TP 2287

Transactions of The Indian Institute of Metals

Vol. 62, Issues 4-5, August-October 2009, pp. 315-319

Influence of grain refinement on hot tearing in B206 and A319 aluminum alloys

F. D'Elia and C. Ravindran

Centre for Near-net-shape Processing of Materials, Ryerson University, Toronto, Canada

Email: rravindr@ryerson.ca

Received 31 July 2009
Revised 17 October 2009
Accepted 19 October 2009
Online at www.springerlink.com

***Keywords**:*
casting; hot tearing; grain refinement; aluminum alloys

Abstract

Aluminum-copper (Al-Cu) and aluminum-silicon-copper (Al-Si-Cu) alloys are among the most common aluminum casting alloys. Aluminum alloy B206 is a relatively new Al-Cu alloy with high strength and ductility at room and elevated temperatures, while A319 is an Al-Si-Cu alloy with good strength and excellent wear resistance. However, despite their advantages, when these alloys are cast via the permanent mold casting (PMC) process, they show a high susceptibility to hot tearing. Grain refinement has shown promise as a means to reducing hot tears in aluminum alloys.

In this study, Ti-B grain refiner was used to investigate the effect of grain refinement on hot tearing in B206 and A319 aluminum alloys during permanent mold casting. The results suggest that Ti-B additions significantly reduced hot tearing in B206 and A319. Grain sizes were also seen to reduce significantly in both alloys with addition of Ti-B grain refiner. However, Ti-B grain refiner had a diverse effect on alloy grain morphology, as a dendritic morphology in B206 was transformed to a more globular one, while in A319, the grain structure remained dendritic.

1. Introduction

Aluminum alloys are very important to the automotive and aerospace industries. The interest in these alloys is spurred by the need to produce lighter and more fuel efficient vehicles. Advantages of aluminum alloys stem mainly from their low density, good castability and excellent mechanical properties. Two of the most common groups of aluminum alloys are the aluminum-copper (Al-Cu) and aluminum-silicon-copper (Al-Si-Cu) systems. Casting is the primary manufacturing process for these alloys. However, when these alloys are cast via the permanent mold casting (PMC) processes, they show a high susceptibility to hot tearing.

Hot tears are cracks forming in a semi-solid alloy prior to its complete solidification [1]. Two factors that are generally attributed to the formation of hot tears are: insufficient feeding of liquid metal and tensile loading of the mushy zone. The size of the mushy zone and grain refinement also impact hot tearing [2]. Hot tears limit the use of Al-Cu and Al-Si-Cu alloys, as their excellent mechanical properties are offset by their high susceptibility to hot tearing. A better understanding of the methods to improve the hot tearing resistance of Al-Cu and Al-Si-Cu alloys would enable wider use of these alloys in industrial applications.

Grain refinement has been reported to increase an alloy's resistance to hot tearing [2-8]. Globular grain morphology, resulting from grain refinement, enabled improved feeding of liquid during casting solidification and improved solidification strain homogeneity [3,4]. Further, in a recent study, Eskin *et al.* [5] found that grain refinement decreased the onset time of thermal contraction. As a result, the thermal contraction started at a later stage of solidification and less thermal strain was imposed on the mushy zone. Thus, grain refinement was seen to improve the hot tearing resistance of many Al alloys.

The aim of this paper is to investigate the influence of Ti-B grain refinement on hot tearing in B206 and A319 aluminum alloys. The casting surfaces were examined for hot tear presence. Grain size measurements were performed and microstructure was characterized using optical microscopy.

2. Materials and methods

2.1 Melting and casting

The chemical compositions of the B206, A319 alloys and Al-Ti-B master alloy used in this study as measured from an emission spectrometer is presented in Tables 1, 2 and 3 respectively.

