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A New DC Casting Technology for Extrusion Billets with Improved Surface Quality

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Abstract

A new casting technology, Low Pressure Casting (LPC), for aluminium extrusion billet casting has been developed by Hydro Aluminium and Hycast. The new technology produce billets with improved surface appearance and sub-surface microstructure. The technology is validated trough production in two casthouses in regular production. The technology is verified for the dimension range Ø152-405mm (6-16").

The new technology uses siphon feeding of liquid metal to the casting moulds, and has thus eliminated the metallostatic pressure in the liquid metal inside the moulds. The sub-surface microstructure is improved compared to billets cast with conventional technologies since exudation of enriched residual melt on the billet surface is eliminated. The surface segregation is significantly lower in depth and in alloying element enrichment compared to billets produced with conventional gas-assisted graphite wall moulds. The surface appearance is improved due to the elimination of the pulsing nature of the meniscus in conventional casting technologies and the elimination of exudation.

The improved surface quality has the potential of giving increased yield and productivity in the extrusion process. For hard alloys the machining of the billet surface may be reduced or even eliminated.

Introduction

In 1977 Showa Denko filed a patent on a new hot-top casting technology for extrusion billets where gas (air) was introduced into the mould, [Mitamura 1977] [Mitamura 1978]. This new casting system produced billets with a reduced segregation zone and an improved surface quality compared to the traditional spout and float system based on open moulds or the hot-top moulds used in the casthouses at that time. In 1984 Wagstaff published a variant of this technology where the gas was introduced through a graphite ring, giving further improvements in surface quality, [Faunce 1984]. Some years later Hydro filed a patent based on the Showa concept but here oil and gas was introduced in separate graphite rings. This technology is named Gas-Cushion (GC), [Steen 1997].

After the innovations mentioned above no real step change in surface quality has not been published on extrusion billet casting. This work describes a new casting technology developed to give a smoother surface with less surface segregation compared to the state-of-the-art air (gas) assisted moulds with graphite mould wall. This technology is named Low Pressure Casting (LPC), see Figure 1 for an example of billets produced with this technology.

The surface segregation zone including the depleted zone normally found just inside of the enriched zone at the surface may cause problems in the downstream homogenisation and extrusion process of the extrusion billets. This may be related to local melting of the enriched layer or aesthetic effects on the finished product due to chemistry differences [Reiso 2012].

For hard alloys the common practice is to machine off the outer surface of the billets prior to extrusion by turning or peeling. This because these billets normally have very severe surface segregation due to the casting technology used for these alloys (normally hot-top mould with no gas).

Figure 1. Ø405mm (16") LPC billets just after casting, AA6060 alloy.

Theory

Surface segregation in Aluminium DC cast ingots is caused by a combination of several mechanisms such as inverse segregation (feeding of shrinkage of columnar grains toward the mould wall), and exudation which normally will give the most severe segregation, [Emely 1976] [Mo 1993] [Haug 1995].

Exudation is residual melt enriched on alloying elements who is squeezed through the partly solidified ingot surface during casting. The exudated material will exit the original surface of the billet below the air gap position. Exudation will give a solute enriched layer on the ingot surface and a solute depleted zone near the surface. The driving force for exudation is the pressure in the melt (due to melt head), see Figure 2. The metallostatic pressure is given by Equation 1.

$$\Delta p = \rho g h \tag{1}$$

ρ is the density of the Aluminium melt, g is the acceleration of gravity and h is the height up to the free surface of the melt (exposed to the atmosphere).

In conventional gas assisted moulds an excess of gas is supplied into the mould cavity during casting. This gives a gradual growth of the gas volume inside the mould until gas escapes downwards or bubbles upwards. After this the gas pocket is reduced and a new pulsing sequence will start. The typical ring pattern on the billet surface is related to this pulsation of the gas pocket inside the mould cavity during casting. An typical example may be seen in the top left corner of Figure 8.

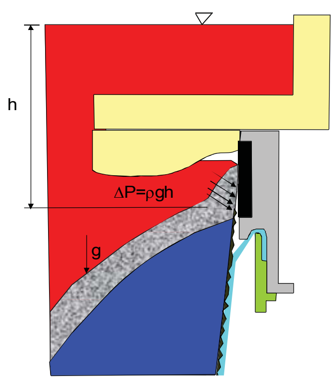

Figure 2. The mechanism of and driving force for exudation.

