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Low electrical resistance of aluminum to copper joints achieved with temporal and spatial laser beam modulation

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Abstract

Laser welding of pure copper (Cu-OF) to aluminum (Al99.5) in overlap configuration was investigated. It is shown, that temporal modulation of the laser power reduces the electrical resistance by suppressing inherent instabilities in the welding process when using copper as the top sheet. The resistance could be reduced by about 12% down to 1.7 μΩ in this configuration. Spatial modulation of the laser beam allows to adjust the averaged copper content of the weld seam when using aluminum as the top sheet by controlling the width and depth of the junction. With this, aluminum to copper welds with low electrical resistance of 1 μΩ could be achieved.

Keywords: laser welding; copper; aluminum; dissimilar metals; laser power modulation; spatial beam modulation

1. Introduction

Joining of aluminum (Al) and copper (Cu) is of interest for electrical applications, such as e-mobility as shown by Kirchhoff, 2013. Therefore, especially the electrical resistance of the joints is important for this material combination. Besides the differing thermophysical properties of the two materials the formation of intermetallic phases in the weld seam poses a challenge for the joining process. These intermetallic phases have a higher electrical resistivity than the base materials as shown by Rabkin et al., 1970. So the formation of intermetallic phases increases the electrical resistance of the joint which is unfavorable and therefore the formation of intermetallic phases has to be minimized by the application of appropriate processing strategies.

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In this proceeding it is shown that temporal and spatial modulation of the laser beam are suitable means to reduce the electrical resistance of aluminum to copper dissimilar welds.

2. Results

The materials used for the experiments were pure copper (Cu-OF) and pure aluminum (Al99.5). The material sheets had a thickness of 1 mm each and were joined by remote laser welding without additional material in overlap configuration. The length of the weld seams was 35 mm. The electrical resistance of the welds was measured to evaluate the quality of the produced weld seams. A four point measurement setup was used for the measurement of the electrical resistance. Fig. 1 shows a sketch of the measurement setup. The measured resistance $R_m = R_{Cu} + R_{Al} + R_{weld}$ is the sum of the resistances of the copper sheet (R_{Cu}), the aluminum sheet (R_{Al}), and the weld seam (R_{weld}). Of interest for the investigations is only the resistance of the weld seam itself R_{weld}. The contribution of $R_{Cu} + R_{Al}$ to the measured resistance R_m was deduced to be 21 µΩ. This offset was subtracted from each measurement to obtain the resistance of the weld seam itself. All the values of the electrical resistance reported in the following were obtained in this way.

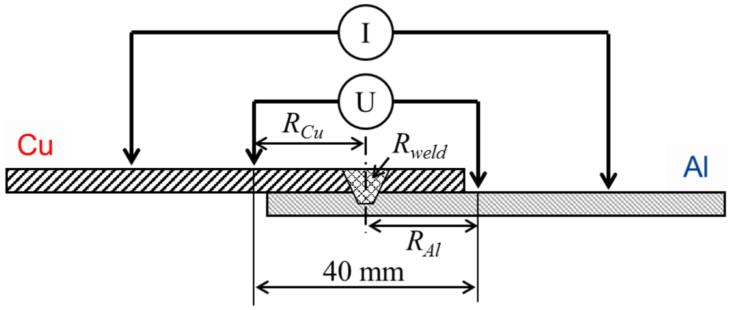

Fig. 1. Sketch of the setup used for measurement of the electrical resistance.

2.1. Temporal modulation of laser power

Cw laser welding of Cu to Al shows inherent instabilities when Cu is used as the top sheet as shown by Jarwitz et al., 2015(1), Fetzer et al., 2015(1), Fetzer et al., 2015(2), Jarwitz et al., 2015(2), Fetzer et al., 2015(3), and Jarwitz et al., 2017. These instabilities lead to large fluctuations in the penetration depth of the lower sheet. The top of Fig. 2a) shows a longitudinal section of such a weld. These instabilities can be suppressed by applying a temporal modulation of the laser power. In this case a sinusoidal modulation of the laser power was used. A longitudinal section of a weld produced with a modulation frequency of 200 Hz is shown at the bottom of Fig. 2a). In Fig. 2b) the electrical resistance of the welds is shown as a function of the modulation frequency of the laser power. The electrical resistance of the weld can be reduced by about 12% to a value of about 1.7 µΩ by applying a temporal modulation of the laser power.

