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Technical Paper

Microstructural and mechanical performance of ultrasonic spot welded Al–Cu joints for various surface conditions

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ABSTRACT

The ultrasonic metal welding (USMW) offers a potential solution to join highly thermal conductivity dissimilar materials like aluminium and copper. In this work, the effects of different welding parameters and surface conditions like lubricated, normal, electrolytic polished and emery polished are investigated to obtain the maximum mechanical strengths of the weld joints. The results show that tensile shear and T-peel failure loads increased with weld time and reached the highest value of 1550.48 N and 370.46 N, respectively. It is also observed that these joint strengths decreased with the increase of surface roughness because of the disappearance of relative motion between the sheets. Thus, the temperature that is obtained from emery paper condition is the lowest among all the four surface conditions. Meanwhile, the maximum interface temperature obtained when the ethanol droplet is added to the faying surface. This is to say, a substantial plastic deformation is observed at the welded region due to this high temperature of 375 °C and thus, it facilitates the rupture of the oxide film. From the microstructural analysis, a dimple pattern is noticed in the welding zone, indicating an expansion of weld area and grain refinement has been taken place due to the adhesion of ethanol. Similarly, the microhardness study also revealed that there is no formation of the large heat affected zone in USMW. An average microhardness of HV 88.45 is observed for the joint which is quite high than other solid state welding processes.

1. Introduction

Battery electric vehicles (BEVs) involving hybrid electric vehicles with improved microelectronics circuits have received a lot of consideration in the automobile sector. The performance of these vehicles depends solely on power and energy of the batteries. So, to fulfil this objective, dissimilar material joining is necessary. Aluminium (Al) and copper (Cu) materials are desired due to its higher thermal and electrical conductivity, mechanical and corrosion resistance properties. These properties make Al–Cu joints more suitable for steel in electronics systems [1]. Unfortunately, joining of these materials by traditional fusion welding process produces bulk and brittle intermetallic compounds (IMCs), average weld strength and a high degree of distortion [2]. Due to this reason, an alternative solid state welding process came up with the absence of these inferior properties. However, when Al–Cu was tried to weld by friction welding, it showed poor weld strength with IMCs at the weld interface [3]. Likewise, Ouyangetet al. [4] reported that when the friction stir welding (FSW) employed to weld Al–Cu, then brittle IMCs like Al_4Cu_9 and Al_2Cu formed along with micro cracks in the interface zone. But, ultrasonic metal welding (USMW) is one such type of welding process, which uses high-frequency vibration energy to weld Al–Cu with a reasonable amount of weld pressure [5]. The major advantages of this process are the short welding time and low energy consumption. This makes the process more efficient than the resistance spot welding (RSW) and FSW [6].

From the previous literature, it can be concluded that vibration energy and weld time are the two key factors for the formation of joints between dissimilar materials in USMW. At the same time, the size and growth of the IMC layer also determine the weld strength. However, there are still many points related to the surface conditions of the weld interface, but they are not adequately defined and explained. Watanabe et al. [7] investigated the effects, thermal conductivity and roughness on the bond strength of Al–Cu and Al-SUS304 materials. They found the high thermal conductivity materials like Al–Cu showed little bond strength than the low thermal conductivity combinations like Al-SUS304. Hiraishi and Watanabe [8] also examined the weldability of specimens by preheating and adding alcohol (ethanol) with water to the faying surface. They observed the amplified relative motion between the sheets and highest interface temperature during the welding with ethanol adhesion. Thus, the weld area sharply increases, and the

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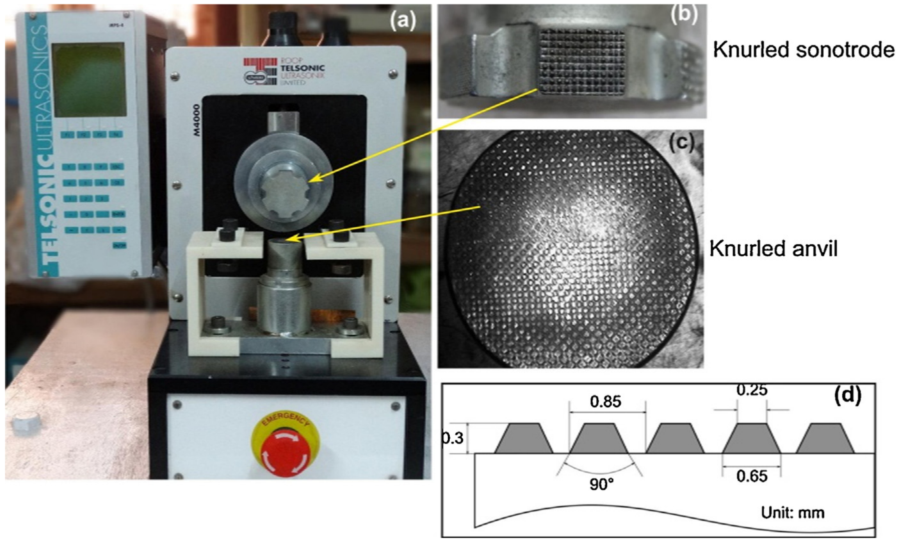

