Monitoring of the Reactive Air Brazing by Acoustic Emission Analysis

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Abstract. The reactive air brazing (RAB) is a relative new brazing process, which enables to join ceramics and steel without the need of an oxygen-free atmosphere. Thus the brazing does not have to be carried out in a vacuum furnace. Due to this fact, the joining process can be realized by simple and fast heating sources such as induction coils, laser- or light-beams. One challenge of this method is to ensure, that the quality of the joints is sufficient enough to fulfil the needs of the later application. The fundamental challenge for brazing ceramics on steel is the large difference in the coefficient of thermal expansion of the ceramic, the filler metal and the steel. When cooling from the brazing temperature, this mismatch can induce high internal stresses that can cause cracks in the brittle ceramic, especially at high cooling rates. Therefore, an online monitoring during the development of RAB as well as for the later series production is of significant importance. Such a monitoring system is able to observe the processes of heating, holding and cooling during the brazing. One possible non-destructive testing method is the acoustic emission analysis which can basically detect cracks in the whole component during brazing in real time.

In the presented study, the authors have integrated an acoustic emission analysis system into a RAB process. First results of the new system will be presented for the monitoring of the brazing process with respect to the melting and solidification of the solder. Another focus is the detection of cracks that may arise during the cooling phase. Finally, a review of the acoustic emission method with regard to a practical process monitoring is done.

Introduction

The novel Reactive Air Brazing (RAB) method [1-3] allows the joining of ceramics and metals with less effort compared to conventional methods such as vacuum- or active soldering. The reactive air brazing requires high temperatures of about 1000°C. The challenge is to control the process with respect to the thermally induced internal stresses. The properties of the joining materials, e.g. the thermal expansion coefficient, can be particularly very different at high temperatures. In this way defects like cracks can occur in the brazed joint or the ceramic itself [4]. Therefore the joining process should be monitored online.

One way to detect the crack initiation is the analysis of the acoustic emission (AE) during the brazing. The acoustic emission analysis was successful used to detect cracks in similar applications for example the online detection of cracks during a heat treatment [5,6]. This non-destructive testing method can be used during the whole production

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process. With increasing demands on quality and a constant manufacturing cost the detection of defects is important especially in the industrial production. With regard to the economy, the cost of a defect can be reduced, when the defect is detected at the beginning of the production process.

In this work an investigation of crack detection during a RAB process by means of the acoustic emission analysis is presented. First, a possible integration of the measuring system in a brazing system is checked. Subsequently, brazing tests by flame as well as by electromagnetic induction were carried out. The resulting signals are documented and evaluated. The aim of this work is to detect defects which are generated during the brazing process or in the cooling phase by the acoustic emission analysis.

Reactive air brazing

Reactive air brazing (RAB) is a low cost alternative to join steel and ceramics without an expensive vacuum atmosphere. This method is comparable to conventional brazing. During heating, the substrate is not melted but metallurgical interaction and wetting result in a strong joint. Since RAB based on filler metal alloy composition, it needs temperatures of 1000°C or higher and is comparable with the high-temperature brazing (900 °C). As heat sources a flame or induction can be used which shows the simplicity of this kind of joining process.

The filler metal can be applied as a paste or foil on the ceramic. An important factor for the mechanical properties is the dimension of the brazing gap, which can be determined by an additional external pressure. In this way the diffusion processes are favored during the joining process. In the following figure 1 a basic structure of a brazing process is shown.

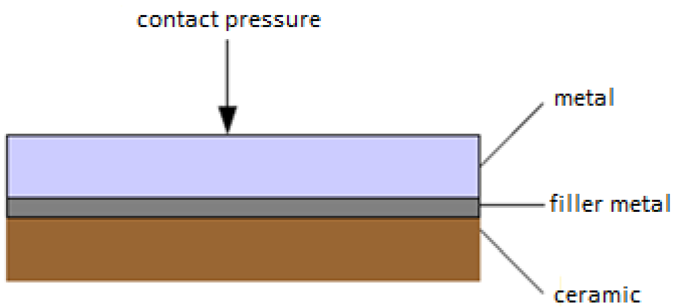

Fig. 1. Principle of the reactive air brazing (RAB).

The metallurgical interactions between the substrate and the filler metal can produce brittle phases and are critical to the mechanical properties.

