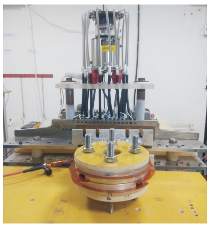
Magnetic Pulse Welding

Magnetic Pulse Welding of AA 5052 "Tube-Plug"

JMVVS Aravind*[1], Shobhna Mishra[1], Surender Kumar Sharma[1], G. Kiran Kumar[1], Rishi Verma[1], Rashmita Das[1], Basanta K. Das[1], Renu Rani[1], N. Sathi Babu[1] and Archana Sharma[1,2]

[1]*Pulsed Power & Electro-Magnetics Division, Bhabha Atomic Research Centre, Visakhapatnam, Andhra Pradesh-531011, INDIA*
[2]*Beam Technology Development Group, Bhabha Atomic Research Centre, Mumbai-400085, INDIA*



Magnetic Pulse Welding Experimental setup

ABSTRACT

Magnetic Pulse Welding (MPW) is a solid-state joining process, in which a conductive flyer metal is accelerated to impact a target metal with high energy, thus forming a metallurgical bond. In the present article, compression MPW of Al-5052 tube (21.3mm I.D., 1.5mm thick) to Al 5052 plug is demonstrated. The impact velocity and time of impact are estimated using analytical equations. The experiment is performed at 15kV/295kA/23kJ, to obtain a helium leak rate better than 10^{-12}mbar. lit/s. Also weld interface morphology is studied and observed to be of wavy nature.

KEYWORDS: *Magnetic Pulse Weld (MPW), High Impact Welding, Interface Studies.*

Introduction

Magnetic Pulse Welding (MPW) is a well-established technology under the branch of solid-state joining processes, in which high impact pressure is generated to form a weld joint between two overlapping surfaces, by sequential collision of one metal over the other metal[1]. Fig.1. shows the schematic layout of MPW process.

The impact pressure is generated by discharging the electrostatic energy stored in a capacitor bank into the tool coil, which produces a magnetic field. This time-varying magnetic field when interacts with the flyer tube, it produces eddy currents in the flyer tube, which in turn shield the magnetic field from entering the flyer tube. This differential magnetic pressure on both sides of flyer tube accelerates it towards the target metal to collide with a high impact velocity. The main advantage of MPW is jetting action during the process cleans the contaminants, dirt, oxide layers and makes the clean metal surfaces to interact to form joining[1]. Along with the tool coil, a replaceable field shaper is used[2]. Usually, copper material is used for tool coil/field shaper because of its high electrical conductivity.

The chemical composition of AA 5052 is shown in Table. 1.

Table 1: Chemical composition of AA 5052 (in %)

Al	Mg	Si	Mn	Zn	Cr	Fe	Cu
95.7-97.7	2.2-2.8	0.25	0.1	0.1	0.15-0.35	0.4	0.1

AA 5052 is used in marine atmospheres because of its high corrosion resistance properties. Usually, welding of AA by Gas Tungsten Arc Welding (GTAW), Gas Metal Arc Welding (GMAW), *etc.*, faces a lot of drawbacks due to its high co-efficient of thermal expansion (α) and high thermal conductivity(κ). In MPW, there is no application of heat to melt the base metal, hence the tendency of cracking and HAZ is reduced. Also, the jet formed during the phenomenon itself clean the two mating surfaces to remove oxides. Expansion studies on AA 5052 has already been done[3].

**Author for Correspondence: JMVVS Aravind*
E-mail: jaravind@barc.gov.in

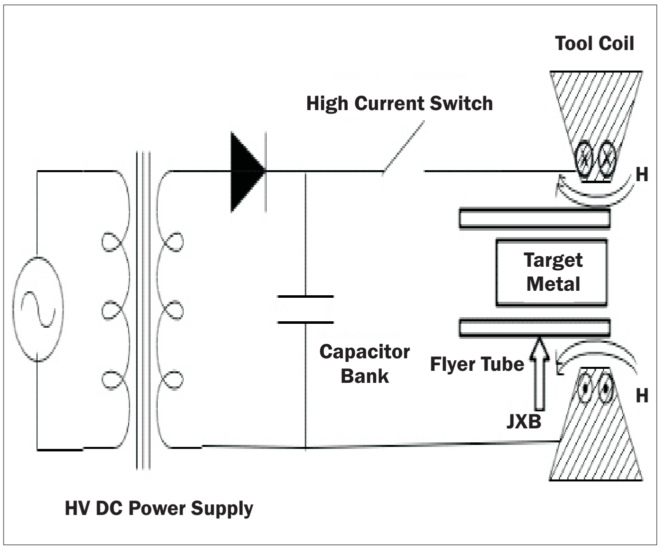


Fig.1: Schematic layout of MPW system.

