Temperature Control for Friction Stir Welding of Dissimilar Metal Joints and Influence on the Joint Properties

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Motivation

- The move towards electromobility and lightweight design comes with a need for suitable joining processes for multi-material components.
- Conventional fusion welding techniques are not suitable for welding mixed-material joints such as Al-Ti and Al-Cu.
- Friction Stir Welding (FSW) has been proven to be a suitable welding process:
  - Welding without the need for protective gases
  - Minimal amounts of adverse intermetallic phases

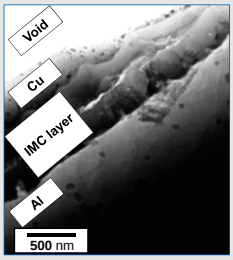
State of the Art and Methods

State of the Art:

- Formation of an intermetallic compound (IMC) layer is key joining mechanism
- Thickness of IMC layer correlates with process temperature
- Mechanical properties depend on IMC layer thickness

Approach:

- In-situ measurement of the temperature in the stir zone
- Development of a temperature-controlled FSW process



TEM image of interface

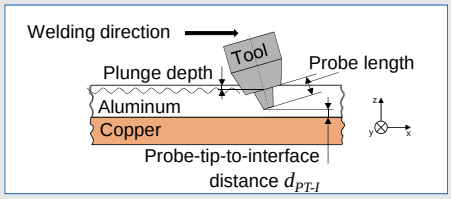
Process

Temperature-controlled FSW:

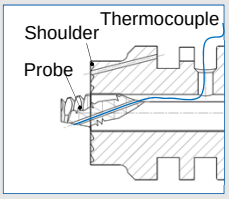
- Measurement of the welding temperature using a thermocouple in the probe
- PI controller adjusts the rotation speed of the welding machine to control the welding temperature

Experimental parameters:

- Lap joints of EN AW-1050 aluminium and EN CW008A copper
- Constant welding speed v = 300 mm/min
- Constant probe-tip-to-interface distance $d_{PT\text{-}I}$ = 0.1 mm
- Variation of the welding temperature T in the probe: 410 °C, 430 °C, 465 °C, 500 °C, 535 °C, and 570 °C
- Shear tensile tests with 3 samples taken out of a single specimen performed to analyse joint strength F_{avg}



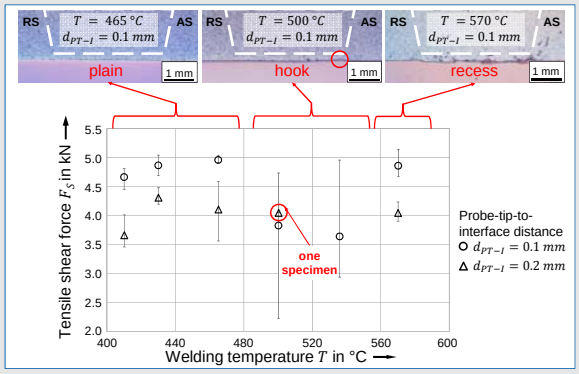
Schematic of the welding task



Schematic of the tool

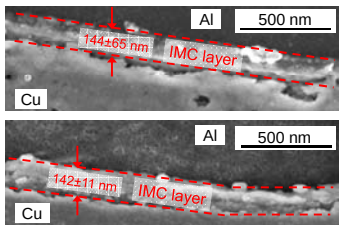
Controller set-up

Results

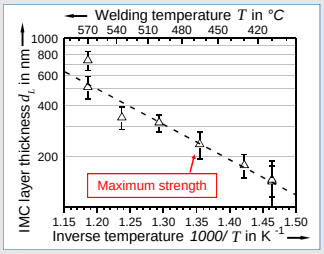


Images of the Al-Cu interface and results of the tensile tests

- No evidence of macroscopic form fit at low welding temperatures
- Hook formation on the AS when the welding temperature increases
- Sufficient joint strength results from low and high temperatures during FSW
- Temperature-controlled FSW results in reproducible IMC layers



SEM images of IMC layers of two different seams welded with T = 410 °C



Arrhenius plot: IMC layer thickness against inverse temperature

Conclusion

- Temperature-controlled FSW can be used to influence the thickness of intermetallic layers as well as the interface morphology in copper-aluminum FSW welds.
- No evidence of macroscopic hooking was found in the cross section of the sample with the highest tensile shear strength. Consequently, the dominant joining mechanism is assumed to be atomic bonding by interdiffusion.
- Employing temperature-controlled FSW ensures a constant IMC layer thickness along the welding line.

References and Relevant Publications

Krutzlinger, M.; Marstatt, R.; Costanzi, G.; Bachmann, A.; Haider, F.; Zaeh, M. F. *Temperature Control for Friction Stir Welding of Dissimilar Metal Joints and Influence on the Joint Properties*. In: Key Eng.Mat.767, 2018, 360-368.

Marstatt, R.; Krutzlinger, M.; Luderschmid, J.; Constanzi, G.; Mueller, J.F.J.; Haider, F.; Zaeh, M.F. *Intermetallic layers in temperature controlled Friction Stir Welding of dissimilar Al-Cu-joints*. In: IOP Conf.Ser.: Mater.Sci.Eng.373, 2018, S.12017.

Bachmann, A.; Gamper, J.; Krutzlinger, M.; Zens, A.; Zaeh, M.F. *Adaptive model-based temperature control in friction stir welding*. In: Int.J.Adv.Manuf.Technol. 93, 2017, 1157-1171.