A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 54 2009 Issue 2

W. K. KRAJEWSKI*, J. BURAŚ*, M. ŻURAKOWSKI*, A. L. GREER**

STRUCTURE AND PROPERTIES OF GRAIN-REFINED Al-20wt% Zn SAND CAST ALLOY

STRUKTURA I WŁAŚCIWOŚCI ZMODYFIKOWANEGO STOPU Al-20 wag. % Zn ODLANEGO DO FORMY PIASKOWEJ

Recent foundry industry requires a development of cast alloys whose melting is both energy saving and environmentally friendly; these are two important priorities of the EC programme. The Al – based cast alloys with increased Zn content could response to these demands because of their good mechanical properties, especially the strength and damping ones, and also relatively low melting temperatures. However, the AlZn – based alloys require grain refining to improve their plastic properties. The presented work is devoted to structural characteristics of the grain – refined high – zinc aluminium alloy Al - 20 wt% Zn. The system studied was Al - 20 wt% Zn alloy (AlZn20), Zn - 4.6 wt% Ti master alloy (ZnTi4 MA), ZnAl - 4 wt% Ti (ZnAl -Ti4 MA) as well as the traditional refiners Al - 5 wt% Ti - 1 wt% B (AlTi5B1 MA) and Al - 3 wt% Ti - 0.15 wt% C (AlTi3C0.15 MA). SEM (scanning electron microscopy), LM (light microscopy) and TA (thermal analysis) investigations showed high effectiveness of the used master alloys as grain refiners of the inoculated with them AlZn20 alloy. The initial examinations of the damping properties were performed using an ultrasonic pulse - echo method. The obtained results showed, that attenuation coefficient of the grain refined AlZn20 alloy, naturally aged before casting during 1 year, decreases by about 10 - 30 % together with increased structural fineness. It was stated that the higher grain refinement of the examined AlZn20 sand cast alloy, the higher decrease of its attenuation coefficient.
Keywords: Al-Zn alloy, sand casting, grain refinement, attenuation coefficient

Współczesny przemysł wymaga rozwoju stopów odlewniczych, których przetapianie jest energooszczędne oraz przyjazne środowiskowo – są to dwa ważne priorytety programów Unii Europejskiej. Odlewnicze stopy na osnowie Al o podwyższonej zawartości Zn powinny odpowiadać powyższym wymaganiom, ponieważ cechują się one dobrymi właściwościami mechanicznymi, szczególnie wytrzymałościowymi i tłumiącymi, i równocześnie stosunkowo niską wartością temperatury przetapiania. Jednak stopy na osnowie AlZn wymagają zabiegu rozdrobnienia struktury w celu polepszenia ich właściwości plastycznych. Niniejsza praca jest poświęcona charakterystyce zmodyfikowanych, wysoko-cynkowych stopów Al. Badaniom poddano stop Al - 20 wag% Zn (AlZn20), zmodyfikowany przed odlaniem do formy piaskowej dodatkiem nowych zapraw modyfikujących typu Zn - 4.6 wag. % Ti (ZnTi4 MA), ZnAl - 4 wag. % Ti (ZnAl -Ti4 MA) oraz zapraw tradycyjnych Al - 5 wag. % Ti - 1 wag. % B (AlTi5B1 MA) i Al - 3 wag. % Ti - 0.15 wag. % C (AlTi3C0.15 MA). Badania SEM (scanning electron microscopy), LM (light microscopy) i TA (thermal analysis) wykazały wysoką efektywność rozdrabniania ziaren stopu AlZn20 przez zastosowane zaprawy modyfikujące. Wstępne badania właściwości tłumiących, wykonane przy pomocy ultradźwiękowej metody wykazały, iż współczynnik tłumienia zmodyfikowanego stopu AlZn20, naturalnie starzonego po odlaniu przez okres 1. roku, zmniejsza się o około 10 - 30 % wraz ze wzrostem stopnia rozdrobnienia struktury. Zmniejszenie to jest tym większe, im większy jest stopień rozdrobnienia ziaren badanego stopu AlZn20.

1. Introduction

Recent efforts of the European Community are aimed, among others, at energy saving and improving environmental protection at the same time. From this point of view, foundry industry production should be focused on wider application of the alloys, which are less energy consumable during their melting process. The, so called, high-zinc aluminium cast alloys are a good example of those alloys, which could replace other, more energy consumable ones. However, wider implementation of the high-zinc aluminium cast alloys requires improving their plastic properties.

* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, 23 REYMONTA STR., 30-059 KRAKÓW, POLAND
** UNIVERSITY OF CAMBRIDGE, CB2 3QZ CAMBRIDGE, PEMBROKE STR., UNITED KINGDOM

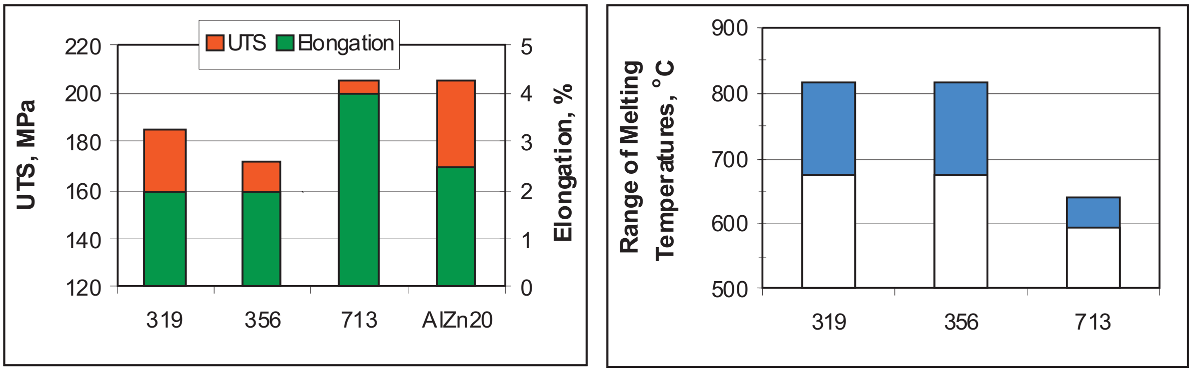


Fig. 1. Ultimate tensile strength UTS, elongation and range of melting temperatures (blue areas on the right-side diagram) of the typical foundry sand-cast alloys 319 (AlSi6Cu4), 356 (AlSi7Mg0.3), 713 (AlZn8Cu1Mg) and the high-zinc AlZn20 aluminium alloy. (Diagrams based on data published in [1] and [2])

As it appears from Fig 1, the AlZn20 alloy, selected here as the representative of the high-zinc aluminium alloys, requires increasing its plastic properties. On the other hand, it appears from Fig. 2, that die-cast Al-Zn alloys have higher elongation as the sand-cast alloys, which is most probably due to their finer structure. Thus, the high-zinc aluminium alloys require grain-refinement, which could allow to improve their elongation.

It is well known from literature, that Al-Zn alloys are numbered into the group of increased damping properties [3]. However, recent literature lacks information about the relationship between grain fineness and damping properties. The presented work is focused on obtaining such information.

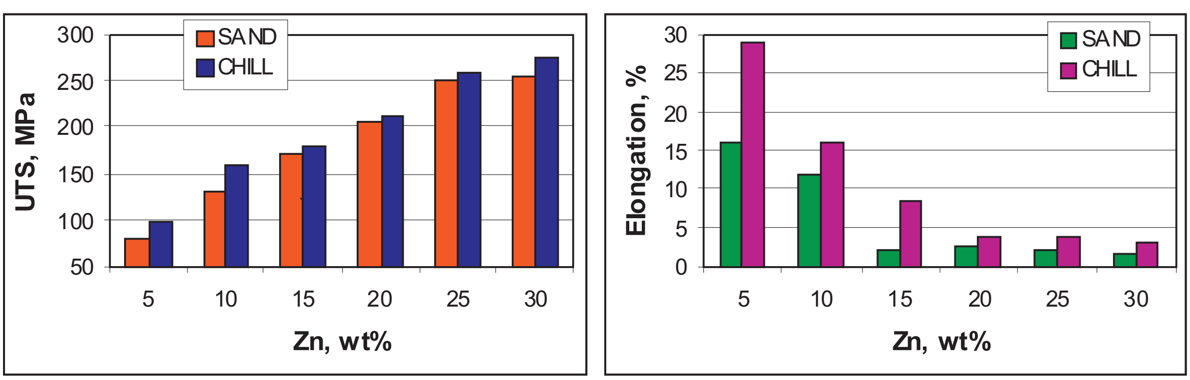


Fig. 2. UTS and elongation vs. Zn content of cast Al-Zn alloys (Diagrams based on data published in [2])

