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Research Article

On Some Critical Concepts of Magnetic Pulse Welding Technology

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A B S T R A C T

Electromagnetic pulse welding technology is a relatively new manufacturing, promising and attractive technology emerging these days. Electromagnetic pulse welding is achieved by impact where the pieces to be welded are accelerated towards each other by the Lorentz force established between the two. This welding technology works to weld for both similar and dissimilar metals within a few microsecs which is found to be difficult to get welded by conventional welding methods. An attempt is made to study the phenomena of electromagnetic pulse welding of both similar and dissimilar metals. SS316L tube having diameter of 6.5 mm, with a thickness of 0.5 mm is welded to SS316L rod such that it discharges a very peak current of 130 KA at 25.65 µs. Another similar metal combination of Aluminium 6061 tube having diameter of 6.5 mm, with a thickness of 0.5 mm is welded to Aluminium 6061 Flange. Standoff distance of 1 mm is chosen to move the job piece so that it grasps to gain maximum velocity to have the impact on the Aluminium 6061 tube to Aluminium 6061 flange produced a very high discharge current of around 161 KA at 32 µs Electrical circuit consists of capacitance of 2 µF, circuit's total inductance of 2 nH and resistance of 0.02Ω is considered. Dissimilar metal combination of Cu-DHP tube of diameter 22.22 mm is welded to 11S MnPb 30 steel target tube. Discharge electrical circuit consists of a resistance of 14.3 mΩ with circuit inductance of 0.55 µH and a capacitor bank of 160 µF discharges a peak current of 160.1 KA at 21.38 us has been observed from Matlab programming.

Keywords: Electromagnetic Welding, Capacitor Bank, Magnetic Flux Density, Electromagnetic Pr Pressure, Skin Depth, Magnetic Pulse Welding

Introduction

Electromagnetic welding is basically considered as an impact welding process, where the welding gets resulted by the penetration of the pieces into each other. The most used and the existing welding process, i.e fusion welding not only causes defects such as oxidation of layer, cracking, porosity, solidification but also corrosion and transformation, common Welding process. Since the need to achieve welding for dissimilar metals of different material properties has increased tremendously which is only possible by the EMW process. Therefore, the demand to get pieces welded through electromagnetic means has been increased in recent years. It has also been found that in the present research field, especially the development of Aluminium space frame for automotive body structure.

These days welding dissimilar metal combination has been prominently increasing. Owing to its ability of offering different material properties which enhances the weld strength, its conductivity and even the toughness of the weld, as mentioned by Simoen et al.,[8] though Cu-SS combination is a low weight combination, but this is also found not easily welded by the normal conventional process which was observed by.[9] For tube-tube welding of such combination, Non-Conventional methods such as the Electromagnetic crimping are preferred.[10] Since welding of dissimilar metals is avoided, then it offers the possibility of welding materials with higher melting difference which further reduces the possibility of occurring defects like that of in Fusion welding.[11] A detailed analysis is needed to understand the deformation of flyer and the target tubes as the flyer moves with a high velocity on to the target piece, thus marking its importance to know about its internal tube dimensions clearly. The electromagnetic fields and the pressure distribution were mainly influenced by the conductivity and permeability of the weld pieces. Welding of Al-Cu posseses some pores and crakes when flyer velocity increased, as mentioned by Raoelison et al.[12]

Challenges in Conventional Welding Process

In conventional welding methods, welding is achieved by the action of some mechanical tools on the welding pieces which creates some marks on the tool. So, initial preparations such as surface cleaning and preheating are need to be taken. Conventional welding process also possess great challenge in welding dissimilar metals. Welding dissimilar metals possess a great task since they have a large difference in their melting points. Since Solid State welding does not involve melting points consideration, this gives a alternative approach.

Literature Survey

Electromagnetic forming precedes the electromagnetic welding because the energy required for welding pieces is higher than the forming, as the two colliding pieces should have very high sufficient velocity to get bonded together. The pieces should undergo deformation before they collide thus making electromagnetic forming.

Initially, work was carried out in EMW of flat sheets which is difficult to weld by conventional methods. Some work has been done nationally in the direction of EMW of flat sheets of similar/ dissimilar material combinations which were difficult to weld using conventional welding techniques. To know about the weld quality and its performance, more research has to be carried out in designing of electromagnetic coil and therefore microstructural and metallurgical analysis of weld can be known. It is also found that no work has been carried out yet nationally in welding of tubular job pieces with Al, SS, Cu, tubes. Such welds are desired to work out at very high temperatures without having any failures at heat exchangers or nozzles etc.

