electric current produces only electroplasticity and Joule heating effects can be used to predict the bending forces. In addition, the springback reduction depends on current parameters such as a longer

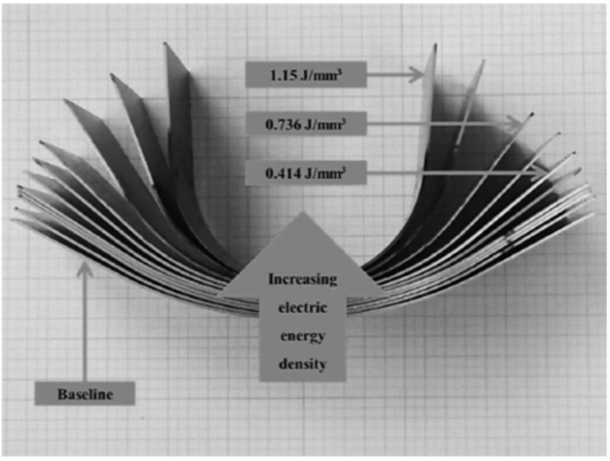

Fig. 5 Springback reduction of advanced high-strength steels with various current densities[67]

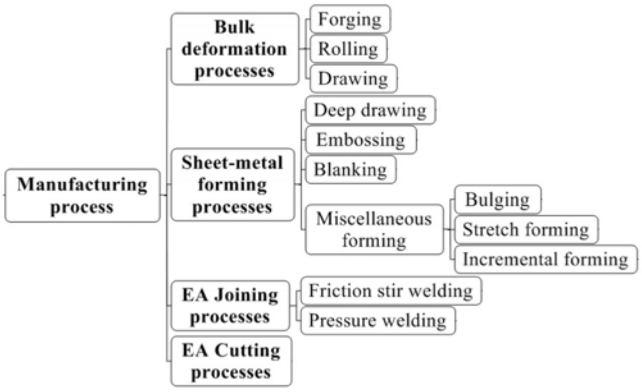

Fig. 6 A list of EAM processes

pulse duration and higher current density.[68] Fig. 5 shows springback with respect to current density in the electrically-assisted bending test.[67]

3.4 Hardness Test

Parkansky et al.[69] reported the dependence of electroplasticity on a magnetic structure (Cu and Ni) at low current density. The current density (100 A/cm^2) significantly affected the ferromagnetic nickel indentation but only weakly influenced copper. They argued that this is due to the interaction between the current-induced magnetic field and magnetic domain wall. Moreover, Ge, Si, and CdS can be easily indented by applying a continuous electric current.[29] In addition, in the bulk materials, the hardness of the specimen has only been mentioned before or after the electric current treatment. Therefore, electroplasticity has not been completely investigated in hardness testing.

4. Electrically-Assisted Manufacturing Processes

As electroplasticity has been widely studied, EAM processes have been increasingly suggested. The suggested EAM processes are mainly associated with bulk deformation and sheet-metal forming, as shown in Fig. 6. Furthermore, other processes such as joining processes and material-removal processes are considered to be potential applications in manufacturing processes.

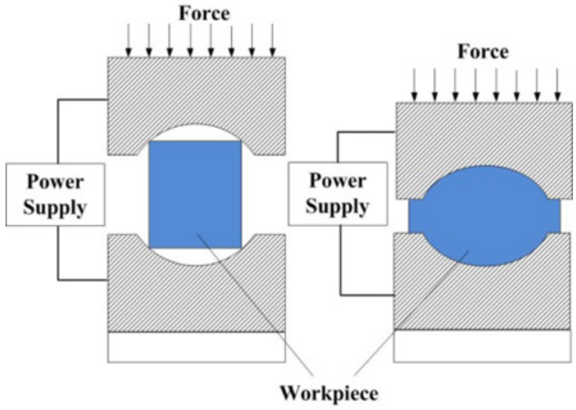

Fig. 7 A schematic of the EA forging process (modified and redrawn from Ref. 70)

