Low-Pressure Casting Technology Represents Step Change in Producing High Quality Forging Stock

By Ulf Tundal, Knut Omdal Tveito, Sigrun Sofie Berg, Lars Moen, and Magne Boge, Hydro Aluminum Primary Metal, and Arild Håkonsen and Rune Ledal, Hycast AS

Introduction

More and more car manufacturers are using closed die forging to manufacture aluminum wheel suspension parts. This is because forged aluminum parts provide a combination of lightweight design, high strength, durability, and fatigue resistance properties. Being undamped parts, the inherent mass savings also play a significant role in achieving the required noise, vibration, and harshness properties of the vehicle.

However, forged aluminum parts currently have a relatively high production cost, due to a long, complex value chain. The traditional route for producing forging stock involved melting, billet casting, homogenizing, ultrasonic processing, and finally extruding of the material into forging stock (Figure 1). In recent years, a new processing route has been developed,[1] which has shifted toward the casting of small diameter billets followed by scalping to remove the segregation layer of the billet. Due to the multiple steps involved, the material costs for forging stock typically account for 50% of the production of a finished forged suspension component.[2] A scalp-free alternative was discussed by Wiel and Muckelbauer,[3] but production of the material is still limited.

Hydro has developed a low pressure casting (LPC) technology, which presents a third option for producing high quality forging stock.[4] The new casting technology is able to offer forging stock in diameters of about 80 mm or wider. One of the main benefits of the LPC technology is that the friction between the ingot surface and the mold during casting is reduced, nearly eliminating the inverse segregation zone. This produces logs with a very smooth surface. As a result, the number of processing steps is reduced (Figure 1) and the HyForge™ material can be used directly in the forging process.

Moreover, Hydro has invested NOK 150 million (US$17 million) to upgrade its casthouse at its Husnes smelter in Norway. Implementing the LPC technology in combination with large scale production in a smelter is expected to provide a 20% cost reduction on a material level—a major step change in aluminum forging. In addition, installing the technology at a smelter eliminates the need for remelting, further reducing costs. This will enable Hydro to deliver top quality forging material at a substantial cost reduction compared to present alternatives.

This article will provide an introduction to LPC technology, noting how it has been optimized to cast small diameter logs. In addition, it will discuss how the technology will be implemented in the large-scale billet casthouse at Husnes and how the cast forge stock will enable the production of high quality forged parts at minimal costs.

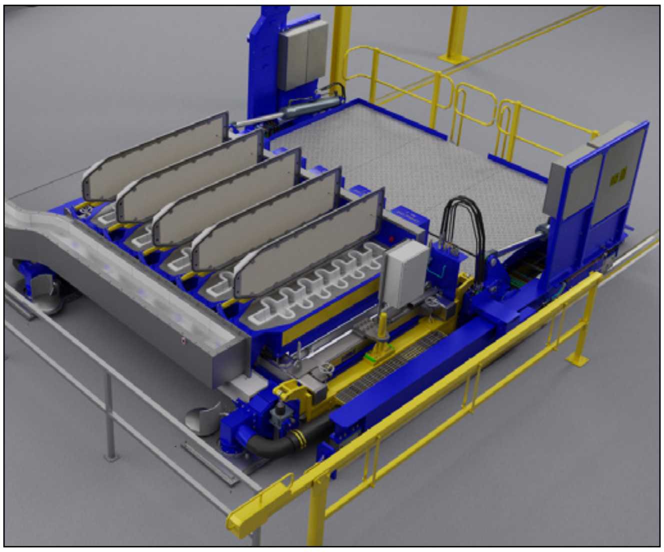


Figure 2. The LPC vertical DC casting machine.

The New Production Route

The new LPC production line will be in operation at Husnes by the end of 2020, with a capacity of 40,000–60,000 tonnes per year. The production route at the plant will consist of a 55 tonne casting furnace, a Hycast I-60 SIR inline melt refiner,[5] ceramic foam filter, the Hycast LPC vertical DC casting machine (Figure 2), homogenizing as required, automated ultrasonic testing, sawing, and packaging capabilities.

The LPC vertical DC casting technology is the core of the production line. Capable of producing forging stock in several diameters, the technology has been installed in several casthouses around the world, where it has been proven to provide superior surface quality for all alloys and dimensions of extrusion billets. At Husnes, the LPC technology has been further developed to produce smaller diameter forging stock. Since the surface quality is very smooth and the surface segregation is close to zero the cast forging stock may be forged without requiring any scalping of the surface.

Filling and Temperature Considerations: The casting of small diameter billet on an industrial scale can be challenging due to a narrow process window for the casting start-up phase. Since a large number of molds need to be evenly filled, a careful balance is required. There must be enough time to form a solidified shell before casting can start, but not too much time, otherwise the molds may completely freeze. As the diameter decreases, this time window narrows.