2. Materials and experimental

The examined alloy AlZn20 and the master alloys Zn-4.6wt%Ti (ZnTi4) and Zn-20wt%Al-4wt%Ti (ZnAl-Ti4) were prepared from electrolytic aluminium (minimum purity 99.96%), electrolytic zinc (99.995%) and titanium sponge (98-99.8%, from Johnson Matthey Alfa). The AlZn20 alloy was melted in an electric resistance furnace, in an alumina crucible of 0.2 litre capacity. The AlZn20 melt was superheated to ~720°C. After introducing a master alloy the melt was held in the crucible for 2 minutes, then the melt was stirred for 2 minutes with an alumina rod, and the alloy was cast into a dried sand mould (Fig. 3(a)) or into a preheated graphite-chamote crucible (Fig. 3(b)). To monitor the cooling process – two thermocouples NiCr-NiAl0.5 Ø0.20 mm were mounted in the sand mould cavity or were introduced from the top into the melt in a preheated graphite-chamote crucible.

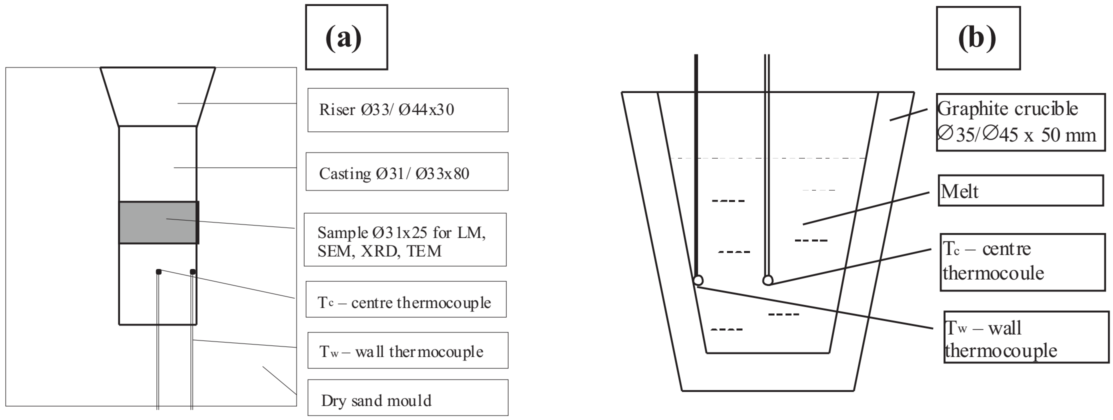


Fig. 3. Schematic sketch of the system: (a) sand mould – casting with mounted thermocouples, (b) chamote-graphite crucible with thermocouples introduced from the top into a melt [4, 5, 9]

Temperatures (accuracy ± 1°C) were recorded using a multi-channel recorder Agilent 34970A (Agilent Technologies Inc., USA). Microsections for LM examinations were ground on abrasive paper (grit 200-1000) and then were polished using sub-microscopic aluminium oxide in water-alcohol suspension. The AlZn20 samples, used in macrostructure examinations, were etched with Keller's reagent. SEM investigations were performed using ESEM Philips XL30 microscope equipped with an EDS system EDAX Gemini 4000. The examinations of damping properties were performed on the AlZn20 alloy using ultrasonic technique. The used samples were discs Ø31x12mm cut from the sand-castings (Fig. 3(a)), whose parallel surfaces were ground on abrasive paper of 1200 grit. A DI-4P ultrasonic defectoscope (UNIPAN – Poland), operating at constant frequency of 2.0 MHz, was used as a source of the longitudinal ultrasonic wave. The attenuation coefficient α was obtained using pulse-echo method.