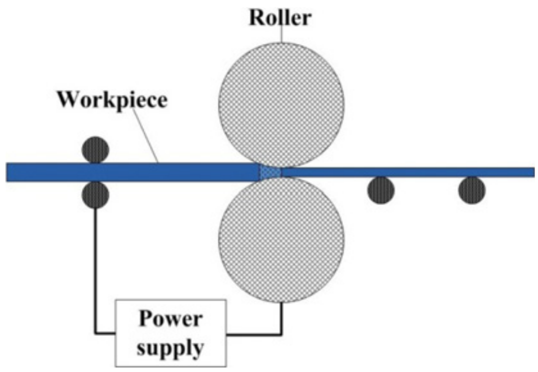

Fig. 8 A schematic of the EA rolling process (modified and redrawn from Ref. 75)

4.1 Bulk Deformation Processes

4.1.1 EA Forging Process

Ross et al.[39] reported that the forgeability of Ti6Al4V was clearly enhanced by a continuous electric current. Bunget et al.[71] suggested that electroplasticity and Joule heating can be separated in energy modeling, which was confirmed in Perkins' studies on Al6061 specimens, in order to analyze and predict electroplastic behavior in the EA forging process. The schematic of the EA forging process is shown in Fig. 7.

Jones et al.[70] also reported that the forgeability was significantly increased as the continuous electric current increased. The ability to form a final geometry, which is not achievable at room temperature, was achievable in the EA forging process. In addition, the overall required forces decreased at higher current densities. However, lower current densities provided similar forgeability enhancement at a particularly slower platen speed.

4.1.2 EA Rolling Process

Fig. 8 shows a schematic of the EA rolling process. With regard to the EA rolling process, Xu et al.[72] report that the rolling force of a magnesium AZ31 alloy was largely reduced and its deformation was significantly improved while a satisfactory surface quality was obtained at room temperature. With similar results, Lu et al.[73] reported that the rolling force and deformation of Bi2223/Ag were reduced and improved, respectively. Furthermore, the tensile fracture of a magnesium AZ91 alloy was brittle fracture in warm rolling, while it

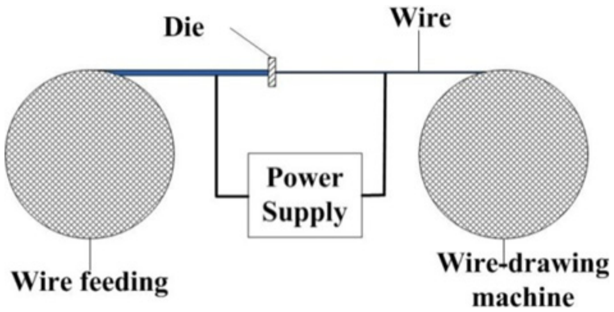

Fig. 9 A schematic of the EA drawing process (modified and redrawn from Ref. 77)

was dimple fracture in EA rolling at a pass reduction of 35%. In addition, NiTiNb[74] and TiNi[75] were successfully rolled by a EA rolling process at a relatively low temperature or without intermediate annealing compared to traditional hot rolling.

In EA micro rolling, the texturing capability and channel depth of Ti-6Al-4V and AA3003-H14 were apparently enhanced. The forming pressure of EA micro rolling was lower than that of conventional micro rolling.[76]

4.1.3 EA Drawing Process

Tang et al.[77] suggested the common EA drawing process shown in Fig. 9. The drawing forces of austenitic stainless steel wires,[77-79] copper wire,[80] and cast-ion wire[81] decreased in the EA drawing process, while their surface qualities improved.

Tang et al.[79] claimed that the temperature increase did not significantly contribute to the changes in mechanical properties, resistivity, and surface quality of austenitic stainless steel in the EA drawing process. In particular, Stashenko et al.[82] stated that the EA drawing process can reduce the production cycle and product cost due to the decreased drawing force and increased drawing velocity.

4.2 Sheet-Metal Forming Process

4.2.1 EA Deep Drawing Process

Wang[83] suggested a schematic for the EA deep drawing process using a pulsed electric current (Fig. 10). The lower resistance to deformation, better plasticity, improved ductility, dynamic recrystallized grains at low temperature, and low energy consumption are the advantages of the EA deep drawing process. Magnesium AZ31 alloy cups were successfully drawn by applying a pulsed electric current, and their plasticity was enhanced. The dynamic recrystallized grains of this process occurred at a lower temperature (above 200°C) than conventional hot drawing (350°C) due to thermal and athermal effects.