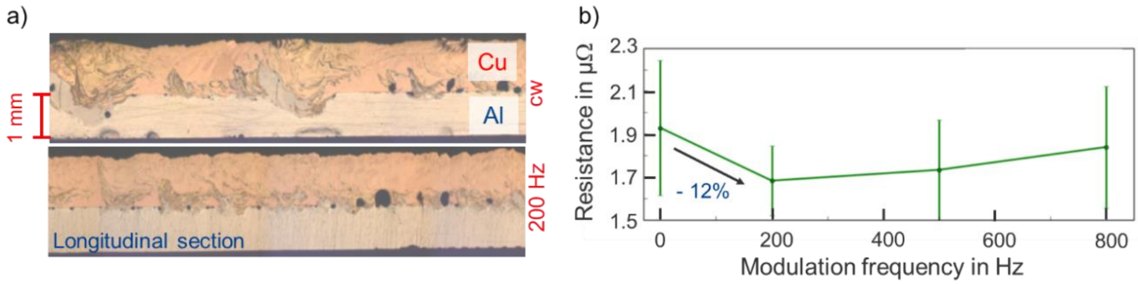

Fig. 2. a) Longitudinal sections of copper to aluminum welds produced by cw welding (top) and temporal modulation of the laser power with a frequency of 200 Hz (bottom). b) Resistance of the weld seams in dependence on the modulation frequency of the laser power. Parameters: P_{av} = 3.5 kW; a = 0.5 kW; v = 9 m/min; d_f = 260 µm, λ_{Laser} = 1.08 µm.

2.2. Spatial modulation of laser beam

Spatial modulation of the laser beam has already been used successfully in laser welding of aluminum-copper dissimilar joints as shown by Gedicke et al., 2007, Solchenbach et al., 2014, Walter et al., 2014, Fetzer et al., 2016, and Jarwitz et al., 2017. For the investigations reported here, spatial modulation of the laser beam was applied to laser welding of aluminum to copper with aluminum as the top sheet. The laser beam was oscillated perpendicular to the feed direction. A Scansonic RLW-A scanning optics was used for this. The frequency was varied between 0 Hz and 1000 Hz and the amplitude between 0 mm and 1 mm. The calculated, averaged copper content was taken as a measure for the mixing of both materials. It was obtained from the molten areas of copper and aluminum from the cross-sections, weighted by their densities. The spatial modulation of the laser beam allowed to adjust the seam width at the interface of the sheets and the penetration depth in the lower sheet virtually independently of each other. This allowed to adjust the mixing ratio of the two materials. Fig. 3a) shows a cross-section of an aluminum to copper weld produced with spatial beam modulation with a frequency of 1000 Hz and an amplitude of 0.5 mm. Fig. 3b) shows the electrical resistance of the welds as a function of the averaged copper content of the weld seam produced with and without spatial modulation of the laser beam. Spatial modulation of the laser beam allowed to reduce the electrical resistance of the welds down to about 1 µΩ. Low electrical resistances were obtained at low averaged copper contents of < 10 weight-%. With unmodulated welds it was not possible to achieve such low electrical resistances.

