Effect of Energy and Circuit Parameters on Electromagnetic Forming of AA-6061 Tube

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Abstract- *Electromagnetic Forming (EMF) is a high velocity forming process that can be utilized to form and join sheet and tube. It has several advantages over conventional forming as there is improved formability and wrinkling of the workpiece in EMF as compared to conventional process. In this paper, study on effect of energy on electromagnetic compression of high strength aluminum alloy has been reported. Aluminum alloy AA 6061 tube with outer diameter of 57 mm and 1mm thickness was compressed with 4 turns multi-turn axisymmetric compression coil. Energy up to 8kJ through single and double capacitor bank was supplied. Result shows that multi-turn coil can produce significant deformation of the tube and there is co-relation of energy and circuit current with deformation.*

Keywords- Electromagnetic forming (EMF), Aluminum alloy AA 6061, Multi-turn coil, Tube compression

I. INTRODUCTION

Normal trend in automobile manufacturing is to reduce the cost of the components, emission (for safer environment and human being) and weight. Now-a-days lightweight materials like alloys of aluminum and magnesium alloys are used for the purpose. In convention route of manufacturing, properties and long processing procedure are the problem. This becomes more difficult for intricate shape and geometry. High strain rate manufacturing can solve some of the problems. Electromagnetic forming facilitate high strain rate forming leading to high quality of the product like strength surface finish etc. Forming by EMF takes less time as compared to many advanced forming and joining processes. Usually, the process is completed in microseconds (μs). Electromagnetic forming is an eco-friendly process. So it is a green technology. Fastening has always been a challenging task in the field of joining especially in the automobile industry. Solid-state welding plays a vital role to join similar and dissimilar materials. There is no need of melting the base metals, no filler material is required.

These are the primary reason to use this process widely in the field of automobile, aerospace, and electronics based manufacturing areas. It gives an excellent product with enhanced productivity with financial benefits as suggested by A. Ben-Artzy et al. [1] and I. Oliveira [5]. According to the Choudhary et al. [2] the deformation of AA5182 sheets at elevated temperatures indicates the feasibility of the process in the temperature range of 50°C to 500°C. Kore et al. [7] studied the effect of process parameters like energy, stand-off-distance (SOD) and coil geometry on welding of Al-1050-O sheets. There is always an optimum SOD value which gives the highest strength and maximum weld width. Technique for welding Cu-to-Al, Cu-to-SS, Al-to-Al, Cu-to-SS, and Mg-to-Al has also been demonstrated successfully Kore et al. [8-13]. Hwang et al. [4] reported joining of a structural part using EMF for underwater applications. Joint strength has been studied theoretical as well as experimentally effect of various parameters like discharge energy, no. of discharge energy on joining of copper tube to polyurethane tube has been reported. Haiping et al. [3] reported bulging

Test conducted through two advanced processes that are electromagnetic forming (EMF) and electrohydraulic forming (EHF) on the aluminum tubes. Fan et al. [19] studied cladding of bi-metallic tube experimentally and through Finite Element Simulation. The Field shaper and its effect on the change in inclination angle were also investigated numerically and experimentally. Zhang et al. [17] reported riveting of aluminum alloy rivet (2A10) using the electromagnetic riveting technique. Dynamic mechanical properties of 2A10 were evaluated by the Split Hopkinson pressure bar while Johnson-cook material model has been used for describing it. Multi-field material model was used to carry out to calculate magnetic pressure, adiabatic temperature and deformation during the analysis of electromagnetic riveting. Maximum temperature and discharge voltage was found 252°C and 2.0 kV respectively, under the electromagnetic process. Park et al. [18] studied the joint strength of framework for automotive applications and analyzed with the help numerical simulation and strength test. The influence of geometrical parameter was also studied. Designing of axial joint and torque, joint has also been proposed for electromagnetic forming.

