Bond Quality Investigation of Ultrasonic Assisted Composite Casting

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Abstract:

In the process of composite casting monolithic structures consisting of copper and aluminum, which may be used as a heat sink, can be created during master forming. To enhance the connection between solid copper blocks and aluminum melt ultrasonic excitation is used to generate cavitation. This cleans the copper's surface to improve surface wetting. In this way the bond quality of solid copper blocks and aluminum is increased. In this article polished micrograph sections are analyzed to evaluate the quality of the resulting cohesive bonds.

Key words: ultrasonic, cavitation, melt, casting

Introduction

Today's electronic components are getting increasingly powerful, resulting in high amounts of heat that must be dissipated. Therefore heat sinks with a high thermal conductivity are needed. A new approach to produce such heatsinks is to create a monolithic structure consisting of different metals during master forming. The approach being pursued by the authors is to create heat sinks consisting of a copper base plate with aluminum cooling fins by composite casting.

Casting experiments, in which solid copper sheets were placed into a casting mold which then was filled with aluminum melt showed poor connection between the two metals. Contaminations and oxide layers on the copper's surface could be determined as reasons for poor wetting of the surface resulting in poor connection [1,2,3]. To clean the copper's surface and enhance connection between the two metals cavitation triggered by ultrasonic excitation was proposed. In this article the results of experiments in which copper plates were excited with an ultrasonic transducer and submerged in aluminum melt are presented. Similar experiments with different ultrasonic parameters using different control hardware have already been conducted [4]. The resulting cohesive bonds are investigated using polished micrograph sections.

Experimental Setup

Copper discs were bolted to a sonotrode, which was specially designed for these experiments. The sonotrode was attached to a piezoelectric transducer. The system was driven at its first longitudinal resonance frequency at 20,3 kHz. The transducer was connected to a power amplifier which again was connected to control hardware. The experimental setup is shown in Fig. 1. The control hardware, consists of an amplitude control and a frequency/phase control (IDS Digital-Phase Control 500/100k). This hardware made it possible to drive the transducer at set phase shift and set vibration amplitude even when load changes occurred. The transducer was operated at a phase of 45 ° between current and voltage. This was necessary to compensate for an initial load change occurring upon immersion. With this control hardware changes in impedance, for example occurring when the sonotrode was submerged in melt, did not affect the transducers operation point. Also changes of the sonotrode's temperature due to contact with the 720 °C hot melt, leading to elongation of the sonotrode, resulting in a change of resonance frequency, did not affect the operation point either. To keep the influence of temperature as low as possible, the copper discs attached to the sonotrode were submerged for 30 seconds only. The melt was constantly heated and kept liquid throughout the experiments. To ensure similar thermal conditions inside the melt, temperature was measured gradually and before a copper plate was submerged. With a linear guide, the transducer was equally lowered each time so that the sonotrode was always immersed in the same depth in the melt.

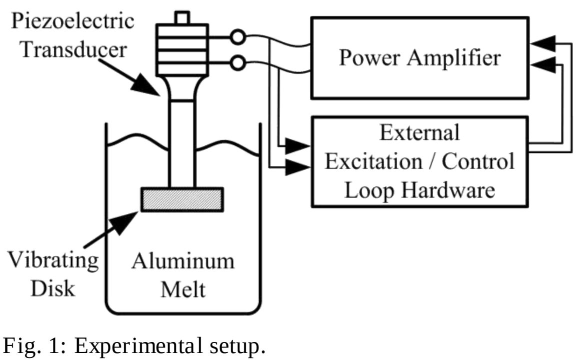

Fig. 1: Experimental setup.

Because in resonance the transducer's velocity v is proportional to the transducer's electric current i, the harmonic displacement amplitude $\hat{x}$ can be determined by the current's amplitude $\hat{\imath}$.

$$\hat{\imath} \propto \hat{v} \propto \hat{x} \quad (1)$$

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Figure 2 shows the linear relationship between the transducer's driving current and displacement amplitude measured at the sonotrode's tip.

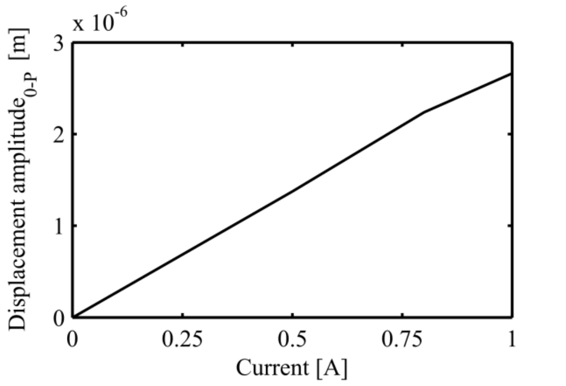

Fig. 2: Dependence of displacement amplitude at the *sonotrode's tip on transducers driving current* (phase shift between current and voltage: 45 °).

