MuthuKumuran et al. 2014. *Int. J. Vehicle Structures & Systems*, 6(4), 120-123
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.6.4.07

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Contemplating Magnetic Pulse Welding of Dissimilar Materials for Automotive Applications

S. Muthukumaran[a], S. Kudiyarasan[b], S. Arungalai Vendan[c] and A. Senthil Kumar[a]

[a]*Dept. of Mechanical Engg., University College of Engineering, Panruti, India*

[b]*Technical Group, Bharatiya Nabhikiya Vidyut Nigam Limited, Kalpakkam, India*

[c]*Industrial Automation & Instrumentation Div., School of Electrical Engg., VIT University, Vellore, India*
Corresponding Author, Email: arungalaisv@yahoo.co.in

ABSTRACT:

Experimental investigations on magnetic pulse welding of dissimilar materials are carried out in this study. Detailed studies are carried out to assess the mechanical properties, microstructure and interface pattern of lapped joint of Aluminium alloy tube and Copper alloy rod by Magnetic Pulse Welding (MPW). The torsion strength values are higher than that of the aluminium tube when the discharge voltage of MPW process is not less than 6 kV. The joint basically comprises of interfaces, non-uniform transition zone and base metals obtained under discharge voltage of 10 kV, the contact angle being 50° and radial gap of 1.2-1.4 mm. It is observed from microstructure examinations that high-density dislocations are present in basic metals along the interfaces. The transition zone appears to have higher hardness as compared to the other classified zones based on the metallurgical configurations. The multidirectional micro-cracks and micro-apertures characterise the transition zone of MPW joint. The mutual diffusion of Cu and Al elements occurs in the transition zone, where content of Al element is higher than Cu element besides a narrow region close to the interface of Cu and Al zone. Through this investigation, the suitability of MPW for joining dissimilar conductive materials is established.

KEYWORDS:

Magnetic pulse welding; Microstructure; Dissimilar materials joints; Interface; Flyer

CITATION:

S. Muthukumaran, S. Kudiyarasan, S.A.Vendan and A.S. Kumar. 2014. Contemplating Magnetic Pulse Welding of Dissimilar Materials for Automotive Applications, *Int. J. Vehicle Structures & Systems*, 6(4), 120-123. doi:10.4273/ijvss.6.4.07.

1. Introduction

Magnetic Pulse Welding (MPW) is solid-state cold joining process engaged for similar and dissimilar conductive metals viz., aluminium, brass, or copper to steel, titanium, stainless, aluminium, magnesium, copper and most other metals. MPW system [10] comprises a power supply, bank of capacitors, a high-speed switching system and a coil. The parts to be joined are inserted into the coil. The capacitor bank is charged and the high-speed switch is activated. A strong magnetic flux is created around the coil when the current is applied and as a result eddy currents are formed in the parts. The eddy currents oppose the magnetic field in the coil and an opposing force is generated [1]. This force drives the materials together at a tremendous high rate of speed and creates an explosive type of weld. For more conductive metals such as aluminium and copper, the less energy is required to achieve a weld. Owing to the impact velocity and pressure, the inner material must have sufficient structural strength to withstand the impact without deformation [2]. It’s imperative for the parts undergoing plastic deformation to possess good electrical conductivity which enables lesser energy consumption [3]. It is essential to maintain higher security level and special safety precautions [4] due to the high current intensity and voltage. MPW welding is associated with reduced formation of these intermetallic phases [5, 6]. The experimental results and welding characteristics for several samples such as Al-Fe [8], and Al-Al [9] are reported in the available literatures.

However, Al-Cu tubular combination which has greater demand in automobile industries has been less reported with respect to MPW process. Moreover, the metallurgical characterization and non-destructive tests on MPW specimens in the available literatures are scanty. Hence, in this study, an attempt is being made to weld Al-Cu tubular components with the dimensions of inlet value in automobile industries using MPW process. Further, mechanical testing and metallurgical characterizations are being carried out.

