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Grain Refinement and Castings

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EFFECT OF GRAIN REFINER AMOUNT ON THE HOT TEARING OF 6XXX ALLOYS DURING DC CASTING

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Abstract

In this work full scale DC casting trials of 6xxx alloy were performed. The purpose of the trials was to study the effect of the grain refiner amount on the critical casting speed at which hot tearing occurs during DC casting of extrusion ingots. Four addition rates of grain refiner were used. For each amount of grain refiner the speed of casting was increased step by step after each half meter of casting until hot tears formed in the centre of the ingots. Two alloys, AA6060 and AA6082, and one diameter, Ø203mm (8") were investigated. The effect of water amount on centre cracking was also investigated. The results have shown that the critical casting speed for centre cracking is highly dependent on the grain refiner addition level. Even though no further grain refiner effect could be observed in the trials high addition rates did still influence the critical casting speed. The effect of water amount on centre cracking was not significant.

Introduction

The purpose of grain refiner (GR) addition during the Direct Chill (DC) casting of ingots is to obtain fine homogeneous grain size and to avoid the hot tearing for a given set of DC casting parameter. It is known that hot tearing is one of the most important limiting factors for casting speed when producing 6xxx extrusion ingots [1-4]. However the relation between the grain refiner amount and the critical casting speed at which centre cracking occurs is not well known. Therefore, casting trials of AA6xxx alloys were conducted to determine this relation for two different alloys and one diameter. Even though the critical casting speed for cracking is highly dimension dependent the relative effect of grain refinement is likely to be independent of dimension.

Experimental

Full scale DC casting trials of two 6xxx alloy were performed at Hydro Aluminium Research and Technology Development Reference Centre, Sunndalsora, Norway. The composition of the two alloys is presented in Table I.

Table I. Composition of the alloys

Alloy	Si	Fe	Cu	Mn	Mg	Zn	Al
AA6082	1.0	0.20	0.01	0.54	0.65	0.01	97.54
AA6060	0.43	0.2	0.001	0.02	0.46	0.004	98.9

Casting trials were performed using Hycast Gas Cushion (GC) DC casting moulds. A schematic view of a module with 12 GC moulds is shown in Figure 1, which reveals positions of different moulds on the casting module. Ingots 1 and 12 are closest to the casting launder and ingots 6 and 7 are the farthest. The diameter

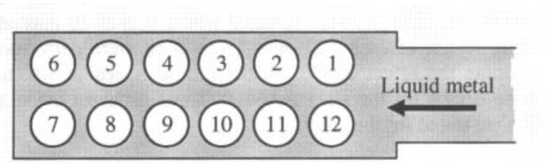

Figure 1. Casting module with 12 moulds. The metal entered the module from the side of moulds 1 and 12.

of the tested moulds was 203 mm (8"). The GR rod addition speed was increased with the increasing casting speed so that a constant amount kg/tones GR for a given amount of liquid metal could be maintained. Figure 2 depicts the way the casting speed was increased step by step for the casting trials. The figure also shows the melt temperature at different casting speeds and casting length at which hot tears appeared in different ingots for casting trial 1. Formation of hot tears was confirmed with ultrasound instrument Krautkramer USM 25 by scanning the ultrasound probe on the ingot surface during casting. After casting trials the macro and microstructure of the ingots was studied using light optical microscope Reichert-Jung MeF3. The grain size was measured with the intercept method along the orthogonal lines in the light microscope using polarized light. At least 100 grains were measured for each sample. For chemical analysis optical emission spectrograph ARL 4460 was used.

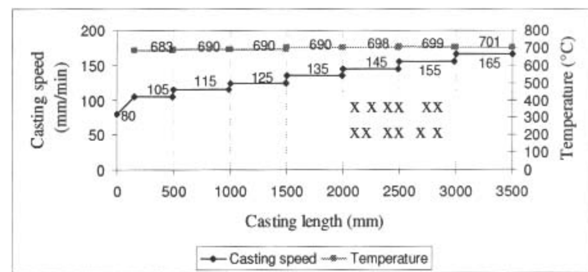

Figure 2. Casting speed and casting temperature logging curve for trial 1. Crosses indicate approximate casting length when hot cracks appeared.

