

Material Properties of Various Light Metals Produced by Heated Mold Continuous Casting

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Abstract— In the present work, an attempt was made to develop high quality cast aluminum alloys via a new casting technology, e.g., the heated mold continuous casting (HMC) with ultrasonic vibration (UV) process. With the UV process in the continuous casting process, fine and spherical grains were obtained, where the lattice structure is formed similarly before the UV process while dislocation density increases. The mechanical properties of the UV-HMC Al alloys are higher than those for the related cast Al alloys without UV although still high material ductility is obtained. The lattice and dislocation characteristics of the continuous cast samples made with and without the UV processes were analyzed systematically by the EBSD observations to interrupt clearly their mechanical properties.

Index Terms: aluminum alloy; ultrasonic vibration; continuous casting; mechanical property; microstructural characteristic

I. INTRODUCTION

In recent years, high fuel efficiency of automotive is required in our society, because of environmental issue. To make this, the reduction in exhaust gases from the automotive, such as carbon dioxide and nitrogen oxide, would be required, as the number of automotive has been increasing to be more than 1 billion in the world. The automotive consists of a number of the related parts, and many of them have been made by cast irons and steels. It has been expected to replace Fe-based automotive parts with more lightweight metals, e.g., aluminum alloys. The specific weight of Fe is about 7.8, which is more than 2.8 higher than that for Al. Recently, the production amount of automotive parts, made of Al alloy, has been increasing gradually.

It is general consideration that small grains with spherical shape are significantly important to make excellent mechanical properties. To obtain such microstructural characteristics, some practical techniques of rapid solidification, high casting flow and adding fine nucleating elements are employed. Furthermore, new technologies have been proposed with mechanical modification, including electromagnetic vibration [1], mechanical vibration and mechanical shearing processes.

Aghayani and Niroumand [2] have examined the effects of ultrasonic vibration (UV) treatment on microstructural features and tensile strength. The melt alloy in sand molds was

subjected to ultrasonic waves of different power levels for 5 min under frequency of about 20 kHz and the maximum power of 600 W, in which strong effect on the size and sphericity of alpha dendrites is obvious. Moreover, high applied ultrasonic power resulted in small, more rounded and uniformly distributed α -grain and eutectic particles. Feng et al. [3] have attempted to treat UV into the melt hypereutectic Al–23%Si alloy in a horn crucible.

From the above previous works, it appears that a number of experimental works have been conducted to make high quality cast Al alloys by the UV process [3]. However, the authors believe that there would have still chance to apply the UV technology in casting process. This is because, in the previous studies, the ultrasonic vibration is conducted only to the melt in crucibles and molds, i.e., simple approach. Moreover, there is apparently lack of the investigations to understand clearly the detailed vibration effect on the material properties. This is because the previous examination has been executed with the limited vibration conditions, e.g., a few vibration amplitudes and frequencies.

Thus, in the present study, an attempt was made to propose a new casting system of a heated mold continuous casting method with ultrasonic vibration in advance. With this casting system, mechanical properties of several Al alloys have been investigated. To understand clearly the effects of the UV process on the material properties of the cast Al alloys, the lattice and dislocation characteristics were scientifically analyzed.

II. EXPERIMENTAL PROCEDURE

II-1. Material preparation

In the present study, two aluminum alloys (AC4CH and ADC6) and pure aluminum (99.9% Al) were used. In order to create the high mechanical properties of cast aluminum alloys, a hybrid casting system was originally proposed, where an ultrasonic vibration (UV) device was added to our original heated mold continuous casting system, see Fig. 1. In this case, a small UV device (PEF-L25A, Sanki Corp.) was employed. The specification of this device is as follows: electric voltage: 0–240V and frequency: 40–400Hz. Such vibration is applied directly to the cast sample during the casting process. The HMC arrangement consists of a graphite crucible in a furnace, a graphite mold of 5 mm in diameter, a cooling device and a dummy rod for withdrawal of the cast sample. The graphite mold is jointed with the graphite crucible. The cooling system

was set just out of the mold. The ultrasonic vibration system was attached near the cooling system, and the vibrations were executed directly to the casting rod during the casting process. The melts in the crucible were fed continuously into the mold at 1.9 mm/s.

