Investigation on the Simultaneous Effects of Zn Additions and Critical Ingate Velocity on the Hot Tearing Susceptibility of A356 and A206 Aluminum Alloys

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Abstract

In this study, the simultaneous effects of Zn addition and critical gate velocity on hot tearing susceptibility of A356 and A206 aluminum alloys were investigated. In order to investigate these two parameters, ingate velocities of 0.5, 0.75, 1, 1.5 m/s were taken into account. After performing the casting process, the samples were investigated by visual examination, and scanning electron microscopy. In order to quantitative evaluation of results, ProCast software were used. The results of the present study showed that increasing the Zn content for alloy A356, had no effect on hot tearing susceptibility of this alloy, and while with increasing the Zn content from 0.01 to 2.8 wt. %, the number and severity of the tears were increased.

Keywords: Al Alloys, Hot Tear, Zinc, Critical Ingate Velocity, Simulation.

1. Introduction

Hot tear or also called hot cracking is a flaw which occurs during solidification of cast alloys. Once this happen, the casting product should be repair or recycle [1]. Hot tears can be a serious problem in some alloys and specially alloys with large extent of mushy zones [2,3]. Based on the studies performed, it can be concluded that this phenomenon is complex and difficult to predict as so many parameters are involved. Factors such as chemical composition, thermodynamic features of alloy, melt treatment, mold can effect hot tearing susceptibility of an alloy [4,5]. Based on the previous studies, it is found that hot tears occur in the last stages of solidification, when there is a thin film of liquid exists in grain boundary [6,7]. According to wang et al. [4] investigations, Zn additions increase the hot tearing susceptibility of Mg-9Al-xZn alloys. They concluded that Zn has two effects on solidification of alloy, decreasing the melting point of metals in grain boundaries and increasing the quantity of these metals. On the other hand, Song eta al.[5] Studies showed that addition of Zn to 6 wt% could even improve the resistance to hot tearing in Mg-0.5Ca-xZn alloys. Base on the previous studies, it is found that hot tears occur in the last stage of solidification, when there is a thin film of liquid exists in grain boundary [6,7]. A356 aluminum alloy has very good casting and machining characteristics. Typically, they are used in the heat-treated condition of T5 and T6 hardness properties. Corrosion resistance of this alloy is excellent and it has very good weldability characteristics [6]. A206 alloy is a high strength and a light alloy used in automotive suspension components in order to reduce overall weight of vehicle [7]. High susceptibility of A206 alloy to hot tearing is the major problem inhibiting the use of this alloy [6]. The aim of this research is to investigate the simultaneous effects of Zn addition and ingate velocity on A356 and A206 aluminum alloys through practical and simulation procedures comparing these two together.

2. Materials and Methods

The chemical composition of A356 and A206 alloys before and after additions of Zn determined using spark emission spectroscopy are given in Table. 1. and Table. 2.، respectively. Ring model test were used for evaluation of hot tearing susceptibility which is shown in Fig. 1. A round mold with diameter of 108 mm was cast, while four chills are located in the center of mold. The diameter of the round steels was 90 mm. In order to perform the casting process, electrical furnace was used, and pouring temperature was about 800

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Table. 1. Chemical composition of A356 before and after addition of Zn (wt. %).

A206	Cu	Si	Mg	Fe	Mn	Zn
Before	4.50	<0.05	0.15–0.35	<0.10	0.20–0.50	<0.01
After	5.00	0.05	0.20	0.10	0.20	2.80

Table. 2. Chemical composition of A206 before and after addition of Zn (wt. %).

A356	Cu	Si	Mg	Fe	Mn	Zn	Ti
Before	0.10	7.40	0.38	0.25	0.031	0.10	0.05
After	0.09	7.00	0.31	0.20	0.02	1.21	0.04

The process, then, conducted with and without Zn additions to the melt.

