

Proceeding Paper

Electromagnetic Processing during Directional Solidification of Particle-Strengthened Aluminum Alloys for Additive Manufacturing

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Abstract: The rise of metal additive manufacturing technology has increased the demand for high-performance alloys such as metal matrix composites (MMCs). The metallurgical production of MMCs remains a challenge. The nano-powder of dielectric particles does not mix well into the liquid metal because of several reasons. On a macroscopic level, the powder is rejected by the molten metal through buoyancy and surface tension forces. On a microscopic level, the particles are held together by Van der Waals forces forming particle agglomerates. Our research strategy is to address these issues separately in two steps. We are investigating an electromagnetically assisted MMC casting method for the production of particle-strengthened, directionally solidified aluminum alloys. In the first step, nanoparticles are mixed into melt while it is in a semi-solid state by efficient permanent magnet stirrers. Then, the alloy is subjected to ultrasound treatment for fine particle dispersion. Semi-continuous casting of MMC is used to obtain material for additive manufacturing process. Material is cast in 6–20 mm rods by a direct chill casting method and can be made into wire with the application of wire-feed additive manufacturing. We investigate the possibility of improving Al alloy SiC composite material properties by applying electromagnetic interactions during solidification. Electric current and a moderate static magnetic field (0.1–0.5 T) creates melt convection in mushy zone. Such interaction enhances heat and mass transfer near the solidification interface and hinders the re-agglomeration of the added particles.

Keywords: aluminum alloys; metal matrix composites; directional solidification

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1. Introduction

Aluminum alloys are one of the prospective materials used for additive manufacturing. Aluminum is prospective because it has low melting temperature and lots of different alloys with fine-tuned properties for specific applications. There are several additive manufacturing methods for making aluminum parts. The most common are additive manufacturing from powder [1]. The problem is that for successful additive manufacturing, aluminum powder should consist of spherical particles with narrow size distribution and an isotropic microstructure. Another alternative method is additive manufacturing, using wire as a starting material. This process is like the metal inert gas (MIG) process. Powder additive manufacturing is less efficient, because of large material losses and slower speed; however, it is possible to achieve better quality, and the printing of more complex geometry is possible.

Electromagnetic methods for improved solidification processes are one of the ways to decrease grain size and improve homogeneity of the aluminum materials. Electromagnetic force near the solidification interface modifies the heat and mass transfer. To investigate this process, directional solidification is usually used.

The experimental setup (Figure 1) was designed to investigate electromagnetic interaction on the solidification interface. Principles of direct chill casting of aluminum are explained in our previous article [2]. A static magnetic field of 0.4 T was provided by a NdFeB permanent magnet assembly placed around the solidification zone. Aluminum A360 was induction-melted in the top crucible and pressure-casted in the boron nitride tube. At the end of the tube, a water jet removed most of the heat. A solidification interface was located in the middle of the BN tube. This ensured that from solidification, interface heat was only evacuated in an axial direction.

If an electric current is applied parallel to the magnetic field, then a Lorentz force appears at the solidification interface. In such a configuration, the Lorentz force drives small-scale melt rotation around each individual dendrite [3].

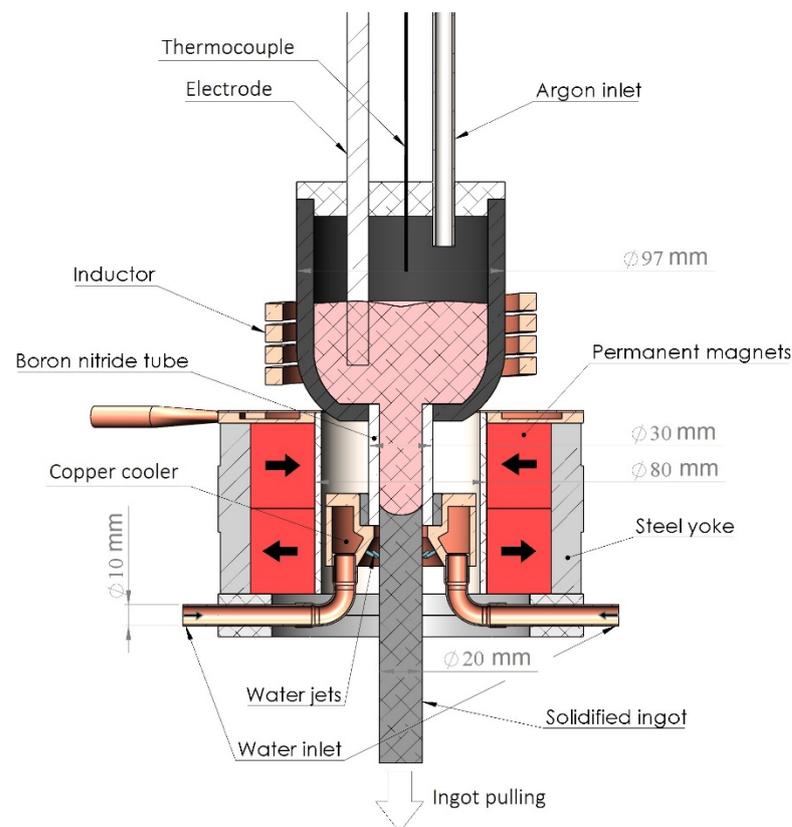


Figure 1. Directional solidification experiment schematics used in these experiments.