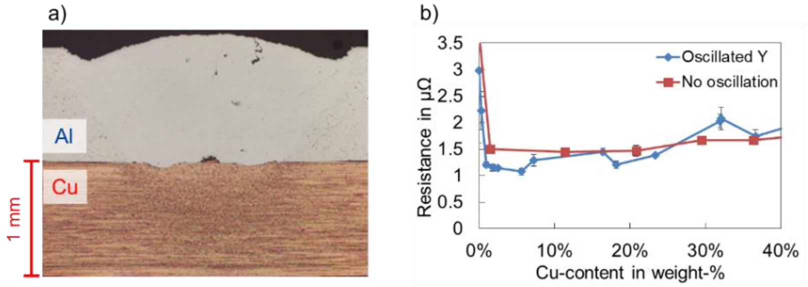

Fig. 3. a) Cross-section of an aluminum to copper weld produced with spatial modulation of the laser beam with a frequency of 1000 Hz and an amplitude of 0.5 mm. b) Resistance of the weld seams in dependence on the averaged copper content. Parameters: P = 3.25 kW; v = 6 m/min; d_f = 280 µm, λ_{Laser} = 1.08 µm.

3. Summary

Laser welding of aluminum to copper dissimilar welds was investigated. Inherent instabilities in the cw welding process with copper as the top sheet could be suppressed by applying a temporal modulation of the laser power. Thereby, the electrical resistance could be reduced by about 12%. The use of a spatial modulation of the laser power allowed to adjust the averaged copper content by control of the width and depth of the junction. With this and aluminum as top sheet, electrical resistances as low as 1 μΩ could be achieved.

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References

Fetzer, F., Jarwitz, M., Stritt, P., Weber, R., Graf, T., 2015(1). „Welding Copper to Aluminum: Diagnostics and Implications on Electrical Resistance,” 17th International Workshop Process fundamentals of laser welding and cutting, Hirschegg, Austria.

Fetzer, F., Jarwitz, M., Stritt, P., 2015(2). „Comprehensive Diagnostics of CW and Power Modulated Welding of Dissimilar Metals,” Proceedings of LAMP – the 7th International Congress on Laser Advanced Materials Processing, Japan.

Fetzer, F., Jarwitz, M., Stritt, P., Weber, R., Graf, T., 2015(3). „ Laser Power Modulation to Minimize the Electrical Resistance of Aluminum-Copper Welds,” Lasers in Manufacturing Conference, Munich, Germany.

Fetzer, F., Jarwitz, M., Stritt, P., Weber, R., Graf, T., 2016. Fine-tuned remote laser welding of aluminum to copper with local beam oscillation, Physics Procedia 83, p. 455.

Gedicke, J., Olowinsky, A., Artal, J., Gillner, A., 2007. “Influence of temporal and spatial laser power modulation on melt pool dynamics,” Proceedings of the 26th International Congress on Applications of Laser and Electro-Optics (ICALEO), Orlando, Florida, USA.

Jarwitz, M., Fetzer, F., Stritt, P., Weber, R., Graf, T., 2015(1). „Temporally resolved temperature measurements during power modulated welding of copper to aluminum,” 17th International Workshop Process fundamentals of laser welding and cutting, Hirschegg, Austria.

Jarwitz, M., Fetzer, F., Stritt, P., Weber, R., Graf, T., 2015(2). „ Influence of laser power modulation on the time-resolved temperature distribution in the weld pool during laser welding of copper to aluminum,” Lasers in Manufacturing Conference, Munich, Germany.

Jarwitz, M., Fetzer, F., Weber, R., Graf, T., 2017. „Beam modulation to reduce electrical resistance in laser welded Al/Cu dissimilar joints,” 19th International Workshop Process fundamentals of laser welding and cutting, Hirschegg, Austria.

Kirchhoff, M., 2013. “Laser applications in battery production—From cutting foils to welding the case,” 3rd International Electric Drives Production Conference (EDPC), IEEE.

Rabkin, D. M., Ryabov, V. R., Lozovskaya, A. V., Dovzhenko, V. A., 1970. Preparation and properties of copper-aluminum intermetallic compounds, Powder Metallurgy and Metal Ceramics 9(8), p. 695.

Solchenbach, T., Plapper, P., Cai, W., 2014. Electrical performance of laser braze-welded aluminum–copperinterconnects, Journal of Manufacturing Processes 16, p. 183.

Walter, D., Schmieder, B., Moldovan, V. R., 2014. Nothing Less Than More Affordable Lithium-Ion Batteries, Laser Technik Journal 11, p. 44.