After joining the metals, the bond quality is assessed by Destructive tests *viz.* Tensile test, Micrographic studies, *etc.* and Non-Destructive techniques *viz.* helium leak test, ultrasonic test, etc. In the present study, an attempt is made to perform the MPW of AA 5052 and to validate the joint established by Helium leak test and to study weld interface morphology.

Experimental Set Up

The MPW experimental installation is as shown in the Fig.2. It is having five sub-systems as explained in this paper.

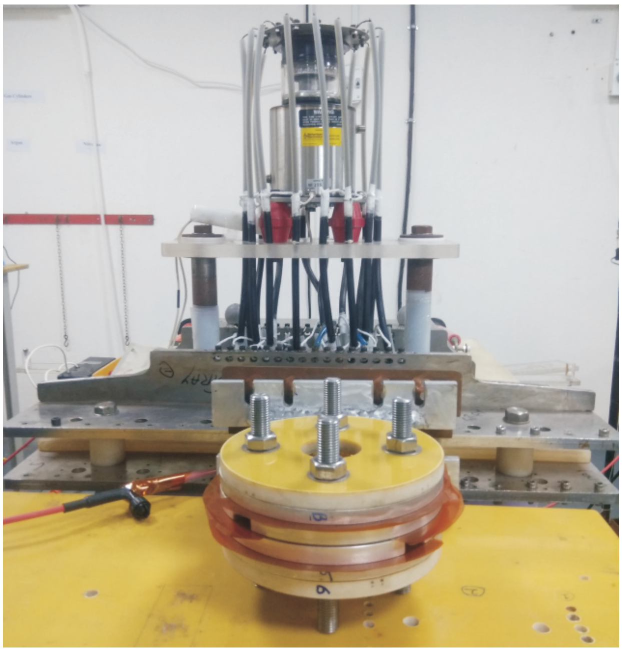


Fig.2: MPW experimental setup.

- ***Power Supply:*** A 25 kV/ 800 mA HV DC power supply is used to charge the capacitor bank.
- ***Energy Storage:*** A 208μF/44kV capacitor bank is used to perform the present MPW studies. For the present study, the capacitor bank is charged up to a voltage of 15kV, with a stored energy 23kJ.
- ***High Current Switch:*** A high voltage and high current Ignitron switch (model NL8900) and trigger module is used to discharge the stored energy in the capacitors into the load.
- ***Tool coil and field shaper:*** A four-disc Aluminium bitter coil and field shaper (ETP grade copper) as shown in schematic Fig.3 is used for the present study.

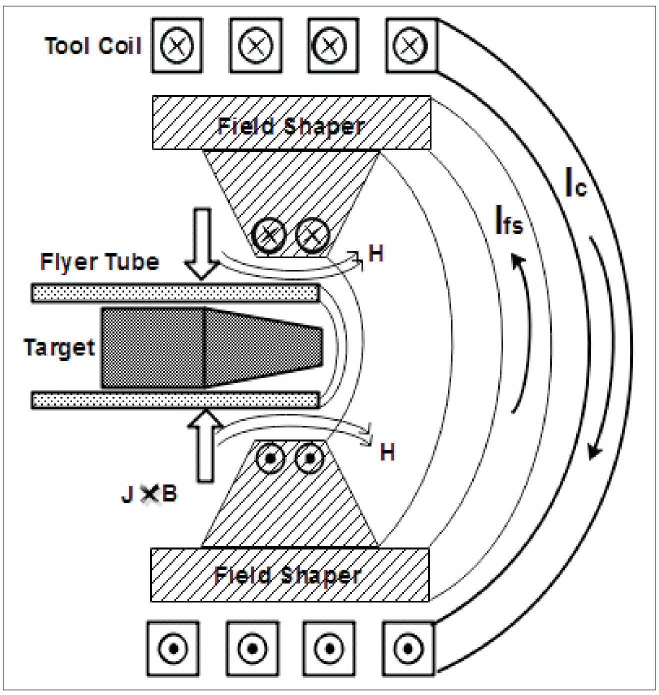


Fig.3: Schematic showing 4-disc coil, field shaper and weld sample.