2. Results and Discussion

We conducted a series of experiments using our experimental setup. Directional solidification with direct chill casting of A360 aluminum was performed with a solidification velocity of 2 mm/s. Primary dendrite size in our experiments was around 50 μm [4], which agrees well with observations from our experiments.

Temperature gradient at the solidification interface was 20 K/mm, which led to a mushy zone with a thickness of several millimeters [5]. Experimental results are summarized in Figure 2, showing both transverse and longitudinal cross sections of the crystallized aluminum. Experimental results demonstrate that solidification without electromagnetic fields leads to a longitudinal microstructure, which can be seen in Figure 2d. The applied static magnetic field causes this longitudinal structure to disappear (Figure 2e). Such a shift is columnar to equiaxed grain structure transition due to electromagnetic effect known and reported in several scientific studies. If electrical current is injected parallel to the magnetic field, significant small-scale melt convection takes place around the

primary dendrites. This leads to radically increased heat transfer between solid and liquid phases. This results in fine-grained structure formation and lots of eutectic phase pockets.

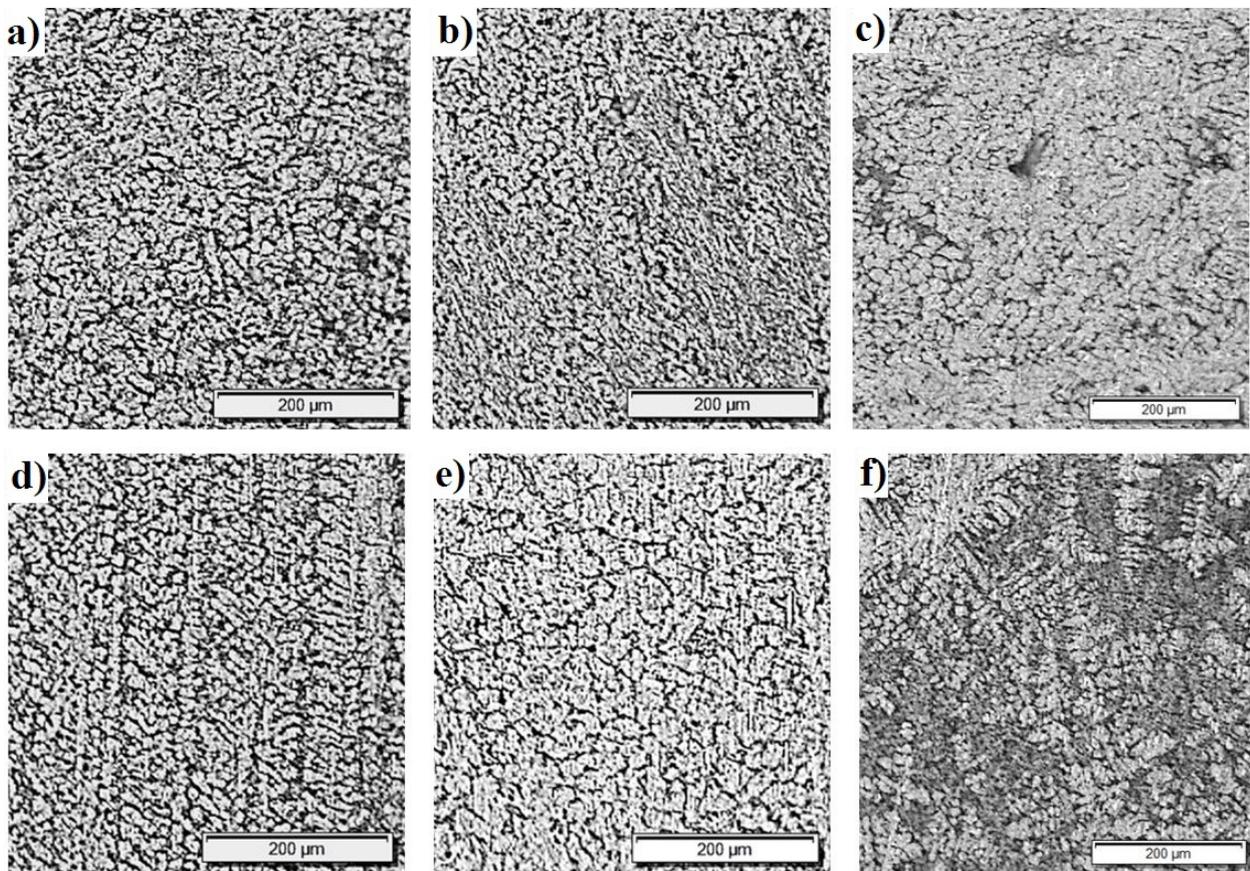


Figure 2. Directionally solidified A360 aluminum with solidification velocity of 2 mm/s. (a,d) reference; (b,e) $B = 0.4$ T; (c,f) $B = 0.4$ T, $I = 157$ A.

3. Conclusions

This work demonstrates that solidification microstructure and impurity distribution in aluminum alloys can be modified by applied electromagnetic interactions. Applied magnetic field and electric current modifies columnar to equiaxed transition and refines grains, leading to a more isotropic structure of directionally solidified A360 aluminum. As a continuation of this work, it is planned to develop this method for an electromagnetically improved Al alloy and Al-based metal matrix composites. The aim is to produce wire for additive manufacturing by directional solidification.

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Informed Consent Statement: Not applicable.

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The data presented in this study are available in article.

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