THE EFFECT OF THE INTERACTION OF VIBRATION AND COOLING DURING CASTING ON THE TENSILE STRENGTH OF THE ZnAl 22% Al ALLOY

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ABSTRACT

The changes in the ultimate tensile strength and the microstructure as a function of frequency and duration of applied vibration during casting for ZnAl 22% Al alloy were investigated experimentally. It was found that the tensile strength may be increased by as much as 67% of its value without vibration for certain frequencies and duration of vibration. Improvements in microstructure refinement were also observed for these frequencies and durations of vibration. These preliminary results indicate that mechanical vibration if properly applied at the early stages of solidification can be used as an effective grain refining technique.

INTRODUCTION

Grain refinement in casting is metallurgically very significant as the grain structure of a cast product determines to a great extent its various technologically important properties. The more commonly used method of grain refinement is by enhancing nucleation on suitable active subtrates which are added into a metallic melt via a grain refiner. This method has the disadvantages that the added refiners may form clusters with effective particle sizes that cause severe damage to the roller or dies during further working, and could be very expensive since large quantities of the refiner may be needed [1].

It is well known that the number of effective nuclei during solidification and the final grain size of a cast product depend on the rate of cooling which in turn depends on the heat transfer phenomenon which was found to be effected by the frequency and amplitude of vibration.

Considerable work has done to study the problem of interaction between vibrations and convective heat transfer [2-4]. It was found that by applying mechanical vibration in a direction normal to a heated surface the convective heat transfer coefficient may be increased as much as three times its value without vibration. The amount of increase in the heat transfer coefficient and hence the cooling was found to depend very much on the amplitude and the frequency of the applied vibration.

When a molten metal cools, solidification begins by nucleation and grains start to grow on the nucleation sites. The final grain structure depends on both the nucleation process and the grain growth, so by introducing vibration to the metal during solidification the cooling rate and the distribution of nucleation through the mould will change.

The aim of this investigation is to explore the possibility of using mechanical vibration employed during solidification as a grain refining technique. The idea of using this method stems from the fact that by inducing vibration of various frequencies and amplitudes during casting it is possible to obtain a more homogeneous distribution of the active nucleation throughout the mould, hence producing a more refined structure which gives a superior mechanical properties. The advantages of using this technique over other grain refining processes involving chemical additives are obvious in terms of cost and alloying effects. To the best of the authors knowledge the effect of vibration on casting has not been studied much, except using ultrasonic vibration before aging to increase the hardness of 7075 aluminum alloys and using vibration for stress relieving [5].

The concern of this paper is to report preliminary experimental results carried out to investigate the effect of vibration during casting on the tensile strength of the ZnAl 22% Al alloy.

EXPERIMENTAL SET-UP AND PROCEDURE

The experimental set up used in this investigation is schematically shown in Figure (1). The configuration of the mould assembly is shown in Figure (2). It consists of two-identical aluminium halves with three cylindrical equally spaced cavities each of 10 cm in depth and .5 cm radius. The mould was firmly bolted to the center of a light aluminum tray 30 cm in diameter. The tray was used in order to protect the vibration instruments from accidental spill over of the molten metal. The mould and the tray were made of aluminum in order to minimize the static load effect on the exciter so that it was possible to achieve high acceleration levels without overloading the exciter. The tray was attached at its center to an aluminum block which in turn was attached to another aluminum block fixed to the exciter head. This arrangement was necessary in order to provide space between the tray and the exciter head for mounting the accelerometers. The blocks and the tray were attached so that the center of the mould lies above the exciter head center, to ensure that the vibration signal is applied to the mould. Insulating material was inserted between the blocks and the tray in order to protect the accelerometers from overheating.

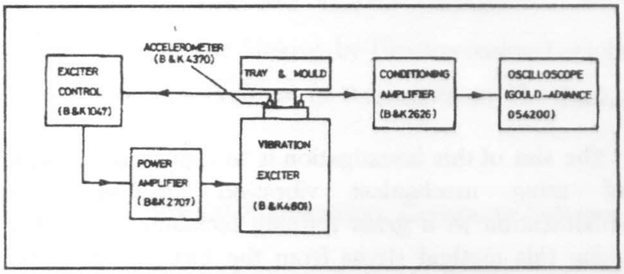

Figure 1. Schematic Diagram of the Experimental Set-up.