Principle of Operation

Electromagnetic forming process basics needs to get understood to understand the concept of EMW, the job pieces get deformed as the eddy currents formed gets interacted with the magnetic field that is produced by the forming coil. So, this method is more suitable for materials conducting electrically and also for tubular geometric pieces. It can also be applied to non conductors and flat strip configurations also. The main components of EMF equipment are:

- High voltage charging supply
- Capacitor bank
- Spark gap switch
- The forming/ welding of the coil

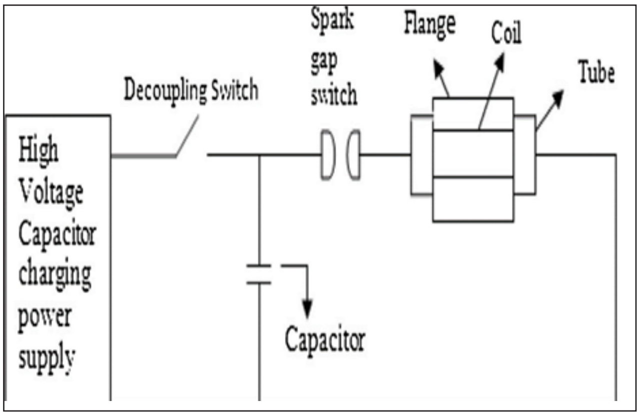

Figure 1.MPW Welding Machine

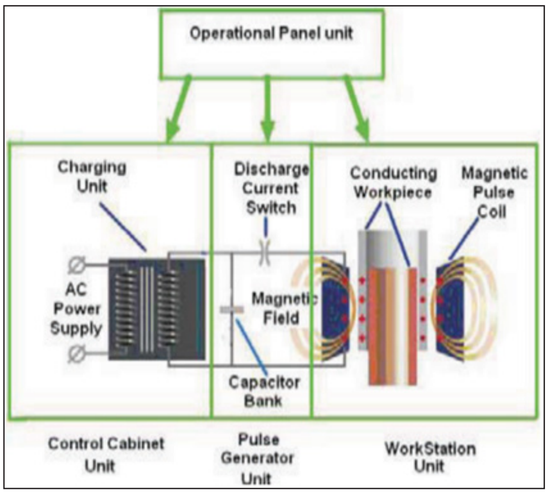

Figure 2.Schematic Diagram

Initially the capacitor bank is charged to a high voltage, then the energy stored gets discharged into the welding coil. During the positive half cycle, the capacitor delivers

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energy to the inductor and during the negative half cycle, the inductor returns back the energy to the capacitor. However, the current decreases continuously due to energy dissipation in the resistance of the circuit. The job piece is placed near to the coil which maintains good magnetic coupling with the coil. Here the coil acts like the primary welding of the air core transformer and the job pieces is like the short circuited secondary. By the principle of mutual induction of the transformer, the induced current in the job piece is in antiphase with the current in the coil. In electromagnetics, the conductors carrying current in opposite directions repel each other which gives rise to the Lorentz force. This force on the job creates expansion of the pieces and the job.

Governing Equations

In MPW, weld is formed at a high velocity because of the magnetic pressure produced by the capacitor bank current in the coil. Maxwell's equations govern the welding process Magnetic flux density produced in the coil is given as:

$\nabla * H = J_{coil}$ (Ampere's circuital law).

The relation between B and H can be given as:

$B = \mu H$

Where J_{coil} = density of current in welding coil,

H=intensity of magnetic field and µ is the permeability of the medium

When the flyer piece is placed inside the coil, then eddy currents are produced in the opposite direction due to the transient magnetic fields which exerts Lorentz force

$= \nabla * E = -\frac{\partial B}{\partial t}$ (Faraday's Induction law)

The induced current in the job piece is given by:

$= J_w = \boldsymbol{\sigma}\mathrm{E}$ (Ohm's law)

Where is current density of the coil. The magnetic field produced interacts with the current and gives rise to Lorentz Force given by:

$F = J_w * B$ (Fleming's left hand rule)

The developed magnetic field generates magnetic pressure which gets absorbed on the job piece given by:

$$P = \frac{B_0^2 - B_I^2}{2\mu}$$

Where

$$B_i^2 = B_0^2 e^{\frac{2t}{\delta}}$$

where and are the developed magnetic field inside and outside the job piece, with δ be the skin depth and f is the capacitor discharge bank frequency.

