VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EFFECT OF COMPOSITION ON THE MICROPOROSITY, MICROSTRUCTURE, AND MACROSTRUCTURE IN THE START-UP DIRECT-CHILL CASTING BILLET OF AL-CU ALLOYS

Suyitno
Casting and Solidification Technology, Laboratory Department of Mechanical and Industrial Engineering, Gadjah Mada University Jl., Yogyakarta, Indonesia
E-Mail: suyitno@ugm.ac.id

ABSTRACT

Direct-Chill (DC) casting is a process where the liquid metal is poured in a water cooled mold and then the formed solid shell is extracted at downwards and is directly sprayed by water. Almost universally, the cooling medium is water, both for mold cooling (primary cooling) and direct or secondary cooling. Start-up phase is a crucial step during the casting, in which is prone to casting defects such as porosity and hot crack. The aim of this research is to study the effect of copper content in microporosity, microstructure and macrostructure in the start-up phase of DC casting of Al-Cu alloys. The porosity is maximum in the center of billet and maximum at low copper concentration (1 pct). The porosity is minimum in the bottom of billet and it increases for a low copper concentration (1 pct). The grain size depends on chemical composition. Most coarse structure is observed at low concentrations of copper (1 pct). The dendritic arm spacing is unaffected by the chemical composition. The grain size and dendritic arm spacing are predominantly fine in the surface.

Keywords: microstructure, porosity, direct-chill casting, aluminum alloys, alloy composition.

INTRODUCTION

Direct-Chill (DC) casting is a principal casting proces of Aluminum alloys where the liquid metal is poured in water cooled mould and then the formed solid shell is extracted at downwards and is directly sprayed by water. Almost universally, the cooling medium is water, both for the mould cooling (primary cooling) and the direct or secondary cooling (when is extracted downwards). The vertical direct casting process, patented by Alcoa in 1942 [1], is shown schematically in Figure 1. The process can directly prepare billet for extrusion, blocks for rolling, and sheet fabrication, thus eliminating intermediate mechanical working processes by casting near- shapes.

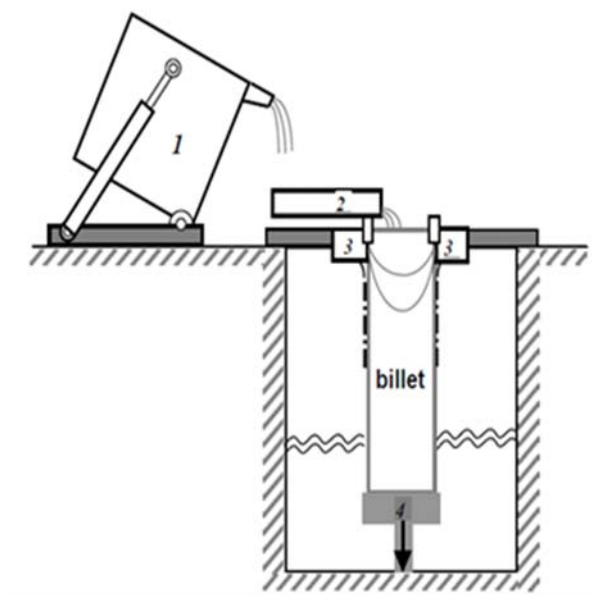


Figure.1 Schematic diagram of DC casting apparatus. 1) tilting furnace, 2) launder, 3) hot-top round mold, and 4) bottom block [2].

