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# INTERFACE MORPHOLOGY IN ELECTROMAGNETIC WELDED ALUMINIUM- STAINLESS STEEL TUBULAR STRUCTRE

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**Abstract:** Electromagnetic welding (EMW) uses high speed Lorenz force for joining two materials. Unlike conventional welding, EMW takes place in the solid state. This paper presents behaviour of interface morphology for EMW of tubular 6063-Aluminium to 304 stainless steel rod. The interface changes from flat morphology to wavy morphology when welded at higher input energy.
**Keywords:** Electromagnetic welding, Dissimilar materials, Aluminium, Stainless Steel.

## I. INTRODUCTION

In spite of recent developments, fusion welding techniques are limited to joining of metallic parts with comparable melting temperatures. Cold welding techniques like explosive welding (EXW) or electromagnetic welding (EMW) provide an alternative for joining of dissimilar metals of large difference in melting temperature. In both EXW and EMW, joining takes place under high velocity impact force, establishing an atomic bonding at the interface. Due to the environment-friendly nature of welding which takes place in few micro seconds, EMW has gained more focus over EXW in the last decade. EMW uses pulsed magnetic force to generate repelling Lorenz force on the surface of one the parts called as flyer which is driven on to another part to be joined called as target [1].

EMW has been extensively used for joining large combinations of dissimilar materials which are used in several applications like air conditioning chambers, drive shafts, micro devices, air conditioning accumulators [2]and so forth. Though EMW has been used for several metal pairs, weld features differed among the investigators. Among the many process parameters impact velocity has a major influence on the morphology of the interface. Correlations between weld strength and interface morphology has been reported by many researchers. Several literature indicated that presence of wavy morphology is a prerequisite for good bonding [3]. However few other investigators contradicted that presence of wavy morphology at the interface is not a prerequisite for an effective bonding [4].This paper attempts to explain the morphology of the interface for EMW of6063-Aluminiumto304 stainless steel tubular structure under different discharge energies.

## II. METHODOLOGY

Commercially available 6063-Aluminum tubular structure was welded to 304 stainless steel rod in the as received condition. Based on the rated energy of the EMW machine and easy availability, the flyer tubes were selected at diameter of 47mm, 2mm thickness with a standoff distance of 1mm and impact angle of 5º for the study. Schematic diagram of the EMW set up is shown in Fig.1



 

The experiments were carried out using a 40kJ/ 20kV electromagnetic welding machine. The electromagnetic coil used in the experiment was made of copper beryllium, three effective turns with an active length of 20mm (**Fig. 2**). The welding set up includes parallel connected capacitor bank, triggering switch, flyer tube with the target rod assembly placed inside bitter coil. Input energy for welding was varied from 18.9 kJ to 27.4 kJ. The weld qualities were evaluated by sectioning the sample and analyzing the interface under scanning electron microscopy (SEM).

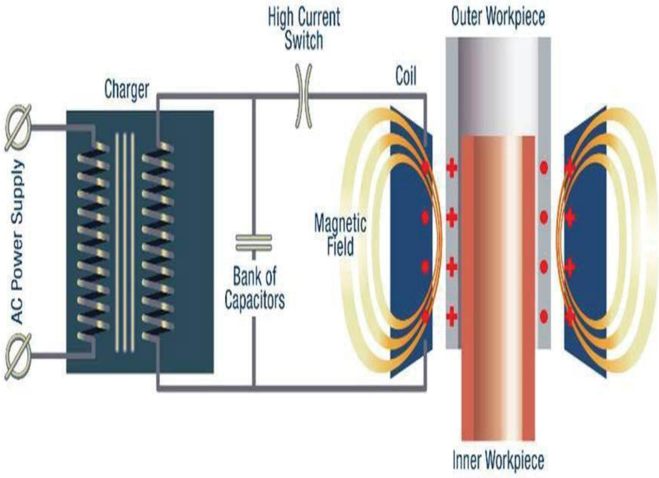


Fig. 1 Schematic diagram of EMW setup [5]