4.2.2 EA Embossing Process

Mai et al.[84] proposed an EA embossing process to improve the formability of material by applying a continuous electric current. Fig. 11 shows the schematic of the EA embossing process. This process was used to successfully fabricate micro channels on a SS316L plate at 110°C in the present study. Compared to the traditional process, the die pressure was reduced, and the channel shape and the channel depth were enhanced. Moreover, in numerical simulation results, the residual stress was decreased in the high-residual stress region. The high-residual stress region was more concentrated at the corner of the channel.

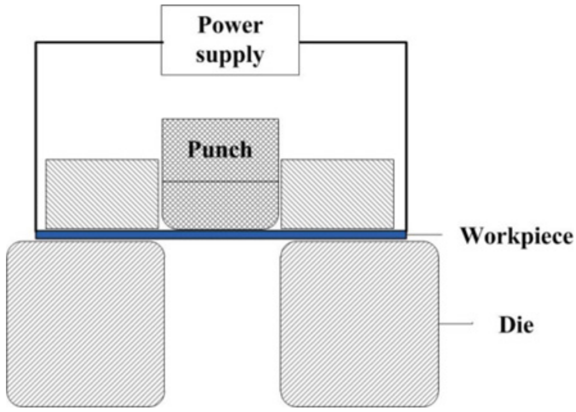

Fig. 10 A schematic of the EA deep drawing process (modified and redrawn from Ref. 83)

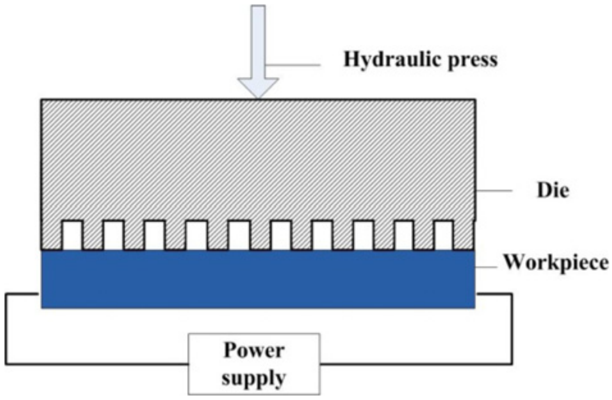

Fig. 11 A schematic of the EA embossing process (modified and redrawn from Ref. 84)

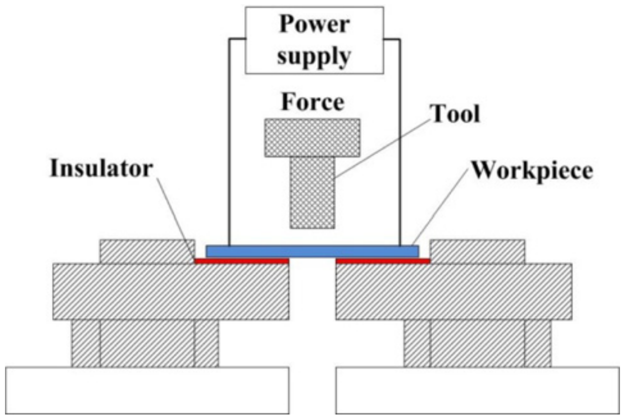

Fig. 12 A schematic of the EA blanking and RH blanking processes (modified and redrawn from Ref. 85)

4.2.3 EA Blanking Process

Kim et al.[85] suggested EA blanking and local resistance heating blanking (RH blanking), which are described in Fig. 12. In EA blanking, a single pulsed electric current is connected to a workpiece while it is blanked. In RH blanking, only Joule heating is utilized to heat a workpiece before banking. Compared to RH blanking (nearly 175°C) and cold blanking, the EA blanking load of ultra-high strength steel (90 A/mm^2-174°C) was decreased by approximately 20% and 85%, respectively, due to electroplasticity.