The Al alloys were melted in a silicon-carbide crucible using an electric resistance furnace. Virgin ingots weighing approximately 1 kg were used for each casting run. For each pour, the alloys were degassed at 780°C using Hexachloroethane tablets prior to adding the Ti-B grain refiner (in cut rod form) to the melt at 760°C. After five minutes of adding the Ti-B grain refiner, the melt was mechanically stirred for one minute. Finally, the melt was poured at 710°C. The PMC process parameters used in this research for B206 and A319 are presented in Tables 4 and 5, respectively. The process parameters (i.e., mold temperature and pouring temperature) were selected based on preliminary experiments. It is well established that increasing the mold temperature during permanent mold casting can reduce hot

Table 1: Actual composition of B206 alloy (wt%).

Cu	*Mn*	*Mg*	*Fe*	*Si*	*Ni*	*Zn*	*Sn*	*Ti*	*Al*
4.9	0.38	0.24	0.05	0.04	<0.01	<0.01	<0.01	<0.01	Bal.

Table 2: Actual composition of A319 alloy (wt%).

Cu	*Mn*	*Mg*	*Fe*	*Si*	*Ni*	*Zn*	*Ti*	*Al*
3.65	0.31	0.01	0.47	6.15	0.01	0.71	0.14	Bal.

The Al alloys were grain refined using Al-5Ti-1B Tibor® master alloy, whose composition is given in Table 3.

Table 3: Al-5Ti-1B master alloy composition (wt%).

Al	*Ti*	*B*	*Fe*	*V*	*Si*	*Zn*
93.6	5.0	1.0	0.1	0.1	0.06	0.01

tearing [9,10]. As a result, in this research, the mold temperature was systematically varied to induce the worst-case scenario for each alloy. In the case of the B206 alloy, the 180°C mold temperature produced a severe hot tear for the unrefined alloy, while for the A319 alloy, it was necessary to lower the mold temperature to 100°C to produce a severe hot tear for the unrefined alloy.

Table 4 : PMC process parameters for B206 alloy.

Parameters	*Levels*
Pouring Temperature	710 °C
Mold Temperature	180 °C
Titanium Levels	0.02 and 0.05 wt%

Table 5: PMC process parameters for A319 alloy.

Parameters	*Levels*
Pouring Temperature	710 °C
Mold Temperature	100 °C
Titanium Levels	0.15 and 0.20 wt%

The permanent mold used in this research is shown in Fig. 1. The casting cavity consisted of a downsprue and a 260 mm long casting bar with an end restraint. The casting thickness was 20 mm. Once the molten metal filled the horizontal bar, solidification initiated from the end restraint towards the downsprue. As the bar solidified, it contracted. However, the end restraint prevented the casting bar from contracting freely, which induced tensile stresses in the bar. If these tensile stresses exceeded the semi-solid strength of the alloy, a hot tear formed in the casting bar.

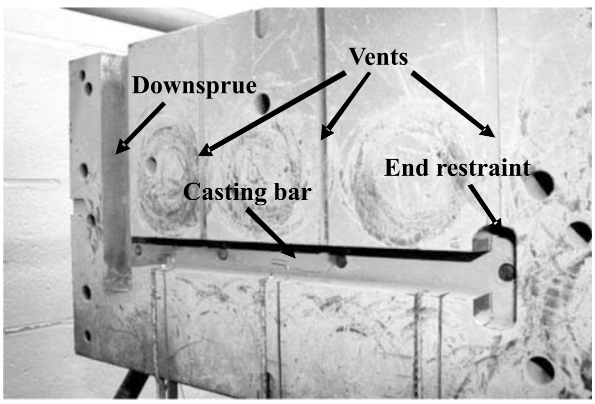


Fig. 1 : Permanent mold.

2.2 Grain size measurements and optical microscopy

Representative samples were sectioned from the casting bar and polished using standard procedures. The B206 and A319 samples were etched using Keller's reagent to view grain size. Buehler OmniMet® image analysis software was used in conjunction with an optical microscope to characterize the microstructure and measure the grain size of the alloys. Grain size measurements were performed using the linear intercept method.