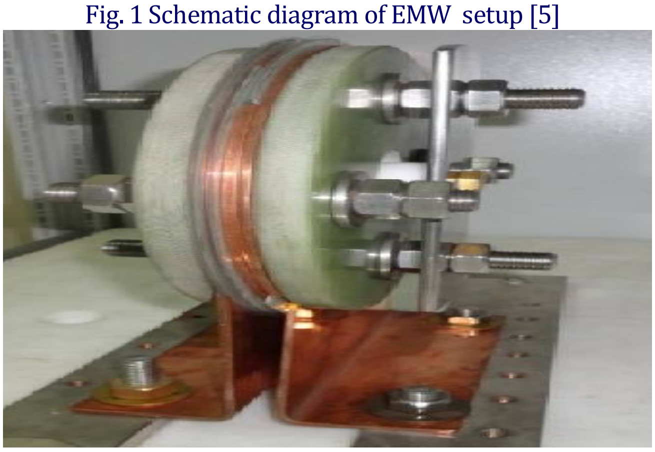

Fig.2 Electromagnetic coil [6]

## III. RESULTS AND DISCUSSION

The general appearance of the welded and cross sectioned samples for the input energy from 21.5 kJ to 27.4 Kj indicated forming of the aluminium flyer on to the steel target (**Fig.3**). Visual examination of the cross sectioned sample indicated absence of any gap at the interface of the Al-Steel.

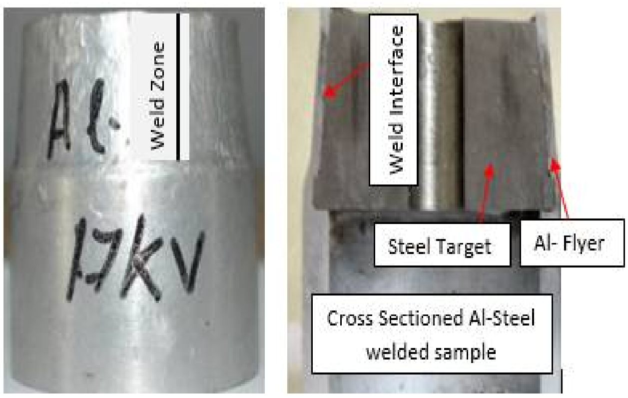


Fig. 3 Welded and Cross-sectioned Al / SS Tubular sample



 

Interface images from SEM for different input energies are shown in the **Fig.4 to Fig.6.**At 21.5kJ input energy, the interface looked flat, devoid of any gap between the two metals, though aluminium side looked buckled at some locations along the interface (**Fig. 4**).

At 24.3 kJ input energy, the interface had very smooth and regular wavy morphology ideal for any EMW (**Fig. 5**). A thin boundary line in the corrugated form was separating both the flyer and target. There were no transition or intermediate zones for both the input energies as observed under different magnifications. Interface transformed from flat at low energy to smooth regular wavy structure at higher energy.

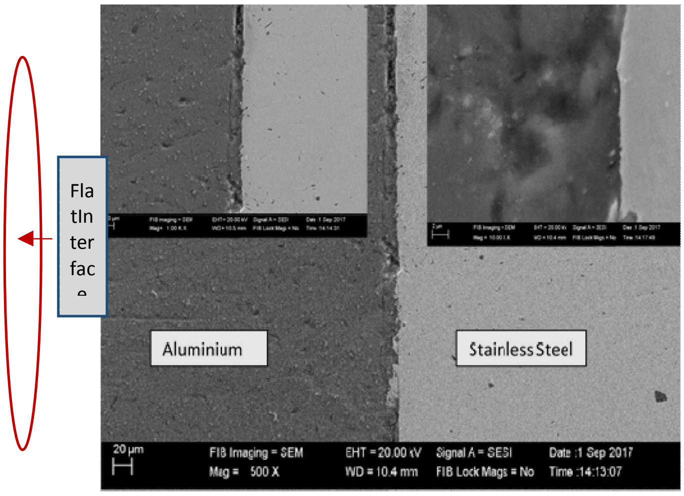


Fig. 4 Al / SS interface at 21.5 kJ

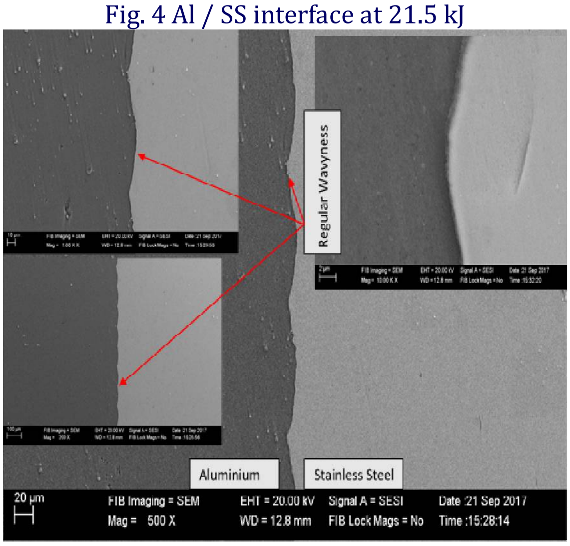


Fig.5 Al / SS interface at 24.3 kJ



 