Technology

The basic idea of the Low Pressure Catstin (LPC) technology is to avoid metallostatic pressure in the mould cavity, and thus eliminating the driving force for exudation. Extrusion billets are today produced in a semi-continuous DC casting process with casting tables with up to 160 moulds, [Steen 2011]. It is vital to have an even and controlled feeding to all moulds and to have a controlled process. The LPC process ensures an accurate metal level control in all moulds utilizing only one control dam and one laser.

Figure 3 shows the LPC principle. To ensure feeding to each mould the LPC technology utilizes siphon filling to each mould by applying a under-pressure in the basin above the moulds, see Figure 3. An ejector is used to generate and control the under-pressure so that the position of the metal in the basin is stable during casting.

The mould is ventilated towards the casthouse atmosphere. This ensures that the pressure above the metal in the mould cavity is the same as pressure on the outer surface of the billet below the air gap position – the point at which the billet moves away from the mould wall and an air gap forms between the billet and the mould. In this way there is no driving force for exudation since the pressure in the residual melt between the grains just below the air gap is virtually the same as the air pressure outside the billet surface. In addition the LPC concept with ventilated moulds will give a stable meniscus in the mould without any pulsation.

The mould height is defined by the metal level in the distribution launder which is controlled within ±1mm using a laser and a control dam. The LPC principle thus makes it possible to use different mould height for different alloys in the same casting mould. It is also possible to change mould height during casting at different stages of casting.

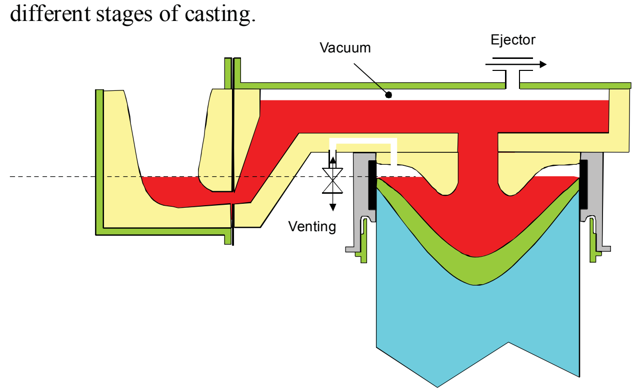

Figure 3. The basic principle of LPC casting.

Figure 4 shows a typical industrial setup with 48 moulds. The lids on the casting table are there to be able to apply an under-pressure in the basin during casting. The casting table and the starter block and moulds are based on the well proven Hycast® GC Billet Casting System but some modifications have been made to be able to use the LPC principle. Figure 5 shows a LPC table in production.

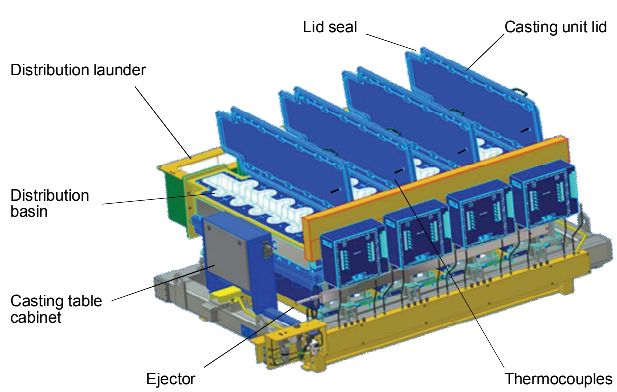

Figure 4. A typical layout of a industrial LPC casting table.

Figure 5. LPC table in production

The LPC technology is protected by two patents, [Ånesbug 2003] [Fagerlie 2007].

Results

6xxx alloys

Figure 6 is a presentation of several experiments where the metallostatic pressure is varied and the resulting width of the inverse segregation zone (ISZ) is measured. The dimension is Ø203mm (8") and the alloy is AA6060. These results are partly from GC and partly LPC billets. The width of the ISZ is increasing with the metallostatic pressure. For zero metallostatic pressure in the mould cavity, corresponding to LPC, the width of the ISZ is only ¼ of the width for conventional cast billets which typically has a metal head of ~150mm (35mbar).

