Joining of High-Strength Aluminum-Based Materials with Tin-Based Solders

Microstructure, thermal behavior, and mechanical properties of soldered joints were investigated

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Aluminum matrix composites (AMC) are characterized by excellent strength-density ratio and improved wear resistance. Because of the rather expensive production of composites, they are applied only locally in places where their special characteristics are necessary. Thus, suitable joining techniques are very important. Soldering offers some advantages in comparison to other joining processes. Compared to welding, the thermal influence on the base material is clearly lower. Also, compared to bonding, soldering is characterized by higher strength and thermal resistance of joints.

The production of composites with equal channel angular extrusion (ECAE) allows a very fine-grained structure to be achieved (Refs. 1–4). These materials are characterized by very high strength. To avoid grain growth and the associated decrease in strength, the joining temperature must be kept low. For this purpose, Sn-based solders are suitable because of their low melting point, which is below 300°C. To improve the mechanical properties of the joint, the solders can be reinforced with ceramic particles.

Previous investigations by Klose (Ref. 5) and Blugan et al. (Ref. 6) demonstrated the successful application of ceramic particles for adapting of the coefficient of thermal extension (CTE) of filler metals.

In the current study, the optimized joining parameters for solders reinforced with SiC or Al_2O_3 particles are presented.

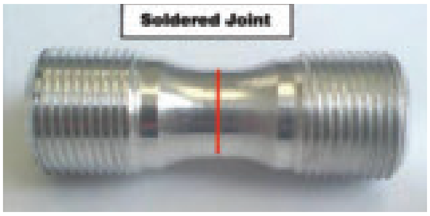

Fig. 1 — Tensile sample with diameter of 10 mm.

The microstructure and properties of the filler metals are investigated using differential thermal analysis (DTA), scanning electron microscopy (SEM), and energy-dispersive X-ray analysis (EDX). Tensile tests were carried out on cylindrical specimens with a diameter of 10 mm — Fig. 1.

Materials for the Experiment

The solders reinforced with SiC and Al_2O_3 particles are produced by high energy milling (HEM). A maximum of hard particles up to 35 vol-% can be obtained using this method. As matrix material for the filler, near-eutectic alloys with 3.5 wt-% Ag or 3 wt-% Cu are used. These materials are characterized by a low melting point of approximately 230°C. An average particle size of SiC and Al_2O_3 is approximately 2 µm. The HEM production method permits a homogeneous structure for the solder composition.

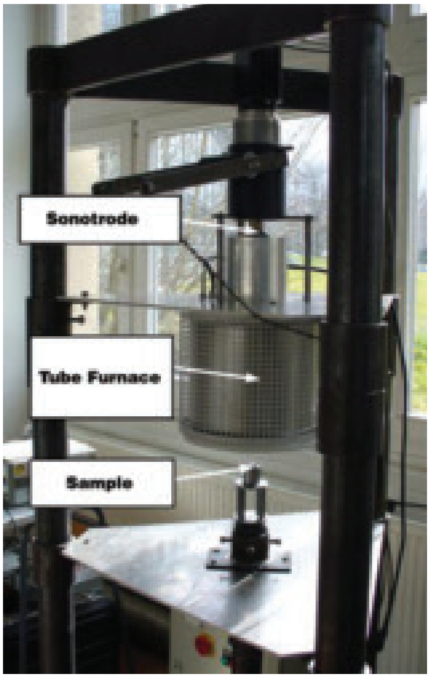

Fig. 2 — Ultrasonic soldering system for aluminum matrix composites.

