

APPLICATION OF THE FREQUENCY ANALYSIS OF ACOUSTIC EMISSION IN THE STUDY OF THE METAL ALLOY SOLIDIFICATION

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A frequency analysis of the acoustic emission signals was applied for the investigation of the solidification of a Pb-Sb alloy. Spectra of continuous emission and short-time acoustic emission impulses were investigated. It has been stated that, together with structural changes of the Pb-Sb alloy, significant changes occur in the spectra of the acoustic emission impulses generated in different phases of solidification. Less significant changes were observed in continuous acoustic emission spectra.

1. Introduction

The research on the metal alloy solidification concerns the process of passing of alloys from the liquid to the solid state. In a solidifying metal alloy, there occur periods of separation of individual phases at particular temperature-pressure conditions. This depends on the alloy type and on how fast the heat is carried away from the solidifying area. During the research on alloy solidification, it is possible to analyse such basic phenomena as nucleation and phase growth, behaviour of a phase in the presence of other ones, and many additional phenomena which often decide about the properties of an alloy in the solid state. These include among other: things solidifying contraction phenomena, and the mass and capillary flows which compensate them; segregation phenomena; separation of endogenous pollution; sedimentation of endogenous pollution; convection phenomena; solidifying contraction in the solid state. The phenomena mentioned above do not occur simultaneously in the whole alloy, and their intensity depends on the direction and speed of carrying the heat away. Many of them cause a deterioration of mechanical and operational properties of the alloy. In order to reduce these negative effects, researches make use of different research methods; measurable physical quantities have been carried out. Scientists have still searched for new methods of investigation of the alloy solidifi-

cation. However, the knowledge about the phenomena occurring in such processes and their interpretation is still limited to some hypotheses.

To identify the phenomena occurring in a real time in solidifying alloys, researchers have looked for unconventional methods. The acoustic emission (AE) method, which consists of recording and analysing the AE time signals generated in a solidifying alloy, is one of them.

Generally, acoustic emission can be defined as a phenomenon that consists in the generation and propagation of elastic waves, inside or on the surface of a medium, which can be characterised by a broad frequency band within the limits of 1 Hz to 100 MHz, i.e. from infrasounds to ultrasounds.

The previously mentioned phenomena accompanying the solidification can be sources of AE in a solidifying alloy.

2. Research on the alloy solidification by means of the AE method

Acoustic signals emitted during phase transitions in the solid state were observed in the 1930s. The first researches concerned martensite transformation in steel during hardening [1] and were repeated many times. WLODAWER [2] investigated solidification of cast steel observing acoustic effects generated during casting mould filling, convection of the liquid alloy and its crystallisation, and during a reaction inside the material of a mould. For the last few years now, of the fast development of new methods of signal acquisition and processing, the number of studies in that AE signals are used for the identification of phenomena accompanying the alloy solidification has been growing. The authors of the papers [3–7] investigated the solidification of metals applying the sum of AE impulses as a measure of its intensity. In the papers [5] and [6], the mean value of root mean square values (RMS) of the AE signals were used additionally and in the paper [6] the maximum amplitude was applied as well. Since 1990, the analysis of AE signals in the frequency domain has been used more and more often for the investigation of the metal alloy solidification. It has been stated, in the research report [10], basing on the analysis of the time function of the AE signals, that it is possible to identify phase transitions in solidifying alloys. As a continuation of the research started and described in [10], the authors tried to assess structural changes in solidifying alloys basing on the frequency analysis of AE signals [11].

3. Scope of the research on Pb-Sb alloy solidification

It was tried to identify the phase transitions in the alloy during its passing from the liquid to the solid state. To this end the AE method, based on the amplitude-frequency analysis of AE signals received from two different micro-regions of the alloy and on a simultaneous analysis of the self-cooling curves (thermal analysis), was used (Figs. 1 and 2).