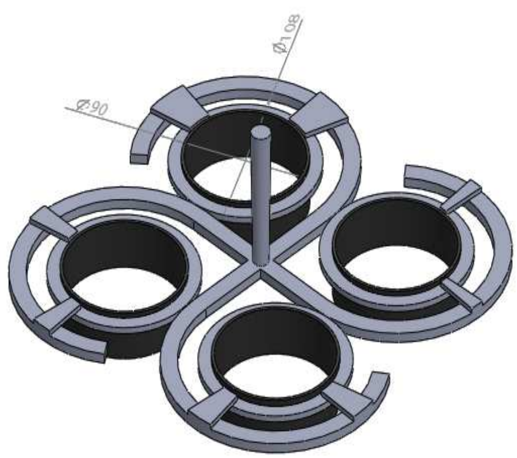

Fig. 1. Ring mold designation for hot tearing susceptibility evaluation.

In order to investigate the effects of ingate velocity simultaneously with Zn addition on hot tear formation, the ingate velocities of 0.5, 0.75, 1 and 1.5 m/s were employed. The dimensions and the ingate velocities for each one of the gates are shown in Fig. 2. and Table. 3.

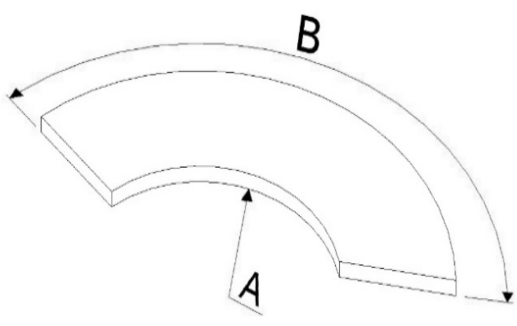

Fig. 2. Schematic of the gates.

Table. 3. Dimension of the gates.

Number of the Ring	Theoretical ingate velocity	B(Degree)	A (mm^2)
1	0.50	22.50	42.5
2	0.750	15	28.34
3	1	11.25	21.25
4	1.50	7.50	14.17

Tear surface examinations were conducted using a Scanning Electron Microscope (SEM), Seron Technology AIS2300C, equipped with an energy dispersive X-ray spectrometer (EDS). The acceleration voltage was 25 kv, the filament current 23-30 µA, and the working distance were around 20-25 mm. In order to quantitative investigation and provide a better understanding about the Hot tearing susceptibility with increasing the amount of Zinc content, ProCAST software was employed for Casting simulations. Liquid penetration test (LPT) was used to determine the cracks in the casting parts.

3. Results and Discussion

3.1. Visual Examination

Visual examination test results of castings were presented in Table. 4., the length, width, and number of formed tears are denoted in Table. 4.

Table. 4. Hot tears characteristics formed in samples.

Sample	Ring No.	Tear length (mm)	Tear width (mm)	Number of tears
A356	-	-	-	-
A356-1.21%Zn	-	-	-	-
A206	3	17	1	1
	4	18	0.5	1
A206-2.8%Zn	2	18	Broken	1
	3	18	Broken	1
	4	18	Broken	2

The data obtained from visual examination and NDT showed that, as expected, no tears were found as in case of A356 alloy castings. As indicated in

Table. 4., even with increasing in Zn content (from 0.1 to 1.21 wt. %), A356 alloy shows a good resistance to the formation of hot tears. In alloy A206, only two rings showed susceptibility to hot tear formation, while in A206 alloy with 2.8 wt. % Zn, hot tear susceptibility increased by tear formation in three rings. It is also observed that forth ring of A206-2.8%Zn with ingate velocity of 1.5 m/s at two areas, tears were formed. This demonstrated that hot tearing susceptibility increased with increasing in Zn content of A206 alloy. On the other hand, because no sign of hot tear were observed on A206, A206-2.8%Zn samples filled with ingate velocity of 0.5 m/s (close to critical velocity calculated for aluminum alloys, 0.25 m/s [8,12]), the effect of critical velocity on hot tearing susceptibility can be concluded. This also can be seen in rings with ingate velocity more than critical velocity. Fig. 3. shown the digital photographs of A206 different samples.