Integration of the acoustic emission system in the brazing process

In order to study the acoustic emission during the RAB process a measuring system from the company "Physical Acoustic" named "PCI-2 based AE system" was used. The computer integrated PCI-based plug-in card has an 18-bit analog-to-digital converter with a sampling rate of 40Msps. The system also includes two pre-amplifier of the type "2/4/6 Preamplifier" also from "Physical Acoustic". The acoustic emissions were measured by two piezoelectric sensors which were fixed with magnetic holders on the workpiece. In addition, a coupling gel was used for better and reproducible sound transmission between component and sensors. The sound events were recorded and analyzed by the software AEWIN. The complete experimental setup is shown in figure 2.

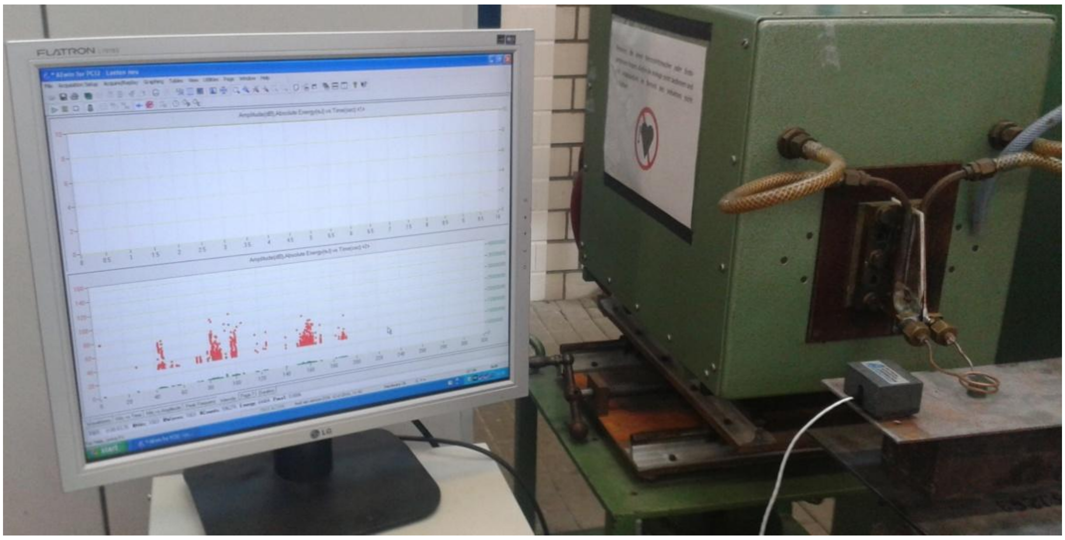

Fig. 2. Experimental setup for the process control of the RAB process

To test the functionality of the system, signals produced by a Hsu-Nielsen source were detected. The analysis for this experiment is exemplary shown in figure 3. The upper image shows the signal against time and the bottom image the intensity as a function of frequency.

