Subproject A5

Title
Influence of solid-liquid reactions in the soldering gap on solder properties and precision

Project management/-processing

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Task definition
According to the current state of the art, the process requirements for brazing hot work steels with Ni-based brazing alloys using TLP bonding are contradictory. With regard to the brazing zone, high temperatures and long holding times are advantageous. This prevents the formation of brittle phases in the brazing zone. On the other hand, these parameters have a negative influence on the mechanical and corrosive properties of the base material through undesirable phase transformations and the associated grain growth. The aim of the project is to reconcile these opposites. For this purpose two compensation approaches were developed. The first is a material-technical approach and provides for a solder development based on the industrial solder Ni 620. The second, process-technical approach comprises current-supported brazing. Here, the electric current accelerates the diffusion processes during the brazing process, so that the formation of brittle phases in the brazing gap can be prevented despite considerably lower brazing temperatures and holding times.

In 2018 both compensation methods were pursued. For this purpose, an experimental test stand for current-assisted brazing was first integrated into the conventional furnace brazing process. A further objective was to identify potentially suitable material concepts for brazing development.

Procedure

In order to work out the basics of the current-supported soldering process and the influencing variables, conventional plant technology had to be adapted to the new requirements. The requirements can be divided into two categories, electrical contacting of the samples during a furnace brazing process and measurement acquisition. The concept shown in Figure 1 was developed for this purpose. The most important point of the electrical contacting in the furnace is the safe and easy fixing of the samples. This ensures the reproducibility of the tests. For this purpose, a sample holder was manufactured as shown in Figure 1 on the right. It consists of two metallic base plates and Al_2O_3 linear guides. The base plates can be moved vertically along the linear guides, so that different sample geometries can be used. The use of electrically conductive and insulating materials ensures that the current only flows through the sample. Due to sufficient electrical conductivity and temperature resistance, nickel is used as the material for the conductors. Al_2O_3 ceramic beads are used to insulate the electrical conductors. The temperature and current intensity are measured with the aid of a measuring amplifier.

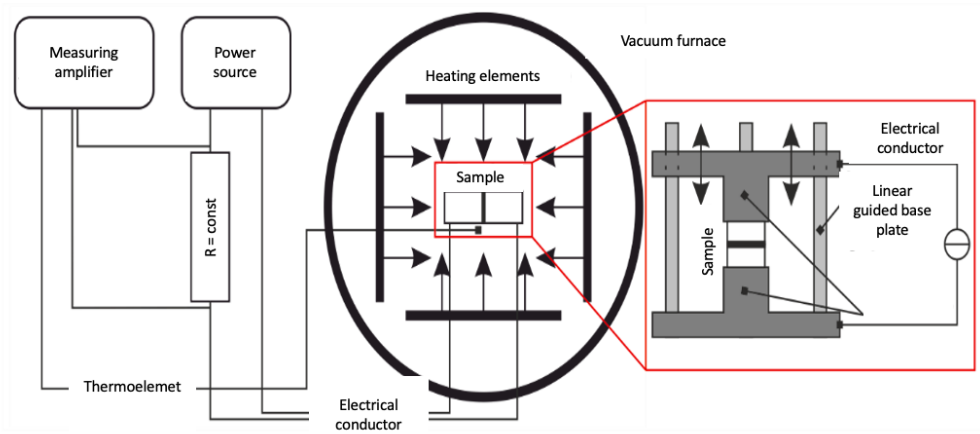

Figure 1: Schematic diagram of the experimental test stand at the Institute of Surface Technology

The first step in solder development was to determine the requirements for the solder. Here, in addition to the formation of the brazed seam and the base material, the effect of the diffusion processes on the base material had to be taken into account.

The requirements on the solder can therefore be summarised as follows:

- Avoid austenitisation of the base material
- Maintaining critical temperatures (T = 1,040 °C) of the base material
- No use of austenitizing agents or compensation of their effect by using ferrite formers
- No use of boron to prevent the formation of Cr-borides in the soldered seam
- Enhancing the TLP effect to reduce holding times and minimize grain growth

Due to good mechanical properties of industrial Ni solders, nickel should be a basic element of the solder to be developed. In order to increase the TLP effect and thus reduce the holding times, iron was determined as the second base element. Silicon was chosen because of its effect as a ferrite former and as a potential diffusion element to increase the TLP effect. Furthermore, according to literature, silicon as a semi-metal is advantageous for the production process of the solder film by means of melt spinning. In order to prevent a potential Cr depletion of the base material due to the diffusion processes and due to its ferrite-forming properties, chromium was determined as a further element. Aluminium, which is also a ferrite forming element, was used as a melting point lowering element. Master alloys with varying proportions of the respective elements were produced with the elements mentioned. In order to make a preliminary selection and to check the master alloys for their thermal suitability, they were thermally characterized by means of DSC analyses.

Results

Figure 2 shows the results of the DSC analyses performed. On the basis of these results, master alloys V1.06 and V1.07 could be identified as initially potentially suitable with regard to the critical temperature of the base material. These alloys exhibit endo¬thermal peaks at temperatures of T = 900 °C and T = 1,040 °C for case V1.06. This indicates phase transitions below the critical temperature of the base material. For case V1.07, the determined temperature of the phase transition is T = 950 °C.

The type of phase transition is unknown at first.