The Pb-Sb alloy was obtained by smelting products containing 8% Sb. The liquid metal was smelted in ceramic-graphite melting pots in an electric chamber furnace. Thick-

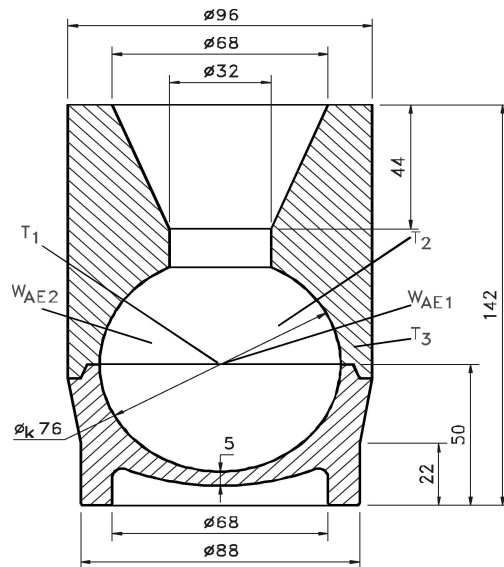


Fig. 1. Ball shaped grey iron mould with the feeding system end temperature and one AE measuring points: T_1 , W_{AE1} — thermocouple and AE wave-guide in the sphere centre, T_2 , W_{AE2} — thermocouple and AE wave-guide 15 or 20 mm away from the alloy surface, T_3 — thermocouple 5 mm away from the internal surface of the mould.

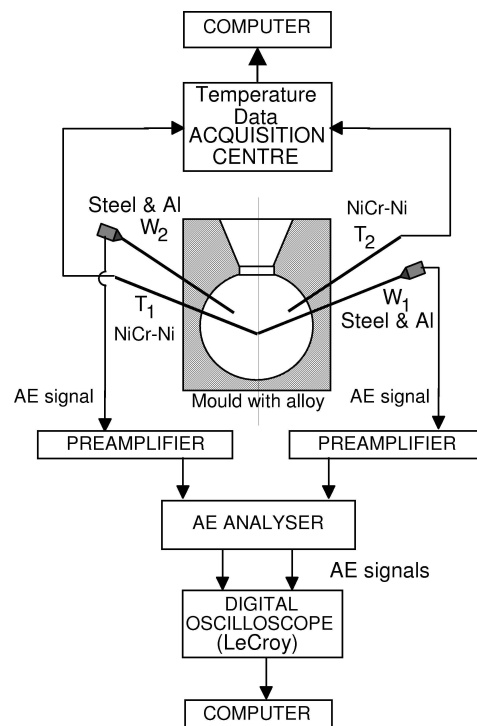


Fig. 2. Measuring system for two-channel acquisition of temperature and AE from the solidifying alloy.

walled grey cast iron moulds with a metal supply system were used (Fig. 1). During the pouring of the moulds the following parameters were used:

- pouring temperature: $T_z = 438 - 464^\circ\text{C}$,
- initial mould temperature: $T_p = 197 - 215^\circ\text{C}$,
- pouring time: $t_z \approx 5\text{ s}$.

The internal surfaces of the moulds were not coated by any protective coating.

The wave-guides for the AE signals consisted of steel bars length $l = 193\text{ mm}$ and diameter $\varnothing = 1.5\text{ mm}$ coated with glass fibre jackets of length $l = 120 - 140\text{ mm}$. There were aluminium cones with AE transducers mounted on the tips of the wave-guides.

To create files containing temperature, the authors' own computer programs were used. The analysis of AE signals was performed using MATLAB software.

4. Results of the experiments

Basing on the self-cooling curves of the Pb-Sb alloy, the time of the occurrence of individual phases of the solidification process in the thermal centre of the casting (the sphere centre) was determined. The alloy solidification phases were difficult to identify at a distance of about dozens of millimetres away from the surface of the mould.

For the individual phase transitions in the solidifying alloy (the sphere centre), the following points were determined:

- Beginning of the separation of the hypo-eutectic phase at the crossing of the liquidus line: -25 s after the mould was poured.
- The end of the temperature hold in the range of the liquidus temperature: -65 s after the mould was poured.
- Beginning of the eutectic transformation: -220 s after the mould was poured.
- The end of the eutectic transformation: -435 s after the mould was poured.