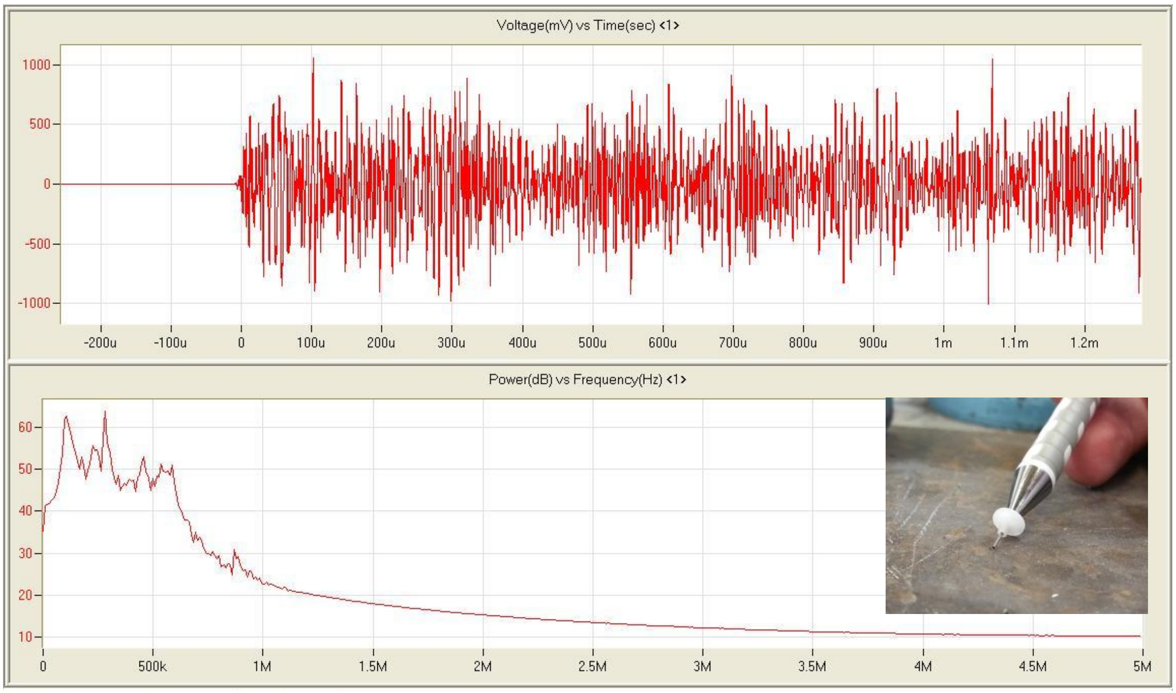

Fig. 3. Result of the function test by using a Hsu-Nielsen source.

To obtain further information on the cracking behaviour of the ceramic samples and the resulting SE signals, a rod of Al_2O_3 was manually broken in the close by a sensor (see figure 4).

Fig. 4. Calibration by cracking a ceramic sample

In addition the signals from the ceramic cracks were compared with the signals from the Hsu-Nielsen source in order to analyse the differences. At a distance from 5 cm near the sensor the Hsu-Nielsen test as well as the ceramic test was done three times. Figure 5 shows the amplitude (red) and energy (green) plotted over the time. The first three signals correspond to the Hsu-Nielsen sources, whose amplitude is slightly above 80dB. It is striking that the signals are very low in energy. The cracking of the ceramic, however (the last 3 signals in figure 5) is energetically significantly stronger and louder by about 20dB. The amplitude is approximately 100dB in case of the ceramic.

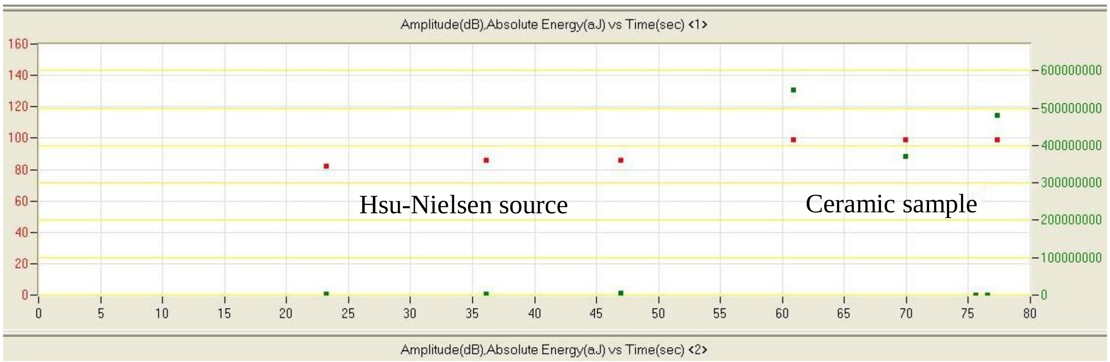

Fig. 5. Comparison of the Hsu-Nielsen source and the ceramic sample.

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The analysis of the signal duration of the individual signals is shown in figure 6.

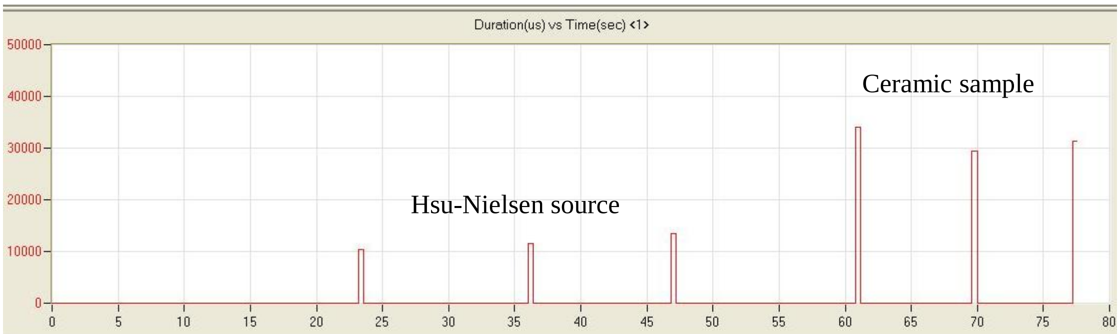

Fig. 6. Analysis of the signal duration.