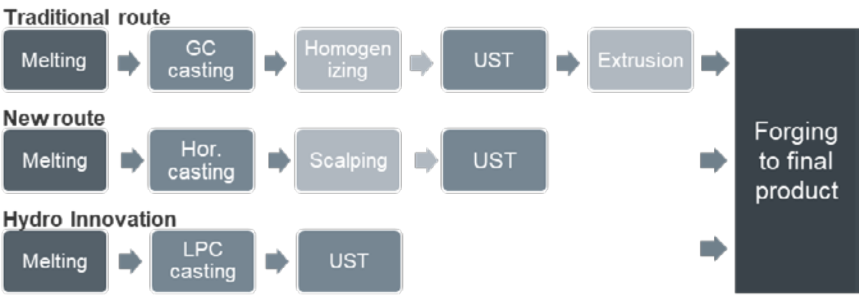
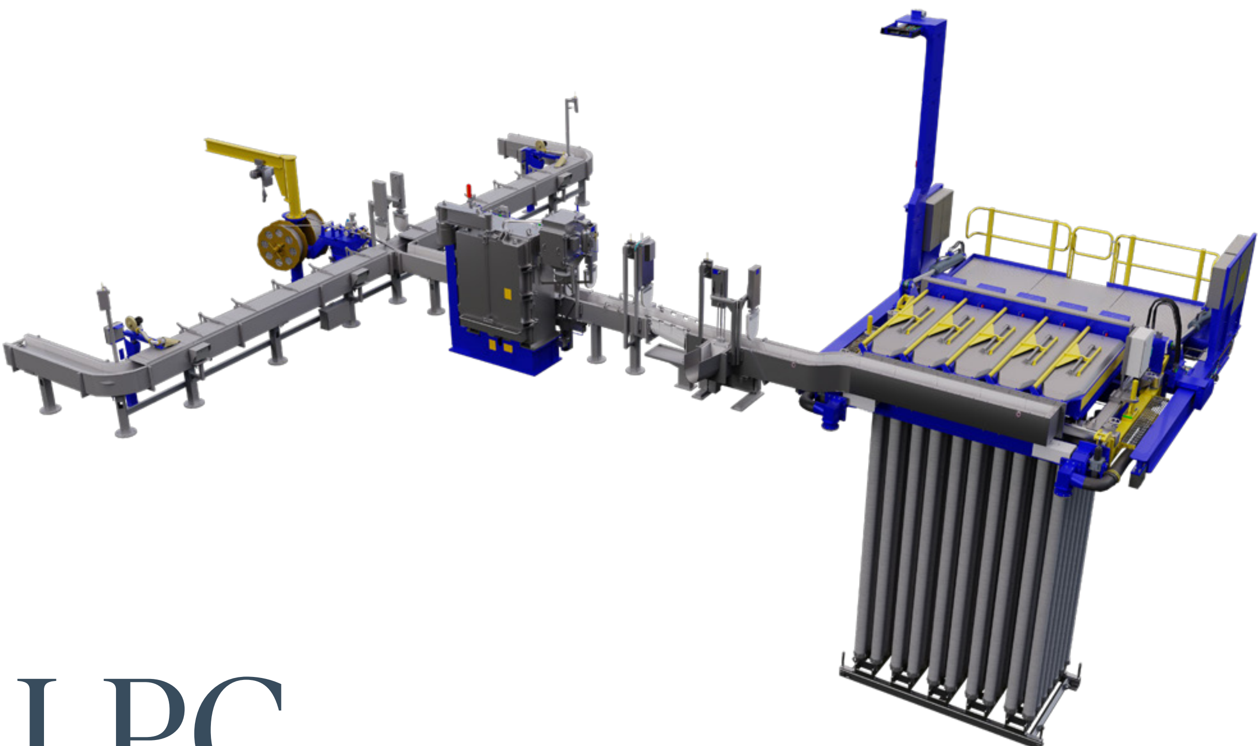


Figure 1. Alternatives for producing forging stock.

HYCAST®

Game Changer Casthouse Solutions



LPC

Billet Casting Technology

The Hycast® LPC (Low Pressure Casting) Billet Casting Technology is designed for the production of high quality extrusion billets with excellent surface quality and extrudability, ideal for larger diameters and hard alloys.

www.hycast.no

By Hydro

To address the many variables in the start-up phase, an advanced computational fluid dynamics (CFD) model was developed. Three key features were considered in the 3D model, including:

- *Filling:* Understand how to create a turbulent free-surface flow (air/metal) and solidification (liquid/solid).
- *Heat-Transfer:* Develop a model of the various forms of heat transfer and free-surface radiation.
- *Automation*: Determine ways of integrating an automation system through numerical simulation (furnace tilt, dam control, vacuum regulation, casting parameters, and start-up criteria).

A numerical model of the pilot casting line at Hydro's Reference Center in Sunndal, Norway, was created. The model included the furnace, launder system, dams, SIR refiners, and a single module of the LPC casting unit. Figure 3 shows the predicted and measured metal level in different locations in the launder system during start-up. By including the automation aspect in the simulations, a good agreement with experimental data is achieved.

