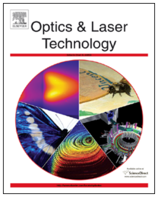
Optics & Laser Technology 54 (2013) 249–256

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec



Mechanical characteristics of laser braze-welded aluminium–copper connections

Tobias Solchenbach*, Peter Plapper

University of Luxembourg, FSTC, 6, rue Coudenhove-Kalergi, L-1359 Luxembourg, Luxembourg

ARTICLE INFO

Article history:
Received 17 January 2013
Received in revised form
27 May 2013
Accepted 4 June 2013
Available online 29 June 2013

Keywords:
Laser braze-welding
Aluminium
Copper

ABSTRACT

The mechanical characteristics of dissimilar Al–Cu connections, joined by a novel, robust laser braze-welding process are reported. A fiber laser is used in combination with a 2D galvoscanner to provide spatial power modulation by superposed circular beam oscillation. With the help of statistical experimental design, a broad range of processing parameters has been investigated in order to understand their effects on the joint characteristics. A maximum shear strength of 121 MPa has been detected within the scope of the experiments.

1. Introduction

The growing demand for complex and highly integrated products leads to the need of combining the very specific characteristics of dissimilar materials. Especially the combination between aluminum and copper provides very complementing properties, i.e. high thermal and electrical conductivity of the copper and the low volumetric density of the aluminum.

Beside applications like heat exchangers or solar absorbers, mainly the electric and electronic sector uses aluminum and copper in several areas. A battery module assembly task is exemplary shown in Fig. 1, where the terminals of several pouch type Li-ion cells have to be interconnected. Generally, the battery terminals have a thickness of 0.2 mm. Also connections of battery cells to bus bars are common which means combining different gauge sizes, e.g. thin Al to thick Cu.

From the Al–Cu equilibrium phase diagram [1], several intermediate intermetallic compounds (IMC) can be found. Table 1 shows the main properties and characteristics of four selected compounds, which are taken from [2].

It can be seen that intermetallic compounds feature very different mechanical properties compared to pure aluminum and copper.

The increased hardness can be explained by the increasing ionic, covalent and the reduced amount of metallic bonding phenomena. Furthermore, the complex crystal structure restrains the reduction of stress which leads to high brittleness. Reduced metallic bonds, thus, the non-existence of an electron gas, also results in higher electrical resistivity compared to the high-conductive base materials. Especially the copper-rich compounds feature the highest hardness.

From Braunovic [3], it is known that an Al–Cu interface behaves highly brittle for intermetallic layer sizes over a width of 2–5 μm. Below this critical width, a ductile behavior has been observed [4]. Furthermore, also the interface strength increases strongly with decreasing phase width. Thus, the size of the intermetallic compounds must be as small as possible to provide ductile interface characteristics with high strength.

Due to the formation of intermetallics, aluminum and copper have to be considered as “not weldable” with conventional joining methods [5]. However, several other technologies are subject of current research.

Beside solid-state welding technologies, i.e. friction stir welding, ultrasonic welding, electro-magnetic pulse welding or laser roll cladding, especially laser beam welding has been subject of many researchers, see [6–9], to name only a few. The main idea is to minimize the heat input and the processing time as well as to have temperature gradients far away from equilibrium in order to limit the formation of intermetallics. Laser light poses some distinctive advantages due to the very high intensity and flexibility in controlling the heat input into the materials.

As the mentioned approaches are based on deep welding phenomena, the main disadvantage is the intermixture of both aluminum and copper as a result of Marangoni convection which leads to a strong formation of intermetallic compounds. Fig. 2 shows a SEM micrograph of a fiber laser welded aluminum—Ni-plated

---

* Corresponding author. Tel.: +352 466644 5849.
E-mail addresses: tobias.solchenbach@uni.lu (T. Solchenbach), peter.plapper@uni.lu (P. Plapper).

0030-3992/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.optlastec.2013.06.003

copper connection at 400 W and 200 mm s^{-1} [10]. The high intermixture between both materials can be clearly seen by high aluminum amounts in the copper layer and the light-gray shadows of copper in the aluminum melt. The right half of the graph indicates the wide spread intermetallic layer in detail.