The signal duration for the pencil fracture is about 1000µs, the signals from the ceramic fracture are about 3 times longer.

Overall, the studies have shown that the signals from the ceramic fracture are much louder and stronger than the reference signals from Hsu-Nielsen source. This means for the subsequent brazing experiments, that, if the Hsu-Nielsen source is detected, the experimental setup is able for crack detection of the ceramic components.

Monitoring of the brazing process

For the following investigation an electromagnetic induction brazing system was used, shown in figure 2 and 4. The system for electromagnetic induction consists of a high-frequency generator Himmel type "HA5-2 / 22 HG54-15" whose specifications are listed in Table 1.

Table 1. Specifications of the induction system

Power supply	
Operating voltage	Three-phase 380V 50Hz
Control voltage	220V
Power consumption	Max. 29,5kVA
High frequency	
HF terminal power	15kW
Operating frequency	300kHz

For experiments, different combinations of materials were investigated, which are listed in Table 2. The filler metal was provided from our project partner Fraunhofer-Institut für Keramische Technologien und Systeme (IKTS) in Dresden, Germany.

Table 2. Experimental design

Number	Metal	Cermet	Filler metal	Temperature/Holding time	Cooling
2	DC04	Al_2O_3	Ag_4CuO	1000°C/ 5 min	Argon
3	DC04	Al_2O_3	Ag_4CuO	700°C/ 0 min	Argon
4	DC04	Al_2O_3	Ag_4CuO	1000°C/ 5 min	Argon
5	X5CrNi18-10	Al_2O_3	Ag_4CuO	1000°C/ 20 min	Argon
6	X5CrNi18-10	Al_2O_3	Ag_4CuO	1070°C/ 20 min	compressed air

The target temperature during induction brazing was about 1000 °C, to ensure a cohesive connection and was realized in all experiments. The monitoring of the temperature took place with a thermocouple, which was attached directly to the contact point of metal and ceramic. Figure 7 left shows the setup with the coil, metal, cermet and filler metal before brazing and on the right side during the brazing.

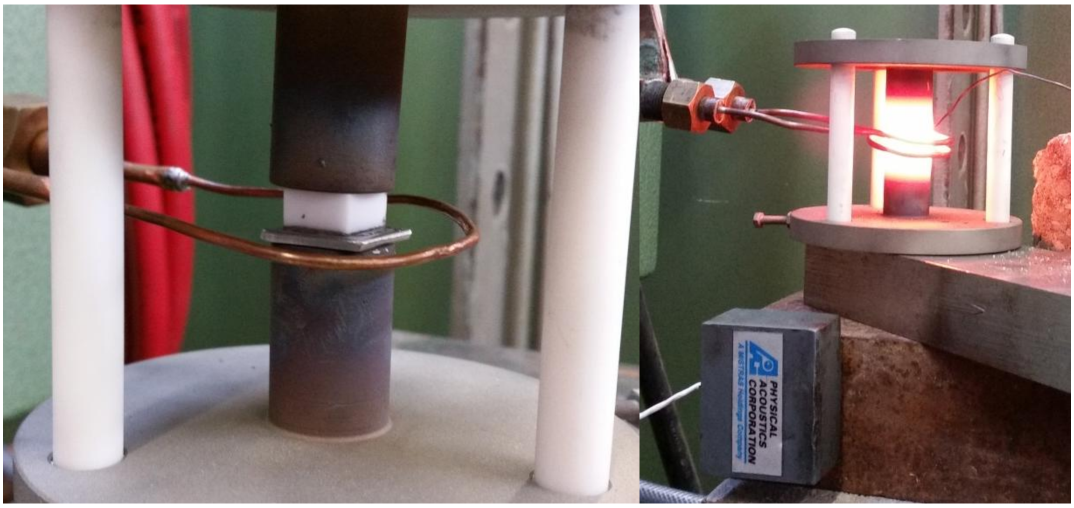

Fig. 7. Experimental setup (left: before brazing, right: during brazing).

A disadvantage of inductive heating is the electromagnetically noise, caused from the induction system. Figure 8 shows the interference as time (above) or as a frequency response (below). The high frequency generator operates at a frequency of 300 kHz that can be found along with the events at 600 kHz as the strongest signals in the evaluation.