An ultrasonic soldering process (Fig. 2) was used (Ref. 7) to join AMCs in this experiment. The flux-free procedure consisted of two steps: solder application and joining. In the first process stage, the solder layers (200–500 µm thick) were ap-

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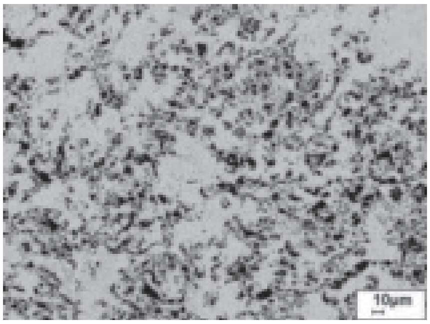

Fig. 3 — Microstructure of SnCu3 + 30 vol-% $(SiC)_p$ filler metal after processing by HEM.

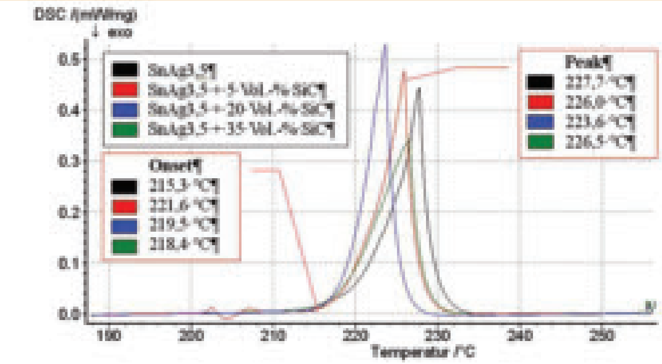

Fig. 4 — Results of differential thermal analysis (DTA) of the reinforced SnAg 3.5 solders in comparison with conventional solder.

plied on the base material surfaces by friction soldering. The second step was a combination of ultrasonic and heat treatment processes for joining the specimens. The time for additional ultrasonic treatment was about 10 s.

Results of the Experiment

Production of Reinforced Solders

The metallographic investigations showed a good connection between the ceramic particles and the matrix in the solders produced by HEM. No pores were detected on the interface by SEM observations — Fig. 3. Nevertheless, the distribution of the reinforcing particles is nonuniform. Homogeneity can be significantly improved by the use of ultrasonic treatment during the joining process.

The heating curves obtained by differential thermal analysis (DTA) of different reinforced filler metal alloys are shown in Fig. 4. The comparison of the onset and peak temperatures between conventional and modified solder exhibited no noticeable change in the melting range by the addition of ceramic particles. This proves that on the interface between the matrix and the particles, only mechanical anchoring is the bonding mechanism without the occurrence of new phase formations. The melting temperature of about 227°C determined a joining temperature range of 250°–280°C.

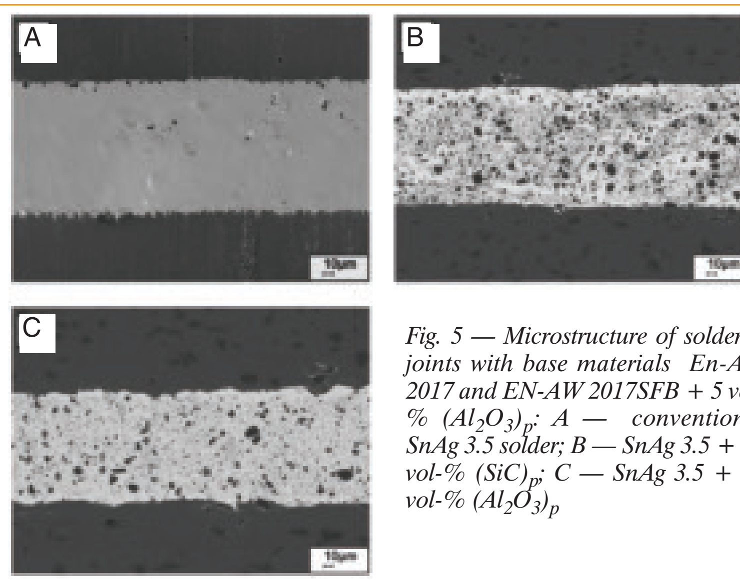

Fig. 5 — Microstructure of soldered joints with base materials En-AW 2017 and EN-AW 2017SFB + 5 vol-% $(Al_2O_3)_p$; A — conventional SnAg 3.5 solder; B — SnAg 3.5 + 20 vol-% $(SiC)_p$; C — SnAg 3.5 + 20 vol-% $(Al_2O_3)_p$