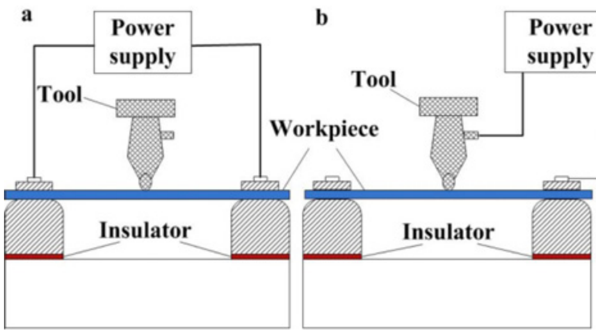

Fig. 13 A schematic of EA stretch forming processes; (a) Across the workpiece (b) Through the tool to the workpiece (modified and redrawn from Ref. 86)

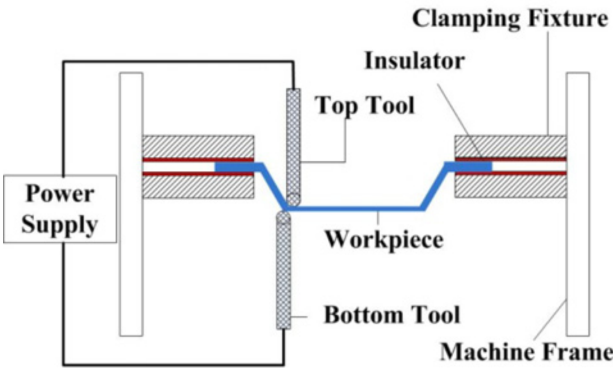

Fig. 14 A schematic of the EA incremental forming process (modified and redrawn from Ref. 88)

4.2.4 Miscellaneous Forming Processes

4.2.4.1 EA Stretch Forming Process

Jones et al.[86] provided a schematic of the EA stretch forming process, as shown in Fig. 13. Compared to the traditional process, the formability and forming force of a 6061 aluminum alloy were reduced in the pulsed electric current-assisted stretch forming process. However, the low current density (10 A/mm^2) did not appreciably reduce the forming force. Furthermore, the direction of the pulsed electric current and different application schemes did not significantly affect the formability or forming force.

4.2.4.2 EA Incremental Forming Process

Cao et al.[87] suggested EA double-side incremental forming equipment for enhanced formability and geometrical flexibility. This equipment possessed high process controllability, low energy consumption, good typical part accuracy, and high part complexity. Asghar et al.[88] also successfully formed a titanium alloy using an EA double-side incremental forming process (Fig. 14). The pulsed electric current applied to the part of tools can greatly improve the forming limits of incremental forming parts and probably allow formation of exotic materials. Ti6Al4V, which can only be formed at temperatures of 900-930^{o}C, was successfully formed by applying a pulsed electric current at 47^{o}C to a tool-sheet interface. Its force and the distortion of shape were reduced compared to those in the traditional process. In addition, electrically-assisted tools ensure that the zone of current conduction is as small as possible in order to enhance the formability due to electroplasticity.

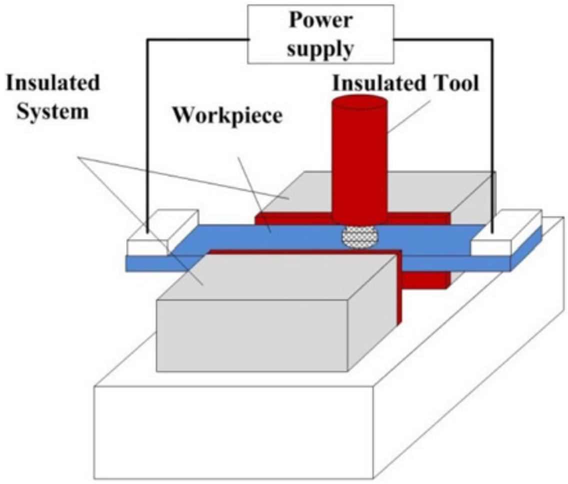

Fig. 15 A schematic of the experiment setup of the EAFSW process (modified and redrawn from Ref. 91)

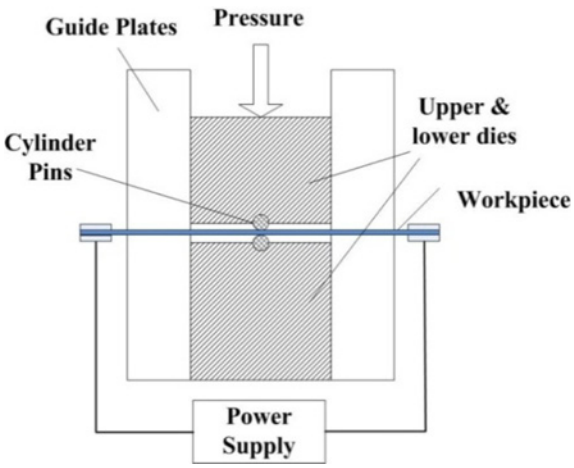

Fig. 16 A schematic of the EA pressure welding process (modified and redrawn from Ref. 92)