Energy Distribution and Dissipation in the Process

The energy equations are given below:

U=Capacitor charging voltage
V=job pieces
m=job piece mass
v=job piece velocity, m/s
C=Capacitance, F
L= Total circuit Inductance, H
R=Total circuit Resistance, ohm
Losses=energy loss at the time of switching,

The above equation describes that the energy stored in the capacitor gets transferred to inductor, some part of it gets consumed in the form of light and sound which happens during switching, the energy remaining gets stored inductively which further gets used as deformation, joule heating and Kinetic energy pieces thereby gets welded. Also, in another terms, the force is also generated due to the pressure difference caused by the magnetic field. There is more magnetic field inside the tube than on the outer tube side skin depth for the tube material with the tube thickness.

MPW of SS316l Tube to SS316l Rod (Similar Metals)

SS316L tube having diameter of 6.5mm, with a thickness of 0.5mm is welded to SS316L rod. Initial standoff distance of 1 mm is chosen to move the job piece so that it grasps to gain maximum velocity to have the impact on the rod. The final Pressure required to move by deforming the tube is given by:

$$P_{required} = t\left[\rho\frac{V^2}{2s} + 2\frac{Y}{R}\right]$$

Where

t= thickness of the tube(m), t=0.005
ρ= tube material density(kg/m^3), ρ=7999
V=velocity of the impact(m/s), V=600
s=Standoff distance(m), s=0.005
Y= Yield Strength (MPa), Y= 690
R=Radius of the tube(m), R=0.00275

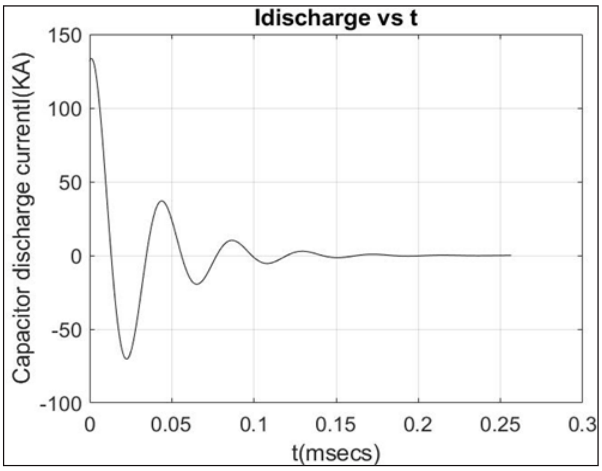

Figure 3.I(KA) Vs t(msecs)

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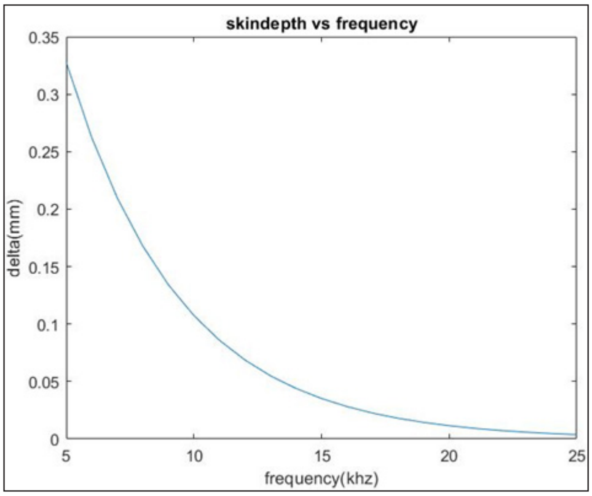

Figure 4.Skin Depth Vs Frequency

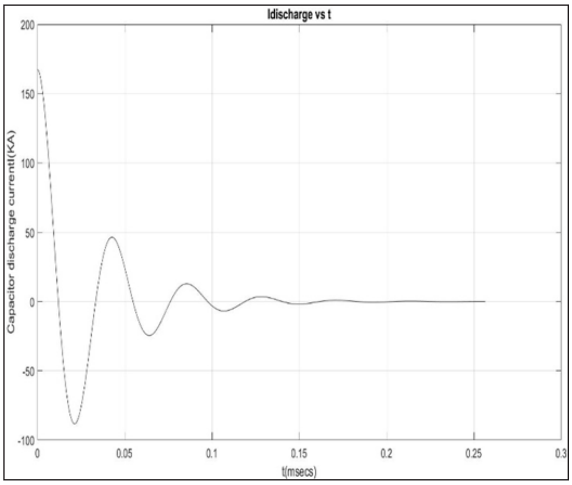

Figure 5.I(KA) Vs t(msecs)