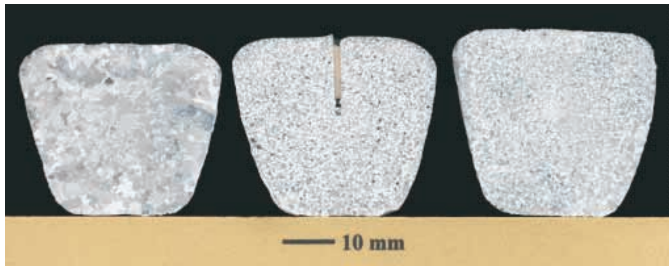
3. Results and discussion

3.1. Structure refinement

The initial macrostructure of the AlZn20 alloy poured into the preheated chamote-graphite crucible is shown in Fig. 4(a). Fig 4(b) shows the macrostructure obtained in the same conditions, but after addition of the 0.04 wt% Ti, introduced as Al-0.12 wt% Ti MA, to show the influence of Ti solute on the grain refinement.

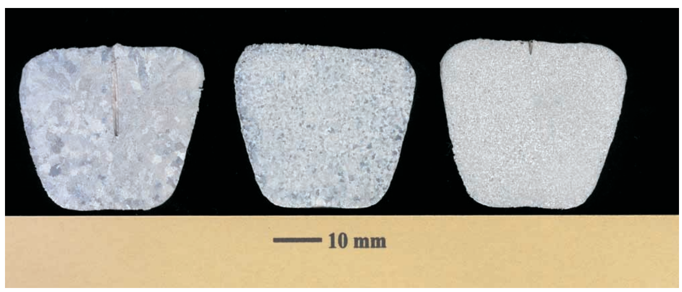
(a) (b)

Fig. 4. AlZn20 alloy. Macrostructure obtained in a preheated graphite crucible. (a) Unrefined alloy. (b) Influence of Ti solute introduced with Al – 0.12 wt% Ti MA [9]



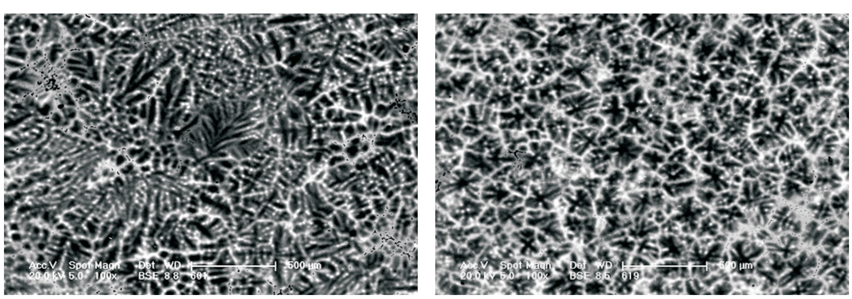
(a) (b) (c)

Fig. 5. AlZn20 alloy. Macrostructure obtained in a preheated graphite crucible. (a) Unrefined alloy. Influence of 0.04 wt. % Ti addition introduced with ZnAl-Ti4 (b) or Al-Ti3-C0.15 (c) MA [9]



(a) (b) (c)

Fig. 6. AlZn20 alloy. Macrostructure obtained in a preheated graphite crucible. (a) Unrefined alloy. Influence of 0.08 wt. % Ti addition introduced with Zn-Ti4 (b) or 0.04 wt. % Ti addition introduced with Al-Ti5-B1 (c) MA [9]



(a) (b)

Fig. 7. SEM – BSE micrographs of unrefined (a) and refined (b) Al – 20 wt% Zn alloy. Al-Ti5-B1 MA; 0.01 wt% Ti [9]

Figs 5 and 6 show that all the used master alloys cause significant grain-refinement and also refinement of the microstructure, as it is clearly seen in Fig. 7. The observed structure refinement, both grains and dendrites of the solid solution of Zn in Al, should positively influence plastic properties of the inoculated AlZn20 alloy.

3.2. Changes of attenuation coefficient

Grain size is a key factor influencing strength properties of metals and alloys. It is commonly known, that refinement of the macrostructure positively influences plastic properties measured by elongation and fracture toughness. However, changes of the structure fineness can cause also changes of the damping properties, which in many applications are key property of an alloy. Fig.

8 presents results of the performed measurements of attenuation coefficient for AlZn20 alloy inoculated by constant addition of 0.04 wt% Ti, however introduced with different master alloys. From Fig. 8 it can be seen, that attenuation coefficient decreases together with the observed grains refinement.