Table 2: Dimensions of job sample

Description	Value
Outer Diameter, O.D	21mm
Inner Diameter, I.D	18mm
Thickness, t	1.5mm
Total flyer length, T.L	15mm
Over Lap length, O.L	8mm
Target taper angle, θ	10^0

- ***Job Sample:*** The job assembly is composed of flyer tube and target. The dimensions of assembly are tabulated in Table. 2.

Theoretical Details

- ***Generation of Magnetic Pressure on flyer tube***

When the sinusoidal current passes through the tool coil, magnetic field density (B) is generated in the annular air region between the field shaper and flyer tube as shown in Fig.3. The magnetic field intensity (H) can be solved using the Magnetic Diffusion equation.

$$\frac{1}{\mu\sigma} * \nabla^2 H = \frac{\partial H}{\partial t} \qquad (1)$$

where, μ and σ represents the magnetic permeability and electrical conductivity of the respective medium.

The current density J in the flyer tube can then be find out using Ampere law.

$$\nabla \times H = J \qquad (2)$$

This time varying magnetic field B, interacts with the eddy currents generated in the flyer tube with a current density J, which in turn develops a radial inward Lorentz force (F=JXB) on the flyer tube. The dynamic impacting pressure generated on the tube can be evaluated as,

$$P_{mag} = \int_0^t F.td = \frac{(B_{out}^2 - B_{in}^2)}{2}$$

$$P_{mag} = \frac{B_{out}^2 (1 - \exp(-\frac{2t}{\delta}))}{2} \qquad (3)$$

B_{out} and B_{in} are the magnetic field densities outside and inside the flyer tube. The skin depth at operating frequency can be calculated using $\delta = 1/sqrt(\pi f \mu \sigma)$.

- ***Kinematics of flyer tube***

The magnetic pressure used to initiate the deformation in the flyer tube is estimated using the mechanical properties of the material *viz.* yield strength, strain rate, *etc.*

$$P_{def} = \frac{\sigma t}{r} \qquad (4)$$

Once this pressure is exceeded, the extra pressure applied is utilized to accelerate the flyer to sufficient impact velocity towards the target material. Hence, the pressure used to accelerate the flyer is solved using Eq. 5.

$$P_{acc} = P_{mag} - P_{def} \qquad (5)$$

The instantaneous velocity profile and radial displacement of the flyer can be solved by integrating the above equation with respect to time.

$$vel(t) = \frac{1}{m} * \int Facc.dt$$

$$vel(t) = \frac{1}{m} * \int (Pacc * As).dt \quad (6)$$

$$dis(t) = \int vel(t).dt \quad (7)$$

where, As= l*2pr is the surface area of the tube.

The time required to impact the target material is called as impact time T_{imp}. This impact time depends on annular gap (between tube and target), magnetic pressure, discharge frequency, and varies along the weld length.

Results

Simulation Results

The Magnetic Field Density (B) and Magnetic pressure corresponding to the experimental conditions are calculated by solving the Eq. (1), (2) and (3) with the help of FEMM, version 4.2 software. Fig.4 shows the distribution of B field in shaper-flyer tube region at peak current instant. The peak values of B field, magnetic pressure is found to be 22Tesla, 192MPa, respectively. The radial gap between the tube and target is maximum at free end of flyer tube and decreases along its length towards the other side. Hence, for a uniform pressure over its length, the collision is at an oblique angle and Fig.4 Magnetic field, B pattern in field shaper-flyer tube assembly sequential collision takes place along its length. Analytical equations are solved to estimate the velocity profile, radial displacement and time of impact.

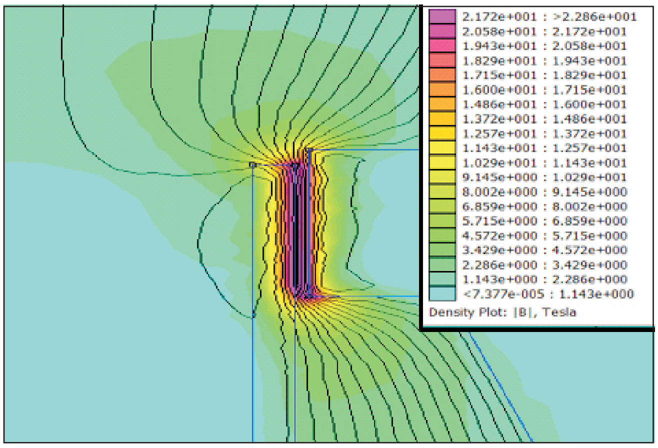


Fig.4: Magnetic field, B pattern in field shaper-flyer tube assembly.