In the gravity casting (GC) process, the melt was poured directly into a metal mold. Note, the GC process would not be a represent conventional gravity casting process, as our gravity casting system does not include sprue, runner and gate.

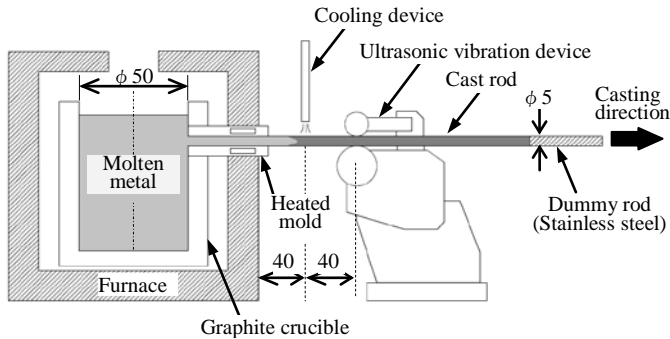


Fig. 1 Schematic illustration for the heated mold continuous casting device with ultrasonic vibration system.

II-2. Experimental

Microstructure, lattice structure and strain characteristics were investigated by various approaches including energy-dispersive X-ray spectroscopy (EDX), electron backscatter diffraction (EBSD).

EDX analysis was carried out to investigate the microstructural characteristics with an acceleration voltage of 20 kV a scanning electron microscope. The EBSD analysis was conducted to observe the crystal orientation characteristics with an acceleration voltage of 15 kV, beam current 5 nA and step size 0.5–20 μm . The samples were prepared with sectioning to less than 5 mm thick and with mirror flatness. This EBSD analysis was executed with HKL Channel 5 software.

III. RESULTS

III-1. microstructural characteristics

Fig. 2 depicts the optical micrographs for the pure aluminum, AC4CH and ADC6 alloys produced by GC and HMC processes. In this case, the HMC process was carried out with and without ultrasonic vibration. It can be seen that fine $\alpha\text{-Al}$ phase and tiny eutectic structures are observed in the HMC samples compared to their GC ones. In addition, those grains seem to be altered slightly to more fine spherical shape of $\alpha\text{-Al}$ grains with the ultrasonic vibration. Interestingly, core-like structures can be characterized in the middle of their grain for the UV pure-aluminum. From the EDX analysis, such core-like structure is related with the iron element (Fig. 3).

