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ANALYSIS OF THE PROCESS OF CRYSTALLIZATION OF CONTINUOUS CAST SPECIAL BRASS ALLOYS WITH THE ACOUSTIC EMISSION

ANALIZA PROCESA KRISTALIZACIJE KONTINUIRNO LITE SPECIALNE MEDENINE Z METODO AKUSTIČNE EMISIJE

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Analyses of possibilities of monitoring the crystallization process of continuously cast special brass alloys with acoustic emission and for establishing a correlation between the microstructure and the recorded acoustic emission signals. With appropriate selection of parameters for gravitational casting process, continuous casting was performed and samples with a macrostructure typical of continuous casting were obtained. A laboratory plant for the simulation of the continuous casting and for the analysis of the crystallization process with acoustic emission was designed. Different energy levels in samples with different macrostructure, as well as in the defective and non-defective samples, were observed. Two types of sources of signals were defined: the signal during solidification of correct crystallization and macrostructure of continuous casting and acoustic emission signal during solidification of samples in with flaws. To check the obtained results, after completion of the crystallization process, the samples were submitted to external with mechanical loading. The acoustic activity by loading is in accordance with the results of on-line monitoring of the crystallization process with acoustic emission. The results obtained show that it is possible to use the acoustic emission for monitoring the crystallization process by continuous and gravitational casting.

Key words: continuous casting, crystallization, non-destructive examination, acoustic emission

Raziskava je namenjena možnosti za spremljanje procesa kristalizacije kontinuirne lite posebne medenine z metodo akustične emisije in opredelitvi povezave med makrostrukturo in zabeleženimi signali akustične emisije. S primerno izbiro parametrov procesa gravitacijskega litja je bilo izvršeno kontinuirno litje in dobljeni so bili vzorci s tipično makrostrukturo tega litja. Pripravljen je bil tudi načrt za napravo za laboratorijsko simulacijo kontinuirnega litja in analizo procesa kristalizacije z akustično emisijo. Opaženi so bili različni nivoji energije v vzorcih za različno makrostrukturo in vzorci brez napak in z njimi. Rezultat raziskave je bila definicija dveh izvirov signalov akustične emisije: signal med strjevanjem s pravilno kristalizacijo in makrostrukturo in signal med strjevanjem vzorcev, v katerih nastajajo napake. Zaradi preverjanja dobljenih rezultatov so bili vzorci po končani kristalizaciji izpostavljeni zunanji indukciji makrostrukture z mehansko obremenitvijo. Akustična emisija med to obremenitvijo je skladna z rezultati spremljanja procesa kristalizacije z akustično emisijo. Sklep je, da je mogoča uporaba akustične emisije za spremljanje kristalizacije pri neprekinjenem gravitacijskem litju.

Ključne besede: kontinirno litje, kristalizacija, neporušna preiskava, akustična emisija

1 INTRODUCTION

The quantification of microstructures and of their generating mechanism is a problem that every researcher in the area of materials needs to deal with. The problem becomes even more complicated when it is necessary to define the generated structure of the material without the application of destructive methods.

The field of non-destructive research provides different techniques that are used, or may be used, for controlling the materials quality, such as: vibration analysis [1], thermography [1,2], X-ray analysis [2], ultrasonic examination [3,4] and acoustic emission [5,6].

The principle of the acoustic emission is that, due to changes occurring in the material, there is a sudden release of accumulated deformation energy, in form of mechanical waves that are transmitted through the material, and detected by sensors. The phenomenon of generating mechanical waves with release of a part of the deformation energy in the material is called acoustic emission [7,8].

Given that all the materials used for construction purposes (metals, alloys, glass, ceramics, wood, concrete and polymers) produce, under certain conditions, acoustic emission signals, this method can be very successfully used: [8,9,10]

- in tensile hardness tests,
- for structural composition and material characteristics control,
- in phase transformations in material tests,
- for controlling vessels and water-pipelines,
- for controlling aircraft and spacecraft constructions,
- in welded tacks tests,
- in crack tests,
- in material fatigue monitoring,
- in monitoring a crack's development at low temperatures,
- in material solidification monitoring, which is still in its infancy [11,12].