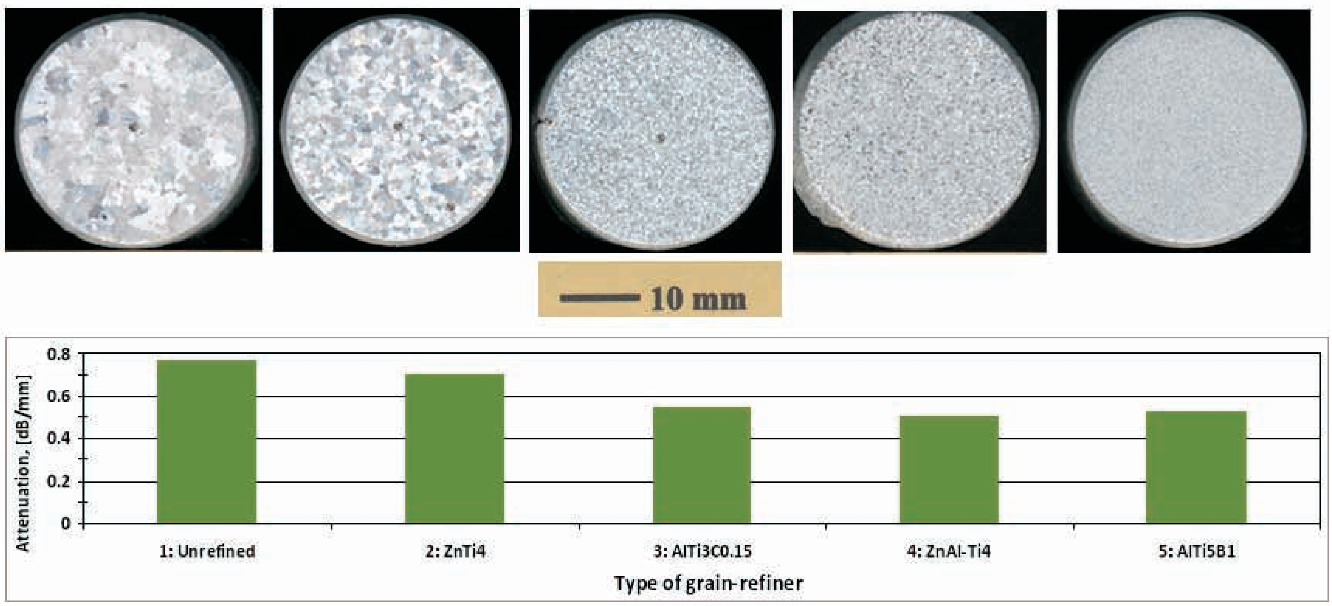


Fig. 8. Relationship: grain density – attenuation coefficient for the examined AlZn20 alloy inoculated with addition of different master alloys [9]

4. Discussion and final remarks

The presented above results show that melt inoculation of the examined AlZn20 alloy causes significant increase of grains population and also refinement of the α(Al) dendrites. At the same time a decrease of the attenuation coefficient is observed. However, the range of changes of the attenuation coefficient is not strictly proportional to the observed range of changes of the grain-refinement. In general, the attenuation coefficient α of the polycrystalline materials can be expressed as:

$$\alpha = \alpha_a + \alpha_d + \alpha_s, \quad (1)$$

where: α_a, α_d and α_s mean absorption, diffraction and scattering terms.

In polycrystalline materials, e.g. metals and their alloys, ultrasonic waves are attenuated mainly by scattering, while absorption and diffraction attenuation are negligible [6, 7]. Scattering attenuation has its characteristic regions, described by the following relationships:

$$\alpha_s \propto \overline{D}^3 f^4 \quad \text{Rayleigh scattering, when } \lambda >> 2\pi \bar{D}, \quad (2a)$$

$$\alpha_s \propto \overline{D} f^2 \quad \text{Stochastic scattering, when } \lambda \approx 2\pi \bar{D}, \quad (2b)$$

$$\alpha_s \propto \frac{1}{\overline{D}} f^4 \quad \text{Diffusion scattering, when } \lambda < 2\pi \bar{D}, \quad (2c)$$

where: λ – length of the longitudinal ultrasonic wave, $\overline{D}$ – mean diameter of grains, f – frequency.