Fig. 1. M4000 ultrasonic welder.

joint strength was improved by the modification of surface conditions and pre-heating of weld samples. Again, Watanabe et al. [9] used ultrasonic welding to join A6061 aluminium alloy for automobiles. As the weld strength is a crucial factor in this type of industries, they added ethanol in a dropwise manner. Therefore, the temperature of the interface increased and created a large plastic deformation area. Similarly, when the joint is formed by mild steel and aluminium alloy sheet, there is a formation of Fe_2Al_5 IMC at the interface. Thus, it decreased the weld strength of joint. In order to avoid this phenomenon and to increase the strength, pure aluminium was used as the insert material [10].

The aim of the present study is to weld Al and Cu using ultrasonic welding method and to investigate the effects of various welding conditions on the tensile shear and T-peel strength of the joint. Furthermore, the impact of different surface roughness and microhardness of the faying surface on the bond strength are also studied. The microstructural analysis of the welded zone is also analysed in detail.

2. Experimental test methods

A Telsonic® M4000 ultrasonic welder was used in this study having a rated power of 3000 W and vibration frequency of 20 kHz which was acted parallel to the faying surface. The maximum amplitude of weld tip was 68 μm under no loading condition. The welding tip of 9 mm × 11 mm with knurled patterns was engaged in welding of Al–Cu samples as shown in Fig. 1. The anvil also had a similar type of patterns on it to provide sufficient relative motion between the sheets and prevent the slippage during the welding. The detailed experimental domain is presented in Table 1. During the experiment, the weld energy is transferred to the faying surface and is controlled by changing the weld time while other two parameters are kept constant.

Table 1
Experimental domain.

Parameters	Terms	Domain of experiment
Amplitude (μm)	A	68
Weld pressure (MPa)	P	0.38
Weld time (s)	T	0.5–0.9
Frequency (kHz)	f	20

The commercially available sheets of 0.7 mm thick AA1100 aluminium and 0.4 mm thick UNSC10100 copper were lap welded. The dimension and shape of the weld samples were rectangular and 20 mm wide × 100 mm long. The configuration is shown in Fig. 2. As the AA1100 samples are softer than UNSC10100 samples, thus Al sheets were placed on the Cu sheets. Table 2 presents the mechanical and thermal properties of the weld specimens. In the meantime, the condition of the welding surface profoundly affected the mechanical strength of joints. So, some treatment of the faying surface was necessary. In this study, four surface conditions like lubricated, normal, electrolytic polished (EP) and emery

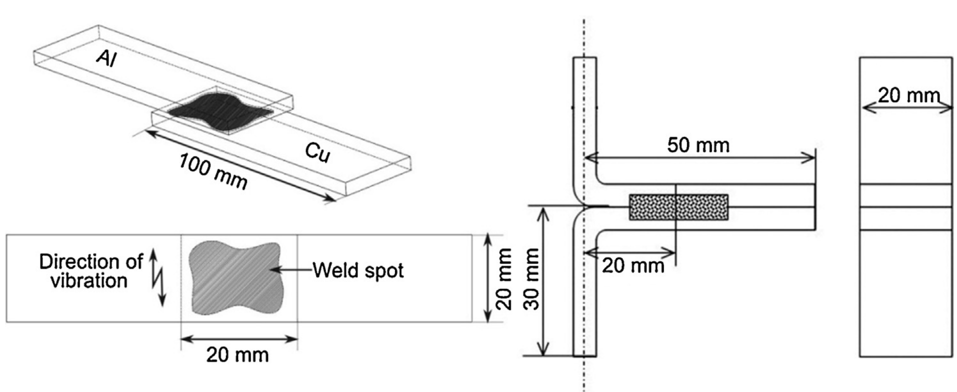

Fig. 2. Schematic diagrams of weld coupons.