For the described experiments the transducer was driven with an alternating current with an amplitude of 0.5 $A_{0\text{-}P}$. From Fig. 2 it can be seen, that this current amplitude corresponds to a displacement amplitude of approximately 1.5 $\mu m_{0\text{-}P}$ at the tip of the Sonotrode.

Experiments

In order to make sure that the discs' surfaces were comparable, the discs were sandblasted before performing the experiments. Prepared in this manner, copper discs were bolted on a specially designed sonotrode, connected to a piezoelectric ultrasonic transducer. The ultrasonic excitation was switched on just before the discs were submerged in aluminum melt. After the discs were excited for 30 seconds in the melt the sonotrode holding the disc was removed from the melt and the ultrasonic excitation was switched off. During the experiments, the electric process data (driving voltage and current) were recorded. In the following the characteristics of the transducer's current amplitude, which is proportional to displacement amplitude of the sonotrode's tip, and phase position between the transducer's current and voltage signal are considered in more detail. For this consideration data for three copper discs, representative of the discs used in the experiments, are discussed.

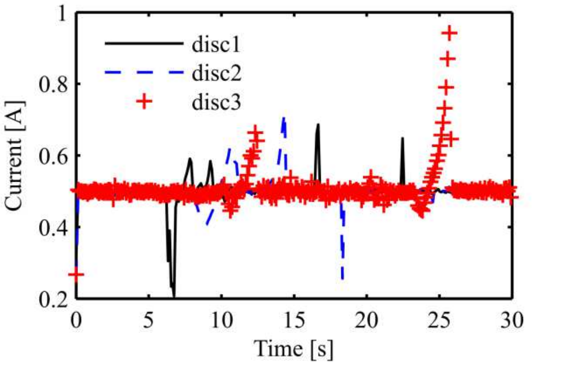

Fig. 3: Piezoelectric t*ransducer's current amplitude* characteristics for three copper discs (setpoint value 0.5 A).

Figure 3 shows the characteristics of the transducer's current amplitude for three copper discs, while the phase position between the transducer's current and voltage signal for the same three discs can be seen in Fig. 4. Both graphs show data over 30 seconds, which is the time span the discs were submerged in aluminum melt.

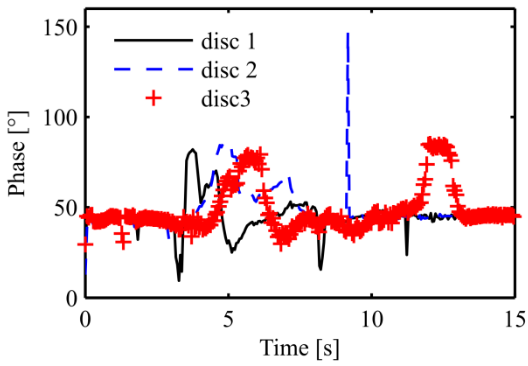

Fig. 4: Phase position between *piezoelectric transducer's* current and voltage signal for three copper discs (setpoint value 45 °).

From Fig. 3 it can be seen, that deviations occur in the transducers current amplitude characteristics which are compensated for by corrective action of the control hardware, and the current amplitude is kept steady at the set value of 0.5 $A_{0\text{-}P}$ for all three discs. The phase characteristics (Fig. 4) also show variations of the desired phase shift of 45 °. These deviations are not compensated for as good as the deviations occurring in the current signal. The compensation in phase is likely to be improved by an adjustment of the control parameters. The occurrence of deviations in both characteristics suggests changes of the mechanical system due to contact with aluminum melt. These changes can be categorized in different types. The first type is temperature induced changes, resulting in an elongation of the sonotrode or the copper discs. While an elongation of the sonotrode results in a shift in the vibratory system's resonance frequency, and does not affect the recorded data, an elongation of the copper discs affects the discs' vibration characteristics and may be a reason for the occurring deviations. The second type of change due to contact with the melt is a change of the copper discs' shape. Partial melting and compounds forming at the surface of the discs lead to changes in mass distribution which affect the vibratory system's mode of vibration as well as the discs' vibration characteristics. The second type is more likely to be the reason for the deviations of the setpoint values in the recorded data.