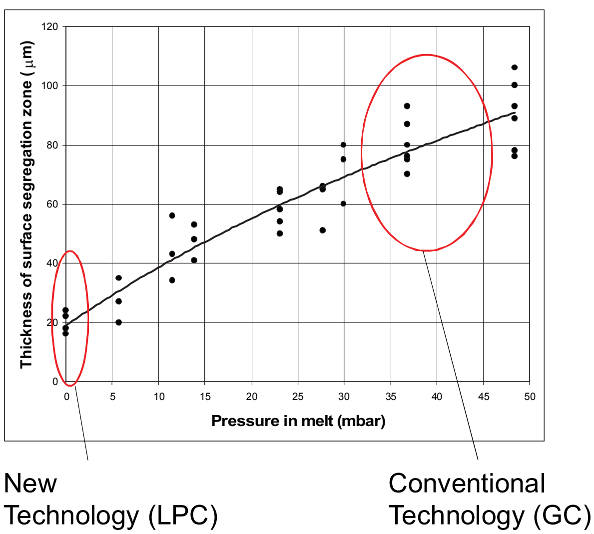

Figure 6. The relationship between the metallostatic pressure in the mould cavity and the width of the inverse segregation zone. Diameter Ø203mm (8"), alloy AA6060.

Figure 7 is a comparison between the width of the inverse segregation zone in LPC billets for varying diameters compared to results for conventional gas assisted moulds and hot-top moulds. The width of the ISZ was measured using light microscope. An average thickness of the zone for several measurements in the casting direction were used.

Figure 8 is a comparison between the as cast surface quality of a billet cast with the GC and the LPC technology respectively. For the GC billet we can clearly see exudated material and clear ring formation. The width of the zone with surface segregation is also clearly visible in the sub surface micrograph in Figure 8. For the LPC billet the rings are almost eliminated due to the lack of pulsation of the gas pocket, and no exudation can be seen.

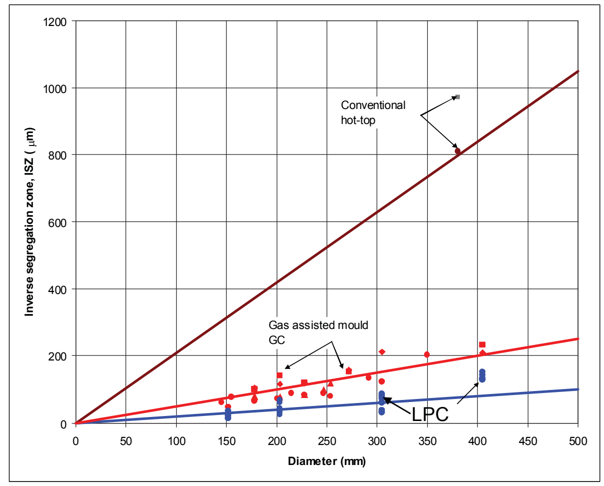

Figure 7. The effect of diameter and casting technology on the width of the inverse segregation zone for AA6060 type alloys.

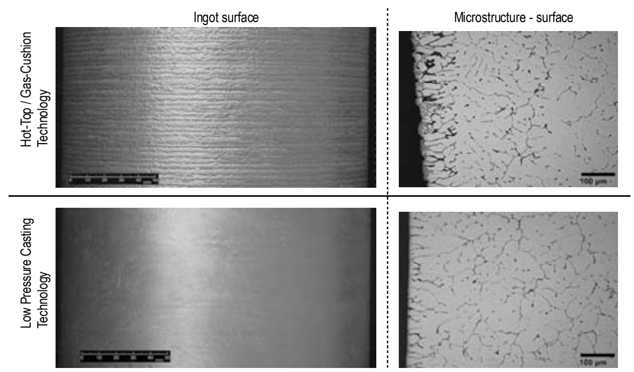

Figure 8. A comparison between the surface quality between a GC and LPC billet. The diameter was Ø203mm (8") and the alloy was AA6082.