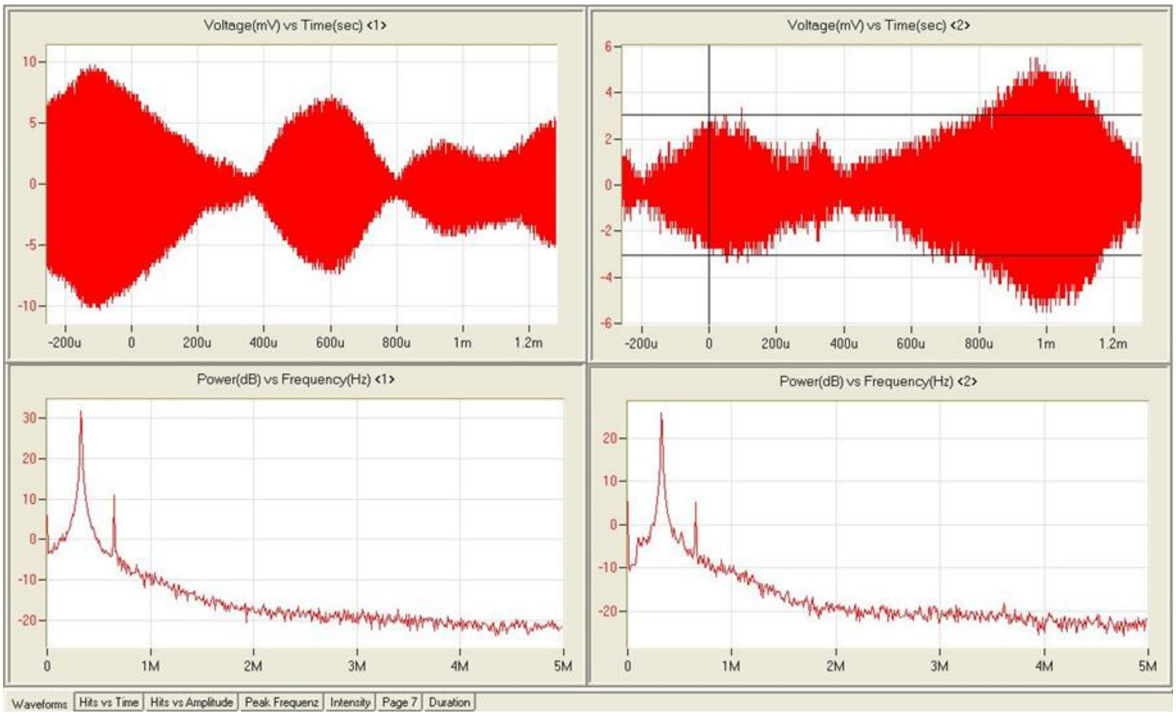

Fig. 8. Acoustic emission analysis during the induction heating

The evaluation of the subsequent brazing operation (holding- and cooling time) is shown in figure 9. In addition to the time profile of the acoustic emission (shown in red), the figure 9 shows the energy (shown in green). During heating the individual burst signals, based on the interferences, are dominant. In particular, at approximately 600 seconds, a high-energy signal was recorded, the cause for this signal could not be analysed in detail. After switching off the brazing unit burst signals were recorded, presumably related to the thermally induced shrinkage as a result of the cooling. Further these signals have a small energy in comparison to a ceramic fracture (see figure 5).

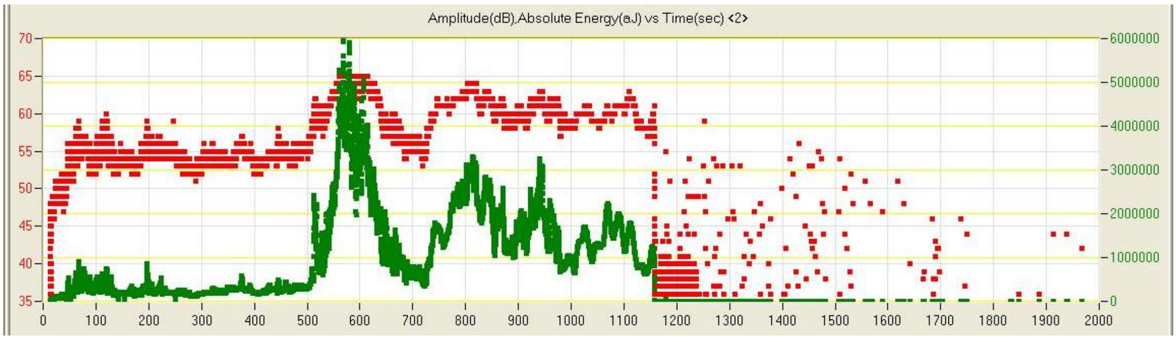

Fig. 9. Acoustic emission analysis during the brazing process

After the experiment no visible cracks were detected, this fact is in agreement with the acoustic emission analysis.

