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Effects of grain refinement and residual elements on hot tearing of A713 aluminium cast alloy

Anil Kumar BIRRU[1], D. BENNY KARUNAKAR[2]

1. Department of Mechanical Engineering, National Institute of Technology, Manipur, Imphal-795004, India;
2. Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, Uttrakhand-247667, India

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Abstract: Some investigations have been carried out on hot tears in the A713 cast alloy, which is one of the long freezing range alloys, with objective to minimize/prevent hot tears. Experiments were conducted by varying pouring temperatures at 700, 750, and 780 °C on the alloy with the addition of grain refiners like Al−2.5Ti−0.5C and Al−3.5Ti−1.5C. It was found that hot tearing was minimized by the addition of Al−3.5Ti−1.5C grain refiner, but grain refinement alone could not prevent hot tearing in A713 cast alloy. This has contradicted the findings of some earlier researchers. Experiments conducted on hot tearing with the addition of iron were found to be interesting. It was found that grain refinement along with iron addition to the A713 alloy has reduced the inter-dendritic separation so that interlocking could take place along the grain boundaries. Thus, iron, which comes as an impurity in commercial aluminum, can prevent hot tearing of A713 alloy.

Key words: aluminium alloy; hot tearing; pouring temperature; grain refinement

1 Introduction

Hot tearing is a severe defect encountered in alloy castings and perhaps the key issue defining alloy's castability. It is identified as a crack, either on the inner or outer surfaces of the casting. Once the hot tear arises in a casting, the casting has to be repaired or scraped, which results in a significant loss. CAO and KOU [1] studied the hot tearing susceptibility of Mg−4Al−0.5Ca, Mg−4Al−1.5Ca, Mg−4Al−2.5Ca, Mg−4Al−3.5Ca, Mg−5Al−2.5Ca, and Mg−6Al−2.5Ca alloys and found that the hot tearing susceptibility decreased significantly with increase in Ca content but did not change much with the Al content. Mg−4Al−0.5Ca alloy had the widest freezing range and the lowest eutectic content and was the most susceptible to hot tearing, while Mg−4Al−3.5Ca and Mg−6Al−2.5Ca alloys were the opposite. RYOSUK et al [2] studied the crack susceptibility of Al−Mg alloy and found that the addition of 0.08Ti−0.016B could prevent the susceptibility to cracking of the alloy. However, it was revealed from the microstructure analysis that the addition of Ti and B was the most effective in reducing globular grain size, which resulted in minimization of the susceptibility to cracking. WANG et al [3] studied the effects of zinc and rare earth additions on Mg−9Al alloy and found that zinc additions decreased the end-solidifying temperature, promoted the precipitation of $Mg_{17}Al_{12}$ phase along the grain boundaries and increased the hot tearing susceptibility. Precipitation of Al_4RE phase slowed down the temperature drop at the initial stage of solidification. ESKIN and KATGERMAN [4] studied the fracture mode of hot tearing at the nucleation and observed that the brittle and intergranular mode fracture occurred mostly when the grain boundaries were covered with liquid metal. The effects of casting speed and alloy composition on the structure formation and hot tearing during the casting of Al−Cu alloys were studied by SUYITNO et al [5] and they found that the grain size depended on the chemical composition. Mostly, coarser structure was observed at low contents of copper of less than 2% at low casting speeds. The phenomenon of hot tearing, a serious defect in castings, has been known for a long time. CAMPBELL [6] defined hot tear as a uniaxial tensile failure, which results in cracks on the outer or inner surface of the casting. However, the precise mechanism of hot tearing was not understood for quite

Corresponding author: Anil Kumar BIRRU; Tel: +91-8331866984; E-mail: anilbirru@gmail.com
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some time. ESKIN et al [7] have made reviews on hot tearing, which show that hot tearing is a complex phenomenon. It lies at the intersection of heat flow, fluid flow and mass flow, and various factors influence its formation. Recently, RAVI [8] has concluded that hot tears usually result during the solidification of a casting in a location that has a high temperature, high gradient, and high cooling rate, coupled with a sharp corner. High temperature contributes to low strength; high gradient and high cooling rates contribute to stresses; and a sharp corner contributes to crack initiation. LANCASTER [9] cited factors influencing solidification cracking of aluminium and its alloys during welding. It was mentioned that the addition of small amounts of Ti and B (grain refinement) had resulted in reducing solidification cracking. Further, it was concluded that enhanced grain refinement could prevent solidification cracking completely.