Results

After the copper discs were submerged in aluminum melt for 30 seconds and excited by a piezoelectric transducer, the discs were removed from the melt and optically inspected. All discs showed differences as well as similarities. The side of the discs facing away from the transducer and towards the bottom of the mold looked different on every disc. While some discs showed severe changes of the whole surface structure due to partial melting and connection with aluminum melt, other discs only showed slight geometric changes at the edge and no changes to the rest of the surface on this side of the disc. In contrast, the other side of the discs, facing towards the

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transducer, looked similar on all discs. This side was coated with a thin film of aluminum. Figure 5 shows three copper discs with the side facing away from the transducer during the experiments. The side which was facing towards the transducer during the experiments of the same three discs can be seen in Fig. 6.

Fig. 5: Copper discs after ultrasonic excitation in aluminum melt (to be seen: side facing away from transducer).

Fig. 6: Copper discs after ultrasonic excitation in aluminum melt (to be seen: side facing towards transducer).

In order to investigate the resulting compounds on the discs' surfaces, polished micrograph sections were made. The discs were cut in the middle in a way that resulted in two separate halves of every disk. In Fig. 7 a section of both halves of a disc is shown. In this figure the two parts are shown on top of each other for better visibility. The word "transducer" and the arrow next to it indicate where the sonotrode was connected to the disc and which side was facing the piezoelectric transducer.

It can be seen that the spot where the sonotrode was connected to the disc has a higher material thickness than the rest of the disc. Here only one side of the disc was in contact with the melt. The rest of the disc shows a removal of material although a thin aluminum coating is present on the side of the disc facing towards the transducer.

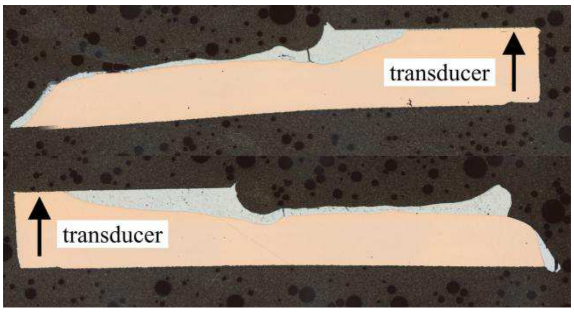

Fig. 7: Polished micrograph section of a copper disc. Two halves of a disc displayed on top of each other.

The side of the disc facing away from the transducer shows no connection with aluminum. To investigate the resulting compounds in more detail, the side of the disc facing the transducer was inspected with a higher magnification. Figure 8 gives a detailed impression of the compounds produced by the experiments. The compound consists of three different zones situated on top of each other. The two outer zones consist of the two metals used in the experiments, aluminum and copper respectively. The third zone in the middle is only a few micrometers wide. This is a zone where alloying occurred. No contaminations or air inclusions exist in this zone. Here copper and aluminum have formed a cohesive bond.

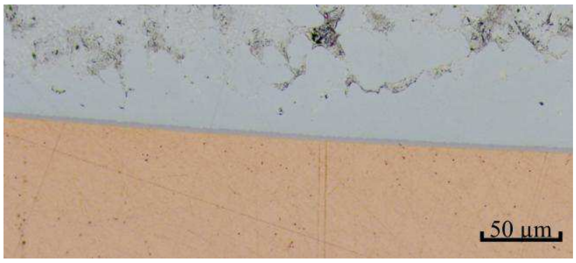

Fig. 8: Detailed view of compounds produced by the experiments.

Discussion

The bond quality of ultrasonic assisted composite casting experiments with copper discs and aluminum melt have been investigated. With the help of ultrasound a cohesive bond between can be generated between the two metals during master forming. This type of processing offers the possibility to create compounds with a high thermal conductivity in one production step. Comparable assembly methods like soldering are more time consuming, have a lower thermal conductivity and cost more. Ultrasonic assisted composite casting is highly dependent on several parameters, for example the amplitude of ultrasonic excitation and sonication time. Optimum parameters for these factors have to be determined. Also for the process to be used in manufacturing a different type of sonication is required. Exciting a copper block placed in a casting mold is difficult and requires some attachment to the block. Here sonicating the melt could be the solution. Experiments concerning these questions will be conducted by the authors. Reasons for the different appearance of the copper plates after sonication have not yet been determined. Also an explanation for aluminum only connecting to one side of the discs needs to be provided.

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