3. Results and discussion

3.1 Effect of grain refinement on hot tears

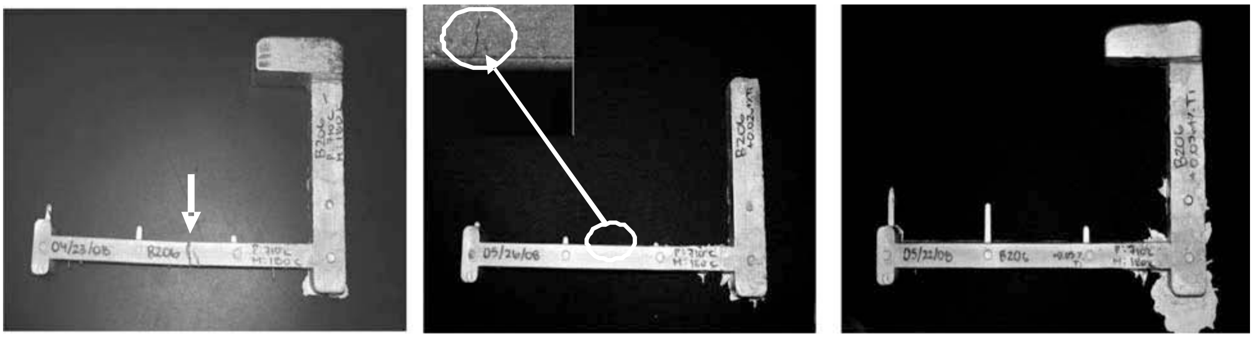
The effect of grain refinement on hot tearing in B206 alloy is presented in Fig. 2. The results suggest that grain refinement had a significant impact on the hot tearing severity of the B206 alloy. Representative castings in Fig. 2 show that with the addition of the Ti-B grain refiner, hot tears were virtually eliminated. A hot tear was present in the middle of the casting bar for the unrefined B206 alloy, as shown in Fig. 2a). This tear resulted in a complete fracture of the casting bar. The reason for the occurrence of the hot tear in the midsection of the casting bar in B206 is addressed elsewhere [2]. When 0.02 wt% Ti was added, only a hairline tear developed at the same location as that of the unrefined alloy. The hairline tear is shown magnified in the top left corner of Fig. 2b). At 0.05 wt% Ti concentration, surface hot tears were eliminated.

Figure 3 displays the effect of Ti-B grain refiner on hot tearing of A319 aluminum alloy. Hot tears were present at the 90° junction between the downsprue and the casting bar. As a result, the complete casting is not displayed in the figure, but only the location where the hot tear occurred.

Hot tearing severity significantly decreased in A319 with additions of Ti-B grain refiner. A hot tear was initially present in the base A319 alloy, as shown in Fig. 3 a). At 0.15 and 0.2 wt% Ti concentrations, hot tear severity was reduced but was not eliminated, as only small tears were visible on the casting surface.

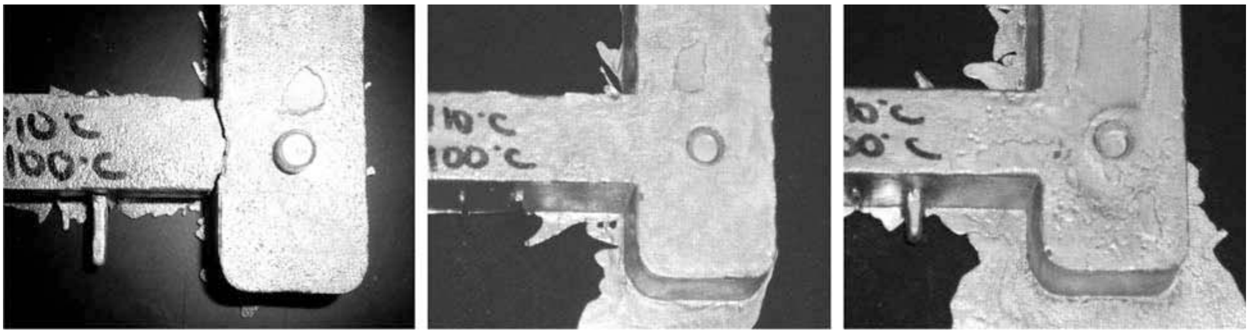
3.2 Grain size measurements

Grain size measurements were carried out on the cross-section of the microscopy samples. A minimum of 100



a) unrefined alloy b) 0.02 wt% Ti alloy c) 0.05 wt% Ti alloy

Fig. 2 : Effect of grain refinement on hot tearing in B206.



a) unrefined alloy b) 0.02 wt% Ti alloy c) 0.05 wt% Ti alloy

Fig. 3 : Effect of grain refinement on hot tearing in A319.

measurements were taken across each sample. The results are presented for B206 and A319.