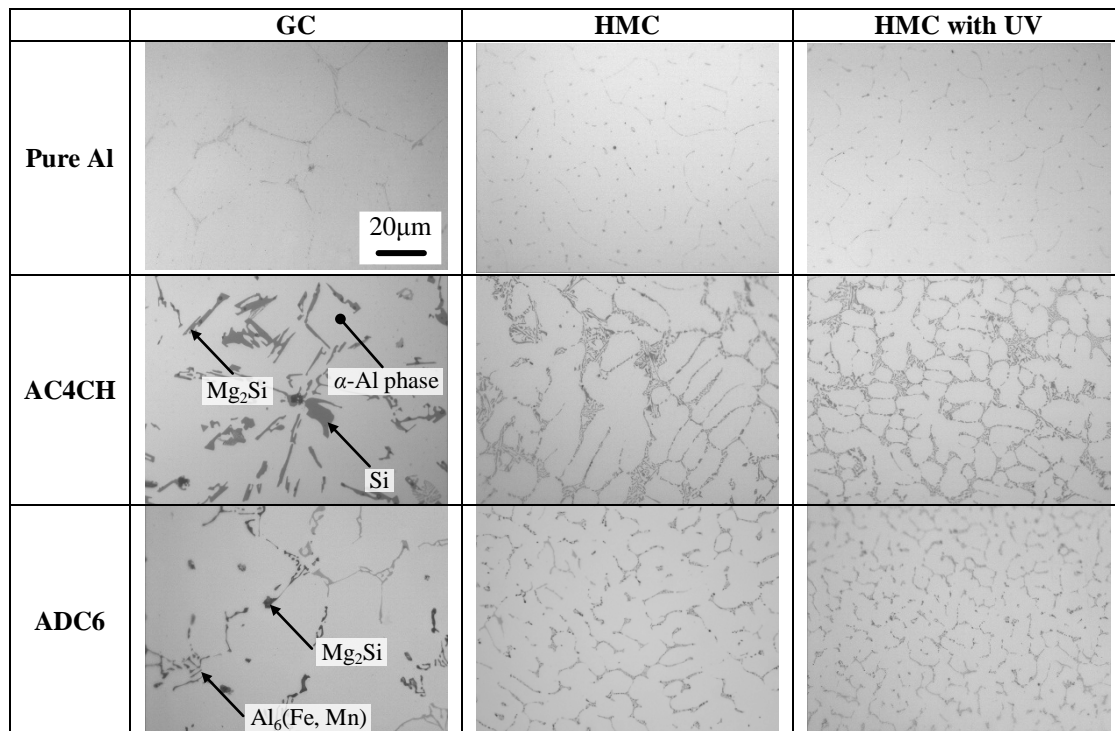


Fig. 2 The optical micrographs for the pure aluminum, AC4CH and ADC6 alloys produced by GC and HMC processes with and without ultrasonic vibration.

Fig. 4 presents the crystal orientation maps (IPF) for pure Al and ADC6, obtained by the EBSD analysis. It is obvious that a relatively uniform lattice structure is obtained over a large area in the HMC samples without ultrasonic vibration, where almost perfectly orientated crystal structure, i.e., single crystal-like formation.

It is interest to mention that even if the UV process conducted strongly, the crystal orientations are still relatively organized. However, their lattice structures, i.e., misorientation angle, are slightly disordered.

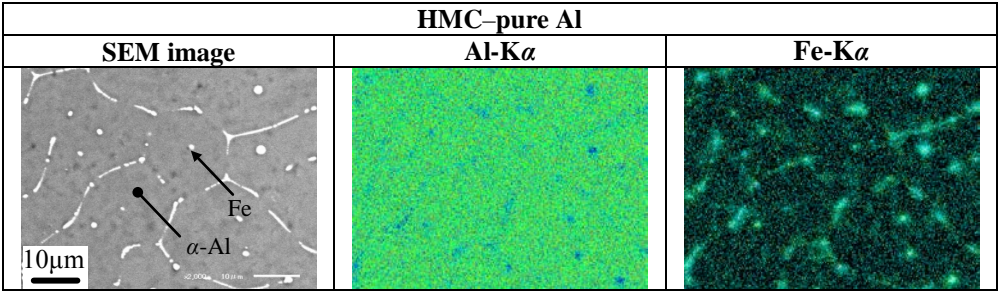


Fig. 3 EDX analysis for HMC samples of pure aluminum without UV.