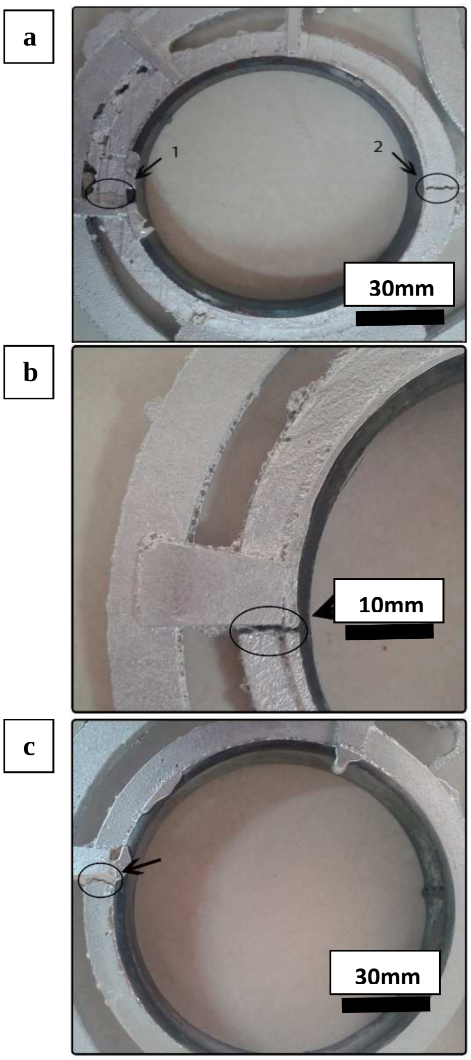

Fig. 3. Formation of hot tears in a) ring No. 4 of A206-2.8%Zn, b) ring No. 2 of A206-2.8%Zn, c) ring No. 3 of A206 alloy.

3.2. Simulation Results

The results obtained from simulation the casting process showed that in higher content of Zn, solidus temperatures of A206, A356 alloys decreased [13-15]. Variation of solidus temperatures is given in Table. 5. This temperature range was determined using thermal analysis. As it is concluded from Table. 5., Zn addition in A356 alloy results in slight decrease in solidus temperature, and this variation for A206 alloy is considerable. As a result, freezing range of this alloy is increased. Based on previous studies [16,17], higher freezing ranges could lead to further enhancement of hot tearing susceptibility because the vulnerable time of liquid film existence between dendrites is increased.

Fig. 4. shown the variation of solid fraction as a function of temperature for A206, A206-2.8% Zn alloys.

Table. 5. Variation of solid fraction with Zn addition.

Sample	Liquid temperature (°C)	Solidus temperature (°C)	Freezing range
A356	611	513	98
A356-1.21% Zn	609	497	112
A206	647	530	117
A206-w.8% Zn	643	516	127

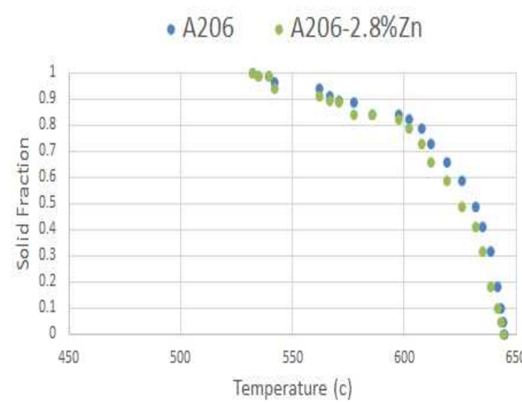

Fig. 4. Variation of solid fraction as a function of temperature.

With more attention in Fig. 4., it can be concluded that in a given temperature, solid fraction of A206 and A206-2.8%Zn alloy are 0.98, 0.90, respectively. Fig. 5. and Fig. 6. shows the potential sites susceptible to hot tear for A206 and A356. In Fig. 5., as found in practical procedures, A356 alloy had no trend to hot tear formation. Even further addition of Zn had no effect on hot tearing resistance of A356 alloy. From Fig. 4., it was found that the extent of red areas (areas with more susceptibility to hot tear formation) significantly increased with increasing in Zn content from 0.01 to 2.8 wt. %. comparing Fig. 4. and Fig. 5. resulted from simulation to practical procedure indicated a good compatibility in severity and initiation site of hot tears in castings. However, there is a slight difference in results. For example, in Fig. 7.-b, more susceptible area for hot tear formation predicted in ring No. 1, while in practical procedure, ring No. 4 (with ingate velocity of 1.5 m/s) had the sever tears. This can be seen clearly in other figures. The reason of this difference could be because of the lack of the definition of critical velocity parameter for software. As it is shown by previous researches [15-17], in velocities higher than the critical velocity for entrance of melt into the mold, because the turbulence of the melt is increased, gas or air was trapped in between of liquid surface films.