Figure 4 displays the grain size measurements for the B206 alloy with Ti-B grain refiner additions. The results clearly suggest that the Ti-B grain refiner had a significant impact on the grain size. In comparison to unrefined B206 alloy, the average grain size decreased from ~680µm to ~120µm after refinement. Additional decrease below 100µm was observed for the 0.05 wt% Ti concentration.

Figure 5 illustrates the grain size measurements taken along the A319 alloy with Ti-B additions. The results suggest that Ti-B grain refiner was not as effective in A319 as it was in B206, as the decrease in grain size was not as significant. The grain size decreased from ~850µm for the unrefined alloy to ~500µm for the 0.15 wt% Ti alloy. Additional Ti to 0.2 wt% did not have a significant impact on grain size reduction.

The grain size measurements were in correlation to hot tearing severity in B206 and A319, as a decrease in hot tearing severity was in conjunction with a reduction in grain size. The microstructure of the alloys was examined to investigate whether Ti-B additions had an impact on grain morphology in B206 and A319.

3.3 Grain morphology

Figure 6 illustrates micrographs of the unrefined B206 alloy and B206 with 0.02 wt% and 0.05 wt% Ti concentrations at 50x magnifications. The images revealed coarse grains along with a fully dendritic morphology for the unrefined B206 alloy. This coarse dendritic morphology correlates with the alloy's poor resistance to hot tearing. Dendrites, in contrast to equiaxed grains, are not able to slide relative to one another and accommodate strain, and hence promote tear formation.

Upon grain refinement, the grain morphology changed. Figs. 6 a) and b) reveal a significant reduction of grain size. The 0.02 wt% Ti alloys' microstructure was spongy, as there was evidence of both dendritic and equiaxed grains. The B206 alloy refined with 0.05 wt% Ti, on the other hand,

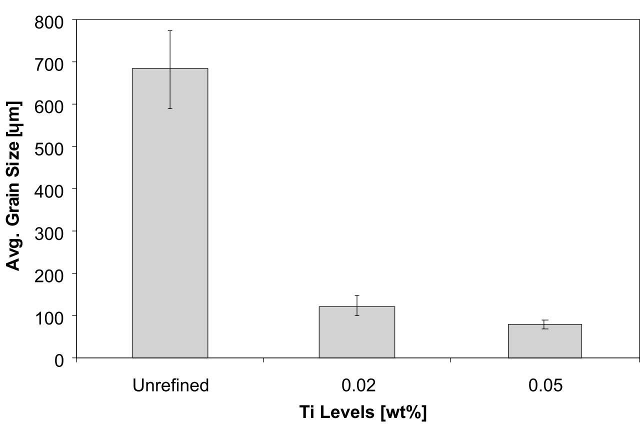


Fig. 4 : Grain size measurements in B206.