There were two kinds of AE signals observed during the solidification of Pb-Sb alloy: a continuous emission with an almost constant root mean square value overlapped by single impulses with various amplitudes. Therefore, the amplitude spectra for both the continuous AE and AE impulses have been recorded.

Figure 3 shows the time functions for the continuous AE and the respective amplitude spectra in the frequency band (0–1) MHz made for different times of solidification t_0 .

In the spectra shown three frequency bands were marked off:

- (120–180) kHz,
- (500–650) kHz,
- (720–750) kHz.

Changes in the components for different solidification phases were observed in these bands.

In order to present the components in the above frequency bands more clearly, the spectra have been performed in different scales (Fig. 4) This allowed to observe the shift of the characteristic components in the first and second frequency bands. At this stage it was impossible to identify unambiguously the components. Their appearance and frequencies

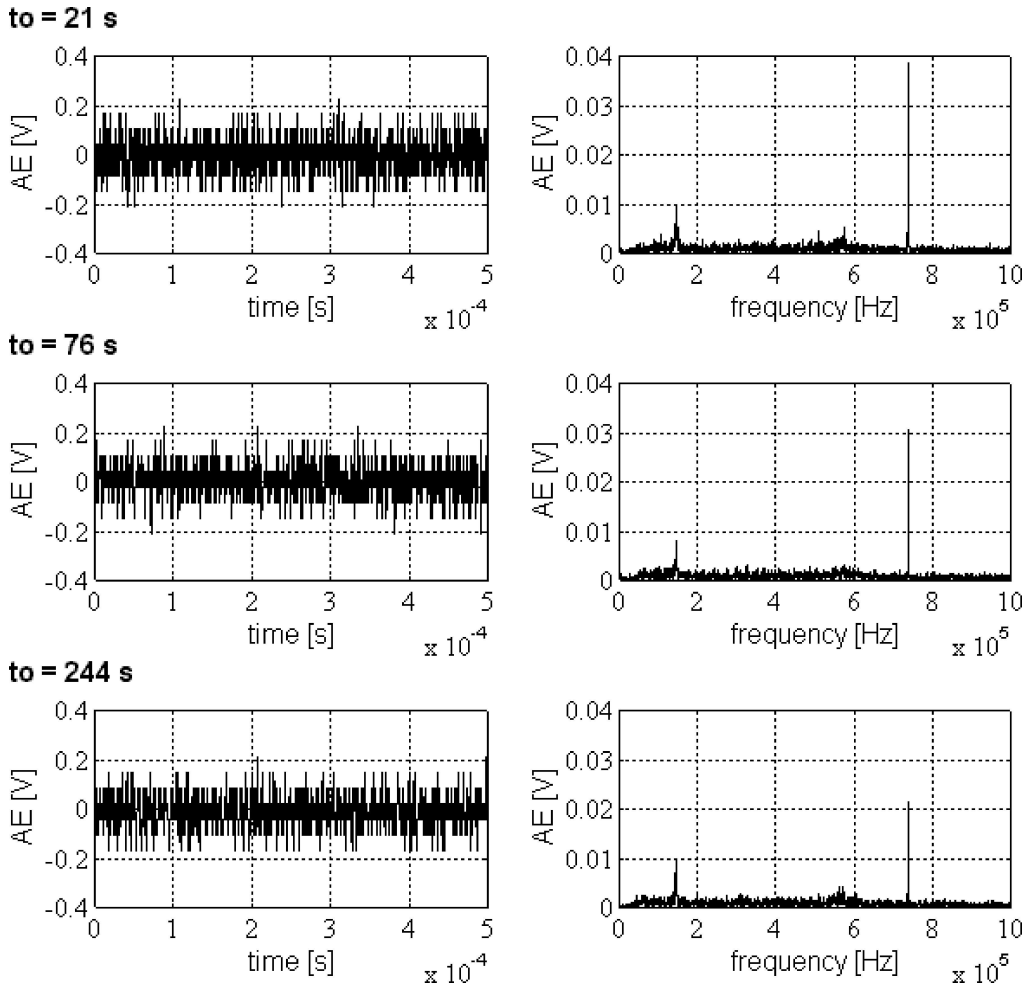


Fig. 3. Continuous AE time functions and their respective amplitude spectra.

can be connected not only with the alloy properties in the respective solidification phase, but also with the alloy defects or with other phenomena occurring during the solidification processes. In the third frequency band there was no shift of the component of a frequency of 738 kHz (Fig. 4) during the solidification. Therefore, it can be inferred that this component is connected with the properties of the measuring system (this component appears also in the AE impulse spectra — Fig. 5).