2. Experimental set up

The specimens used for this study are Al (Driver) and Cu (Flyer). The MPW equipment (see Fig. 1) that is used in this study has a maximum charging energy of 10 kJ. An outer Al pipe was machined to be 0.6 mm thick, 90 mm long, and 10 mm in diameter. An inner Cu rod with an 8 mm diameter was employed. For the pipe joint, the gap between the Al and Cu was 1mm. prior to the experimental trial; the specimens are ground using emery paper to remove marks sustained during machining. First, the voltage had to be charged according to the welding conditions. Then welding is carried out by electromagnetic force from discharged current through a working coil which develops a repulsive force between the induced currents flowing parallel and in the opposite direction in the tube. Fig. 2 shows few typical samples after welding has been performed. It may be observed that there is a reduction in diameter in the area of the weld.

Fig. 1: MPW Experimental setup

Fig. 2: MPW Specimen and their views of cross section & weld top

After welding, the work pieces are cross sectioned and prepared for examination by standard metallographic procedures such as mechanical polishing down to 1-micrometer grit and light chemical etching. The samples were then examined by optical and scanning electron microscopy. Microanalysis by wavelength dispersive spectroscopy was utilized to evaluate the local distribution of alloying elements at the joint and its vicinity. The cut cross section of the specimen in Fig. 2 indicates good bonding with visual inspections. The inner weld view exhibits a defect free weld with good bonding nature. Besides, it is clearly noticed that there are no deformations or cracks in the weld portion.

3. Results and discussions

The welded specimens are subjected to destructive and non destructive tests to evaluate its quality and strength. Metallurgical characterizations are performed to analyze the bond integrity and examined for presences of inter-metallic phases.

3.1. Tensile test results (destructive tests)

Welded samples are tested on a standard tensile testing machine at a test rate of 5 mm/min. In all cases, failure occurred in the region away from the weld area. The tensile results emphasizes that ductile failure of a welded Al-Cu Rod/Pipe occurs at a distant from the weld. There is no failure on the weld interface.

3.2. Radiography (non-destructive tests)

Radiography tests are performed for investigating the presence of pore /cluster of pores if any and also to examine the effectiveness of the fused dissimilar joints. X-ray mode with 50KV and 3mA source is used for this study. The exposure time was about 90 seconds and ASME Sec V is the standard being used (No particular standard given in literatures). Fig. 3 shows the sample subjected to radiography tests. The results of the radiography suggest that the quality is good and free from impurities/pores. Further, it illustrates good fusion in many samples. However, in few more samples, the response appears to indicate lack of fusion. It is important to note the fact that, radiography is not a suitable technique for solid state bonds as the thin line of interlayer's formed at the weldment are not identified generally by x-ray.

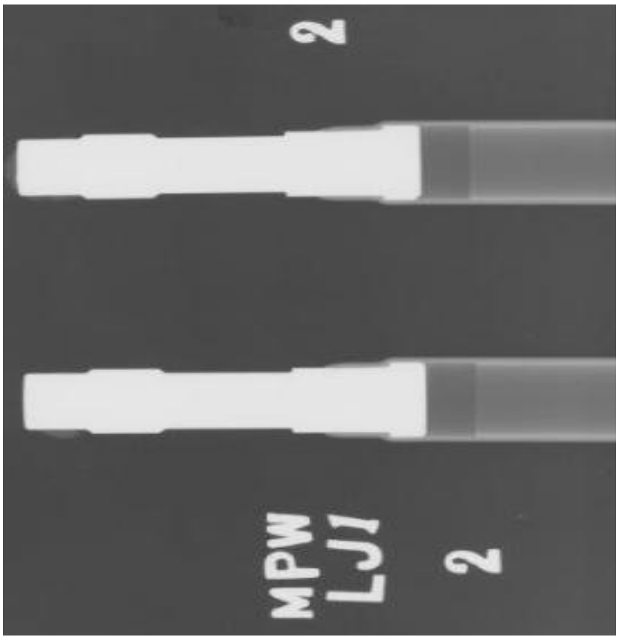

Fig. 3: Al/Cu Weldment specimen subjected to radiography

3.3. Micro-structural analysis

Microstructures of the cross sections of different Al-Cu welds are presented in Fig. 4. Weld quality appears to vary prominently along the interface from start to end for all welds in this configuration. Generally, the start and end zones of the welds exhibited no or only limited bonding. In contrast, the centre portion of the welds showed greater bond integrity. The inadequacy in bonding at the corners of the weld zone is a typical feature of MPW cylindrical parts and according to literature is not critical for many applications [11, 12]. Nevertheless, the non bonded/ improperly bonded corner sections can act as a very strong notch pointing at the weld, which would be undesirable and unfavourable for cyclic load or corrosive environment.