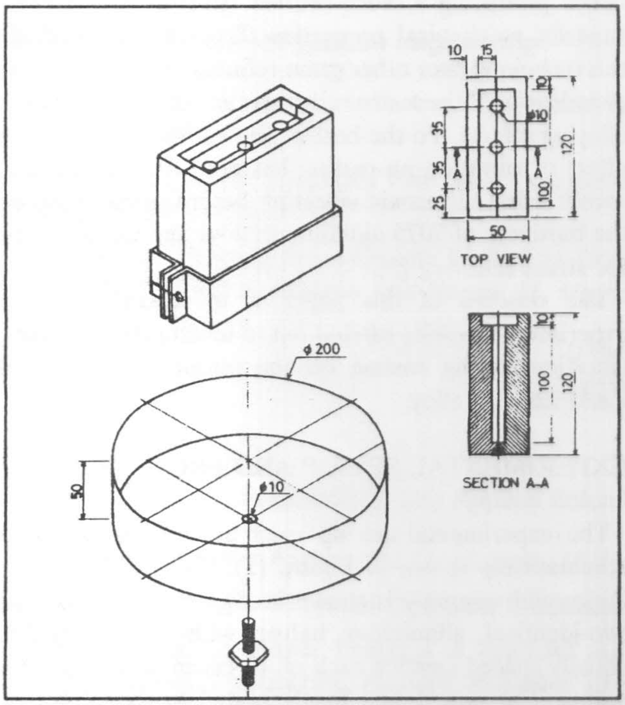

Figure 2. The Experimental Configuration Mould Tray. (Note: Dimensions are in Millimeters).

The vibration exciter used was a high force (B & K 4801) electrodynamic exciter driven by power amplifier (B & K 2707). The desired amplitude and frequency of the sinusoidal vibration signal at the exciter output was generated using the exciter control (B & K 1047) and fed to the power amplifier. Note that the natural frequency of the mould set-up and thus the amplitude of its vibration changes as the molten metal is poured into the mould. In order to maintain a constant level of vibration of the mould at a given frequency, vibration signal from an accelerometer (B & K 4370) placed at the upper surface of the lower aluminum block was fed to the compressor of the exciter control allowing an automatic control of output vibration from the exciter at constant level. The vibration signal at the exciter output was also monitored by placing a second accelerometer (B & K 4370) on the other side of upper surface of the lower aluminum block. The signal from this accelerometer was fed to a conditioning amplifier (B & K 2626) and then was displayed on a digital storage oscilloscope (Gould-Advance 054200). The exciter was isolated from the floor by using rubber pads and a wooden board so as to minimize the transmission of vibration between the floor and the exciter.

The experimental procedure involves first switching the vibrating system on at a given frequency and amplitude which was monitored on the digital oscilloscope and then pouring the molten metal immediately after being taken from the furnace where it was kept for 45 minutes at a temperature of 480°C while the exciter is still on. Note that a constant vibration level of nearly 100 m/s^2 was maintained throughout each of the experimental runs. The time taken for filling the mould was about 3 seconds. The vibration time measured from the start of pouring the molten metal into the mould until the exciter was switched off along with the frequency of vibration were recorded for each experimental run. The vibration time was varied over the range 3 to 45 seconds and the frequency was varied over the range 100 - 500 Hz. The fundamental natural frequency of the empty mould-tray structure, determined using a standard dynamic test, was found to be about 150 Hz. Each of the experimental runs was repeated three times.

EXPERIMENTAL RESULTS AND DISCUSSION

Three standard tensile strength samples were carefully machined from each mould thus giving nine tensile samples for a given vibration time and frequency. Ultimate tensile strength force tests were conducted using

Tensiometer (Monsanto 2000). Throughout the measurements made to establish the data presented in this paper, care was taken to note possible sources of error and an error analysis based on the method of Kline and McClintock [5] was carried out. The error analysis indicated a ±5% possible error in the tensile strength measurements. Any point on the tensile strength-frequency curve was measured three times and the repeatability of the results were within 3%.

