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Evaluation of laser braze-welded dissimilar Al-Cu joints

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Abstract

The thermal joining of Aluminum and Copper is a promising technology towards automotive battery manufacturing. The dissimilar metals Al-Cu are difficult to weld due to their different physicochemical characteristics and the formation of intermetallic compounds (IMC), which have reduced mechanical and electric properties. There is a critical thickness of the IMCs where the favored mechanical properties of the base material can be preserved. The laser braze welding principle uses a position and power oscillated laser-beam to reduce the energy input and the intermixture of both materials and therefore achieves minimized IMCs thickness. The evaluation of the weld seam is important to improve the joint performance and enhance the welding process. This paper is focused on the characterization and quantification of the IMCs. Mechanical, electrical and metallurgical methods are presented and performed on Al1050 and SF-Cu joints and precise weld criteria are developed.

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Keywords: laser; dissimilar; braze-welding; aluminum; copper; evaluation

1. Introduction

The main challenges for the automotive industry are reducing energy consumption and emissions, e.g. by reducing weight and cost of wiring harnesses. Dissimilar aluminum-copper connections could be used to achieve these goals, as described by (Bergmann, et al., 2013). Furthermore, the joining of Li-Ion battery electrodes, usually made of Al and Cu, is a key technology for manufacturing battery electric vehicles.

The welding of non-solvable dissimilar metals, such as Al and Cu, is considered as difficult because of the inevitable formation of intermetallic compounds (IMC). Based on partial covalent and ionic connections, IMC are energetic more stable than pure metallic connections (Worch, et al., 2011). Thus, IMC are hard, weak conductors, see table 1, with reduced elongation properties. Aluminum and copper are two dissimilar metals with reduced

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solubility, the thermal joining will cause brittle joints with higher resistance. In addition, the different melting point and thermal expansion must be considered, as well as the electrochemical corrosion (Kannatey-Asibu, 2009).

In order to maintain the desirable properties ductility and toughness of the metallic base material, the formation of IMC should be avoided. Due to the fact that a material connection of dissimilar metals demands IMC, they cannot be eliminated, but it was shown, that the minimizing of the IMC thickness results in high quality joints, shown by (Borrisutthekul, et al., 2007), (Abbasi, et al., 2001) and (Solchenbach, et al., 2013).

Table 1. Properties of intermetallic phases in the Aluminum-Copper system.

Phase	Nominal composition	% at Al. (Murray, 1985)	Electrical resistivity ρ at 20° C [μΩ cm] (Rayne, et al., 1980)	Hardness HV (10g) (Solchenbach, et al., 2013)	Hardness (Braunovic, 1994)	Hardness HV (Chen, et al., 2007)
(Cu)		0-19.7	2.0	75	-	70
γ	Al_4Cu_9	31-37.5	14.2	770	-	750
ζ	Al_3Cu_4	43.7-44.8	12.2	930	624	850
η	AlCu	47.6-50.2	11.4	905	648	900
Θ	Al_2Cu	67-68.1	8.0	630	413	650
(Al)		97.52-100	2.4	36	-	35

The minimizing of the intermetallic layer can be performed by minimizing the intermixture of the metals and reducing the process time to avoid diffusion. Regarding the solid-state fusion processes (Hügel, et al., 2009), the laser welding presents the advantages of contactless power delivery and fast process times based on the low-inertia positioning system. Copper and Aluminum can be joined by using filler material (Weigl, et al., 2011) or roll-cladded inserts (Weigl, et al., 2010). We will focus on the braze-welding principle (Solchenbach, 2014), which will be explained in the next chapter.

In order to evaluate the quality of a welded joint, the classical pull test can be performed. More dedicated methods to analyze the formatted IMC are described by (Mai, et al., 2004), who used cross sections and x-ray photographs to investigate the mixing behavior, the microstructure and the presence of defects, such as cracks. Based on the electric resistivity of the IMC, a resistance measurement can reveal the joint quality, as shown by (Solchenbach, et al., 2014). The author showed that a low resistance of the weld is equivalent to good mechanical properties. SEM and EDX was used by (Xue, et al., 2013) to characterize the melt pool and to build up a simulation model for attributes prediction. (Weigl, et al., 2011) used a hardness measurement method to rate the sensitivity of the weld towards cracks and to evaluate the ductility of the joint. They declared the joint with lowest hardness as the most ductile, which was also confirmed by fracture surface analysis and bending tests.

In this paper, methods to evaluate the quality of a laser welded dissimilar Al-Cu joint will be described. Current methods will be enhanced and adapted for the braze-welding process. The goal is to use the evaluation methods to rate the overall quality of dissimilar Al-Cu joints. The methods will be described in chapter 2 as they were used in chapter 3 to perform the experiments.

2. Experimental setup / methods

2.1. Braze-welding

The braze-welding principle is a modified laser welding process based on the keyhole welding principle, which is described by (Dowden, 2009). The formation of brittle IMC is minimized by reducing the intermixture of both metals. The aluminum sheet is positioned in overlap configuration on top of the copper sheet, see Fig 1 (a). The aluminum is liquefied by the introduced laser energy while the copper remains in solid state. Thus, a minimized fusion zone between both materials is formed and the formation of IMC is limited. The width of the fusion zone is defined by a spatial oscillation and power input by power modulation, see Fig. 1 (b). (Solchenbach, et al., 2013)