4.3 EA Joining Process

4.3.1 EA Friction Stir Welding Process

Electrically-assisted friction stir welding (EAFSW) was suggested as a new method for easy maintenance and flexible applications. The Z-axis force of EAFSW is decreased more significantly than that of the conventional process,[89] and the weld speed and power consumption are improved.[90] Recently, Potluri et al.[91] reported that this process also eliminated the limited penetration depth and reduced tool wear in the plunge and weld (Fig. 15). A decreased feed force of about 59% was argued to be due to electroplasticity and Joule heating. The torque of EAFSW decreased in the beginning of the welding process. Furthermore, the EAFSW process may be used to weld stronger or thicker materials, which is not possible in the traditional process.

4.3.2 EA Pressure Welding Process

Xu et al.[92] suggested the electrically-assisted pressure welding process (EAPW) described in Fig. 16. EAPW significantly reduced the pressure welding force and improved the bond strength under a continuous electric current. For example, in the warm pressure weld process, SS316L was not bonded at 75^{o}C even with a high welding force. At the same temperature, EAPW can normally weld SS316L at

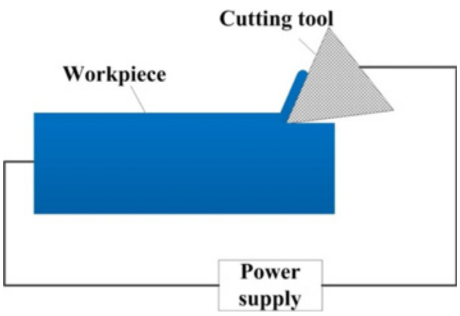

Fig. 17 A simplified schematic of the EA cutting process (modified and redrawn from Ref. 93)

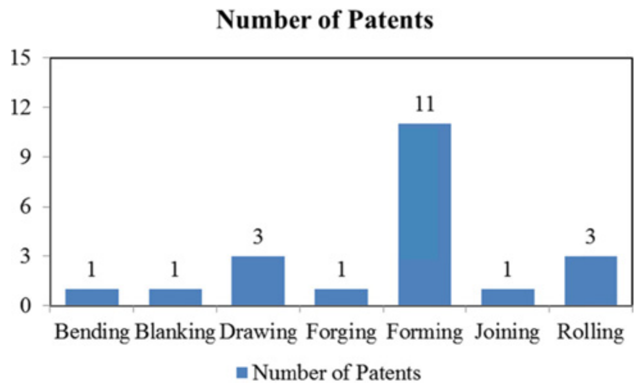

Fig. 18 Number and distribution of EAM patents

a current density of 20 A/mm^2. Both athermal and thermal effects were argued to contribute to the EAPW process. In addition, the bond area significantly increased from 89.4 to 278.6 μm.

4.4 EA Cutting Process

Baranov et al.[93] suggested the EA metal cutting process shown in Fig. 17. A relative change in drilling speed was investigated using pieces of copper, steel, duralumin, and cast iron under a pulsed electric current. The friction force and processing time were decreased by 25-30% and 10-12%, respectively, compared to those of the traditional process. Moreover, the chips, which were produced from a steel piece in the absence of current, were fragile and fine. However, continuous chips also appeared in the EA cutting processes.

5. Patents

Recent patents involving EAM are listed in Table 3. Various processes utilize electroplasticity for convenient processes, as shown in Fig. 18. The number of patents involving the forming process represent about 52% of the total number of patents. In addition to forming processes, rolling processes and drawing processes have also been heavily investigated, each representing around 14% of the total number of patents. Moreover, in the last five years, the number of patents notably increased by about 52% based on the data collection.