During another heating process after 1150 seconds a crack in the ceramic was visual detected. The corresponding acoustic emission measurement is shown in figure 10.

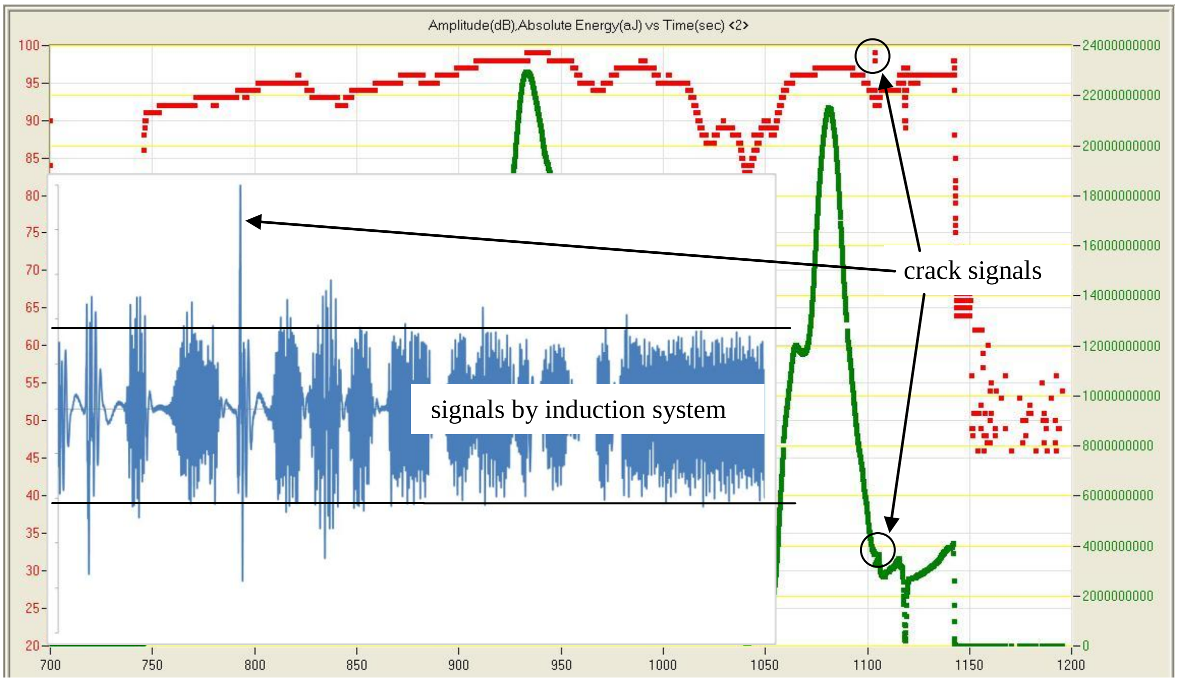

Fig. 10. Acoustic emission analysis during the brazing process

The amplitude and energy of the signals are comparable to the signals from the fracture of the ceramic specimen, which are shown in figure 5. On this kind online flaw detection during the heating phase is possible. The detected signals are burst signals, which are typical for crack initiation and crack growth.

Conclusion

The aim of the work was to investigate the applicability of the acoustic emission analysis for a process monitoring during the RAB process for ceramic to metal joints.

The RAB process is extremely sensitive and showed variations in the recoverable material bonding. Several experiments were carried out under various conditions. The best results were obtained by induction brazing with minimal contact pressure, which should facilitate the diffusion process.

Overall, the experiments have shown that the detection of a crack initiation is possible even during a brazing process by means of the acoustic emission analysis. In general the experimental setup is suitable for process monitoring of the RAB-process with inductive heating and flame. The sensitivity of the acoustic emission system is satisfying, because even events like rubbings were recorded which produced significantly smaller signals compared to the cracks. A fracture of the ceramic was detected with the acoustic emission analysis during the heating process. So the system is able to detected crack initiation and crack growth during the whole brazing process.

For the joining technology and in particular for the RAB process the acoustic emission analysis indicates a high potential for a process monitoring. Before an industrial use, however, further investigations are required.

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