Journal of Mining and Metallurgy, 39 (3–4) B (2003) 527 -532

THE EFFECTS OF ULTRASONIC SOLIDIFICATION ON ALUMINUM

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(Received 5 September 2003; accepted 28 November 2003)

Abstract

The effect of ultrasound on characteristics of solidified aluminum was shown. An ultrasonic head and ultrasonic system for modification was designed and applied to the crystallizing aluminum melt. The ultrasonic generator allows power of 50-500 W, amplitude of oscillations 10-100 μm and the operating frequency of 25 kHz. Ultrasonic modification was done by ultrasound introduced from above into the melt. Microstructure photographs show decreasing of the grain size more than five times.

Keywords: ultrasonic solidification, aluminium, microstructure

1. Introduction

Experimental data attest that the fundamental characteristic of the degree of ultrasonic structural modifications is change in the mean grain size. In the macrostructure of aluminum ingots, for instance, crystals of the control ingot (without ultrasound) have a coarse columnar structure reaching the very center of the ingot. Ultrasonically treated ingot, however, reveals a very fine equiaxial grain. Formation on a very fine equiaxial structure increases the homogeneity of the ingot and prevents the development of zonal and dendritic liquation.

Structural changes observed in the crystallization of aluminum can be systematized as follows: reduction of the mean grain size, elimination of columnar structure and formation of equiaxial grain, change in the nature of phase distribution (quantity, dispersity, relative position), increase of homogeneity of the ingot, reduction of liquation processes, and uniform distribution of non-metallic inclusions throughout the volume of the ingot [1, 2, 3].

Ultrasonic vibrations transmitted into a solidifying aluminum create special conditions influencing the crystallization process. The effects are both in the melt and at the crystallization front. Parameters that determine vibrational pressure and velocity of ultrasound in the melt are the specific energy density, the active component of the input impedance, and the losses. These parameters determine cavitation, acoustic streaming, acoustic radiation pressure, and viscous friction. They altogether are related to structural modification in the ingot [4].

Experiments show an influence of crystallization conditions on the solidification of aluminum. The nucleation rate and dispersion of growing crystals takes place in the ultrasonic field in a supercooled melt. An increase of the ultrasonic intensity increases the relative number of crystals broken away from the crystallization front in comparison with the number of new centers. At a power input above the cavitation threshold the refinement is intensified with the increase in the supercooling of the melt [5].

2. Experimental

An ultrasonic head (Fig. 1) was designed on the basis of the Langeven model of piezoelectric transducers [6]. The ultrasonic head was optimal from the point of relatively easy construction of waveguides (low acoustic losses), easy adjustment of the working frequency, high acoustical efficiency (~ 90 %), and accessibility of semiconductor-based generators of ultrasonic oscillations.

Design of the ultrasonic generator allows change of power in the range of 50-500 W, automatic switch on only when emitter is loaded, and amplitude of oscillations at the end of the emitter of 10-100 μm at the operating frequency of 25 kHz.

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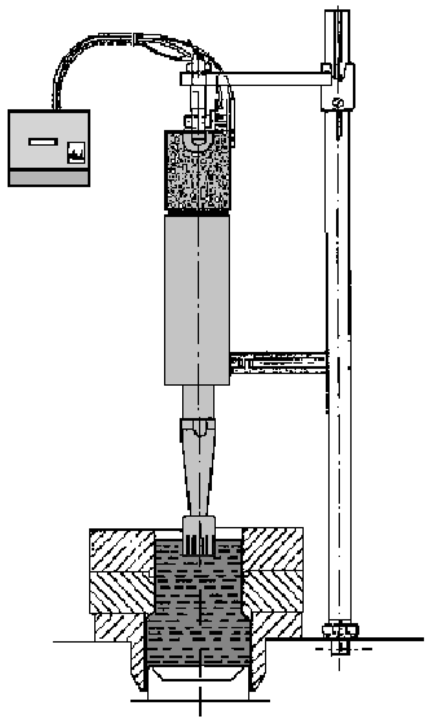


Fig. 1. Ultrasonic head

An intense cooling of the head, which operates above 500 ^{o}C, is done by water flow. The ultrasonic head, and accessories involved, was designed for modification of aluminum structure during its solidification from the melt. Moreover, it can be utilized for ultrasonic treatment of other materials.

Ultrasonic modification was done by ultrasound introduced from above. Pieces of aluminum type EC 99.7 were put into the graphite jar and melt by induction heat. The melt was then heated up to 800 ^{o}C and isothermally heated for 5 min in order to complete breaking of crystalline particles and nuclei within the melt. The induction heat was then switched off and the melt left cooling without forced taking off the heat.

The ultrasonic head was pushed down into the melt when its temperature dropped to 720 ^{o}C, to about 4 cm under the surface. Ultrasonic modification was performed down to 550 ^{o}C. At that point the ultrasonic head was pulled out of the melt. Centers of crystallization were formed in that interval of temperature and the process of solidification begins. Further cooling was done naturally to the room temperature.

Solid samples of aluminum were prepared by cutting, grinding and polishing for micro structural examinations. The grain size was studied. Grain boundaries were emphasized by the Keller's solution and observations performed by optical microscope. The photographs (Fig. 2) show that the effect of ultrasound was manifested by the decrease of grains from about 500 μm down to about 100 μm.