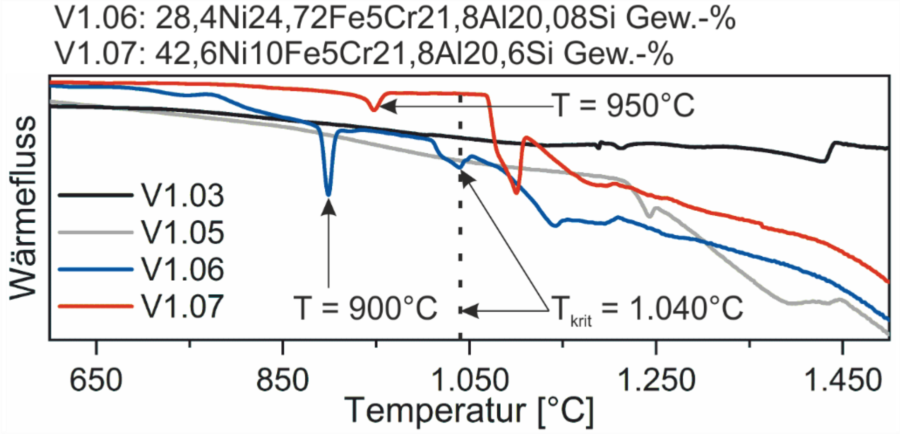

Figure 2: DSC results of master alloys

In order to better understand the measured processes at the mentioned transition temperatures, critical temperatures of the alloys and the phases present were calculated in cooperation with B7 as a function of temperature. The calculated critical temperatures correlate with the experimentally determined data. For V1.06 the calculated solidus temperature is TS = 928 °C and the liquidus temperature TL = 1,148 °C. For V1.07, TS = 896 °C and TL = 1,154 °C. The results of the equilibrium calculations show that at Tkrit = 1,040 °C, two further phases are present in both alloys in addition to the melt. Here the proportion of the melt is 33 wt.% for V1.06 xL,V1.06 and 25 wt.% for V1.07 xL,V1.07. This means that alloy V1.06 is potentially more suitable as a solder. However, it is also possible that the small proportion of melt used in conventional brazing processes results in insufficient wetting of the base material.

To counteract this and compensate for the proportion of melt, current-supported wetting tests can be carried out with the test rig shown in Figure 3. In the previous tests, copper was used as the solder and 1.0036 as the base material. For these tests, the originally developed test stand was extended by an electromagnetic shielding. This is necessary in order to be able to exclude electromagnetic radiation as a disturbance variable in the tests. Electromagnetic radiation in the furnace results from the high currents in the heating elements, which are necessary to reach the required temperatures.

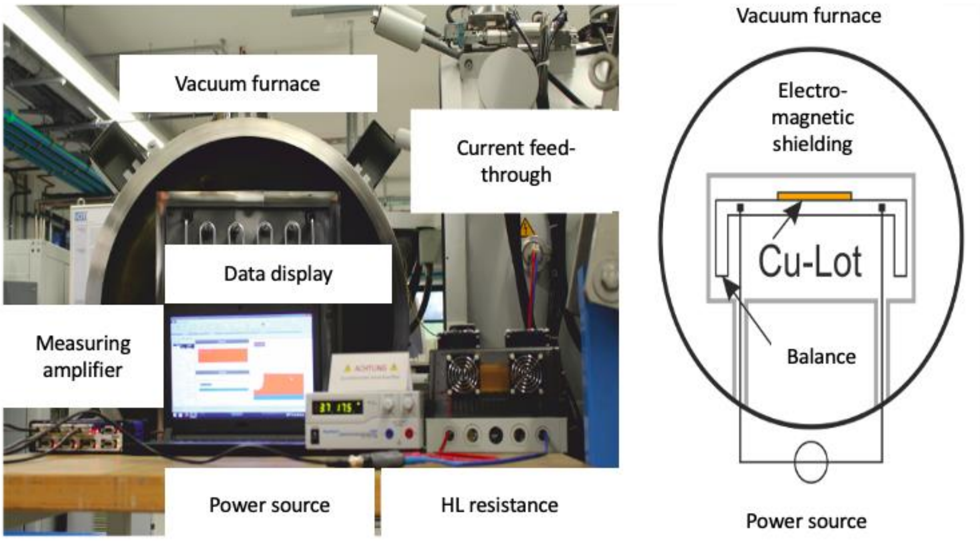

Figure 3: Experimental test rig for current-assisted soldering

Figure 4 shows the results of the current-supported wetting tests. Without the influence of the electric current, the copper solder spreads evenly in all directions. In the test with the current intensity I = 30 A, the copper solder propagates in the direction of the current. It can therefore be concluded that the wetting behaviour during furnace brazing can be actively influenced by means of electric current. According to the literature, the surface tension of the melt is reduced, which leads, among other things, to a better wetting angle or an increase in the capillary effect in the case of gap filling.

Figure 4: Results current-supported wetting Wetting

Summary and Conclusion

The planned targets for 2018 were met. As part of the process engineering approach, the conventional furnace brazing process was expanded to include the component of electrical current. This successfully integrated a new influencing variable into the process. This allows the targeted influencing of the interactions between brazing alloy and base material and thus enables compensation for insufficient wetting, among other things. Furthermore, master alloys were produced within the scope of material-technical compensation. These were characterised for thermal suitability by means of DSC analyses and equilibrium calculations. Thus a potentially suitable alloy could be identified.

Publication

K. Bobzin, M. Öte, S. Wiesner, A. Schmidt: Accelerated and Directed Diffusion during Electric Current-Assisted Brazing. In: Tagungsband zur International Brazing and Soldering Conference (IBSC), 2018, New Orleans, 15.-18.04.2018, S. 126-129, ISBN: 978-0-87171-939-3

A. Aretz, J. Mayer, K. Bobzin, M. Öte, S. Wiesner, A. Schmidt: In Situ investigation of production processes in a Large Chamber Scanning Electron Microscope. In: Ultramicroscopy, 04.07.2018. DOI: 10.1016/j.ultramic.2018.07.002
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