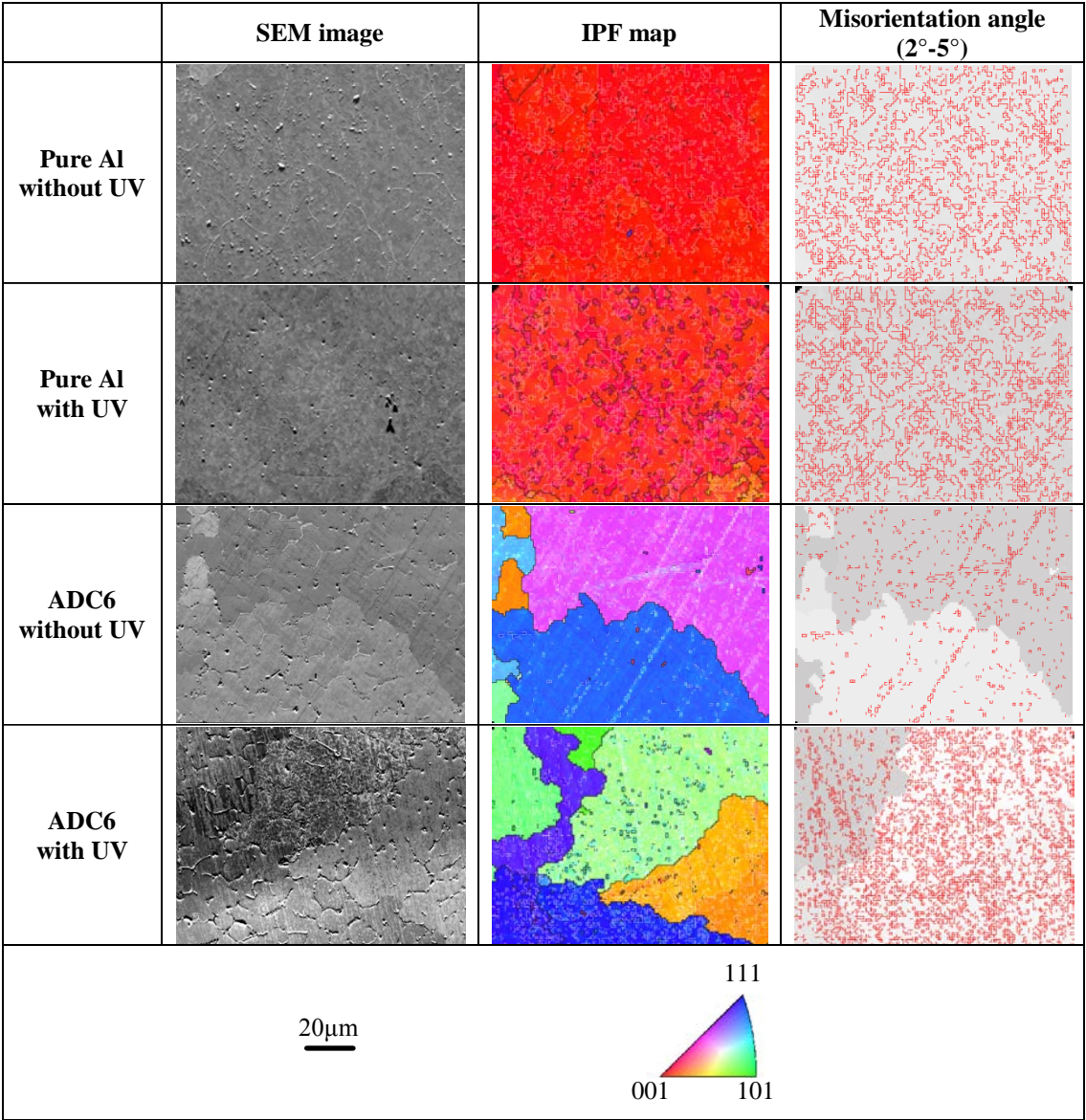


Fig. 4 The crystal orientation maps for pure aluminum and ADC6 by HMC with and without ultrasonic vibration.

Fig. 5 shows the electric conductivity (EC) of the cast samples. Note, in this case, the EC values were measured using the same specimen of $\phi 1 \text{ mm} \times 100 \text{ mm}$. To understand EC characteristics clearly, this was also carried out for commercial wrought pure Cu, wrought pure Al and continuous cast Al alloys. The data obtained in Fig. 5 is indicated with the rate of the EC value based upon the copper wire. It is clear that the electric conductivity for the commercial wrought pure Al wire is about 60% of the Cu wire one. Interestingly, slight improvement of the electric conductivity for the HMC–pure Al is obvious, which is approximately 15% higher than that for the wrought pure Al wire. This may be attributed to the uniformly organized crystal orientation, as mentioned in Fig. 4. Furthermore, it is obvious that the EC values for the cast Al alloys without UV (AC4CH and ADC6) are about 25 % higher than those for UV. This is also influenced by the different crystal orientation characteristics.