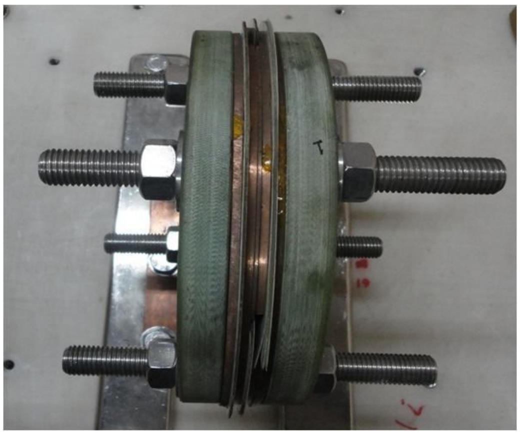
Patra et al. [14] developed a lap joint of pure copper and low carbon steel tubes by a magnetic pulse forming. Welded interface crated wavy and intermixed metal vertices. Microanalysis of interface weld part gives nano-grains along with inter-atomic diffusion. Mishra et al. [15] developed expansion welding of aluminum 6061 alloys with 40kJ magnetic pulse welding. Process parameters like frequency, peak current, magnetic field, workpiece geometry etc. have been studied to achieve the quality of the weld. Ahmed et al. [6] studied the distribution of magnetic force, magnetic field and current density due to flat forming coil. Studies were carried out on coil design. Geometry and material parameters were studied to compare uniform and non-uniform coils. The calculation of self-inductance and its meshing along with boundary conditions using the finite element method (FEM) has also been studied. In this paper, deformation tubes with respect to variable energy and circuit parameters have been studied. Two capacitors bank with different capacitance at different discharge voltage has been used to see the effect on deformation of tube.

II. EXPERIMENTAL

Experimental Description

Energy used for analytical model and experimental was 4.0 and 8.0 kJ and its verification geometry and material model were same. A four turn coil was used for experiments. Magnewin make capacitor bank with a maximum capacity of 40kJ and charging voltage of 20kV was used. The total capacitance of the unit was 200 μF that can deliver maximum short circuit current of 320 kA at 10-15 kHz frequency. The whole setup was divided into four banks. Single and double bank consists of four and eight capacitors with 56 μF and 112 μF capacitance respectively. A four turn axisymmetric multi-turn coil in conjunction with capacitor bank was used to compress aluminum tubes of different diameters and the same thickness of the tube, i.e. 1 mm [Fig 1 (a)]. Experiments were performed at different energy levels taking both single and double capacitor banks. The coil has an inner diameter (ID) of 57mm and outer diameter of 200 mm and effective length of 15.6 mm [Fig. 1 (b)]. The material used in the coil is copper and workpiece is made up of Aluminum Al-6061-T6. Its mechanical properties are listed in Table 1. Chemical composition of Al workpiece is listed in Table 2. During the experiments, some extra preventive measures were taken to prevent arc which was generated due to the high current passing through the primary circuit current is directly measured with the help of Rogowski coil. Gap between ID of the coil and OD of the workpiece was maintained 1.0 and 0.5mm and Deformation of tube was carried at room temperature. The Al tube is compressed at two levels of energy i.e., 4 kJ and 8 kJ discharged from single and double capacitor bank respectively. The waveform obtained from the discharge is shown in Fig. 2. It can be clearly seen that there is effect of capacitance in the resultant waveform. The rise time is slightly higher for double bank discharge as compared to single bank. There is significant increase in peak current at double bank as compared to single bank discharge. The peak current achieved for single and double bank is 50 kA and 100 kA respectively.

(a)



(b)

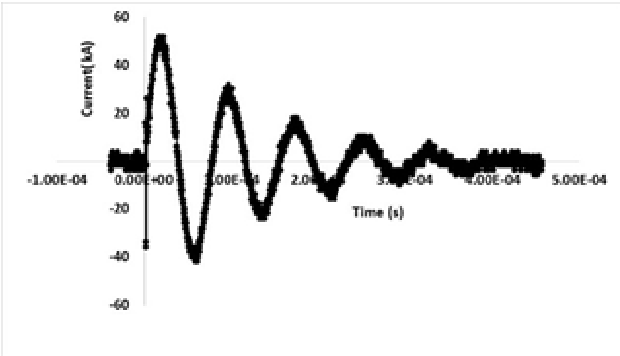
Fig. 1 (a) Al 6061 tube (workpiece) and (b) Four turn coil used in the experiments