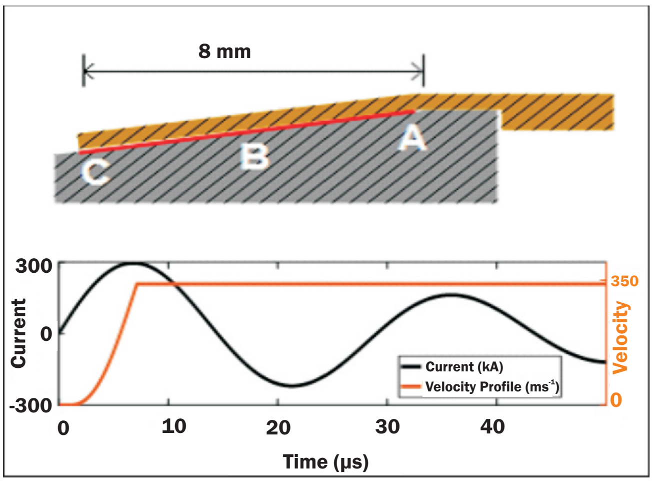


Fig.5: Estimation of coil discharge current and velocity profile at point C.

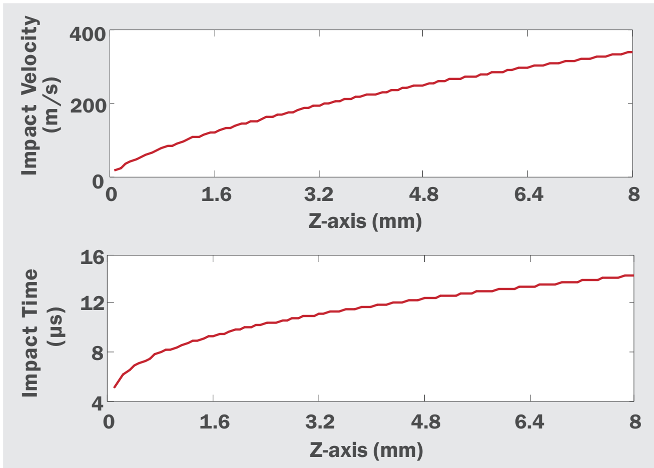


Fig.6: : Estimated impact velocity and impact time (T_{imp}) along length of tube.

Fig.5. shows the plot of estimated discharge current at 15 kV and velocity profile of the point C using numerical code. It is observed that the flyer tube end point C collides with the plug with impact velocity of 350 m/s at 14.5 µs, which corresponds to the quarter cycle of the current pulse.

Fig. 6 shows the plot of impact velocities and time of impact along the length of weld. The time instant of collisions at point A is earlier than point B and point C. This depicts that the sequential collision taking place along the weld length at some oblique angle.

Experimental Results

Fig.7. Shows the measured value of discharge current with a peak current of 295kA, when the capacitor bank is charged to a voltage 15 kV/23kJ. This peak current is obtained at 14.5µs, with a dominant frequency 18kHz. The corresponding skin depth can be evaluated as 0.5mm. The thickness of the Al 5052 flyer tube is 1.5mm (t>δ), to avoid magnetic field diffusion.

The welded sample is subjected to Helium leak test by using Mass Spectrometer Leak Detector (Pfeiffer make). The leak observed in the Helium environment is better than 10^{-12}mbar. lit/s. For further analysis, the Al-Al welded sample is

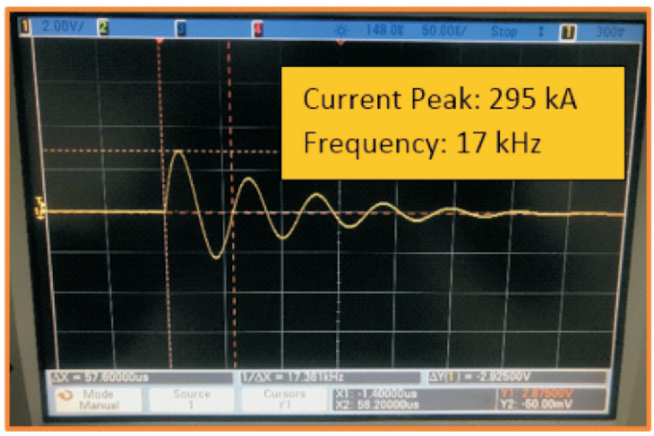


Fig.7: Discharge current waveform.