ARPN Journal of Engineering and Applied Sciences

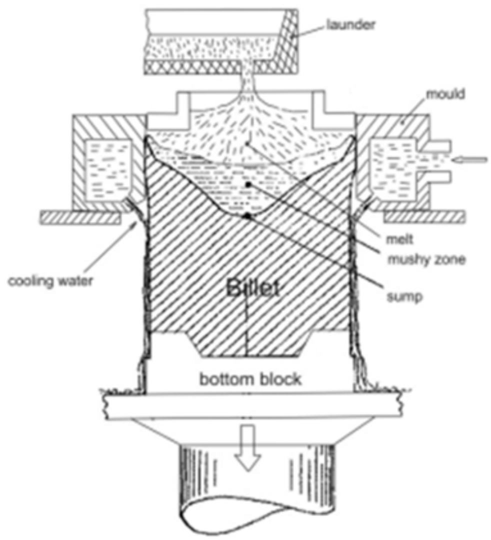


Figure-2. Various cooling processes active during the cast start-up phase of DC casting [2].

The main benefit of direct chill casting is that the solidification (and the formation of structure and defects) occurs in relatively narrow layer of a billet and can be well controlled. The understanding of the processes occurring in this part of billet -e.g. melt flow, termo-solutal convection, grain nucleation and growth, solidification shrinkage, thermal contraction and feeding restrictions is paramount for understanding the cause and for prevention of casting defects [3].

Figure-1 shows a schematic representation of a generic DC casting process. At the start of process an aluminium bottom block is partially inserted into an open water-cooled aluminium mould. The mould/bottom-block assembly is then gradually filled with molten aluminium. Once the metal level rises to a prescribed height, the bottom block is then lowered into the casting pit to facilitate the withdrawal of the ingot. The casting process is stopped when the ingot has reached the desired length (~3-10 m); hence it is referred to as being semi-continuous.

During the start-up phase, it is typical to have stable film boiling develop at certain locations on the ingot surface in the early stages of the start-up phase. In the presence of film boiling, heat transfer become more complicated as a portion of the water may be ejected from the ingot surface. This process is illustrated schematically in Figure-2. During water ejection, the heat transfer rate is significantly lower below the point of water ejection, as there is little or no contact of the water curtain with the ingot surface.

The distribution of solidification and structure parameters across the horizontal section of a billet is reported on steady state section of billet [4]. There is dependences of grain size and dendritic arm spacing on the casting speed and the position in the billet. The grain size depends on chemical composition. Most coarse structure is observed at low concentrations of copper (2 pct) and low casting speeds. The dendritic arm spacing is virtually unaffected by the chemical composition. The number of coarse grains that are concentrated in the center of the billet is found to increase with the casting speed and concentration of copper.

During the start-up phase, it is a critical process due to transient phase. It causes occurence of casting defect such as: hot tearing, porosity, butt-curl, etc. The star-up phase is an important step for a better billet quality in steady state section of the billet.

The effects of composition on the casting defects and structure parameters, especially in the start-up section of the DC casting billet, are much less known and only few data are available on this subject.

The aim of this research is to study the effect of copper content in microporosity, microstructure and macrostructure in the start-up phase of DC casting of Al-Cu alloys.

EXPERIMENTAL METHOD

The effect of copper content was studied for different alloy compositions. The exact composition was described in the Table-1.

Table-1. The composition of Al-Cu billet.

Symbol	Al-1%Cu	Al-2%Cu	Al-3,62%Cu	Al-4,5%Cu
Cu	1.03	1.98	3.62	4.49
Sn	< 0.01	< 0.01	< 0.01	< 0.01
Pb	< 0.01	< 0.01	< 0.01	< 0.01
Zn	0.01	0.01	0.01	0.02
Ni	< 0.01	< 0.01	< 0.01	< 0.01
Fe	0.17	0.18	0.18	0.19
Mn	< 0.01	< 0.01	< 0.01	< 0.01
Cr	< 0.01	< 0.01	< 0.01	< 0.01
Ti	< 0.01	0.01	< 0.01	< 0.01
Si	0.05	0.06	0.05	0.06
Mg	< 0.01	0.01	< 0.01	< 0.01

The casting was performed in Laboratory of Materials Science TU Delft, The Netherlands. Billets 195 mm in diameter and up to 1800mm in length were produced in a pilot scale direct-chill caster. The caster consists of a tilting melting electrical furnace of 200 kg capacity; a flexible closed launder for transferring melt to a permanent launder; a 200 mm hot-top round mold and a PC based process monitoring and control unit. The controlled parameters are water-flow rate, melt and cooling water temperatures, casting speed, melt level, and billet length. The casting condition of of Al–Cu alloy

VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

billets were: casting speed was constant at 200 mm/min, melt temperature was 728 ºC, water flow rate was 150 l/min.