Table-1 Mechanical properties of copper and aluminum

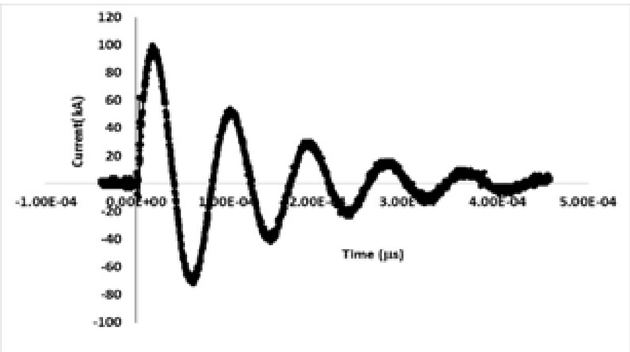
Material	Copper- Coil (Johnson and cook 1985)	Aluminum- tube (Guo et al.2005)
Density (kg/m^3)	8960	2700
Young's modulus (GPa)	124	69
Poisson's ratio	0.34	0.33

Table-2 Chemical Composition of Al6061-T6 (Weight %)

Si	Fe	Mg	Cu	Mn	Al
0.73	0.569	0.507	0.183	0.0924	rest



(a)



(b)

Fig. 2 Current waveform at (a) 4 kJ and (b) 8 kJ discharge

III. RESULTS AND DISCUSSION

The deformed tube was analyzed in terms of final outer diameter (OD) as compared to initial OD Table 3 list the results and percentage deformation of tube at different energy considered in the experiments. The OD was measured at central local of the tube with the help of digital vernier caliper with least count 0.01 mm. The central location is located at the middle of coil. The picture of both the deformed Al tube is shown in Fig. 3. It can be inferred that there is huge effect of energy on the deformation of the tube. The results shows that the tube is just 8.5 percent deformed with single bank 4 kJ discharge whereas there significant deformation of about 50 percentages at double bank 8 kJ discharge. Alternatively it can be argued that the velocity of deformation at single bank discharge must be very low as compared to double bank.

Table 3 Result of Electromagnetic forming of Al 6061 tube

No. of Banks	Energy/Voltage	Gap (mm)	Initial OD (mm)	Final OD (mm)	%age Deformation
Single	4kJ/12kV	1.0	55	50.33	8.5
Double	8kJ/12kV	0.5	56	27.78	50.4

(a)

(b)

Fig. 3. Al tube deformed at (a) 4 kJ and (b) 8 Kj

IV. CONCLUSIONS

Experimental analysis is carried out to study the deformation of the Aluminum tube at a constant thickness. A bitter type axisymmetric 4 turn coil is used to deform the tube. There is a significant effect of energy on the deformation of tube. Compression of more than 50% in tube diameter is achieved by just increasing one number of capacitor banks while keeping the same level of charging for both the bank. Single bank capacitors can only deform/compress the tube upto 8% of initial diameter. The increase in bank also alters the rise time/ frequency of the discharge current but it is not very significant.

V. ACKNOWLEDGEMENT

The authors would like to thank Director CSIR AMPRI, Bhopal for all help in the experiments.

REFERENCES

[1] A.Ben-Artzy,A.Stern, N.Frage, V.Shribman, O.Sadot, "Wave formation mechanism in magnetic pulse welding," International Journal of Impact Engineering, 37, 397-404, 2010.

[2] H.Chaudhary and S. D. Kore, "Electromagnetic forming analysis of AA5182 at elevated temperatures," Int. J. Microstructure and Materials Properties, Vol. 11, Nos. 1/2, 2016.

[3] H. Yu, L. Sun, X. Zhang, S. Wang, C. Li, "Experiments on electrohydraulic forming and electromagnetic forming of aluminum tube The International Journal of Advanced Manufacturing Technology," 89, 3169-3176, 2017.

