

Effect of Chill Parameters on the Residual Strain in Cast 319 Aluminum Alloy: A Neutron Diffraction Study

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ABSTRACT

The demand for light weight vehicles continues to stimulate extensive research into the development of light weight casting alloys and optimization of their manufacturing processes. Of primary relevance are Aluminum (Al) and Magnesium (Mg) based alloys, which have successfully replaced selected iron based castings in automobiles. However, optimization of as-cast microstructure, processing and performance remains a challenge for some Al-based alloys. In this context, placement of chills in castings has been frequently used to locally manipulate the solidification conditions and microstructure of a casting.

In this work, the effect of using an active copper chill on the residual strain profile of a sand-cast B319 aluminum alloy was investigated. Wedge-shaped castings were produced with three different cooling conditions: copper plate chill, copper pipe with cooling water and no chill (baseline). The effect of chill condition on the variation of residual strain in the casting was investigated using neutron diffraction approach. Diffraction from (111) and (311) reflections was studied and revealed that the (311) reflection did not exhibit appreciable strain variation at different chill conditions. In contrast, the (111) reflection exhibited a mix of tensile and compressive strains which varied with a distance from the copper chill. A copper plate chill introduced a fluctuating pattern of strain profile with tensile and compressive strain peaks, while faster cooling (copper pipe with water flow) had attenuated the residual strain profile, suggesting the need to control the chilling condition in order to achieve optimal casting performance.

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INTRODUCTION

Casting is an important manufacturing process for the automotive industry to produce near net-shape parts. Automotive industries require cast products with superior mechanical properties and economic process operations. These requirements drive applied research on optimizing Al alloy's composition and their processing parameters to meet specific application demands. The aluminum 319 casting alloy is finding opportunities for application in the automotive industry in recent years, because of its excellent castability and high temperature dimensional stability in comparison to currently used Al-Si alloys.

The 319 is a hypoeutectic Al-7Si alloy with Cu (3-4%), Fe (~1%) and Mg (~0.5%) as alloying additions, resulting in higher strength and heat treatability [1]. However, in order to replace the existing iron and steel alloys in vehicles, it is necessary to improve the as-cast mechanical properties of the alloy. Effective parameters controlling the mechanical properties are grain size and its morphology, dendrite arm spacing (DAS), size and distribution of secondary phases[2]. Therefore, several studies have been done on increasing the strength of these alloys using grain refiners [3,4], and optimizing process parameters (e.g., pouring temperature and cooling rate) [5,6].

Casting process parameters play an important role in refining the microstructure and increasing the mechanical properties. Shabestari *et al.*[5] demonstrated experimentally that cooling rate is linearly related to DAS on a logarithmic scale and

significantly refines all microstructural features including grain size and DAS of 319 alloy. Moreover, variation of cooling rate allows control over the nucleation temperature of second phases. In the work of Xiaowu on near-eutectic composition Al-11.88%Si-1.75%Cu alloy, a higher pouring temperature increased the UTS and yield strength while reducing DAS, again elucidating the importance of superheat and solidification kinetics on the as-cast performance [6]. These publications also reveal, however, that there is a temperature limit up to which molten 319 alloy can be superheated, since above this temperature a significant amount of hydrogen entrapment induces gas porosity. As a result, focus has shifted to controlling the cooling rate via the use of different mold materials (e.g., sand mold, permanent mold, graphite mold), or to the introduction of chills into the casting cavity, in order to locally enhance solidification. However, the effect of chilling and rapid cooling on the residual strains in a casting remains unknown.

Residual strain measurement using X-ray is a well established Non Destructive Evaluation (NDE) method [7,8]. However, X-rays are typically used for surface analysis or residual strains, due to their limiting penetrating ability. As a result, the use of neutron diffraction, as a much powerful radiation, has been gaining in popularity for measurement of residual strains within the bulk material [9,10].

Neutron Diffraction (ND) is analogous to X-ray diffraction technique, but the significantly higher penetration ability of neutrons into the materials makes it possible to obtain residual strain measurement from the interior of the casting [10,11]. Webster *et al.* have proposed that residual strains can be measured with an accuracy of 10^{-4} using ND [12].

Thus, in this research, neutron diffraction was used to study the residual strain profile in a B319 aluminum alloy casting. Three casting conditions with varying levels of cooling (i.e., copper plate chill, copper pipe with cooling water and no chill), have been studied.

EXPERIMENTAL PROCEDURE

A commercially available B319 alloy (from Rypac Aluminum, Surrey, BC) was used for all work. Chemical composition of the alloy was verified using OES spectrometer to ensure compliance with compositional standard. A wedge-shaped cavity in a sand mold was designed to produce a casting as shown in Figure 1. In order to manipulate the cooling rate during casting solidification, a chill was placed at the narrow end of the wedge. Three different chills were used: copper plate at 175 °C, copper pipe cooled with running water at room temperature and no chill

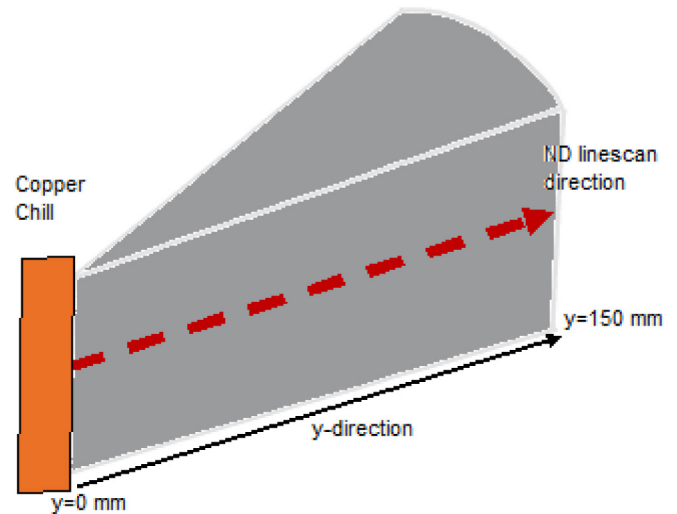


Figure 1. Wedge shaped casting

Neutron diffraction (ND) strain mapping was carried out at the Canadian Neutron Beam Centre in Chalk River, Canada. Elastic residual strain measurement was carried out 12mm below the surface of the casting along the radial direction. Measurements were obtained in 10mm increments. A monochromatic beam of neutrons ($\lambda=1.551$ Å) was used for all experiments and first order diffraction ($n=1$) analysis was performed. Reflections (θ) from two crystallographic planes were examined. Specifically, from close-packed (111) and higher-order (311) planes. A strain-free d spacing (d_o) was calculated from a heat-treated alloy sample. The residual strain (ϵ) was then calculated using Bragg's law and the peak shift method (Equations 1 and 2).

$$n\lambda = 2d \sin \theta \quad (1)$$

$$\epsilon = \frac{(d - d_o)}{d_o} \quad (2)$$

RESULTS AND DISCUSSIONS

The ND residual strain measurements reveal that manipulating the solidification rate significantly influenced the homogeneity of residual strain on the (111) crystallographic plane as compared to (311) plane. Since Al has an FCC crystal structure, (111) plane is more closely packed as compared to (311), and thus transfer of lattice strain is readily accommodated.

Residual Strain for (111) Plane

Figures 2, 3, 4 show the residual strain measured from (111) planes. The residual strain profiles initiate at the chilled edge ($y = 0$ mm) and extend towards the outer edge of the casting ($y = 150$ mm). As figures 2, 3, 4 show, significant residual strains were present in all castings. Fluctuating pattern of compressive and tensile strain has been observed in each of the castings.