The samples were cut from the first 100 mm of start-up section of the billet. The investigation is on vertical direction in the centre of the billet and horizontal direction from the outer surface to the centre of the billet. Figure-3 shows the vertical and the horizontal section for this iinvestigation. The specimens were mounted, grinded and polished. The samples were also electro-oxidizing in a 3% water solution of HBF4 at 20 VDC. The structure was then examined in an optical microscope. The volume fractions of eutectic and porosity were determined from micrographs by the standard linear intercept method.

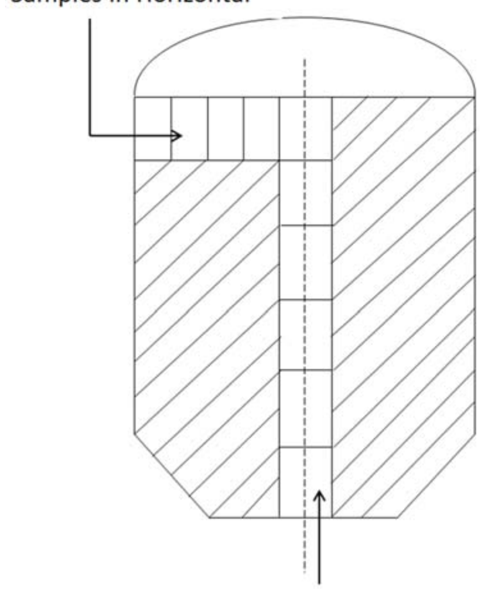


Figure-3. Position of samples from the start-up section of billet.

For measuring the secondary dendrite arm spacing, distance between two neighbouring dendrite arms was measured. Series of straight lines of known length, L, were superimposed on images of the microstructure and the number, N, of arms intercepts on each line counted. The distance between two arms of dendrite is L divided by N. For each pictures measurements were taken from four different places.

RESULT AND DISCUSSIONS

Porosity

Figure-4 shows the microporosity observed in the billet of Al-1%Cu. The microporosity has irregular shape and distributed randomly in the billet.

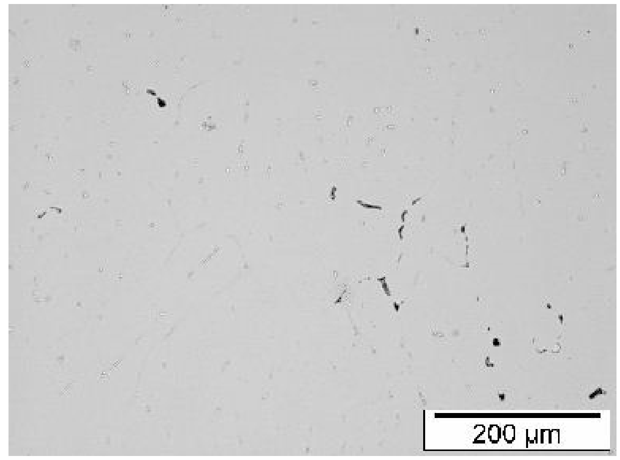


Figure-4. Microporosity in the billet of Al–1%Cu.

Figure-5 shows the effect of distance from the centre (a) and from the bottom of billet (b) on the porosity. The porosity tends to decrease with distance from the center of the billet. The porosity increase with decreasing copper concentration in the horizontal direction. The porosity is not clearly defined along the distance from the bottom of the billet. At very low copper concentration (1 pct), the porosity is highest among other concentration. It confirms the finding in ref. [5]. This concentration is in accordance with a high hot tear susceptibility [6].