The AE impulse spectra (Fig. 5) for different alloy solidification phases differ much more and contain much more components. The spectrum with clear components in the frequency band up to 200 kHz (21 s after the mould was poured) corresponds to the beginning of the pre-eutectic phase separation.

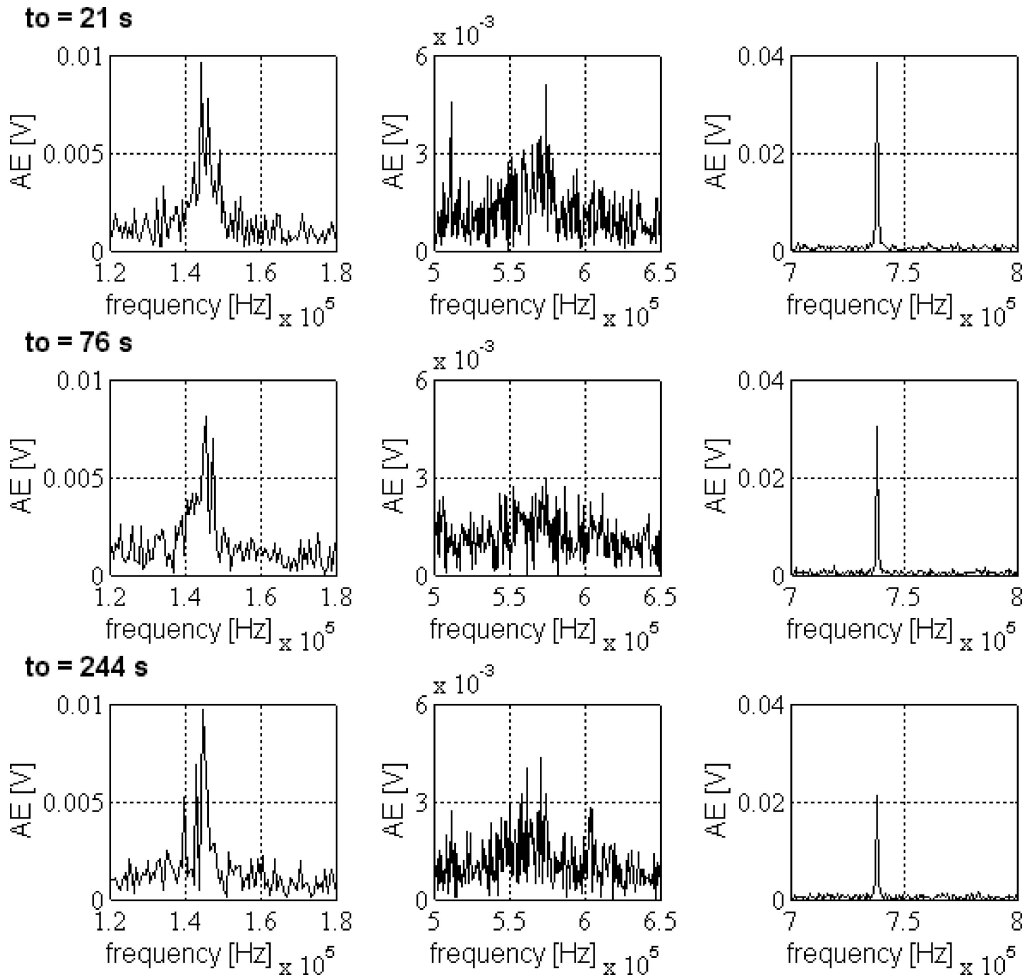
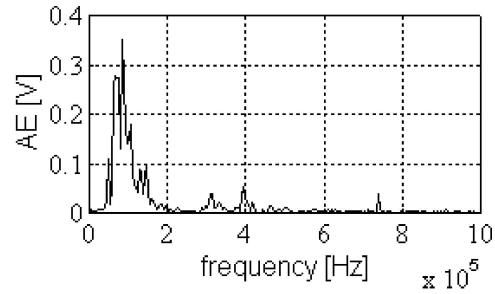
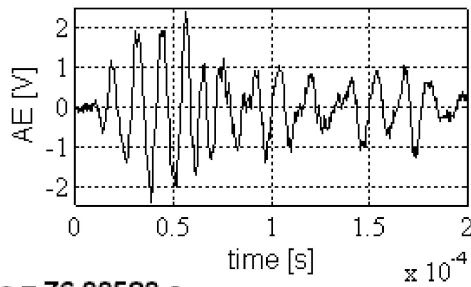