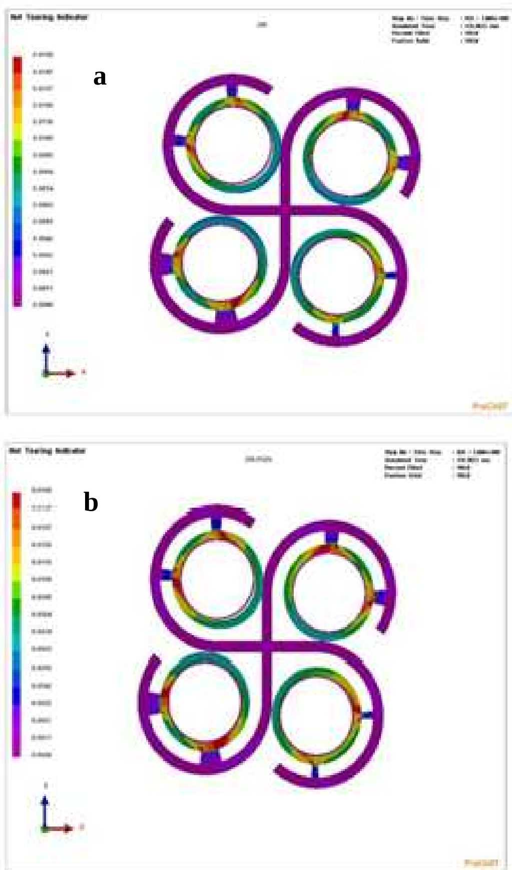

Fig. 5. Susceptibility sites for tear initiation in a) A356 alloy, b) A356-1.21%Zn.

Then during solidification and development of solidification stresses, these films could act as preferential sites for initiation of tears.

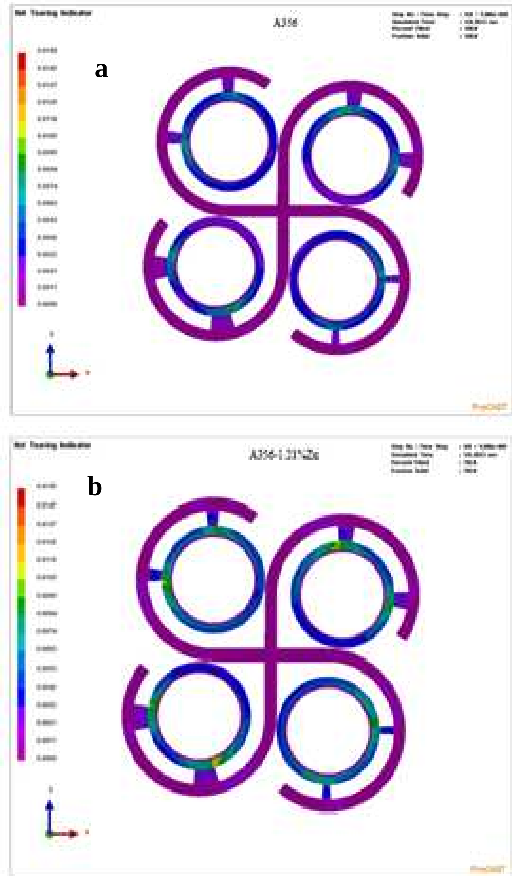

Fig. 6. Susceptibility sites for tear initiation in a) A206 alloy, b) A206-2.8%Zn alloy.

3.3. SEM Investigations

Fig. 7. and Fig. 8., are shown the SEM images of A356 and A206. In order to investigate the samples, these samples were cut mechanically and prepared for SEM analyzes. Dendritic structures can be seen clearly in Fig. 7. and can be found that remained liquid between dendrite arms move toward the dendrite roots and because of no feeding of upper parts, dendrite arm spacing remain empty [17].