The casting parameters for the conducted casting trials are summarized in Table II. In all the tests AlTi3B1 grain refiner rod from London & Scandinavian Metallurgical Co. Limited was used. On the basis of the parameters studied, the trials can be divided into 2 major groups. Trials 1-7 were conducted with the alloy AA6082 and trials 8-10 were conducted with alloy AA6060. The trials for the alloy AA6082 can be further divided into 2 groups. Trials 1-5 were conducted to determine the relationship between the GR amount and the critical speed at which hot tearing occurs for the alloy AA6082. Five different amounts of GR kg/mton were tried for the alloy. For each amount of GR the speed of casting was increased step by step each half meter of casting until hot tears formed in all the 12 extrusion ingots. Casting trials 3, 6 and 7 were conducted to determine the effect of cooling water on the hot tearing speed for the alloy AA6082. The cooling water amount was reduced from 7.5 m^3/h to 4.5 m^3/h in three different casting trials e.i. trials 3, 6 and 7. The GR for these three trials was 1kg/mton. In case of the alloy AA6082 for casting trials with GR lower than 1 kg/mton the casting speed was lowered to 95mm/min after casting 500 mm. This was to avoid out of gas cushion situation in the start of the casting. The casting speed was stepped up again to 105 mm/min after a casting length of 1000 mm and then was increased with a step of 10 mm/min at casting length of each 500 mm. Trials 8-10 were performed to determine the effect of GR on the critical speed at which hot tearing occurs for the alloy AA6060. Three different amounts of GR were tested for the alloy.

Table II. Casting parameters for the trials.

Casting trial	Alloy	Grain refiner (kg/ton)	Water amount (m^3/h)	Temperature at hot tearing (°C)	Casting speed at failure (mm/min)	Casting length at failure (mm)
1	AA6082	3.3	7.5	684	155	2500
2	AA6082	2.2	7.5	699	145	2000
3	AA6082	2.0	7.5	697	135	1500
4	AA6082	0.5	7.5	691	115	2000
5	AA6082	0.2	7.5	699	115	1500
6	AA6082	1.0	6.0	684	135	1500
7	AA6082	1.0	4.5	686	125	1000
8	AA6060	1.0	7.5	700	180	3000
9	AA6060	0.5	7.5	697	170	2500
10	AA6060	0.2	7.5	682	160	3000

Results

The effect of GR on the max casting speed possible before the hot tears appear when casting extrusion ingots with alloys AA6082 and AA6060 is presented in Table II. The melt temperatures at hot tearing are also given in the table. Table III gives the detail of investigation carried out on the extrusion ingots cast with the two alloys according to the parameters given in Table I. This was to determine the effect of the casting parameters on the resulting microstructure. The Ti and B content of the cast alloys were tested with Optical Emission Spectroscopy (OES). This was to distinguish the amount of Ti and B added with the GR rod from the Ti and B already present in the furnace melt. The results are given in Figure 3. As can be seen the Ti and B amounts in the casting are not much different than expected for the alloy AA6082.

The measured grain sizes from ingots 1 and 6 for all the casting trials are presented in Table IV. The grain size was measured for the standard casting speeds 105 mm/min and 120 mm/min for the alloys AA6082 and AA6060 respectively. The grain size was measured at the mid radius of slices taken from the ingots. Comparing the grain size in the first 5 casting trials in Table IV reveals that the ingot cast with 0.2 kg/ton GR amount has the largest grain size while the grain size decreases until trial 3 (1.0 kg/ton GR). For GR amount above 1.0 kg/ton, the grain size is more or less stable and does not decrease further as shown with the help of a plot in Figure 4. The grain size of the alloy AA6060

Table III. Detail of microstructure investigation.