Microstructure of Soldered Joints

The microstructures of typical soldered joints in which filler metals with different reinforcing particles were used are shown in Fig. 5B and C. For comparison,

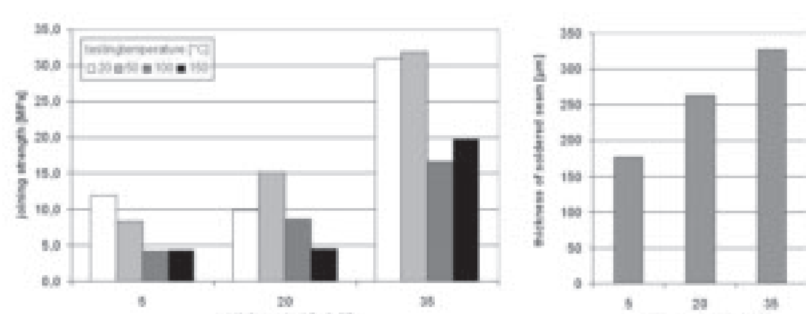

Fig. 6 — Results of tensile tests in the temperature range of 20°–150°C (left) and dependence of soldered joint thickness from the content of reinforcement particles (right). Base material: EN-AW 2017SFB + 5 vol-% $(Al_2O_3)_p$; solder: SnAg 3.5 + $(Al_2O_3)_p$.

Fig. 5A exhibits a conventional soldered joint without ceramic particles. As base materials, the aluminum Alloy En-AW 2017 and the aluminum matrix composite EN-AW 2017SFB + 5 vol-% $(Al_2O_3)_p$ are used.

A good bond between the matrix and reinforcement component can be observed. This is a determining factor in the intended increase of joint strength. The microstructure and the distribution of the phases in the solder joint correspond to the structure of the solder after application. No new phases were detected. In addition to reinforcement particles, the Al_2O_3 particles from the base material can be observed in the soldered joint. They are larger (10–25 μm) than the ceramic particles in the solder (approximately 2 μm) and uniformly distributed. This transfer of the particles from the base material can be explained by the influence of the ultrasonic treatment.

Mechanical Properties

A tensile test was used to determine the joining strength in the temperature range of 20°–150°C. The results are shown in Fig. 6.

From the results of tensile tests (Fig. 6), it was shown that the joining strength decreased when the testing temperature increased. This effect was for all investigated material combinations. It also can be seen that the addition of reinforcement particles provides a significant improvement in joining strength at all test temperatures (20°–150°C). The best results (joint strength: 32 MPa) were at a testing temperature of 50°C for the joining of EN-AW 2017SFB + 5 vol-% $(Al_2O_3)_p$ with SnAg 3.5 + 35 vol-% $(Al_2O_3)_p$. The reason for the improvement in joint strength was the dislocation movement restriction due to the ceramic particles. Also, the soldered joint thickness increased because of the addition of ceramic particles — Fig. 6.

Conclusion

Tin-based solders modified by the addition of reinforcement particles (max. 35 vol-% SiC or Al_2O_3) were used to join aluminum matrix composites. A flux-free joining process based on a combination of ultrasonic and heat treatment was used. With this process, the problem of the oxide layer removal from the surface of base material was solved. The experimental results indicated a clear improvement in mechanical properties when increased temperatures were reached. The proposed solder materials and joining procedure provided little thermal influence on the base material due to the low melting point of approximately 230°C, and it can be recommended for soldering of composites produced by ECAE.♦

Acknowledgment

The authors are very grateful to the German Research Foundation in Bonn (DFG) for the financial support of the subproject D4 joining of high-strength composites and the special research area (SFB) 692 high-strength aluminum-based lightweight materials for reliable components.

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