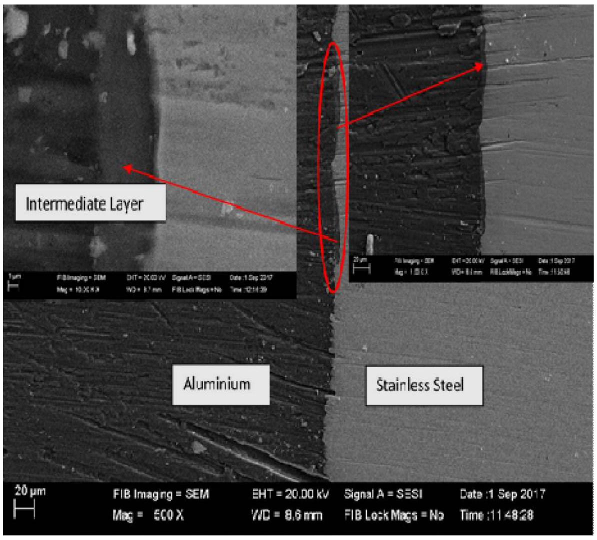


Fig. 6Al / SS interface at 27.4 kJ

At 27.4 kJ input energy, the welded joint was observed with a thin transition zone at some locations along the interface (**Fig. 6**). The transition layer was less than five microns width with the clear disparate structure formed from elements of both the base metal. The literature on Al / Steel welding of tubular lap structure [7] and plate lap structures [8], supported the formation of both types of interface with and without transition zone. According to Fan et al., [9] the interface separating the base metals were characterized by the presence of transition zone with amorphous region of fewer than 10 nanometers attributed to the transient melting.

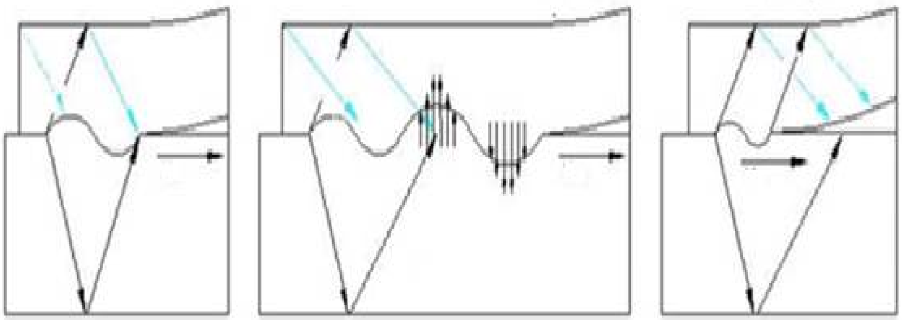

Fig.7 Kelvin-Helmholtz instability versus shockwaves [10]

Wavy morphology was attributed to the Kelvin-Helmholtz instability[10], which is an interaction of pressure waves and collision point velocity (**Fig. 7**). Impact of the flyer induces compressive pressure waves or shock waves at high speed through the target material at the collision point. Target being stationary, velocity difference is created between flyer and target, analogous to movement of two fluids over each other at a velocity difference. Under extreme impact condition of peak pressure and heat, mutual mass transfer of metal takes place between target and flyer.

Formation of the transition zone was attributed to rapid temperature rise combined with increased magnetic pressure associated with increased impact velocity used to drive the flyer. Impact velocity increases with increased input energy. Thus leading to mass transportation of atoms of the base metals in the solid phase. On the whole it may summarised that impact velocity increases with increase in the input energy and the interface morphology changes accordingly from flat to wavy or wavy with transition zone.

## IV. CONCLUSIONS

Electromagnetic welding of 6063aluminium to 304 stainless steel was carried out at different input energies and following conclusions are drawn.



 

- Metallurgical bonding was absent for input energy below 18.kJ, with the flyer debonded from the target.
- Weld interface at input energy of 21.5 kJ was having flat morphology devoid of any gap or transition zones.
- Weld interface at input energy of 24.3 kJ was having wavy morphology devoid of any gap or transition zones.
- Weld interface at input energy of 27.4 kJ was having wavy morphology with a thin transition zone separating the flyer and target. Thus indicating the influence of input energy and change in the morphology from flat to wavy interface with transition zone when welded at increased input energy.

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