Fig. 4. Continuous AE spectra for the different solidification phases.

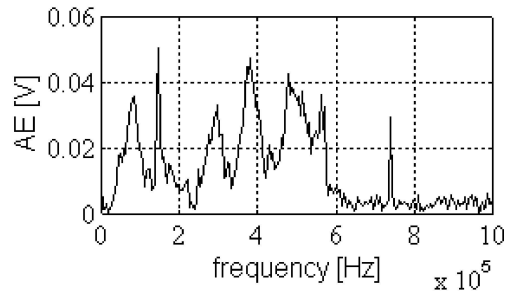
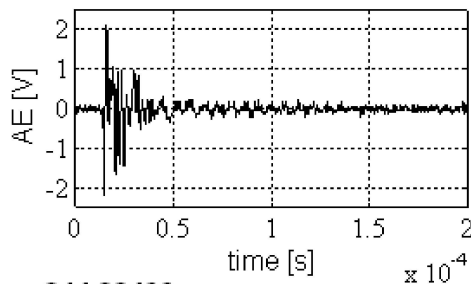
The AE impulse spectrum in the subsequent solidification phase (after the temperature hold at the liquidus temperature range and before the eutectic transformation) contain many components in the frequency band up to 600 kHz.

During the eutectic transformation, the number of components in the AE impulse spectrum decreases. There is only one clear-cut component in the frequency band up to 200 kHz and several others in the frequency band (400–600) kHz.

to = 21.00497 s



to = 76.00580 s



to = 244.00499 s

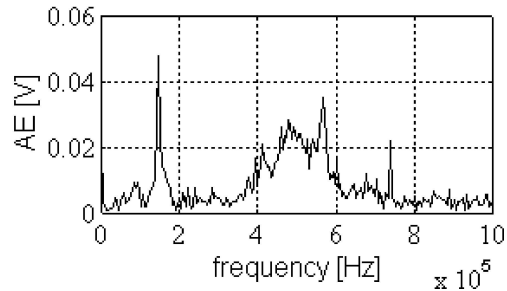
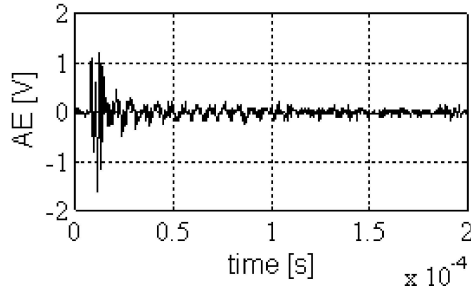


Fig. 5. Time functions of AE impulses and their respective amplitude spectra.

5. Conclusion

The thermal analysis and its respective frequency analysis of the AE signals show that structural changes of Pb-Sb alloys are accompanied by significant changes in the AE impulse spectra generated in different solidification phases. There are less clear changes observed in the continuous AE spectrum.

The results shown allow the authors to say that changes in AE signals have been found which enable the observation of structural changes in the solidifying alloy. However, a comprehensive identification of the solidification phases based on the AE spectrum changes needs further research taking into account other alloys.

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