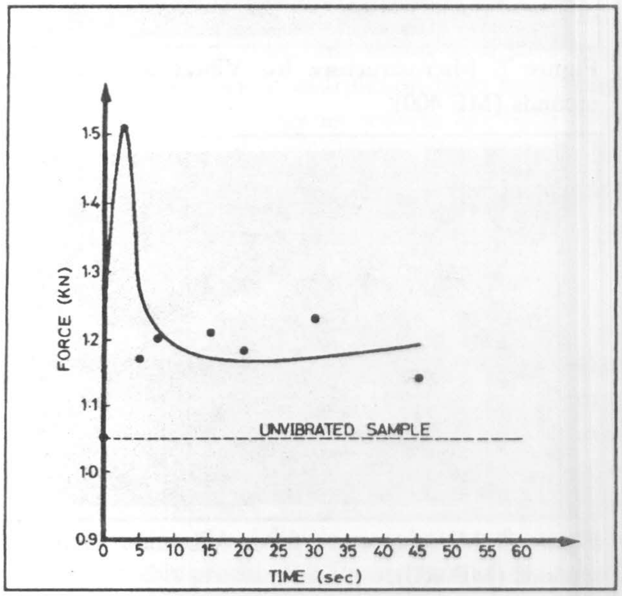

Figure 3. Ultimate Tensile Force vs Vibration Time for a Vibration Frequency of 100 Hz.

The results of the tensile force measurements against time of vibration for different frequencies are shown in Figure (3) to (5). Thee results of ultimate tensile force against frequency for vibration time of 3 seconds is shown in Figure (5). Examples of the effect of vibration time on the microstructure are shown in Figures (7) and (8).

The experimental results, Figures (3) to (5) indicate that the tensile strength of the Al alloy could be increased by 43%-67% if specimens are vibrated for three seconds only. These results indicate that there is a critical point in time (3 seconds) after which vibration starts to have a negative effect on the grain structure. This may be due to the fact that after this critical vibration time the nucleation process stops and growth starts and increases with time in such a way that the vibration tends to separate the grains and opens cracks in the structure. This was evident during the tensile strength test where the sound of the rubbing metal surfaces was heard clearly and at low values of force for specimens vibrated for more than three seconds.

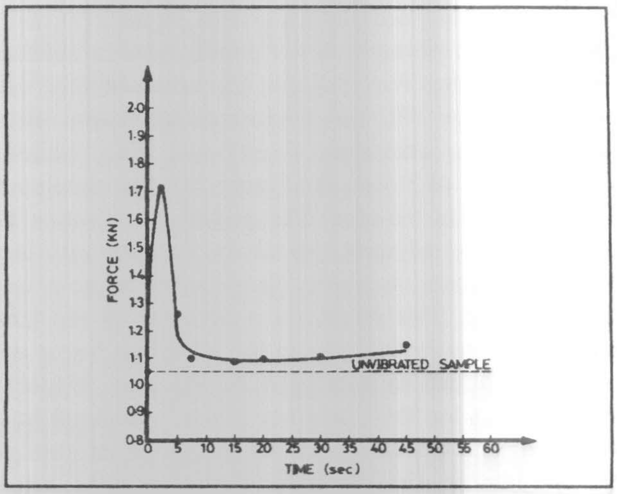

Figure 4. Ultimate Tensile Force vs Vibration Time for a Vibration Frequency 150 Hz.

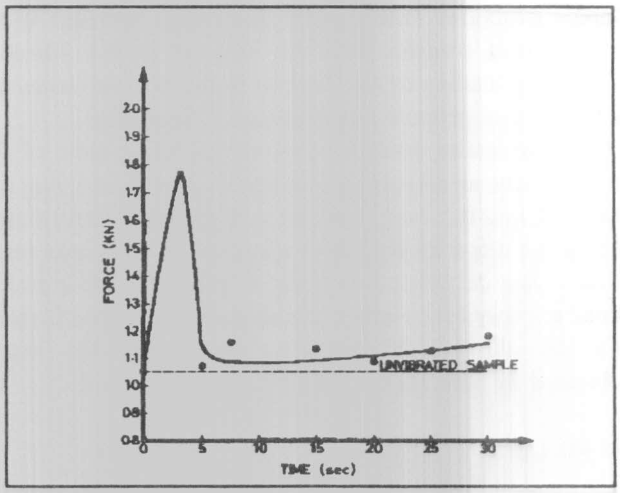

Figure 5. Ultimate Tensile Force vs Vibration Time for a Vibration Frenquency 200 Hz.