Surface grains density N_F of the examined samples ranges between 200 and 2000 grains/1 cm^2. Hence, the mean grain diameter can be evaluated after calculating N_V volume grains density using Voronoi's relationship:

$$N_V = 0.568(N_F)^{\frac{3}{2}}. \quad (3)$$

Length of the longitudinal ultrasonic wave, λ, can be evaluated for the used frequency f = 2 MHz assuming the wave velocity v = 6000 m/s, i.e. the value used for Al and Al alloys:

$$\lambda = \frac{v}{f} = \frac{6 \cdot 10^9}{2 \cdot 10^6} \frac{\mu m/s}{1/s} = 3000\ \mu m. \quad (4)$$

TABLE

Observed surface density of grains and grain mean diameters calculated from Formula (4)

NF : number of grains/ surface of 1 cm^2	NV : number of grains/ volume of 1 cm^3	$\bar{D}$: mean diameter of grain, μm	$2\pi\bar{D}$: mean grain diameter factor, μm
200	1606	1060	6657
500	6350	670	4208
1000	17962	474	2977
1500	32998	387	2430
2000	50803	335	2104

After comparing the mean grain diameter factors collected in Table 1 with the length of ultrasonic wave it should be concluded that rather stochastic scattering takes place or the mixed stochastic-diffusion one. The samples refined with AlTi5B1 and ZnAl-Ti4 alloys have their surface grains density about 2000 and 1500 grains/1 cm^2 (Fig. 8), satisfying the relationship (2b). On the other hand, the samples refined with the ZnTi4 and Al-Ti3C0.15 master alloys have their surface grains density about 250 and 500 grains/1 cm^2 (Fig. 8), satisfying rather the relationship (2c). However, they both show a slight decrease of the attenuation coefficient in comparison to the initial, unrefined alloy, which is unclear. The most probable reason can be as follows: the calculated mean grain diameter factors take values comparable with the wave length. However, it is clear that the grains are not of uniform sizes – there are both grains satisfying relations (2b) and (2c). Thus, the observed values of the attenuation coefficient appear to be sum of the stochastic and diffusion scattering. Elucidation of this requires additional, more detailed examinations.

Acknowledgements

The authors acknowledge The European Community for financial support under M. Curie Transfer of Knowledge grant No. MTKD-CT-2006-042468. The provision of laboratory facilities in the Department of Materials Science and Metallurgy, University of Cambridge UK, is also kindly acknowledged. One of the authors, WKK, thanks the Clare Hall College, University of Cambridge UK, for accommodation and provision of Internet resources when preparing the paper.

REFERENCES

[1] AMS Handbook, AMS International, (2003).
[2] A. E. Wol, Strojenije i swojstwa metalliczeskich sistem, Fizmatgiz, Moskwa, (1959).
[3] S. Rzadkosz, Effect of Chemical Composition and Phase Transformation on the Damping and Mechanical characteristics of Alloys from Aluminium-Zinc System. Habilitation thesis (in Polish). University of Mining and Metallurgy, Krakow, (1995).
[4] W. K. Krajewski, J. Buras, Recent Developments in Grain-Refinement of ZnAl-Based Alloys and Composites. Proceedings of the Scientific Conference "42nd Foundry Days" (on CD), Brno, (2005).
[5] W. K. Krajewski, A. L. Greer, J. Zych, J. Buras, Effectiveness of Zn-Ti Based Refiner of Al and Zn Foundry Alloys, Proceedings of the 67th World Foundry Congress (on CD), Harrogate, UK, (2006).
[6] W. K. Krajewski, A. L. Greer, EBSD Study of ZnAl25 Alloy Inoculated with ZnTi4 Master Alloy, Materials Science Forum **508**, Solidification and Gravity IV, 281-286 (2006).
[7] W. Krajewski, Investigation of the High-Aluminium Zinc Alloys Grain Refinement Process Due to Ti Addition, Archives of Metallurgy **44**, 51-64 (1999).
[8] W. K. Krajewski, A. L. Greer, T. E. Quested, W. Wolczynski, Identification of the Substrate of Heterogeneous Nucleation in Zn-Al Alloy Inoculated with ZnTi-Based Master Alloy, Solidification and Crystallization, chapter 16, pp. 137-147, Wiley-VCH, Weinheim, (2004).
[9] W. K. Krajewski, A. L. Greer, J. Buras, J. Zych, Influence of Grain Refinement on Damping Properties of the Al-Zn Cast Alloys, European Congress Euromat 2007, Symposium C11 – Solidification Processes, Microstructures and Defects. Nuremberg, (2007).

Received: 10 May 2009.