Casting Trial No	Ingot No.	Grain refiner (kg/ton)	Water (%)	Investigation: Grain size	Microstructure	Spectrograph
1	1	3.3	100	X	X	X
1	6			X		
2	1	2.2		X	X	X
2	6			X		
3	1	1.0		X	X	X
3	6			X		x
4	1	0.5		X	X	X
4	6			X		x
5	1	0.2		X	X	X
5	6			X		
6	1	1.0	80	X	X	X
6	6			X		
7	6		60	X		
7	1			X	X	
8	1	1.0	100	X	X	X
8	6			X		
9	1	0.5		X	X	X
9	6			X		
10	1	0.2		X	X	X
10	6			X		

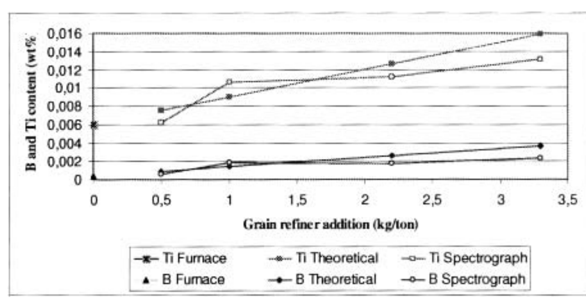

Figure 3. B and Ti content added and analyzed by OES in the alloy AA6082.

Table IV. Grain size measurement.

Casting trial No.	Alloy	Grain refiner amount (kg/ton)	Water amount (m^3/h)	Casting speed at sampling (mm/min)	Temperature at sampling length (°C)	Grain size ingot 1	Grain size ingot 6
1	6082	3.3	7.5	105	675	109	102
2	6082	2.2	7.5	105	683	108	112
3	6082	1.0	7.5	105	674	99	86
4	6082	0.5	7.5	105	687	187	133
5	6082	0.2	7.5	105	692	212	178
6	6082	1.0	6.0	105	663	101	90
7	6082	1.0	4.5	105	673	129	149
8	6060	1.0	7.5	120	672	109	110
9	6060	0.5	7.5	120	672	138	123
10	6060	0.2	7.5	120	686	142	136

ingots cast in trials 8-10 is also plotted in Figure 4, which decreases with increasing GR amount. No casting trials were performed for AA6060 above 1kg/ton grain refiner. Grain size for trial 3 (7.5 m^3/h water) is finer than for trials 6 (6 m^3/h water) and 7 (4.5 m^3/h water). An additional result of the trials is the effect of temperature on the grain size. The grain size decreases with decreasing temperature of the melt as can be seen by comparing the grain sizes of ingot 1 and 6 for all the casting trials except trial 7. The effect of grain refiner amount on the critical casting speed at which hot tears occurred is presented in Figure 5. The critical casting speed increases with the increasing GR amount for the two alloys. The effect of cooling water amount on the critical casting speed at which hot tearing occur for the alloy AA6082 is plotted in Figure 6. The critical casting speed decreases with decreasing cooling water amount.

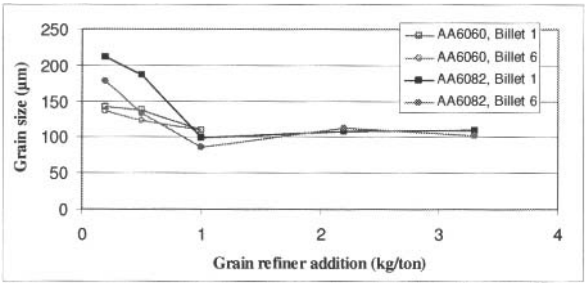

Figure 4. The measured grain size versus grain refiner addition.

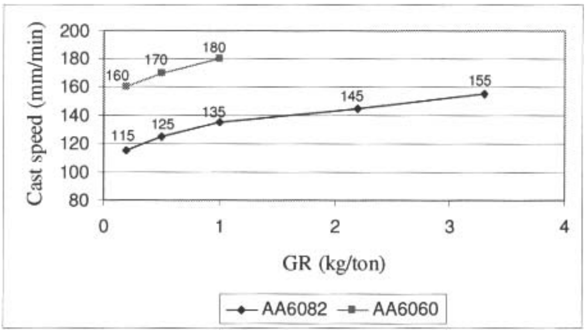

Figure 5. The maximum casting speed possible before a hot tear formed in the DC cast extrusion ingots as a function of grain refiner amount. The diameter of the cast ingots was 203 mm(8").