The surface segregation was also quantified using multiple line scans in SEM. Figure 9 shows results for two billets, GC and LPC of diameter Ø203mm and AA6060. These results shows not only a thinner ISZ for the LPC billet than the GC, but also a much leaner zone, with a chemical composition much closer to the bulk material compared to the GC billet.

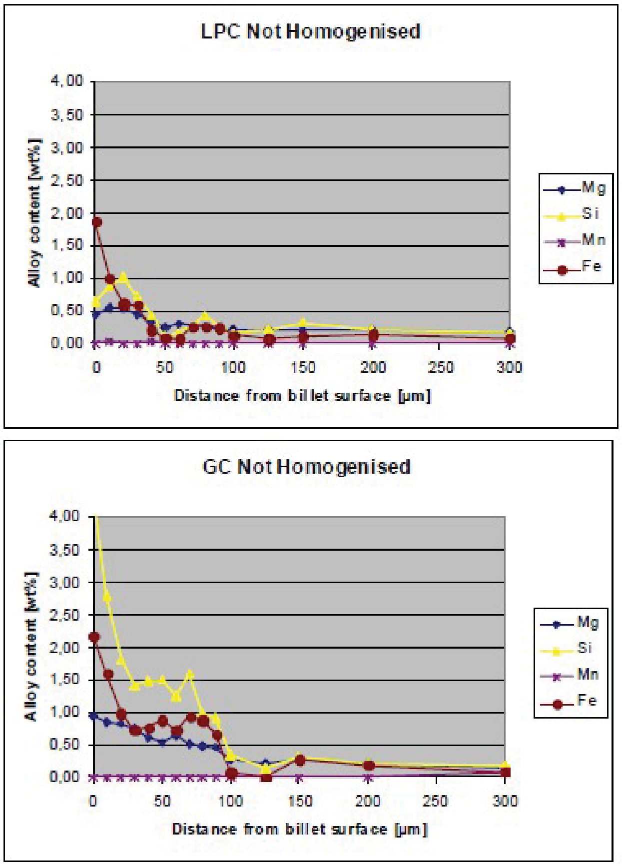

Figure 9. A comparison between the surface segregation pattern for a LPC billet (top) and a GC billet (bottom). Both billets were of diameter Ø203mm (8”) and alloy AA6060.

Hard alloys

Several trial castings with LPC and hard alloys were performed in a Ø152mm (6”) casting table. Figure 10 shows the very smooth as cast surface of the AA2024 billets.

Figure 11 shows the sub surface structure of the same alloy. No surface segregation could be seen in light microscope for this alloy.

The segregation pattern were investigated in the SEM, see Figure 12. Based on these results the width of the ISZ was less than 100µm and the chemical variations were very limited.

Figure 10. AA2024 billets cast with the LPC casting technology.

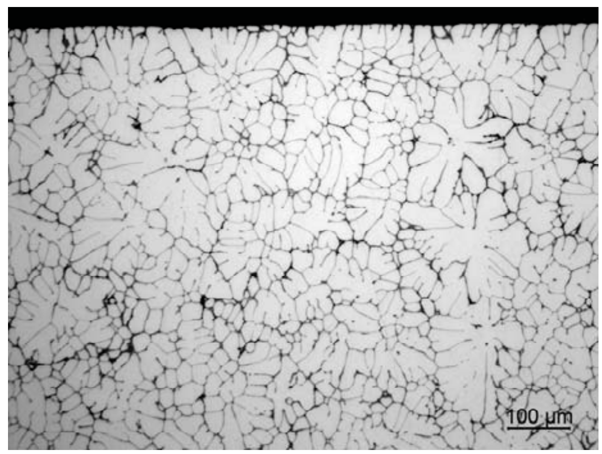

Figure 11. AA2024 billet sub surface micro structure.

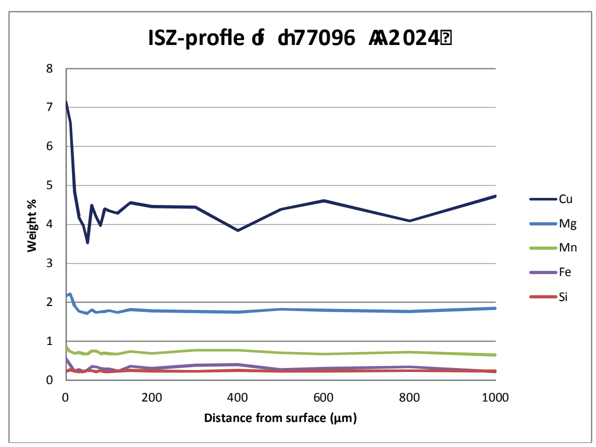

Figure 12. The surface segregation pattern in a AA2024 billet.