In this study, the main objective was to define a method for monitoring the process of continuous casting that might effect the casting quality and enable the monitoring and management. Since this is a continuous process, conventional monitoring methods with destruction are inadequate because the process needs to be decelerated during each sampling. In addition to this, monitoring performed in this way requires much time, labour and material, with the ever-present problem of the casting quality of two samplings. The results of the analysis of the process of crystallization of the continuous casting of brass-type special alloys with acoustic emission are shown here. Every change in the level of the acoustic emission signals characterises a corresponding structure object, which is later identified in a metallographic analysis. Thus, a particular monitoring diagram "structure – the acoustic emission signal" is defined, which may be used for the on-line characterisation of a material during the process of continuous casting.

2 EXPERIMENTAL

The material used in this research belongs to the group of the special brass alloy type $CuZn_{21}Al_2As$.

Two groups of experiments were performed. The objective of the first group was to record the generating of the "ideal" microstructure in terms of acoustic activity, i.e., to determine the belt of acoustic emission signals that guarantees the correct crystallization and the obtaining the continuous casting macrostructure. The second group of experiments included the recording of acoustic emission signals of samples with artificially induced flaws with inadequate cooling regime and the inflow of molten metal.

The experiments comprised the physical stimulation of continuous casting by gravitational casting, the defining the characteristic signals that appear in the processes of solidification and further cooling. A continuous casting simulation combining gravitational casting and changes in velocity of the casting mould may be observed in time and ways of cooling of the casting mould, so that the macro-effect on the mould is the same as if it has gone through the cooling zones of continuous casting. For this reason, an appropriate steel casting mould was designed and produced, which, under specific cooling conditions, has similar velocities of conductivity and heat outlet to continuous casting. **Figure 1** shows the scheme of the experimental casting mould.

The casting mould has sensor holders and thermopair for measuring the temperature during cooling attached. The acoustic emission sensor holder, shown in **Figure 2**, is specially designed for the work at increased temperature. It is made in the form of a ribbed tube of an aluminium alloy and with the aim to prevent thermal damage to the sensor. In its middle part, due to the identity of the material whose acoustic activity is being examined and the material which the signal passes through to the sensor, there is a brass bar that functions as a signal conductor. The sensor is a piezoelectric tile, type BMF 10P-5, with a resonance frequency of 180kHz. The total amplification of the acoustic emission signals is different, from 5000 to 10000. The frequency response of the amplifying level from 100kHz to 3MHz is limited by the use of a filter, which does not affect the total amplification and the resonance field of the sensor. The processing of the acoustic emission signals is performed by the method of oscillation counting recorded by the sensor (the ring-down counting method), which is based on counting each outthrow at the decision level by the signal obtained at the sensor exit. Every time that level is outthrown, it generates a signal registered by the gauge. The total number of signals surpassing the specific (set up) decision level, appears at the unit exi as an analogous signal. This signal is written on the plotter, via an A/D convertor, or a PC. During the research the RMS method (effective value of the voltage) for analysing the acoustic emission signals during the measurement interval, by

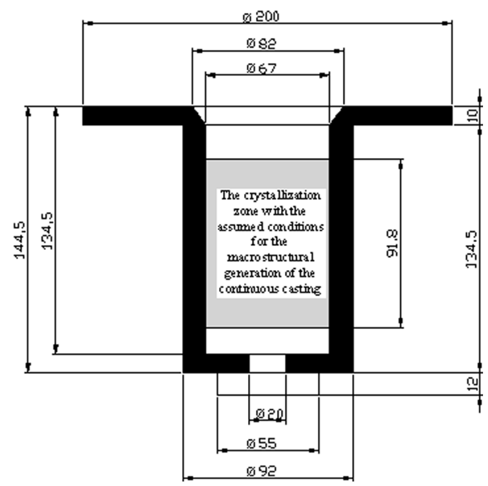

Figure 1: The scheme of the experimental casting mould
Slika 1: Shema eksperimentalne livne kokile

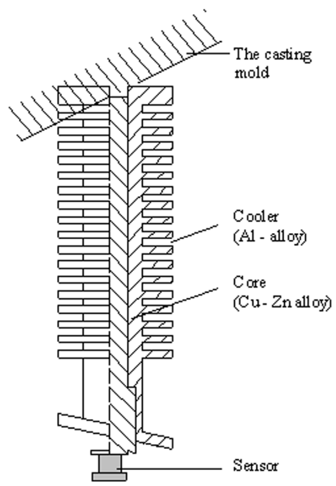

Figure 2: The scheme of the acoustic emission sensor holder
Slika 2: Shema nosilca senzorja akustične emisije

which, applying the appropriate transformations, the original signal is transformed into a signal whose shape is much clearer for reading.