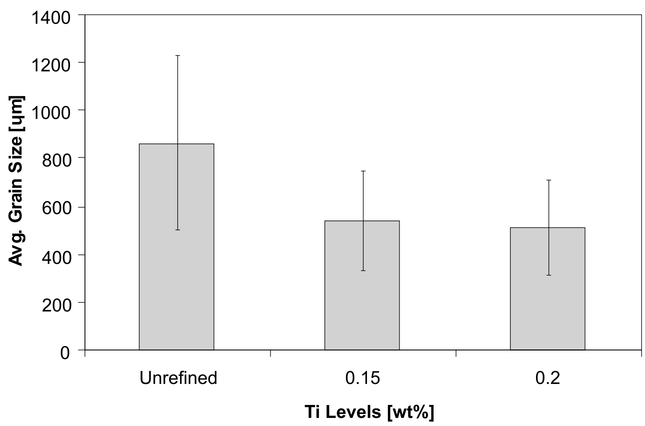
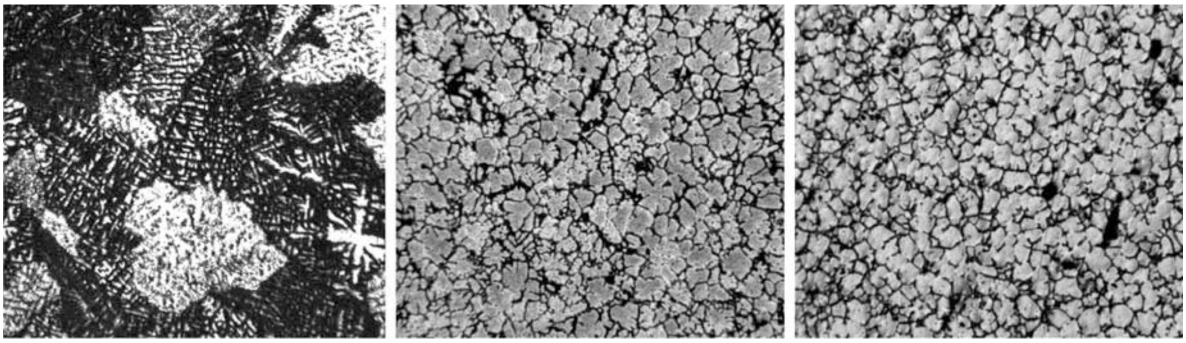
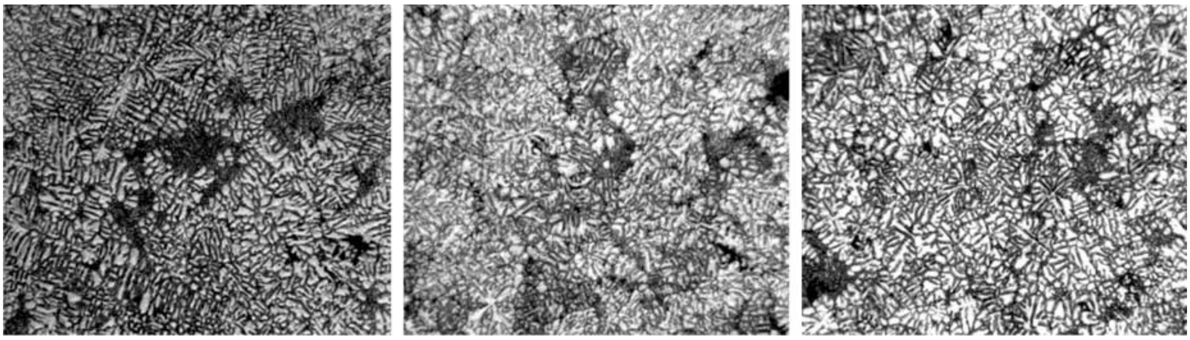


Fig. 5: Grain size measurements in A319.



a) unrefined alloy b) 0.02 wt% Ti alloy c) 0.05 wt% Ti alloy

Fig. 6 : Grain morphology of B206 alloy (50x magnification).



a) unrefined alloy b) 0.15 wt% Ti alby c) 0.20 wt% Ti alloy

Fig. 7 : Grain morphology in A319 alloy (50x magnification).

appeared to have a more equiaxed grain structure, as only small sections of dendritic features were visible in the micrograph.

The change in grain structure from dendritic to globular observed in the Ti-containing B206 alloys was advantageous because the globular grains were likely more ductile and therefore, more able to accommodate the imposed deformation during solidification. As a result, hot tearing severity was reduced in these alloys.

Figure 7 illustrates the microstructure of the unrefined A319 alloy and A319 alloy with 0.15 and 0.2 wt% Ti concentrations at 50x magnifications. A coarse dendritic morphology was visible on the micrograph of the unrefined alloy. These dendrites, as in B206, were likely not able to accommodate the applied strain during solidification and thus promoted hot tear formation.