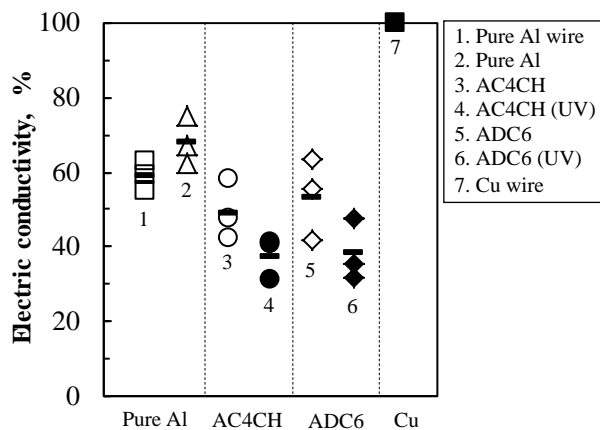


Fig. 5 Rate of the electric conductivity for various metals on the basis of the copper wire one.

Fig. 6 displays the Vickers hardness of HMC–ADC6 alloy as a function of the vibration frequency. As seen, the hardness level of the Al alloy does not change significantly even if the frequency is altered. However, it is obvious that high hardness value is obtained for the sample with higher vibration amplitude. The highest hardness by UV is about 7% high compared to that for the cast samples without UV.

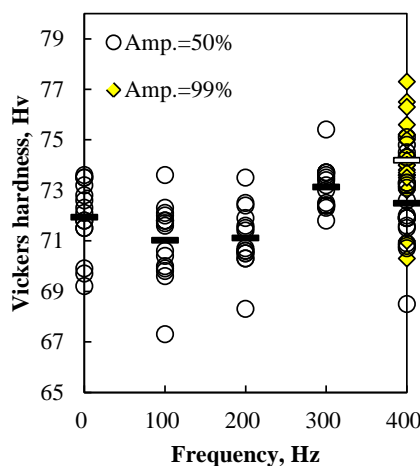


Fig. 6 Vickers hardness of HMC-ADC6 alloy as a function of the vibration frequency and vibration amplitude.

Fig. 7 depicts the representative tensile stress-versus-strain curves for HMC–ADC6 alloys with and without UV process. It is clear that there are different trends of the tensile properties depending on the UV process. Based upon the stress–strain curves obtained, ultimate tensile strength and fracture strain are summarized in Fig. 8. The tensile properties slightly increase for ADC6 with the vibration process. Such increment of the tensile strength would be caused by the change of the microstructural and lattice structures, as mentioned above. On the other hand, slight high ductility for the UV samples is attributed to the grain refinement and spherical structure. Fig. 9 represents the relationship between stress amplitude and cyclic number to final fracture (S–N curve) for ADC6 with and without the UV process. It is obvious that, like the tensile properties, the S–N curve for ADC6-UV is located to the higher level compared to the without UV one, namely the higher fatigue strength for ADC6-UV. On the basis of the above experimental results, it could be briefly summarized that the UV process is useful to improve the mechanical properties of the cast aluminum alloys.

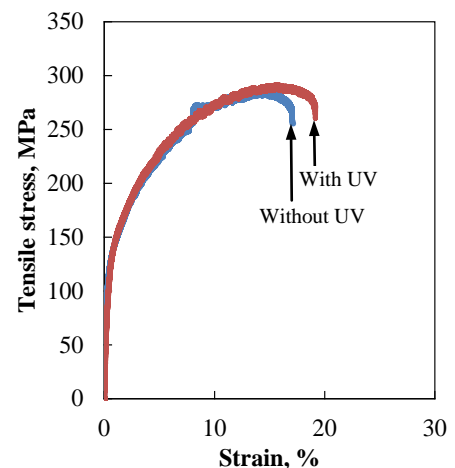
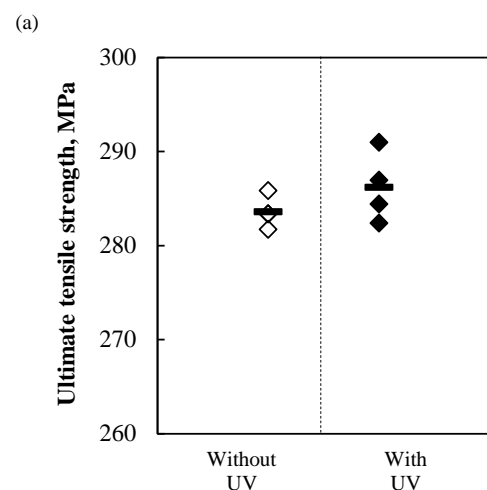