Figure 3 shows the laboratory plant for monitoring the acoustic emission signals. After recording the signals of the acoustic emission, the obtained samples are submitted to the quality control of the macrostructural properties. Finally, in order to check the results of the research, after the completion of the solidification process, the samples are submitted to external induction by mechanical loading.

3 RESULTS AND DISCUSSION

The quality control of the macrostructural properties indicates that with an appropriate choice of parameters of gravitational casting into a designed metal casting mould (a method of pouring molten metal, cooling velocity, etc.), it is possible to simulate the continuous casting and obtain castings with a continuous casting macrostructure.

Figure 4 shows the macrostructure of samples with correct crystallization and continuous casting macrostructure, whereas **Figure 5** shows the recording of the acoustic emission signal for the observed sample.

Analyzing the recording of acoustic emission signal with correct crystallization and continuous casting macrostructure, it can be concluded that there is a sudden increase in the acoustic activity immediately after the pouring of molten metal into the casting mould, which is the result of the primary solidification of the α-solid solution and the occurrence of friction between the solid metal and the casting mould. The next phase is the phase of the linear growth of acoustic activity until the sample is completely solidified. In addition, it is evident that there is a uniform distribution of the effective (RMS) voltage, which indicates the absolutely correct crystallization and the obtaining of samples without flaws. This is illustrated by the recording of the macrostructure of the analysed sample.

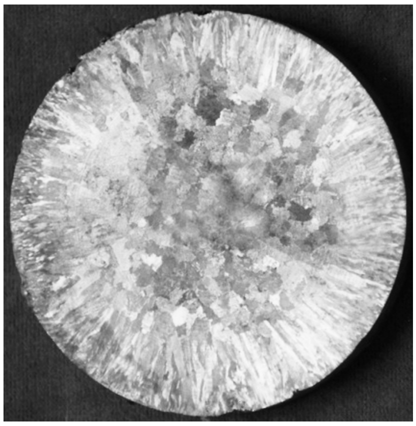

Figure 4: The scheme of the macrostructure of the sample with absolutely correct crystallization and a continuous casting macrostructure

Slika 4: Shema makrostrukture kontinuirno litega vzorca s pravilno kristalizacijo

Figure 6 shows the macrostructure and **Figure 7** shows the acoustic emission signal of samples with a flaw.

There is a more intensive acoustic activity in samples with any type of flaw and gravitational casting macrostructure (**Figure 6**) during the crystallization process (**Figure 7**) in comparison to the acoustic activity of samples with the macrostructure of continuous casting. This results from the fact that the friction between the small grains characteristic of gravitational casting, due to the larger total area, is higher than the friction among large grains characteristic of continuous casting. A more intensive acoustic activity in samples with macrostructure of gravitational casting can be associated with the fact that the grain boundaries represent an area of a disturbed crystal structure and that these disorders are more distinctive if there is a greater difference in orientation of neighbouring crystals. In addition, a small-grained microstructure may be caused by effects preventing grain enlargement, and all this initiates more acoustic activity in comparison to the

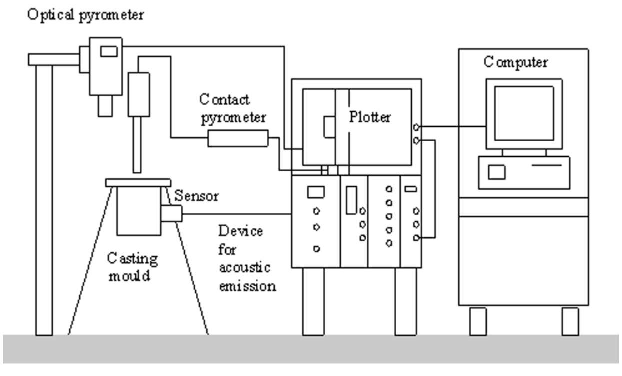

Figure 3: The laboratory plant for monitoring acoustic emission signals during solidification

Slika 3: Laboratorijske naprava za beleženje signalov akustične emisije med strjevanjem