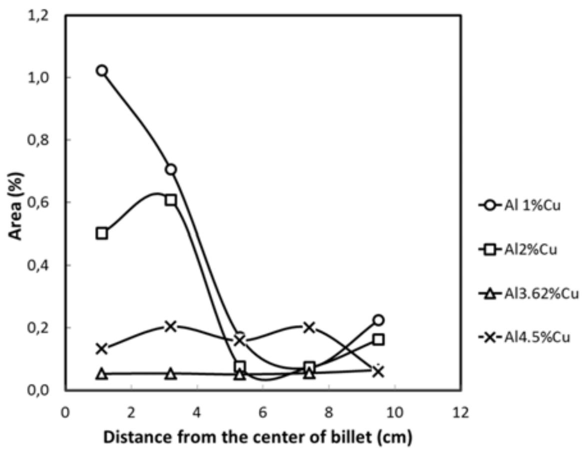
Secondary Dendrite arm SPACING (S.D.A.S.)

The secondary dendrtitic arm spacing (SDAS) observed in the billet is shown in Figure-6. The dendritic structure is clearly shown, and dominate in all section the billet.

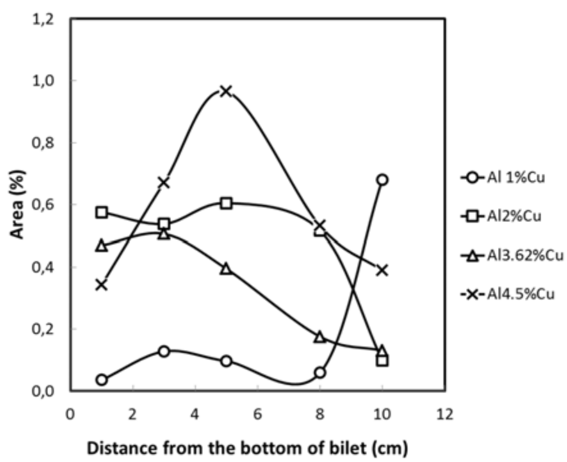
The SDAS of Al-(1-4.5%) Cu alloys from the centre of the billet and in the centre of the billet are shown in Figure-7. One can see that SDAS become larger with increasing distance from the centre of the billet, and becomes smaller at the surface of the billet (see Figure-7a). Figure-7b shows that the SDAS sharply increases in the bottom subsurface of the billet, and then tends to be relatively constant. The effect of copper concentration on the SDAS is not significant. The coarsening structure toward the center of the billet, with a region of finest structure at the billet surface and at about 15 to 20 mm from the surface is confirmed in ref. [4].

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com



(a)



(b)

Figure-5. Effect of (a) distance from the centre of billet and (b) distance from the bottom of billet on the area of porosity.

