Electromagnetic Crimping: Green Pulse Technology Forming

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Abstract

Conventional forming processes suffer from various environmental issues apart from technical limitations like high working temperatures, heavy structures and especially environment pollution. There is a great deal of urgency to develop a process that could form the components without harming environment and still has better technological capabilities. Electromagnetic crimping is the answer to this urgency. It is based on Lorentz force, working with plastic deformation, without any chemical bonding, mechanical contact or fasteners. The electromagnetic pulse technology provides non-contact processes for joining, welding, forming and cutting of metals by application of strong, short pulsed magnetic fields. Electromagnetic pulse technology crimping improves formability and forming can be combined with joining & assembling with dissimilar components including glass, plastic, composites and other metals with close tolerances. It also reduces tooling costs. The foremost advantage is that mechanical contact with the workpiece is not required, this avoids surface contamination and tooling marks. And all these advantages can be obtained at ambient temperatures. Due to these advantages and reduced use of lubricants, it promotes clean room condition and green forming, which is the need of an hour to reduce environment pollution. The present volume of this research papers highlights review, practices and future trends of Electromagnetic crimping for joining process.

Keywords: Electromagnetic Pulse Technology, Crimping, Lorentz force.

1. INTRODUCTION

In Electromagnetic crimping, a sudden discharge of a capacitor battery via a tool coil generates pulsed magnetic fields, due to which contact-free Lorentz forces cause deformation in electrically conductive workpieces. It takes microseconds to complete the forming process. The workpiece reaches velocities in the magnitude of 10^2 m s^{-1} and strain rates of up to 10^4 s^{-1} during the process. A short but very high-power electric current is applied from a pulse generator to electromagnetic coils in this process. The coil produces electromagnetic forces, which can for instance change the diameter of tubes by compression or expansion. Non-magnetic metals such as aluminum tubes can also be processed, as an eddy current is temporarily induced in the skin of the tubes.

2. PRINCIPLE OF ELECTROMAGNETIC CRIMPING PROCESS

Energy of the magnetic field is utilized to deform the metal in this process. For example, let us consider an expansion process. The discharge circuit discharges the capacitor bank across the forming coil, which causes a rapidly changing current to flow through the forming coil. This current has a transient magnetic field associated with it, which induces a current in the workpiece. The direction of this current is such that it opposes the cause that produces it according to Lenz's law. Lorentz force acts between the two current carrying conductors. A repulsive force acts between the coil and the workpiece due to opposite direction of currents. When this magnetic pressure exerted by the coil on the workpiece exceeds the yield stress of the workpiece material, the workpiece is thrown away from the coil, i.e. it plastically deforms and crimped. Figure 1 shows schematic illustration of electromagnetic crimping process.

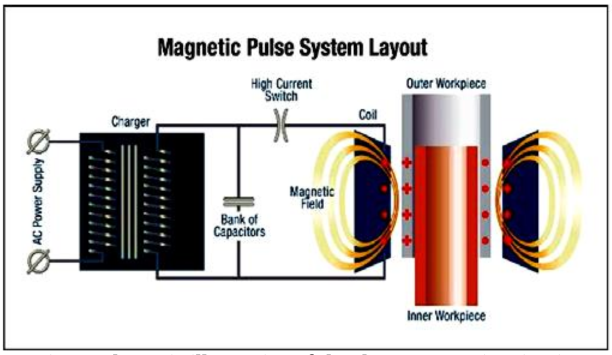

Fig. 1 Schematic illustration of the electromagnetic crimping process

3 EXPERIMENTAL SET UP

Experimental set up of electromagnetic crimping requires following major equipment:

(a) a capacitor bank that stores electrical energy and discharges it across the forming coil in a very short time interval.
(b) a charging unit that is used to charge the capacitor bank.
(c) a discharge circuit, which usually consists of a set of large diameter copper bus bars.
(d) a discharge circuit switch
(e) a forming coil, the geometry of which depends upon the forming operation to be performed.
(f) a conducting workpiece. In the case of a non-conducting workpiece, a conducting driver is necessary.
(g) the die into which the workpiece is to be formed.
(h) a vacuum system is often necessary to complete a successful forming operation.

4 PROCESS PARAMETERS OF ELECTRO-MAGNETIC CRIMPING PROCESS

Following are important process parameters for electromagnetic crimping process.

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4.1 Capacitor Bank

The capacity of energy storage in capacitor E, is given by

$$E = CV^2/2$$

Range of E is 6 kJ to 20 kJ and peak value of voltage V is 10 kV. The ranges of capacitance are 10 µF to 5000 µF and voltage range is 2 kV to 20 kV respectively. Insulation problems need to be considered in excess of about 25 kV.

4.2 Waveform of Discharge Current

The primary circuit current waveform is a damped harmonic function. Range of peak values of current are between 10 kA and 200 kA and the frequency varies between 10 kHz and 75 kHz. The peak value of the current generally becomes unimportant to metal forming after 1.5 to 4 cycles.

4.3 Skin Depth

It represents the depth (or thickness) to which an oscillating magnetic field can penetrate a conductor, which limits the depth upto which current is carried by the conductor. For a non-magnetic material, the skin depth, δ_m is given by

$$\delta_m = \left(\frac{2}{\mu_0 \sigma f} \right)^{1/2}$$

where σ is the electrical conductivity of the material, f is the frequency of the oscillating field and μ_0 is the magnetic permeability of free space. Magnetic field losses increase as the skin depth increases. Hence, a small value of the skin depth is preferred. The skin depth is usually controlled by varying the frequency.