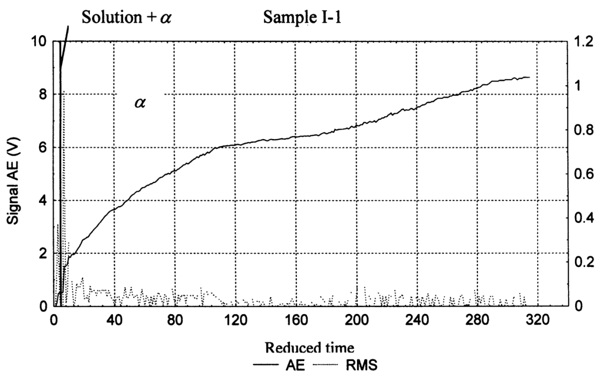

Figure 5: The recording of the acoustic emission signal for the sample with an absolutely correct crystallization and continuous casting macrostructure

Slika 5: Registracija signala akustične emisije za vzorec s pravilno kristalizacijo in kontinurne lite makrostrukture

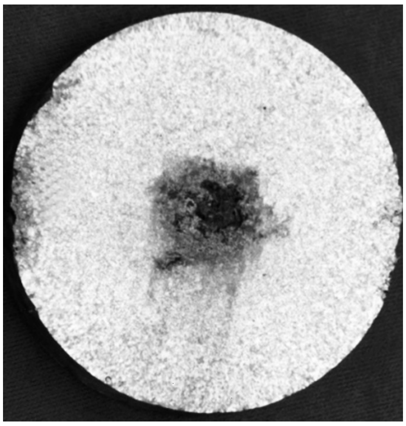

Figure 6: The macrostructure of the sample with a flaw
Slika 6: Makrostruktura vzorca z napako

acoustic activity in samples with continuous casting macrostructure.

When analysing the results of the completed examination, it is evident that all the samples show acoustic activity during the crystallization process. In samples with out flaws in the latter phase (**Figure 4**), the analysis of the RMS voltage of acoustic emission signals (**Figure 5**) does not indicate the existence of any characteristic signal after the crystallization signal. While monitoring the acoustic activity, there is a specific even distribution of RMS voltage, without any distinctive peaks. There is also a specific belt of values of the acoustic emission signals, which, for a particular mould, guarantees a correct crystallization and the obtaining of the continuous casting macrostructure, where a three-zone distribution of crystals (from the small globular and column-like crystals to the large globular ones in the central part of the crystals) are clearly visible. If the signal comes out of this belt, the crystallization is irregular. While monitoring the acoustic activity of samples with flaws of any type (**Figure 6**), the distribution of the RMS voltage is irregular, with clearly visible peaks (**Figure 7**).

The obtained results show that it is possible to use the acoustic emission method for monitoring the crystallization process during continuous casting. Two types of signal sources are defined here:

- the acoustic emission signal during solidification of samples with correct crystallization and continuous casting macrostructure,
- the acoustic emission signal during solidification of samples with flaw (crack, inclusion, etc.) and gravitational casting macrostructure.

With the aim to check the results of the research, the formed (cooled) samples are submitted to changes of the macrostructure with mechanical loading. With changes of structure a specific material activity, i.e., the existence of "frozen" faults in the material is detected.

Figure 8 shows the acoustic activity of loaded sample with an absolutely correct crystallization and continuous casting macrostructure.

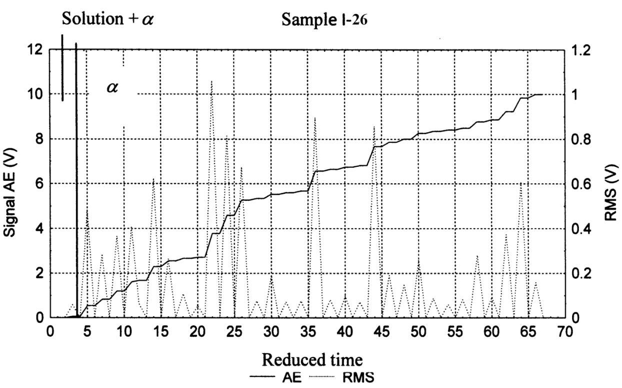

Figure 7: The acoustic emission signal for the sample with a flaw
Slika 7: Akustična emisija vzorca z napako