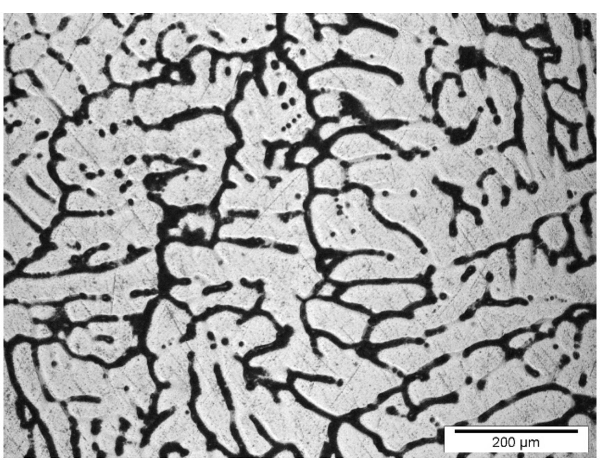
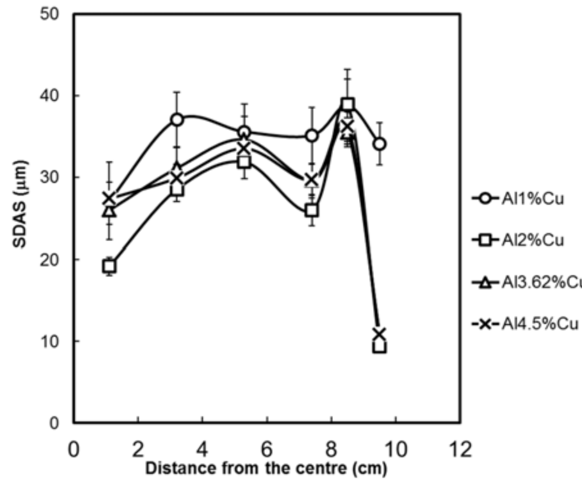
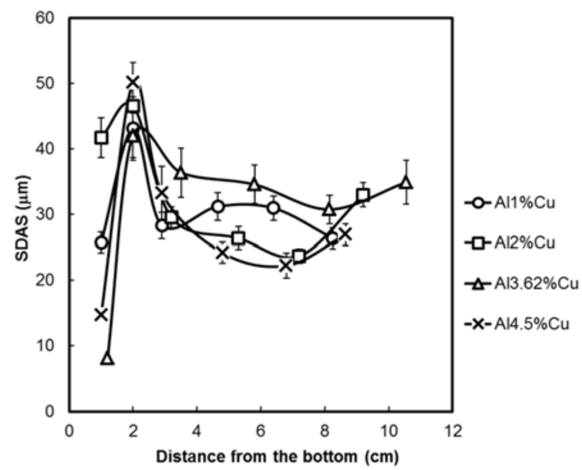


Figure-6. Secondary dendrititic arm spacing of Al–1%Cu.



(a)



(b)

Figure-7. Effect of (a) distance from the centre of billet and (b) distance from the bottom of billet on the secondary dendrite arm spacing of Al–(1–3%) Cu alloys.

Grain

Figure-8 shows the grains observed in the billet. The grain structure is mostly equiaxed grains.

ARPN Journal of Engineering and Applied Sciences

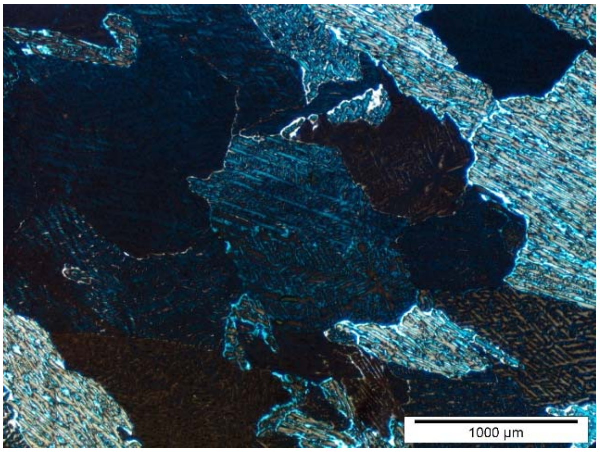
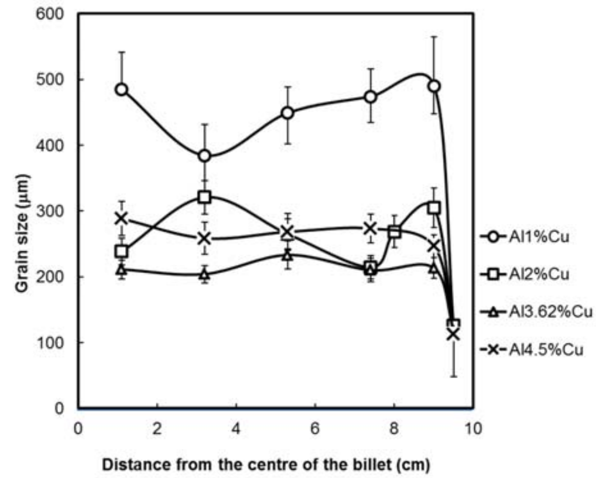


Figure-8. Grains in Al–1%Cu.