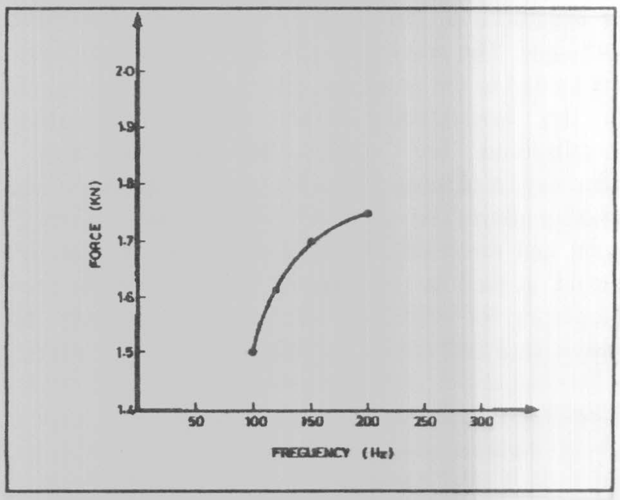

Figure 6. Ultimate Tensile Force vs Vibration Frequency for a Vibration Time of 3 seconds.

It can be clearly seen by comparing Figures (7) and (8) that prolonged vibration of the mould leads to noticeable grain coarsening. For example, for vibration time of 25 seconds, Figure (7), the microstructure shows distinct limits between aluminum (dark) and zinc, while for vibration time of 3 seconds, Figure (8), the aluminum is fairly defused in the zinc. The prolonged vibration time seems to cause adjacent crystals to combine into larger grains and causes aluminum (more solid) to form larger accumulations. This results in a decrease in the tensile strength due to the increase in the attraction forces when aluminum is not well defused in the zinc. Figure (5) indicates that for the frequency range considered in this investigation the tensile strength seems to increase with the increase in the vibration frequency. The rate of increase in the tensile strength is largest for a vibration frequency around the natural frequency (150 Hz) of the mould structure. This may be due to the increase in the rate of heat transfer with the increase in the vibration frequency, leading to a reduction in the critical radius and a more homogeneous distribution of the nuclei.

It is interesting to know that during the course of this investigation an attempt was made to slow the cooling rate by insulating the mould in order to get more information about the effect of the small vibration time. It was found that a slow cooling rate during solidification of a casting does not very much affect the degree of grain refinement for this alloy. This seems to agree with the results obtained by Reif [1] for Al-Ti master alloys.

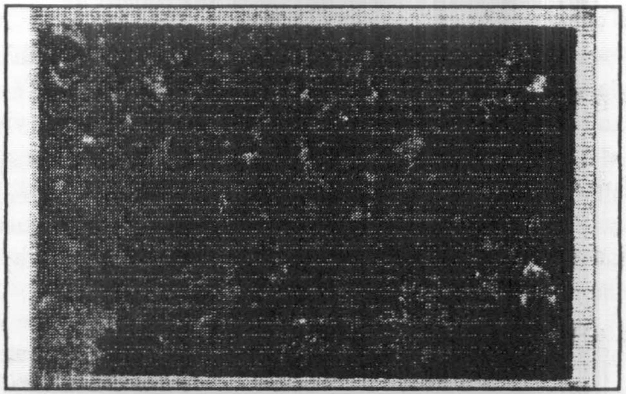

Figure 7. Microstructure for Vibration Time of 25 seconds (MF 400).

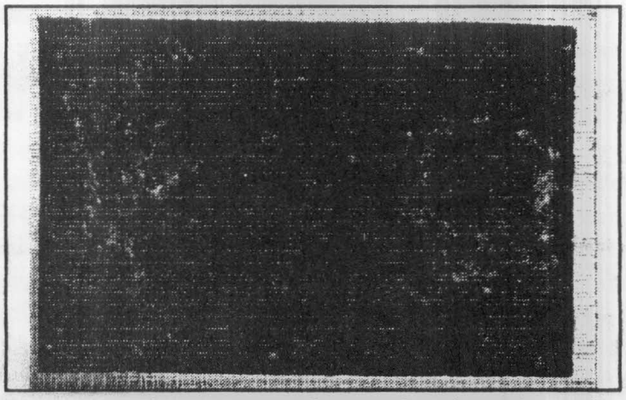

Figure 8. Microstructure for a Vibration Time of 3 seconds (MF 400).

CONCLUSIONS

The present experimental investigation indicates that mechanical vibration if properly applied at the early stages of solidification can be used as an effective refining technique. The results presented in this paper, however, are limited to the particular alloy and conditions specified in this investigation. More extensive experimental investigations are needed before establishing the effectiveness of using this technique for a grain refinement of other alloys. The effect of mould size and geometry, the point and direction of applied vibration relative to the mould, as well as the level of vibration, on the various properties of different alloys are currently being investigated and will be the subject of future reporting.

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