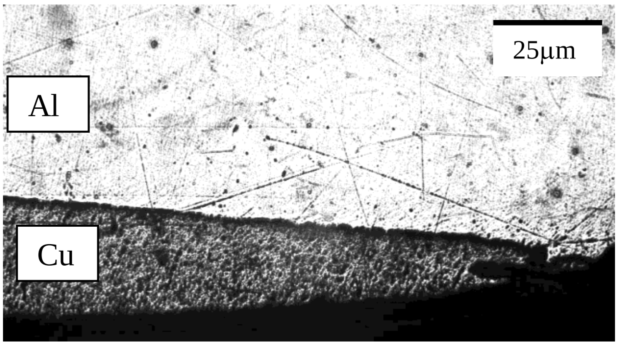

Fig. 4(a): Microstructure of Al/Cu MPW weld sample

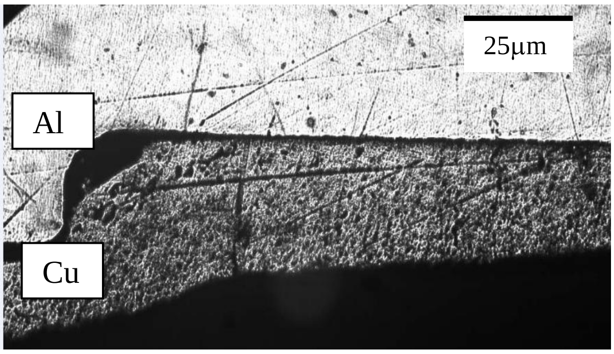

Fig. 4(b): Microstructure of Al/Cu MPW weld sample

The wave pattern by the side of the interface significantly depends on sample geometry and to a negligible degree on the process parameters. Substantial utility of copper cylinders and relatively low pulse energies inhibited the wave formation. Contrary, applying hollow copper cylinders and high pulse energies pronounced waves are visible, especially in the middle section of the welds. This geometrical influence is in accordance with findings in [11]. It is imperative to note that the wave formation process is not mandatory for a good bonding. It is furthermore worth mentioning that to some extent wave formation could also be observed in regions without bonding.

Circumventing the formation of inter-metallic phases at the welding interface is impossible. The extent of interface depends on the process parameters and is fairly connected with the structure of the interface. If the interface shows a wavy appearance, the inter-metallics mainly concentrate in so called “melt pockets”, which are mostly located at the crests of the waves (Fig. 4(a)). If EMP produces a wave less interface, the inter-metallic phases form a film of varying thickness (Fig. 4(b)). It is pointed out that the phase film appears to be interrupted by regions without any inter-metallics. For a thickness below 5 microns the inter-metallics contain rarely any cracks, voids or pores.

3.4. Scanning electron microscopy (SEM)

The SEM investigations present more information on bonding and phase formations. The SEM of the Al-Cu welded specimen is shown in Fig. 5. It may be noted that the dearth of any diffusion layers leads to the postulation that local melting is mainly involved in the phase formation and bonding process along the interface. As for low pulse energies the inter-metallic phases consist primarily of aluminium, it is deduced that solely aluminium but not copper was molten during low energy MPW. Al-rich phases are formed under strong non equilibrium conditions. From the sharp and stepwise transition in chemical composition between the two parent metals and the formed inter-metallic phases it is in accordance with Carpenter and Wittman [13] who deduced that solid state diffusion is not involved as active bonding mechanism in the process of MPW aluminium to copper. Owing to short bonding time and the finite rates of solid-state phase transformations, there is prospectus that a thin layer on the low-melting point material fused and alloyed with the more refractory copper. Rapid melting and solidification explain the formation of inter-metallic phases.