The addition of Ti-B grain refiner did not have a significant impact on the A319 alloy microstructure, as the morphology remained dendritic. However, the dendrites appeared to be more refined in the Ti-containing alloys. As a result, these micrographs confirm that the Ti-B grain refiner was not as effective in A319 as in B206, since a globular grain morphology did not result in A319 with Ti-B additions. This was likely due to the poisoning effect of silicon in grain refinement of Al-Si alloys, which has been reported in literature [11,12]. A detailed analysis has been developed by the authors [13].

4. Conclusions

The results obtained in this study suggest that grain refinement is a viable method for reducing hot tears in aluminum alloys. The results showed a good correlation between hot tears and grain size, as a reduction in hot tearing severity was accompanied by a decrease in grain size in B206 and A319. However, the Ti-B grain refiner was found to more effective in B206 as grains were significantly smaller in this alloy than in A319. Further, Ti-B grain refiner additions resulted in a transformation from a dendritic morphology to a more equiaxed grain morphology in B206. In A319, however, it was likely that the efficiency of Ti-B grain refiner was poisoned by Si, as the A319 grain morphology remained dendritic.

Acknowledgements

The authors are grateful to Natural Sciences and Engineering Research Council (NSERC) of Canada and AUTO21 Network of Centres of Excellence for funding this research. The authors would also like to acknowledge the technical support of Mr. Alan Machin of Ryerson University.

References

1. Eskin D G, Suyitno and Katgerman L, Mechanical Properties in the Semi-solid State and Hot Tearing of Aluminum Alloys, *Progress in Materials Science,* **49** (2004) 629.
2. D'Elia F and Ravindran C, Effect of Ti-B Grain Refiner on Hot Tearing in Permanent Mold Cast B206 Aluminum Alloy, *AFS Transactions*, **117** (2009) 139.
3. Metz S A and Flemings M C, *A* Fundamental Study of Hot Tearing, *AFS Transactions,* 78 (1970) 453.
4. Braccini M Suéry M and Stucky M, Influence of Grain Refinement on Hot-Cracking in Aluminum-Copper Alloys, *Fonderie Fondeur d'aujourd'hui,* **208** (2001) 12.
5. Eskin D G and Katgerman L, Effect of Structure on Hot Tearing Properties of Aluminum Alloys, *Trans Tech Publications,* Switzerland, (2007).
6. Easton M, Grandfield J, StJohn D and Rinderer B, The Effect

of Grain Refinement and Cooling Rate on the Hot Tearing of Wrought Aluminum Alloys, *Trans Tech Publications*, Switzerland, (2006).

7. Spittle J A and Cushway A A, Influences of Superheat and Grain Structure on Hot-Tearing Susceptibilities of Al-Cu Alloy Castings, *Metals Technology,* **10** (1983) 6.
8. Viano D, StJohn D, Grandfield J and Caceres C, Hot Tearing in Aluminum-Copper Alloy, *Light Metals 2005* (2005) 1069.
9. Bichler L, D'Elia F and Ravindran C, Reduction of Hot tears in AZ91 Magnesium Alloy: Effect of Cooling Rate, *AFS Transactions*, **116** (2008) 795.
10. Bichler L, Lee K, Elsayed A and Ravindran C, Effect of Mold and Pouring Temperature on the HotTearing of AZ91 Magnesium Alloy, *Int. Journal of Metalcasting*, **1**(2) (2008) 43.
11. Chakraborty M, Vinod Kumar G S and Murty B S, Poisoning and Fading Phenomena in the Grain Refinement of Al and its Alloys, *Trans. Indian Inst. Met.*, **58** (4) (2005) 661.
12. Vinod Kumar G S, Murty B S and Chakraborty M, Grain Refinement Response of LM25 Alloy Towards Al-Ti-C and Al-Ti-B Grain Refiners, *Journal of Alloys and Compounds*, **472** (2009) 112.
13. D'Elia F and Ravindran C, Poisoning in Grain Refinement of A319 Aluminum Alloy and its Effect on Hot Tearing, *AFS Transactions,* **118**, Paper No. 10-065 (2010) (submitted).