[4] W.S. Hwang, J.S. Lee, N.H. Kim and H.S. Sohn, "Joining of copper tube to polyurethane tube by electromagnetic pulse forming, Journal of Materials Processing Technology," 37, 83-93, 1993.

[5] I. Oliveira, P. Teixeira, A. Reis, "Magnetic Pulse Welding of dissimilar metal: Influence of process parameters," ICHSF2014, May 26th-29th, Korea, 2014.

[6] M. Ahmed, S.K. Panthi, N. Ramakrishnan, A.K.Jha, A.H.Yegneswaran, R. Dasgupta, and S.Ahmed, , "Alternative flat coil design for electromagnetic forming using FEM," Transactions of Nonferrous Metals Society of China, 21(3), 618-625,2011.

[7] S.D. Kore, P.P. Date, S.V. Kulkarni, "Effect of process parameters on electromagnetic impact welding of aluminum sheets," International Journal of Impact Engineering 34, 1327–1341, 2007.

[8] S.D. Kore, P.P. Date, S.V. Kulkarni, "Electromagnetic impact welding of aluminum to stainless steel sheets," journal of materials processing technology 2 0 8,486–493, 2008.

[9] S. Kore, P. Date, S. Kulkarni, S. Kumar, M. Kulkarni, S. Desai, R. Rajawat, K. Nagesh, D. Chakravarty,"Electromagnetic Impact Welding of Al-to-Al–Li Sheets, Journal of manufacturing science and engineering," 131,034502,2009.

[10] S. Kore, J. Imbert, M. Worswick, Y. Zhou, "Electromagnetic impact welding of Mg to Al Science and Technology of Welding and Joining," 14,549-553,2009a.

[11] S. D. Kore, P. Date, S. Kulkarni, S. Kumar, D. Rani, M. Kulkarni, S. Desai, R. Rajawat, K. Nagesh, D. Chakravarty, "Electromagnetic impact welding of copper-to-copper sheets," International journal of material forming, 3,117-121,2010.

[12] S. Kore, J. Imbert, Y. Zhou, M. Worswick, "Electromagnetic pulse welding of magnesium to aluminium sheets," Welding and Joining of Magnesium Alloys, Elsevier, , pp. 367-379,2010a.

[13] S.D. Kore, P. Date, S. Kulkarni, S. Kumar, D. Rani, M. Kulkarni, S. Desai, R. Rajawat, K. Nagesh, D. Chakravarty, "Application of electromagnetic impact technique for welding copper-to-stainless steel sheets," The International Journal of Advanced Manufacturing Technology, 54,949-955, 2011.

[14] S. Patra, K.S. Arora, M. Shome, S. Bysakh, "Interface Characteristics and Performance of Magnetic Pulse Welded Copper-Steel Tubes," Journal of Materials Processing Technology, 245,278-286, 2017.

[15] S. Mishra, S.K. Sharma, S. Kumar, K. Sagar, M. Meena, A. Shyam, "40 kJ Magnetic Pulse Welding System for Expansion Welding of Aluminum 6061 Tube," Journal of Materials Processing Technology, 240,168-175,2017.

[16] W.S. Hwang, J.S. Lee, N.H. Kim and H.S. Sohn, "Joining of copper tube to polyurethane tube by electromagnetic pulse forming," Journal of Materials Processing Technology, 37 83-93,1993.

[17] X. Zhang, H.P. Yu, C.F. Li, "Multi-filed coupling numerical simulation and experimental investigation in electromagnetic riveting," The International Journal of Advanced Manufacturing Technology, 73,1751-1763,2014.

[18] Y.-B. Park, H.-Y. Kim, S.-I. Oh, "Design of axial/torque joint made by electromagnetic forming Thin-walled structures," 43,826-844, 2005.

[19] Z. Fan, H. Yu, C. Li, "Plastic deformation behavior of bi-metal tubes during magnetic pulse cladding: FE analysis and experiments, "Journal of Materials Processing Technology 229,230–243, 2016.