6. Conclusions

The use of electroplasticity in manufacturing processes has many

Table 1 Summarized studies of electroplasticity and mechanical properties

Mechanical & structural properties	Summary of the study	Ref.
Fatigue	Increased fatigue resistance Delayed fatigue crack initiation	22,94
Residual stresses	Decreased residual stress level	84,56,95
Flow stress	Enhanced plastic deformation	34,57
Grain growth Recrystallization	Accelerated recrystallization Reduced temperature of recrystallization	27,28, 96,97
Fracture	Reduced effective cyclic stress intensity factor and the rate of crack growth Crack healing	22
Grains and grain boundaries	Larger grain size leads to a smaller stress reduction	57,64, 98,99
Crystal structure	Stress decrease depends on the crystal structure (e.g., Bcc more significant than Fcc)	56,100
Creep	Increased creep rate	21,101
Stress relaxation	Exhibited only at a higher current pulse density Increases as the time of the applied current increase	100,102
Brittle fracture	Controlled crack speed Current concentrates around the vertex of a sharp notch	21,103
Formability working	Reduction force, temperature Increases in tensile strength and elongation	21,102
Phase transition	Significantly increased	35

Table 2 Review of the advantages of EAM

Processes	Advantages	Ref.
Rolling	Temperature below the recrystallization temperature Increased deformability Increased strength, ductility, and conservation of plasticity	104-107
Blanking	Decreased blanking load	85
Bulging	Increased ratio of height and diameter Increased formability	108
Drawing	Drawing stress decreased by 20-50% Significantly improved plasticity Increased surface quality without annealing treatment	79
Embossing	Improved formability Reduced residual stress Increased channel depth Avoid excessive Joule heat and over-heating of the work piece	84
Stretch forming	Create geometrically accurate parts Smooth surfaces were achievable Reduced flow stress	86
Incremental forming	At low temperature Decreased forming force	87,88
Deep drawing	Reduced temperature and force	83
Forging	Increased forgeability Reduced pressure force	39,71
Joining	Reduced force Increased bond area Applicable to industrial manufacturing on a large scale	91,92
Cutting	Reduced force friction and time cutting	93

Table 3 A brief review of EAM patents

Patent title	Process	Patent number	Year
Electroplastic bending device for light metal section	Bending	CN 102172689 B	2011
Electroplastic drawing device of MgB2 wire and drawing method thereof	Drawing	CN 102489533 A	2011
Trim apparatus and method for high strength parts	Blanking	KR 101368276	2014
Power-Up device for electro-plastic wire drawing	Drawing	CN 201304421 Y	2007
Electric plastic pulling enhancing process for high-carbon steel wire	Drawing	CN 001613566 A	2005
Electro-Plastic open die forging device and method	Forging	CN 102489651 A	2012
Strain weakening of metallic materials	Forging	US 20080277034 A1	2008
Electroplastic rotary pressing device	Forming	CN 102489575 A	2011
Electroplastic incremental forming device and method for plates	Forming	CN 102527830 A	2012
Method for plasticizing and forming TiAl-based sheet alloy caused by electricity	Forming	CN 101327506 A	2008
Efficient electro-plastic punch forming device	Forming	CN 201552232 U	2010
Electrical-Assisted double-side incremental forming and processes thereof	Forming	US 20120055217 A1	2011
Single-Point incremental forming of metallic materials using applied DC	Forming	US 8021501 B2	2008
Method and apparatus for electrically assisting the mechanical shaping of a workpiece	Forming	US 5045161 A	1990
Techniques for manufacturing a product using EC during plastic deformation materials	Forming	US 7302821 B1	2007
Method and apparatus for forming a blank as a portion of the blank receives pulse of DC	Forming	US 7516640 B2	2009
Method for increasing magnesium alloy mechanical property	Forming	CN 100532621 C	2009
Joining apparatus for high-strength parts and joining method therefor	Joining	KR 101368277	2014
High-Tensile strength and high-plasticity TiNi nanocrystal material and preparation method thereof	Rolling	CN 102021364 B	2011
Electroplastic machining device	Rolling	CN 202438539 U	2012
Electroplastic rolling method and apparatus for deformable magnesium alloy sheet, band and wire rod	Rolling	CN 100556565 C	2007

benefits and conveniences such as its ease of manufacture, low manufacturing energy, and good quality of products. Due to the increasing number of recent patents and studies of electroplasticity, many EAM processes are expected to be developed. However, electroplasticity is an on-going study topic and needs to be thoroughly researched. In addition, many processes using electroplasticity have still not been fully developed such as machining, surface treatment, and others bulk deformation processes. Therefore, our work provides an overview of EAM development and insight to manufacturing engineers.

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