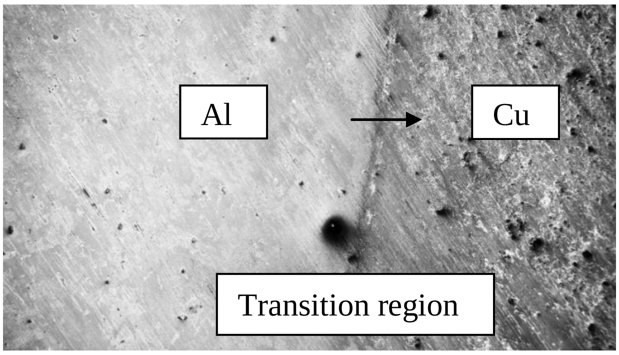

Fig. 5: SEM image of Al/Cu welded specimen

4. Conclusions

Experimental trials are carried out with aluminium and copper as base materials with dissimilar diameter and geometrical configuration by employing magnetic pulse welding. The following conclusions are drawn from this study to analyze the suitability of the process for the chosen material to be employed for automobile applications. Magnetic Pulse Welding of aluminium and copper generates enough heat at the interface to enhance plenty of mass transfer for the precipitation of inter-metallic phases. However, the relative amounts of these phases remained small compared to fusion welding processes because the observed transition region is narrow and discontinuous. The type and chemical composition of the created inter-metallics depend on the pulse parameters chosen. This behaviour is endorsed to different temperature-time system of the process leading to varying amounts of melting of the two base materials. To impound detrimental effects on the mechanical properties of the joints the thickness of the formed inter-metallics should not exceed few microns. Above a critical thickness the inter-metallics are prone to cracking and spallation.

ACKNOWLEDGEMENTS:

The authors sincerely thank SERB, Dept. of Science and Technology, India for providing the financial assistance vide order # FTYSS: SR/FTP/ETA-0134/2011 to carry out this research.

REFERENCES:

[1] Pulsar Ltd. 2006. *Magnetic Pulse Welding Solutions*, Raanana, Israel.

[2] A. Weber. 2002. The cold welding process is being used for more and more high-volume applications, *Assembly Magazine*, 1st August 2002.

[3] V.A. Glouschenkov, F.V. Grechnikov and B.S. Mayshev. 1997. Pulse-Magnetic Processing Technology when making parts units of aerospace engg., *J. de Physique IV France*, 7(C3), 45-48. http://dx.doi.org/10.1051/jp4: 1997310.

[4] R. Neugebauer, F. Loeschmann, M. Putz, T. Koch and G. Laux. 2006. A production oriented approach in electromagnetic forming of metal sheets, *Proc. 2nd Int. Conf. High Speed Forming*, Dortmund, Germany.

[5] V. Shribman. 2007. *Magnetic Pulse Welding of Automotive HVAC Parts*, Pulsar-Magnetic Pulse Solutions, 1-31.

[6] K.J. Lee, S. Kumai, Shinji, T. Arai and T. Aizawa. 2007. Interfacial microstructure and strength of steel/aluminium alloy lap joint fabricated by magnetic pressure seam welding, *Materials Science & Engg. A*, 471(1-2), 95-101. http://dx.doi.org/10.1016/j.msea.2007.04.033.

[7] T. Aizawa and M. Yoshizawa. 2001. Impulse magnetic pressure seam welding of aluminium and cupper sheets, *Proc. 7th Symp. Japan Welding Society*, Kobe, Japan.

[8] I. Masumoto, K. Tamaki and M. Kojima. 1980. *J. Japan Welding Society*, 1(49), 29.

[9] A.K. Jassim. 2010. Magnetic pulse welding technology *Proc. 1st Int. Conf. Energy, Power and Control*, University of Basrah, Iraq.

[10] A. Ben-Artzy, A. Stern, N. Frage, V. Shribman and O. Sadot. 2010. Wave formation mechanism in magnetic pulse welding, *Int. J. Impact Engg.*, 37(4), 397-404. http://dx.doi.org/10.1016/j.ijimpeng.2009.07.008.

[11] M. Marya, S. Marya and D. Priem. 2005. On the characteristics of electromagnetic welds between aluminium and other metals and alloys, *Welding in the World*, 49(5-6), 74-84. http://dx.doi.org/10.1007/BF 03263412.

[12] S.H. Carpenter and R.H. Wittman. 1975. Explosive welding, *Annual Review of Materials Science*, 5, 177-199. http://dx.doi.org/10.1146/annurev.ms.05.080175. 001141.

EDITORIAL NOTES:

Edited paper from International Conference on Advanced Design and Manufacture, 5-7 December 2014, Tiruchirappalli, Tamil Nadu, India.

GUEST EDITORS: Dr. T. Ramesh and Dr. N. Siva Shanmugam, Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli, Tamil Nadu, India.