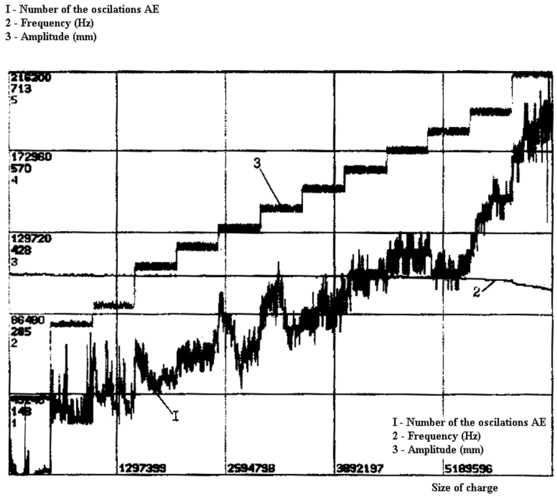

Figure 8: The acoustic activity of the externally induced sample with completely correct crystallization and a continuous casting macrostructure
Slika 8: Akustična emisija obremenjenega vzorca s pravilno kristalizacijo in makrostrukturo kontinuirnega litja

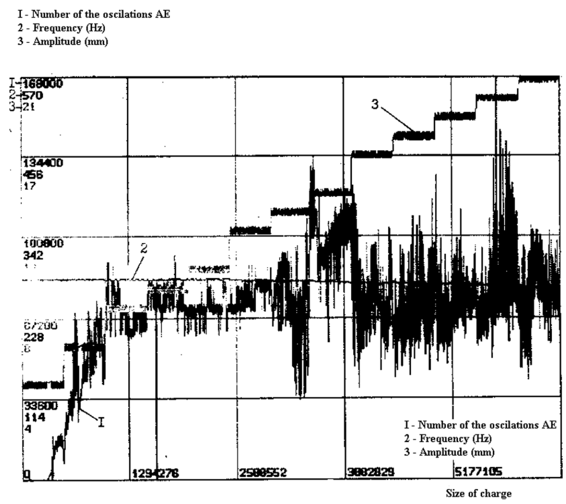

Figure 9: The acoustic activity of an externally induced sample with a flaw
Slika 9: Akustična aktivnost zunanje obremenjenega vzorca z napako

On samples without flaws in macrostructure, a uniform activity increase under the mechanical load is evident, which means that the voltages in the material are uniformly distributed in the volume. There was no particular inhomogeneity of the material, and the analysis of the crystallization process, which leads to that particular structural stabilization, is adequately recorded by the acoustic emission signal.

Figure 9 shows the acoustic activity of loaded sample with a flaw.

The recording of the acoustic activity indicates that during loading of the material with a flaw there are dramatic amplitude oscillations, which means that the voltages in the material are not uniformly distributed in the volume. According to the results of the monitoring of the process of crystallization this is characteristic for defective samples according to the acoustic emission method.

4 CONCLUSION

With an appropriate selection of parameters of gravitational casting into a metal casting mould (the style of pouring, a definite cooling velocity, etc.), it is possible to simulate continuous casting and obtain castings with the continuous casting macrostructure.

The results obtained from the analysis of the process of solidification indicate that it is possible to use acoustic emission as a method for recording and for monitoring the crystallization process during continuous and gravity casting.

Two types of sources of the acoustic emission signals were defined:

the acoustic emission signal during the solidification of samples with a completely correct crystallization and a continuous casting macrostructure,

the acoustic emission signal during the solidification of samples with of flaws (crack, inclusion, etc.) and gravitational casting macrostructure.

All the signals of the acoustic emission show acoustic activity at the beginning of the monitoring process, i.e., the acoustic activity of the crystallization process. In samples with a correct crystallization, the RMS analysis does not indicate the existence of any characteristic signal after the crystallization signal. There is also a specific belt of acoustic emission signals, which guarantees completely correct crystallization for that particular sample. If the signal originates out of this belt, the sample has a flaw.

By inducing the structure with a mechanical load in both samples, defective and non-defective, the acoustic activity is identified, which is in accordance with the results of the on-line monitoring of the crystallization process using the acoustic emission method.

Further research will be aimed to define the dependence of the level of acoustic emission signal on the type and the location of the flaw in the sample on the basis of the analysis of the values of the RMS voltage, the development of the adaptive system for the regulation of the process of continuous casting on the basis of the developed on-line method, as well as on the application of the obtained results of other casting technologies.

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