EFFECTS OF INJECTION SPEED ON MECHANICAL PROPERTIES IN HIGH-PRESSURE DIE CASTING OF MG-RE ALLOY

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In this study, in order to clarify the unknown physical properties of the Mg-Al-Th-RE alloy, the relationship between the injection conditions and the internal porosities and the mechanical properties exerted by the solidification microstructure were investigated. The obtained cast samples were investigated using X-ray CT internal measurements, tensile tests, Vickers hardness tests and solidification microstructure observations. The flow simulation and the X-ray CT analysis results showed that the porosity volume increased as the injection speed increases. The higher injection speed also affected the metal microstructure to become denser, which leads to a higher material strength and hardness. The eutectic phases quickly formed because of the shorter filled and cooled time. Therefore, the growth of the primary phase α-Mg was suppressed. On the other hand, it was considered that the material strength and hardness were greatly reduced by the coarse primary phase.

KEYWORDS

high-pressure die casting, magnesium alloy, simulation, x-ray computed tomography, tensile tests, Vickers hardness tests, microstructure

1 INTRODUCTION

In today's world, where global environmental issues are becoming increasingly important, regulations on carbon dioxide (CO_2) emissions are becoming stricter year by year. In particular, the improvement of fuel efficiency of automobiles, which account for the majority of CO_2 emissions, is eagerly desired from around the world. Among the measures to improve fuel efficiency, weight reduction of the vehicle body is simple and effective, and the conversion of materials from conventional iron parts is being promoted. Among them, magnesium (Mg) is expected to be popular because it has features such as higher specific strength and specific rigidity than iron and aluminum, rich resources, and recyclability. High-pressure die casting (HPDC) is a technology that is indispensable for the production of magnesium auto parts. HPDC is a casting method that injects molten metal into a mold at high speed and high pressure, thereby shortening the manufacturing cycle as much as possible. For this reason, die casting has been established as a system capable of mass-producing products with excellent casting surface in a short time. However, characteristic porosities such as porosity and inclusion of solidified fragments occur in die cast products. In particular, the cavities caused by air entrainment and solidification shrinkage causes not only deterioration of mechanical properties but also leakage of pressure-resistant members. Therefore, there is a need to elucidate the mechanism of porosity generation, and optimization of the injection speed have been performed with CFD [Kuriyama 2012, Cleary 2014, Ibrahim 2017, Roslan 2018, Niida 2020]. Research related to quantitative measurements are also being performed [Yanagihara 2015, Gaspar 2016, Rimar 2016, Gaspar 2019]. These studies have been actively conducted on aluminum alloys and zinc alloys. Although, research and developments on magnesium alloys have not progressed because of material features such as flammability and poor castability. Magnesium alloys are generally difficult to be casted because of the ignition and the low specific heat, easy solidification, and poor fluidity. Heat-resistant and flame-retardant magnesium alloys with improved properties have been actively used and have been applied to automotive parts as practical materials [Beals 2004, Moscovitch 2007, Ebel-Wolf 2008, Mizutani 2019, Fukatsu 2021]. Among them, Mg-Al-Th-RE alloy is a magnesium alloy with improved heat resistance by adding calcium (Ca) and rare-earth (RE) elements, and with excellent fluidity to which aluminum (Al) is added at about 8% or more. It is expected to be used for products with complicated shapes that makes it difficult to fill the molten metal uniformly.

However, Mg-Al-Th-RE alloy internal microstructures and mechanical properties have not been elucidated for those actually casted in die casting processes. Die-casting magnesium alloys generally have eutectic microstructures composed primary and eutectic phases crystallized from a liquid phase. According to Mondal et al., the microstructures of magnesium alloy MRI153M are primary phase α-Mg and eutectic $Mg_{17}Al_{12}$ and (Mg, $Al)_2Ca$ phases, and the amount of (Mg, $Al)_2Ca$ is related to creep behavior [Mondal 2010]. Sun et al. examined the effect of casting thickness on the tensile properties of AZ91 magnesium alloy. The high tensile properties were attributed the low porosity level, fine dendrite microstructure, high eutectic content, and thick skin due to decreasing the thickness [Sun 2020]. From these literatures, it shows that it is necessary to know the correlation between the solidification microstructure and the material strength and to find conditions that can maximize its physical properties.

Taking from some examples of previous researchers conducting modifications of dimension, geometries, and new texturing [Ibrahim 2018, Kikuchi 2019], in this study, the relationship between the injection conditions and the internal porosities, and the mechanical properties exerted by the solidification microstructure were investigated to clarify the unknown physical properties of the Mg-Al-Th-RE alloy. The obtained cast samples were investigated using X-ray CT internal measurements, tensile tests, Vickers hardness tests and solidification microstructure observations.

2 SIMULATION AND EXPERIMENTAL PROCESS

2.1 Simulation method

Tab. 1 shows the chemical composition of the Mg-Al-Th-RE alloy. The Mg-Al-Th-RE alloy is flame-retardant and is from the Mg-Al-Th-RE group. The heat resistance by Th and La of rare earths and the flame retardancy by Ca and Sr have been