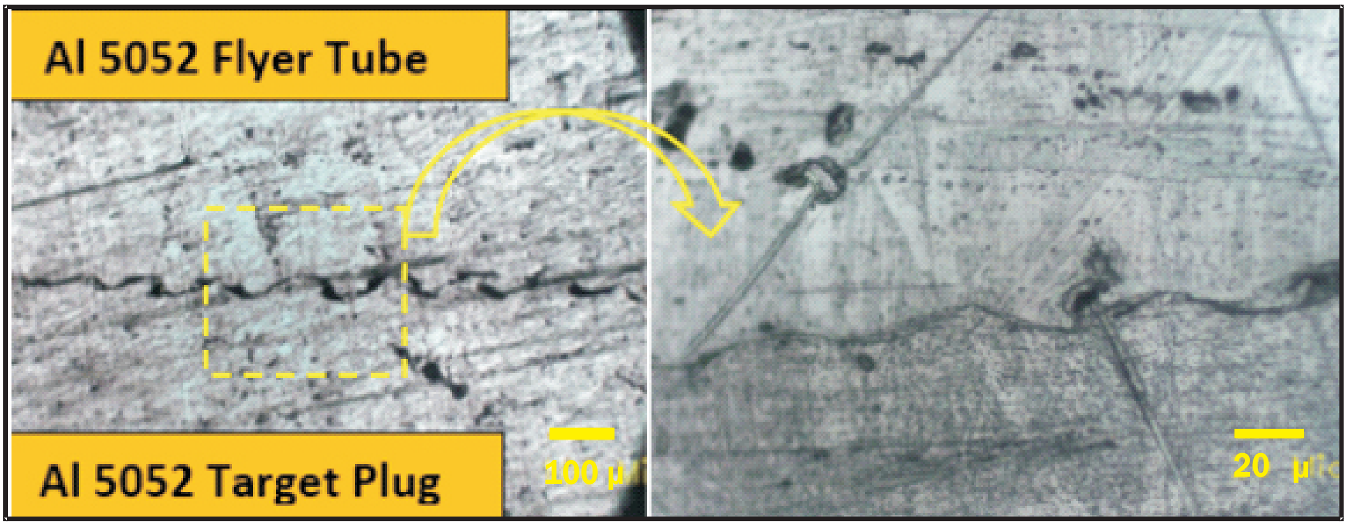


Fig.8: Optical microscopic image at 100x and 500x magnification.

sectionally cut along its length using a wire-cut EDM device. The sample specimen is moulded in Bakelite and polished for weld interface study using Optical Microscope. The metallographic images of specimen are as shown in Fig.8.

The image shows the wavy profile along the weld length which is a characteristic of high impact welding process. There are no signs of melting at the interface, which is an advantage of MPW technique. Out of 8mm overlap length, effective bonding is observed for a length of 2mm. This can be co-related to the simulated impact velocity of 280m/s to 330m/s in the previous section, which corresponds to 1.5mm away from the tip of the tube-target assembly.

Conclusion

The MPW of 21.3mm O.D., 1.5mm thick AA 5052 tube-plug has been demonstrated at 15kV/23kJ using a multi-turn coil. The following observations are noticed during experiments.

- The Al 5052 material can be welded using MPW technique.
- A typical signature of high impact welds i.e. wavy interface has been observed at estimated impact velocities of 280-330m/s.
- An effective bonding is observed over a length of 2mm out of total weld length of 8mm.

Acknowledgments

Authors express sincere gratitude to A. K. Mohanty, Director, BARC and T. V. S. Murthy, Project Director, BARCF(V) for their constant support and encouragement.

References

[1] Psyk, Verena & D. Risch, & Kinsey, Brad & A. Tekkaya, & Kleiner, Matthias, Electromagnetic forming-A review. Journal of Materials Processing Technology, 2011, **211**, 787-829. 10.1016/j.jmatprotec.2010.12.012.

[2] Haiping Yu, Chunfeng Li, Zhiheng Zhao, Zhong Li, Effect of field shaper on magnetic pressure in electromagnetic forming, Journal of Material Processing Technology, 2005, **168**, 245-249.

[3] Shobhna Mishra, JMVVS Aravind, Renu Rani, Surender Kumar Sharma, Premanand Dey, Rohit Shukla, Ramanand Raman and Archana Sharma, Optimization of process parameters for Electromagnetic Expansion Welding of Aluminium Alloy Tube to block, Advances in Materials & Processing Technologies-AMPT, 2017.