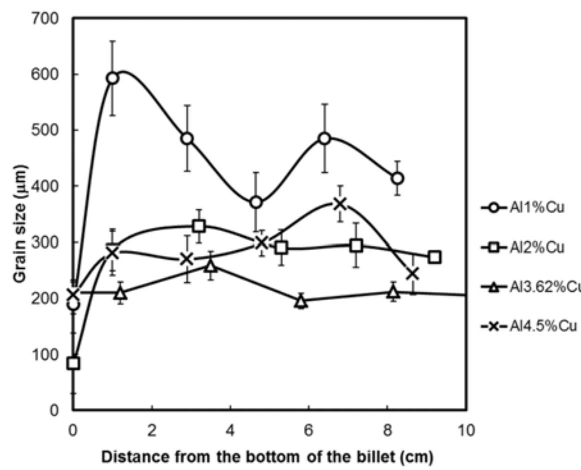
Figure-9 demonstrates the effects of distance from the centre of the billet and copper concentration on the grain size. Increasing distance from the centre of the billet results in refinement of grains in the surface of the billet (Figure-9a). Increasing distance from the bottom of the billet results in coarsening of the grains in the subsurface of the bottom and then relative constant (Figure-9b). The effect of copper concentration is not significantly observed in Figure-9. Increasing copper concentration above 2 pct results in prominent grain refinement but has no effect on the secondary dendritic arm spacing. Their internal structure the diametric distribution being only slightly affected.

The internal grain structure characterized by secondary dendritic arm spacing remains virtually the same irrespective of the copper concentration; it is only affected to the changed cooling conditions.

It can be explained that the secondary dendritic arm spacing has a correlation with the cooling rate or local solidification time [7]. The grain structure is strongly affected by the composition, because a higher solute concentration facilitates the constitutional undercooling and act as grain refiner.



(a)



(b)

Figure-9. Grain size in horizontal (a) and vertical (b) direction in the start-up section of the billet.

CONCLUSIONS

The porosity is maximum in the center of billet and maximum for at low copper concentration (1 pct). The porosity is minimum in the bottom of billet and it increases for a low copper concentration (1 pct). The grain size depends on chemical composition. Most coarse structure is observed at low concentrations of copper (1 pct). The dendritic arm spacing is unaffected by the chemical composition. The grain size and dendritic arm spacing are predominantly fine in the surface.

ACKNOWLEDGEMENTS

The author is grateful to the Delft University of Technology for my research in DC Casting. The data is collected during my Ph.D research under supervising of L. Katgerman, D.G. Eskin and W.H. Kool.

VOL. 11, NO. 2, JANUARY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

REFERENCES

[1] E.F. Emley. 1976. Continuous casting of aluminum. International Metals Reviews. 21(1): 75-115.

[2] John Grandfield, D.G. Eskin, Ian Bainbridge. 2013. Direct-Chill Casting of Light Alloys: Science and Technology. John Wiley and Son Inc. New Jersey.

[3] Suyitno. 2004. Hot tearing and deforman in direct-chill casting of aluminum alloys. Ph.D thesis. Delft University of Technology.

[4] Suyitno, D.G. Eskin, V.I. Savran, And L. Katgerman. 2005. Effects of Alloy Composition and Casting Speed on Structure Formation and Hot Tearing during Direct Chill Casting of Al-Cu Alloys. Metallurgical And Materials Transactions A. 35A: 2004-3551.

[5] Suyitno, D.G. Eskin L. Katgerman. 2006. Structure observations related to hot tearing of Al–Cu billets produced by direct-chill casting. Materials Science and Engineering A. 420: 1-7.

[6] D.G. Eskin, Suyitno, L. Katgerman. 2004. Mechanical properties in the semi-solid state and hot tearing of aluminium alloys. Progress in Materials Science. 49: 629-711.

[7] M.C. Flemings. 1974. Solidification Processing, McGraw-Hill, New York.