4.4 Circuit Resistance and Inductance

The primary circuit conductors and the work coil windings are made of heavy copper strip with very low steady current resistance. Due to the high frequency of oscillation and the presence of intense magnetic fields, the current density in the conductors is far from uniform during the discharge. Typical primary circuit high frequency resistance is 0.01 to 0.1 ohms and often, this is many times the steady current resistance. Due to the effect of skin depth, resistance increases at high frequencies. The major part of the primary circuit inductance is contributed by forming coil. The inductance of a coil would typically be of the order of µH.

4.5 Workpiece velocity and Strain Rate

The workpiece velocity in a typical electromagnetic forming operation varies between 50 m/s and 250 m/s. The strain rates are of the order of 10^3 or 10^4 /s.

4.6 Forming Time

The workpiece moves a distance of about 1 cm before contacting the die in a typical forming operation. The time taken to form the metal would be about 100 µs for an average workpiece velocity of 100 m s^{-1}. Time required to charge up the capacitor bank limits the number of operations possible per hour. This varies widely depending on the capacity of the bank and the charging circuit. The cooling of the forming coils may also be a consideration in some cases. Typically, a machine can be operated up to 600 - 1200 operations per hour. However, a fully automated equipment can reach up to 12,000 operations per hour.

5 APPLICATIONS OF ELECTROMAGNETIC CRIMPING PROCESS

Following are the applications of Electromagnetic Crimping:

i. Automotive application like crimped air suspension as shown in Fig. 2, crimped drive shaft as shown in Fig. 3, small pressure vessels for automotive air condition systems (ø 50 mm.), aluminum-plastic fuel filter with two O-rings (ø 75mm)

Fig. 2 Crimped air suspension [8]

Fig. 3 Crimped drive shaft [8]

ii. Cables and tube connection like joining of tube with different material as shown in Fig. 4, HVAC tube connection, etc.

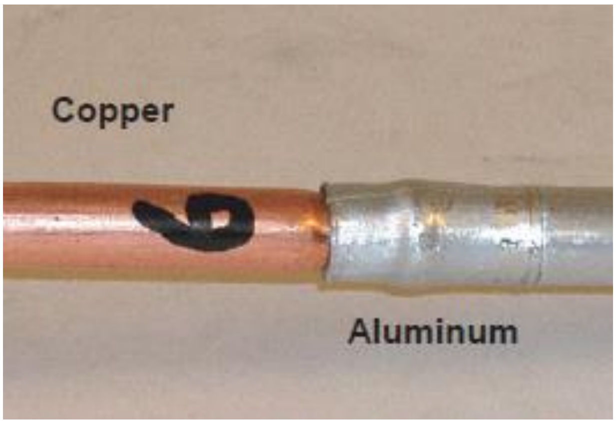

Fig. 4 Joining of two different materials [8]

iii. Filters and Components like HVAC filter as shown in fig. 5, fuel filter, etc.

Fig. 5 HVAC filter[8]

iv. furniture, lighting fittings, refrigerators and freezers
v. shower cubicles, bathroom equipment and decorative strips
vi. products used in public buildings such as shop equipment, display cases, electronics boxes, cooling fins and ladders
vii. load-bearing structures, guides, scaffolding, corner joints, industrial railings, fencing posts, platforms and floors

6 CONCLUSIONS

Conventional forming processes suffer from various problems like wrinkling, high working temperatures, material preparation, reproducibility, tooling cost, surface finish, high weight structures, low production rate, environment pollution etc. Electromagnetic crimping is the answer to all these problems. The Electromagnetic crimping process has several advantages over conventional forming processes.

Following are the salient conclusions from the present research study.

a. It significantly improves formability i.e. the amount of stretch available without tearing and wrinkling can be reduced.

b. As current passed through the forming coils is the only variable to be controlled for a given forming set-up, the process is highly reproducible with same quality, which can be controlled by the amount of energy discharged.

c. Electromagnetic crimping process also reduces the tooling cost as single sided dies are sufficient and forming & assembly operations can be combined into a single operation.

d. Better surface finish is possible in this process as there is no mechanical contact with the workpiece.

e. Weight is not a question in electromagnetic crimping process as light structures are possible due to absence of static forces.

f. Production rate can be increased by controlling the time taken for the capacitor bank to charge. More importantly, it is an environmentally clean process as no lubricants are necessary.

g. All the above-mentioned advantages can be obtained at ambient temperatures without any special material preparation.

h. The non-contact process that Electromagnetic crimping offers, creates a more uniform pressure over the circumference with none of the variation nor tool marks inherent in mechanical processes.

However, EMPT suffers from few limitations also, which are mentioned below:

a. The factors which limit the use of electromagnetic crimping process are only conducting materials can be formed directly. A conducting driver plate must to be used, if non-conductors are to be formed.

b. Process may be unsafe due to high voltages and currents involved.

c. Very large sheet metal components cannot be formed, mainly due to problems in design of very large coils. Electromagnetic crimping can be a perfect solution in the processes like surface embossing due to excellent reproduction of surface details. very close tolerances are possible as spring back can be made minimal or even completely eliminated.

Still Electromagnetic crimping is the forming process for the future due to green pulse technology forming to reduce environment pollution.

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