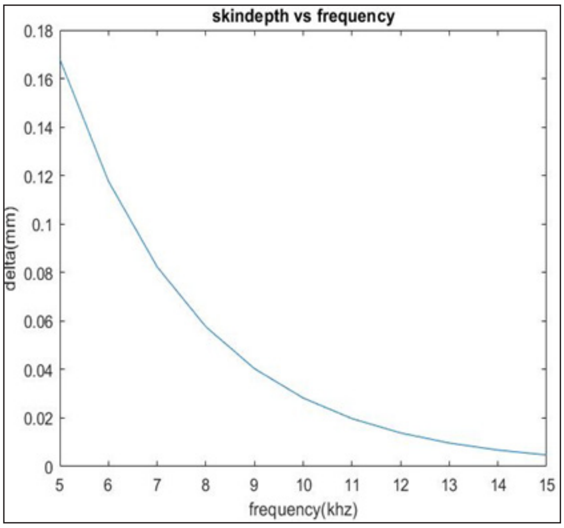

Figure 6.Skin Depth Vs Frequency

MPW oF Cu-DHP Flyer Tube to 11SMnPb30 tubes (Dissimilar metals)

Cu-DHP tube of diameter 22.22 mm is welded to 11SMnPb30 steel target tube. Discharge electrical circuit consists of a resistance of 14.3 mΩ with circuit inductance of 0.55 μH which are connected in series across the capacitor bank of 160 μF to generate a very high electromagnetic damped current within a short time to form a bond with the fixed metal. Cu-DHP tube having its material properties of thickness 3 mm, initial standoff distance of 1mm with electrical conductivity(σ) (S/ m) of 46.9*10^6 of density (kg/ m^3) = 8900.

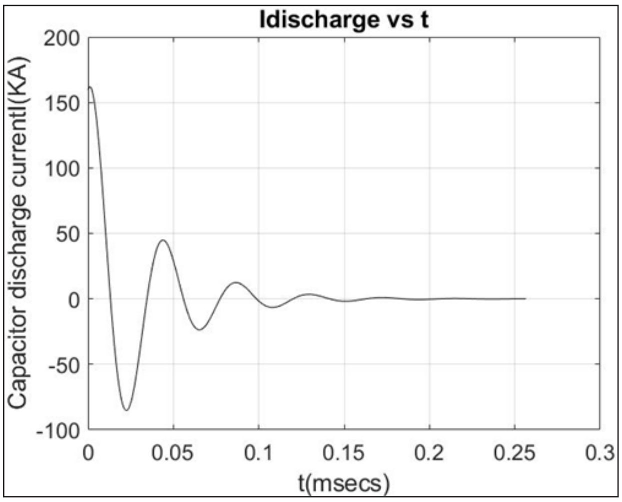

Figure 7.I(KA) Vs t(msecs)

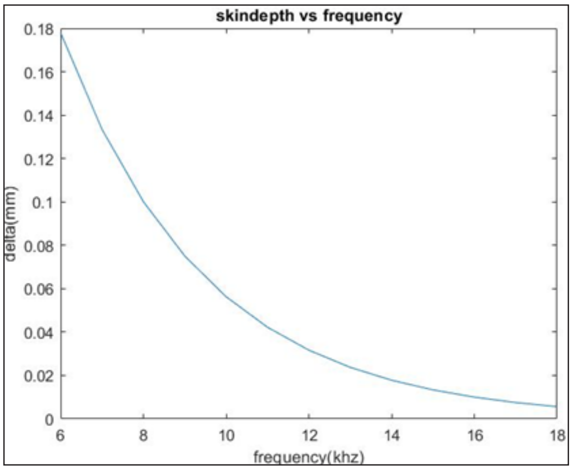

Figure 8.Skin Depth Vs Frequency

Conclusion

Welding of SS316L tube to SS316L rod resulted in discharging a very high current of 130KA at 25.65μs and response at various standoff distance with respect to frequency are observed. Dissimilar metal combination of Cu-DHP flyer tube to 11SMnPb30 tube capacitor bank discharged a high current of 160.1KA at 21.38μs and also its response with frequency at different skin depths has been observed.

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