Figure 13 shows some billets of alloy AA7075 cast with LPC. The same smooth surface as for AA2024 can be seen in these billets. Figure 14 and 15 shows the sub surface micro strucutre and segregation pattern respectively.

Figure 13. AA707 billets cast with the LPC casting technology.

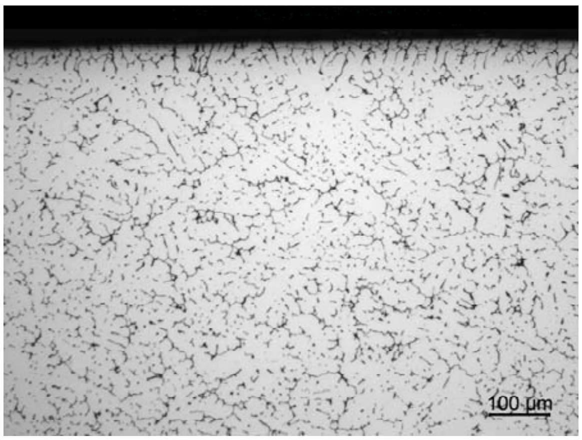

Figure 14. AA7075 billet sub surface micro structure.

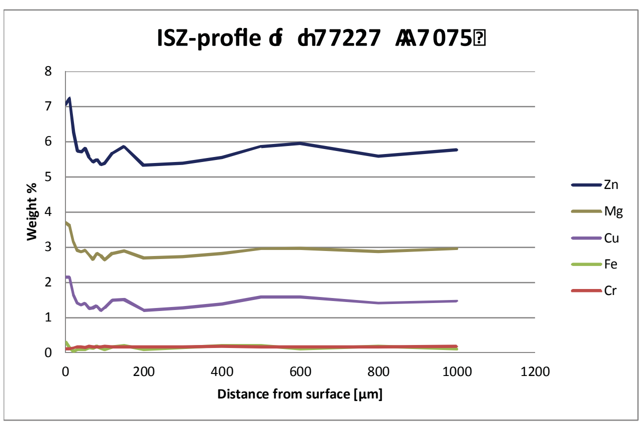

Figure 15. The surface segregation pattern in a AA7075 billet.

Verification/validation

The LPC technology is verified for a wide range of alloys (both soft and hard alloys) and for diameters ranging from Ø150mm (6”) up to Ø405mm (16”).

Operational experience is gained from regular operation in two casthouses. The achieved pit-recovery and cycle time was comparable with typical values for the Hycast® GC Billet Casting System.

Figure 16. LPC casting.

Discussion

For soft alloys the reduction in surface segregation may make it possible to extrude more of the billet until back flow of the segregated layer into the profile. This may reduce the necessary butt end length. If inflow of segregated material is limiting the extrusion in any other way a thinner and less enriched zone may give increased extrusion speed and/or less scrap in the extrusion plant.

The common practice for extrusion billets made from hard alloy is to machine off the outer surface prior to extrusion. If the thickness of the segregated layer could be reduced for these alloys this will give a potential of less scraped material, or even eliminate the need for machining of the billets completely.

Conclusions

A new DC casting technology has been developed for extrusion billets. This new technology is named Low Pressure Casting (LPC) and is characterized by siphon filling to all moulds, zero metallostatic pressure in the mould cavity and a ventilated mould to the casthouse atmosphere.

The surface quality of the billets produced with the LPC technology is superior to conventional technologies. LPC gives a smoother surface and less enriched and thinner surface segregation than other available casting technologies.

Unlike gas assisted moulds used today the LPC technology seems to be well suited for producing hard alloys. Excellent surface quality is demonstrated for alloys such as AA2024 and AA7075 with inverse segregation zones less than 100µm.

The LPC technology is verified for a wide range of alloys and diameters, and validated in regular operation.

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