Fig. 7 Representative tensile stress vs. tensile strain curves for ADC6 produced by the HMC process with and without ultrasonic vibration process.



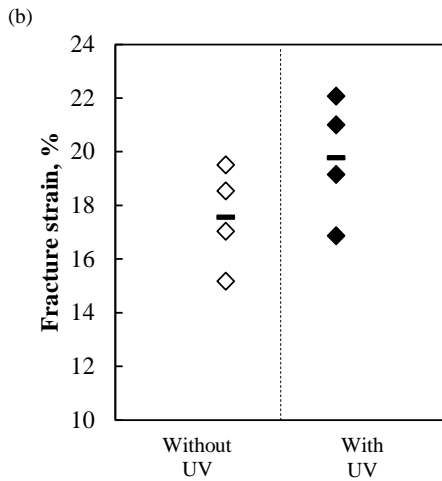


Fig. 8 Tensile properties of the HMC-ADC6 with and without UV process:(a) ultimate tensile strength and (b) fracture strain.

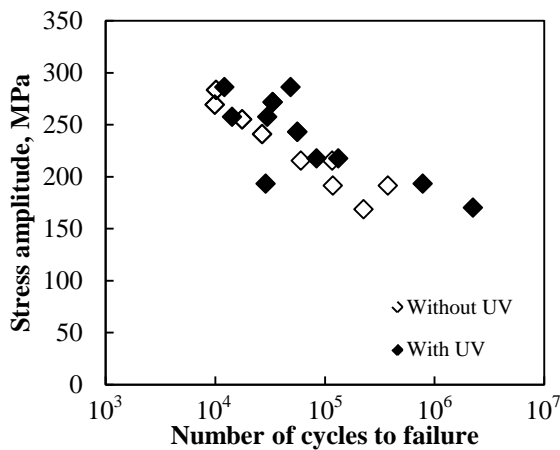


Fig. 9 S-N curves for the HMC-ADC6 with and without UV process.

IV. CONCLUSIONS

- 1) Electric conductivity for the HMC-pure aluminum is about 15% higher than that for the wrought pure Al wire. This is attributed to the uniformly organized crystal orientation. With the UV process, the EC levels for HMC-Al alloys decrease about 25% compared to those without UV, which is affected by the randomly distributed lattice structure arising from the UV process.
- 2) The hardness level of the ADC6 alloy is not changed significantly with increasing the UV frequency. In contrast, the high hardness was obtained as loaded at the high vibration amplitude. The highest hardness by UV is about 7% high compared to the mean hardness of the cast samples without UV.
- 3) The tensile strength and fatigue strength increase for the ADC6 alloy with the UV process. In addition, similar to the mechanical strength, the material ductility is also relatively increased with the UV process. Such increments of the strength are attributed to the change of the microstructural and lattice structures.

ACKNOWLEDGMENTS

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REFERENCES

- 1 C Vivès, Effects of forced electromagnetic vibrations during the solidification of aluminum alloys: Part II. Solidification in the presence of collinear variable and stationary magnetic fields, *Metall. Mater. Trans. B*, 27B(1996)457–464.
- 2 M.K. Aghayani, B. Niroumand, Effects of ultrasonic treatment on microstructure and tensile strength of AZ91 magnesium alloy, *J. Alloys Compd.* 509(2011)114–122.
- 3 H.K. Feng, S.R. Yu, Y.L. Li, L.Y. Gong, Effect of ultrasonic treatment on microstructures of hypereutectic Al-Si alloy, *J. Mater. Process. Technol.* 208(2008)330–335.