ZHANG and SINGER [10] studied two types of Ni-based superalloys of IN792 and found that the effect of Ti content on IN792 is quite interesting. Castings without any crack or only with tiny cracks were obtained when the Ti content was dropped to 2%, compared with the original 3.9% in IN792. Moreover, ZHANG [11] studied the effects of Ti and Ta contents on the solidification behavior and castability of IN792 alloy. Good castability was achieved by proper control of the Ti/Ta ratio. This was due to the increased solidification temperature of remaining liquid in the final stages of solidification, which reduced the possibility of the formation of the detrimental interdendritic liquid film. The hot tearing susceptibility has therefore reduced. KORI [12] investigated the effect of grain refinement and modification of some hypoeutectic and eutectic Al−Si alloys with the addition of various binary and ternary-grain refiners namely, Al−3Ti, Al−3B, Al−3Ti−1B, Al−1Ti−3B, Al−5Ti−1B and Al−1Ti−5B at different addition levels. The holding time was varied from 0 to 120 min. The results revealed that the above grain refiners could fairly refine the grains in the hypoeutectic and eutectic Al−Si alloys. Based on these experimental results, REDDY et al [13] made an attempt to model the grain refinement behaviour of Al−7Si alloy. A feed forward neural network with back-propagation learning algorithm was developed for the prediction of the grain size, as a function of Ti and B addition levels and holding time during grain refinement of Al−7Si alloy. Comparison of the predicted and experimental results showed that the neural network model could predict the grain size of Al−7Si alloy with good learning precision and generalization.

KARUNAKAR et al [14] studied the hot tearing in Al−1Sn alloy with the addition of Al−5Ti−1B grain refiner, and found that grain refinement alone could not prevent hot tearing, but grain refinement plus Fe addition could prevent cracking completely. GUO and ZHU [15] made a correlation between the crack susceptibility coefficient and aluminium content for Mg−Al alloys and also predicted the conditions favouring hot tearing. They found that the addition of carbon had a significant effect on the reduction of hot tearing susceptibility. However, a few of researchers made an attempt on hot tearing of magnesium alloys and super alloys [16−19]. Recently, few researchers also made various defects [20,21] and the investigations and conclusions made by BIRRU et al [22] showed that A713 alloy was extremely prone to hot tearing. Hence, the aim of the present work is to conduct investigations on A713 aluminum cast alloys, which have long freezing range and are sensitive to hot tearing, which will help the foundrymen to minimize such defects that are associated with cracking. The conditions that would result in complete prevention of hot tearing have been investigated.

2 Experimental

2.1 Experimental setup

The hot tear experiments included mould preparation, melting of the charge and pouring. Green sand was prepared with standard binders and the mould properties like permeability and green compression strength, were maintained to be the same for all the experiments. For the present investigation, a special gated pattern has been designed, similar to the one incorporated by KARUNAKAR et al [14], which would produce four rings on four sides simultaneously. The dimensions of a single pattern are shown in Fig. 1. A photograph of the gated pattern designed for the present investigation along with the metallic cores is shown in Fig. 2. The gated pattern was kept inside the lower moulding box (drag) and the green sand was compacted around the pattern. The cope was placed over the drag, filled with the green sand properly and rammed manually. The cope was separated from the drag and the gated

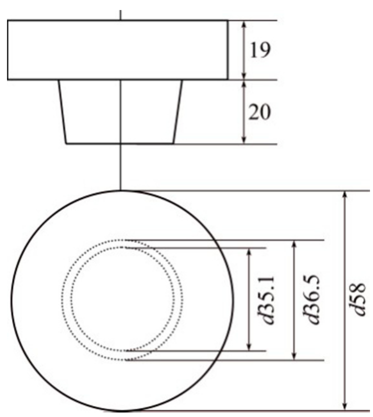

Fig. 1 Dimensions of single wooden pattern (unit: mm)