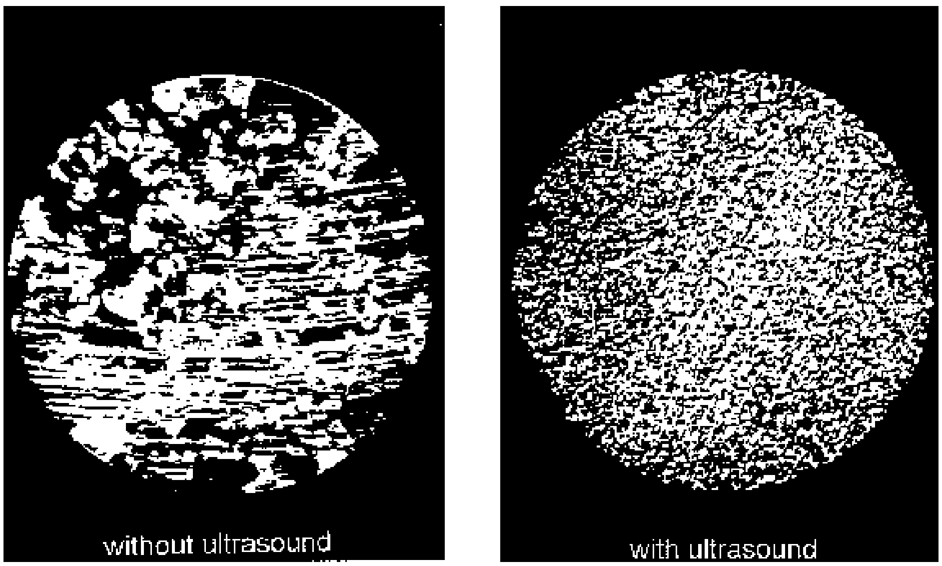


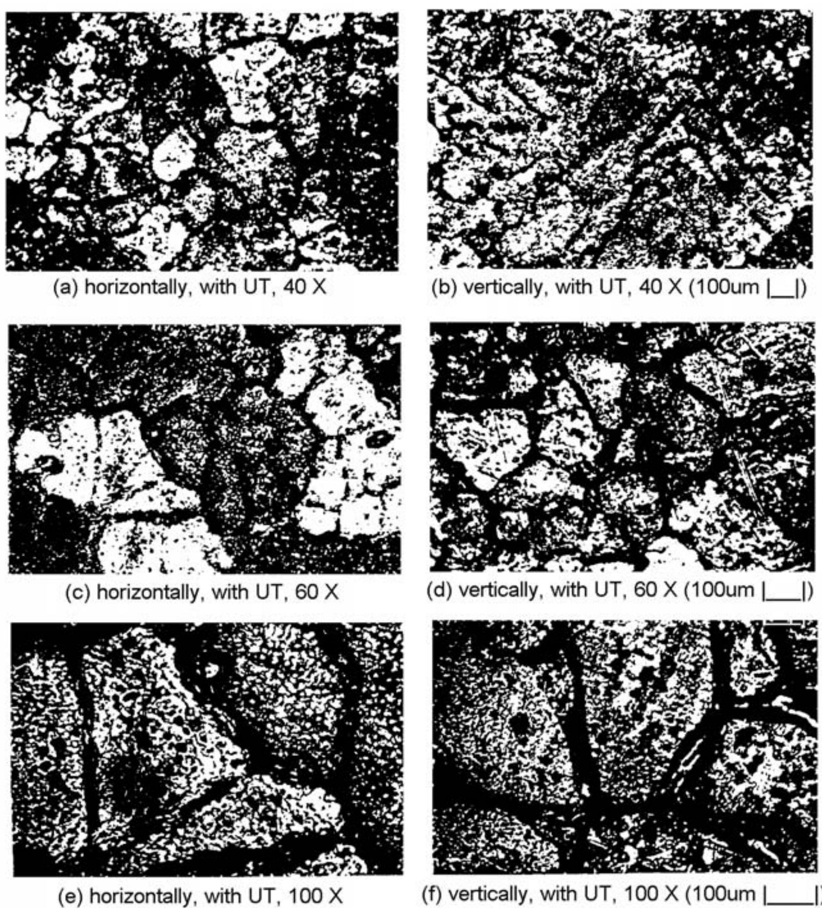
Fig. 2. Aluminum structure without and with ultrasound

3. Results and Discussion

Theoretical analysis of aluminum crystallization [5] shows that as a consequence of ultrasound the number of nucleation centers increases due to cavitation phenomenon in the melt. Increased number of nucleation centers leads to the increase of nuclei and therefore grains in the solid phase.

Our results are in agreement with the above concept. Namely, by comparing photos of microstructure (Fig. 2) it can be seen that the grain size dramatically decreased – more than five times. At the same time the microstructure obtained under ultrasound was with much more homogeneity and of compact small size grains. Having known that by traditional methods such structure is achieved only by adding impurities of Ti, B or other expensive modificators, it is obvious of what significance is the application of ultrasound on modification of aluminum and its alloys.

Analysis of microstructure under bigger enlargements shows the effect of degazation [Fig. 3]. Pores, as a consequence of gas inclusions, are located mostly between grains, while in unmodified samples the pores are within the grains too.



(a) horizontally, with UT, 40 X
(b) vertically, with UT, 40 X (100um |__|)
(c) horizontally, with UT, 60 X
(d) vertically, with UT, 60 X (100um |___|)
(e) horizontally, with UT, 100 X
(f) vertically, with UT, 100 X (100um |____|)

Fig. 3. Microstructure of aluminum

Results and discussion suggest that ultrasound can successfully be applied in industrial conditions benefiting in great save of modificators, energy and aluminum itself.

4. Conclusion

The effect of ultrasound on crystallization process and characteristics of solidified aluminum was shown. An ultrasonic head and ultrasonic system for modification was designed and applied to the crystallizing aluminum melt. The results clearly show the effect of ultrasound on the grain size, homogeneity and gas distribution in the samples. That suggests replacement of expensive modificators by an ultrasonic generator and transducer designed for application into a crystallizing aluminum melt. There is also a possibility of prognosticating and control of other aluminum characteristics like mechanical, electrical, physical and chemical.

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