In some areas, structures similar to eutectic were observed, which is suggestive of liquid that reaches the eutectic temperature and freeze called frozen liquid.

Fig. 8.-a, shows the large extent of dendrite structure. Fig. 8.-b shows the fracture surface of the A206-2.8%Zn sample. White and red arrows in Fig. 8.-b indicate the oxide films and low-melting point phases solidified, respectively. In fact, composition of these phases is similar to eutectic and as a result after solidification eutectic structures were formed.

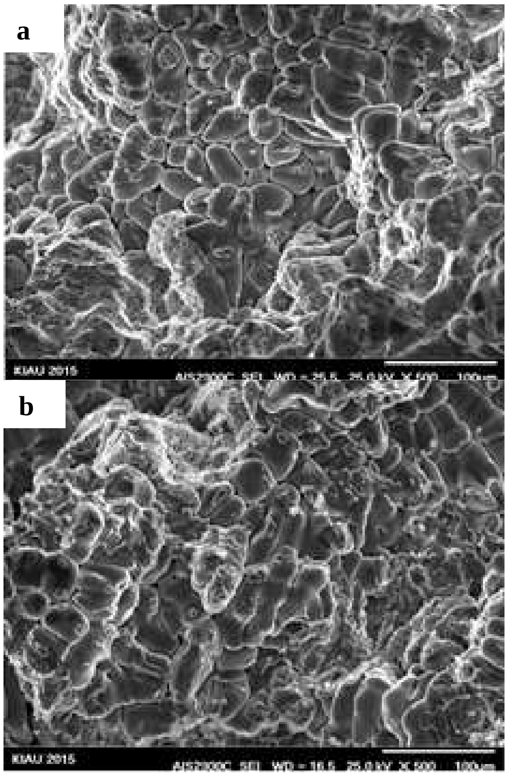

Fig. 7. SEM images of a) A356 Alloy, b) A356-1.21%Zn.

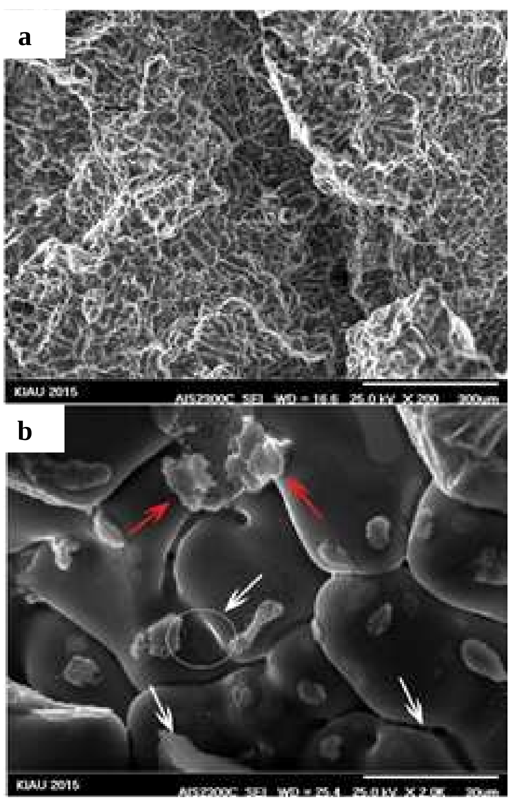

Fig 8. SEM images of a) A206 alloy, b) A206-2.8%Zn alloy.

4. Conclusions

1. By increasing of the Zn concentration in A206 alloy from 0.01 to 2.8 wt. %, the number and severity of tears were increased, while increasing from 0.1 to 1.21 in case of A356 alloy had no effect on hot tearing susceptibility.
2. By increasing the amount of the Zn the solidus temperature decrease and this led to higher extent of freezing range and the hot tearing susceptibility were increased.
3. Simulation and practical procedures determined the good compatibility with each other, but may be because of the lack of the definition of critical ingate velocity parameter for software; there is a slight difference in results.
4. Simultaneous effects of the chemical composition and ingate velocity of the melt on hot tear phenomena showed that even in higher concentration of the Zn, which could cause in more tendencies to hot tears.

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