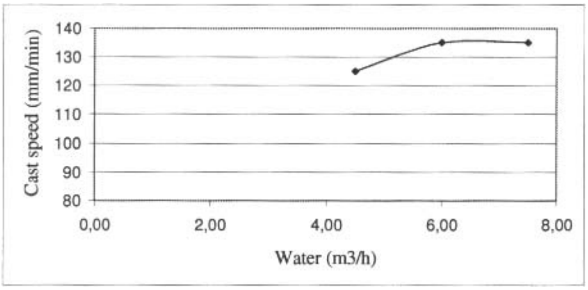

Figure 6. The critical casting speed at hot tearing as a function of cooling water during DC casting. The deameter of cast ingots was 203 mm (8"). The grain refiner amount was 1 kg/ton.

Discussion

A comparison of the first 5 trials given in Table II reveals that the critical speed at which hot tears occur increases with increasing GR amount and is highest for the casting trial 1 which has the highest amount of GR. The effect of increasing GR amount on the critical speed for the alloy AA6082 is presented in Fig. 5. As can be seen from the data plotted in the figure that the critical speed does not increase linearly with the increase in GR amount, but follows a logarithmic relationship with the GR amount. In Table II the casting length at which hot tears were found for trial 3 appears to be lower than trial 4. This is because the casting speed of trial 3 was lowered from 105 mm/min to 95 mm/min to avoid out of gas cushion situation in the start of the casting. For the alloy AA6060 the critical speed at which hot tearing occurs follows a similar relationship as for the alloy AA6082 as is clear from Figure 5. The critical speed at which hot tearing occurs for the alloy AA6060 in the three casting trials are much higher than for AA6082 even for a GR amount of 0.2 kg/mton.

Figure 4 shows that the grain size reduces with the increasing grain refiner addition for both the investigated alloys. However, for the alloy AA6082 the grain size becomes more or less stable after a minimum at 1 kg/ton grain refiner. Earlier work has also shown a limited effect on the grain size for an increase in the GR addition above 1 kg/ton, see e.g. Vatne et al., [5, 6].

The results in Table IV show that the grain size of the ingots decreases with decreasing temperature. This could be because of the fact that for the same amount of cooling water in the mould, a melt with lower temperature will promote undercooling and thus cause higher number of nucleation of grains as compared to a melt with higher temperature.

The grain size for different amounts of grain refiner is plotted in Figure 4. The figure shows that above 1kg/ton grain refiner the grain size does not change considerably. However, it is interesting to note that an increase in the critical speed for hot tearing can still be seen as a result of increasing grain refiner (Figure 5). Though the grain sizes presented in Table IV and Figure 4 are not from the sections of the ingot where hot cracks formed during casting, still they indicate that by merely increasing grain refining amount the grain size did not decrease further. The question then rises, what are the factors contributing to the increase in critical casting speed? D. G. Eskin has demonstrated with experimental work that the grain size during DC casting of a Al-4.3%Cu alloy decreased as a result of increasing casting speed [7]. The grain size decreases with increasing speed due to increasing cooling rate that affects the nucleation and growth of grains. Thus it is likely that in the present work the increase in critical casting speed with increasing grain refiner is due to smaller grain size resulting from increasing casting speed itself.

The results of trials conducted to establish a relationship between the critical speed at which hot tearing occurs and the cooling water during casting for the alloy AA6082 are plotted in Figure 6. Comparison of trial 3, with trials 6 and 7 which had same amount of GR as trial 3 but had respectively 20% and 40% less cooling water also indicates a decrease in the critical speed with decreasing amount of cooling water. However, it is not clear if the relationship is linear. Therefore, more trials will be needed to establish the nature of the relationship. The measured grain size in trial 7 for ingots 1 and 6 is significantly coarser than trial 6, see Table IV. As all the other casting parameters are the same except the cooling water amount. The amount of cooling water for trial 7 is 25% lower than for trial 6. Hence the grain size for trial 7 seems to be larger mainly due to the lower cooling rate in trial 7 as compared to trial 6.

Conclusions

Full scale DC casting trials of 6xxx alloy were performed with Hycast gas cushion moulds for extrusion ingots casting. Different GR amount was used in different trials to determine the casting speed at which hot tears appear during direct chill casting of extrusion ingots of 6xxx alloys. The results have shown that the critical casting speed for centre cracking is highly dependent on the grain refiner addition level. Even though no further grain refiner effect could be observed in the trials high addition rates did still influence the critical casting speed. The effect of water amount on centre cracking was not significant.

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