Different approaches have been taken into account to minimize the growth of intermetallics. Mai et al. [6] have investigated different material combinations in butt joint configuration. By adjusting the laser irradiated zone, the amount of the molten materials can be controlled. However, hardness in the weld zone is still very high. Weigl et al. [8] use filler materials to improve the hardness and therewith the ductility of dissimilar joints. Tensile strength up to 105 MPa has been achieved with this approach. High-frequent beam oscillation is used by Schmidt et al. [9] in deep welding mode in overlap configuration to enhance the intermixture by a more turbulent melt pool. This approach is adapted to butt configuration by Kraetzsch et al. [11]. Here, strength of 80 MPa at butt joints has been achieved. Hailat et al. [12] have measured up to 650 N of shear strength for Al–Cu overlap joints, which corresponds to 146 MPa stress in the aluminum layer. With a tin interlayer between aluminum and copper, the strength has been increased to 780 N.

Summing up, the main drawback of the mentioned technologies is the intermixture of the base materials which, as discussed, leads to a strong growth of intermetallics.

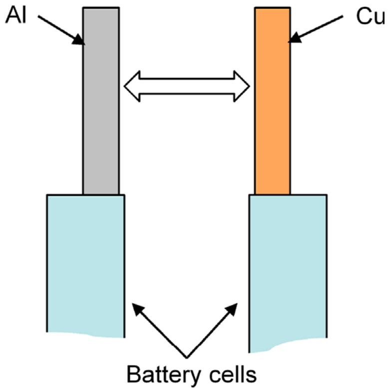


Fig. 1. Battery module assembly.

Table 1
Selected intermetallic compounds in the Al–Cu system.

Phase	Composition	Crystal structure	Atoms per unit cell	Hardness HV (10 g)
Cu	100% Cu	Face-centered cubic	12 Cu	75
γ_2	Al_4Cu_9	Body-centered cubic	36 Cu, 16 Al	770
ζ_2	Al_3Cu_4	Monoclinic	12 Cu, 9 Al	930
η_2	AlCu	Body-centered orthorhombic	10 Cu, 10 Al	905
θ	Al_2Cu	Body-centered tetragonal	4 Cu, 8 Al	630
Al	100% Al	Face-centered cubic	12 Al	36

2. The combined laser braze-welding process

To overcome this issue, laser light can be used for the selective melting of one material for dissimilar combinations during a combined laser braze-welding process [13]. This process has been investigated for several material combinations [14–17]. However, for aluminum and copper, no results have been reported.

A laser beam irradiates the aluminum surface and melts the Al layer. The Al melt wets the copper surface and the diffusion process between both materials is started.

To provide a stable keyhole welding process in the aluminum layer, a small beam diameter is chosen for high intensity on the aluminum surface. Additionally, a circular spatial power modulation is superposed to the feed direction in order to enlarge the interface width, see Fig. 3.

The trajectory of the superposed movement can be described according Eq. (1)

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} -a\ \cos(2\pi f t) + vt + a_0 \\ -a\ \sin(2\pi f t) \end{pmatrix} \tag{1}$$

with

f	repetition frequency (Hz)
a	amplitude of circular movement (mm)

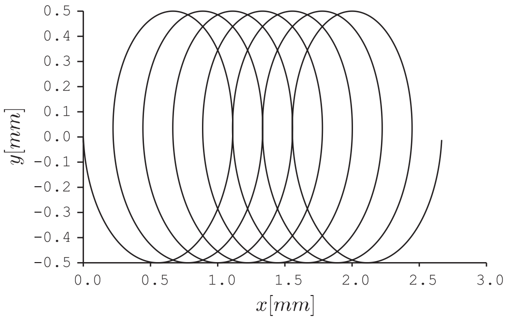


Fig. 3. Superposed circular beam movement.

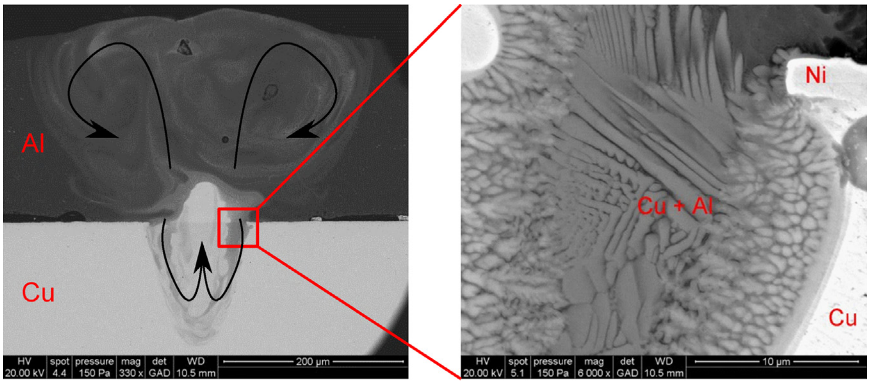


Fig. 2. SEM micrograph of a Al–Cu connection, welded with a fiber laser.