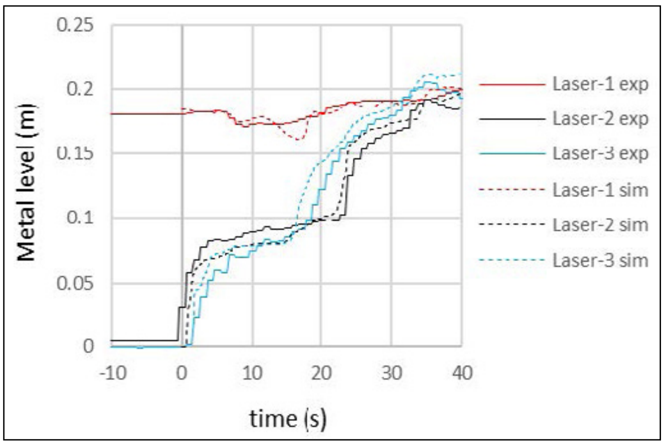


Figure 3. Measured and predicted metal level during filling.

The numerical model is used together with finite element software Alsim[6] to optimize the design of the casting table. Alsim was developed for the DC casting process and includes a thermomechanical model for accurate prediction of heat transfer, solidification, mechanical deformation, air-gap formation, and hot-tearing. Figure 4 shows a detailed view of the filling process and temperature distribution during casting start-up. By optimizing several aspects of the casting table design, the process window could be maximized.

The numerical model was validated with measurements from the pilot casting line. It was used to help develop the layout for the full-scale casting line at Husnes. The model helped to assure similar filling and start-up temperature for pilot-scale and full-scale casting by optimizing the launder system and the automation strategy. It was also used to assess the process window for full-scale production.

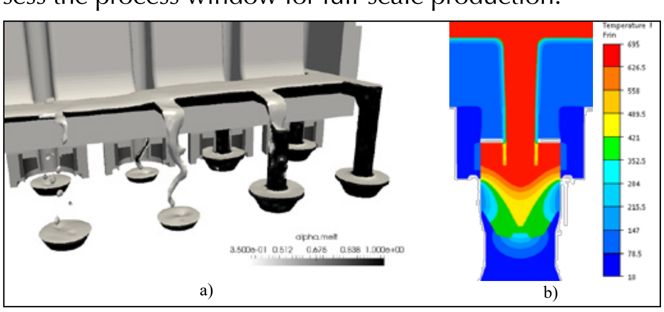
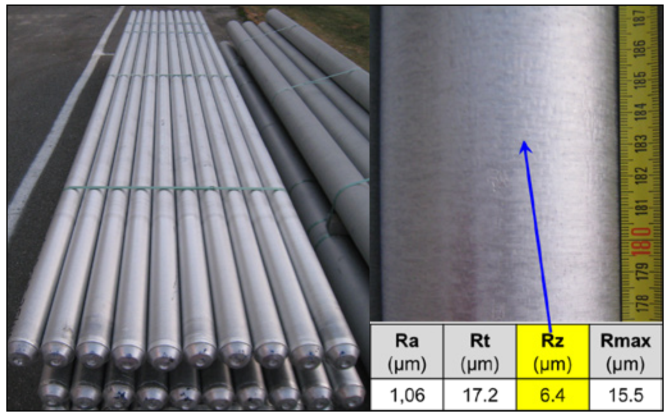


Figure 4. Detail view of predicted filling of the molds (a) and temperature distribution in LPC casting mold during start-up (b).

Results

The main alloy used for aluminum suspension parts is AA6082. In addition to Mg and Si, the alloy typically contains both Mn and Cr, as well as a small portion of Cu (below 0.10 wt%, which is the maximum allowed). Forging ingots were produced in AA6082 with 90 mm diameter. As a result of the LPC technology, the surface quality of the forging ingot was found to be excellent (Figure 5). The roughness values of a typical LPC cast surface were found to be well within the requirement for forging ingots, which typically is below Rz 20 μm.



Ra (μm)	Rt (μm)	Rz (μm)	Rmax (μm)
1,06	17.2	6.4	15.5

Figure 5. AA6082 cast forging ingots in 90 mm diameter (left) and a close-up of a typical surface with corresponding results from roughness measurements (right).

When looking at the microstructure below the surface (Figure 6), it was observed that there is virtually no inverse segregation zone typically found in ingots produced with other casting technologies. One can see some alignment of the primary Al-Fe-Mn-Si particles in the outer surface due to the solidifying conditions, but the concentration of alloying elements is not much higher than in the bulk material.

With proper routines for grain refining during casting, the grain structure of the cast forging ingots will be homogeneous and the grain size typically in the range 60-100 μm. For the as-cast grain structure shown in Figure 6, the grain size was measured to 90 μm with the linear intercept method in a light optical microscope.

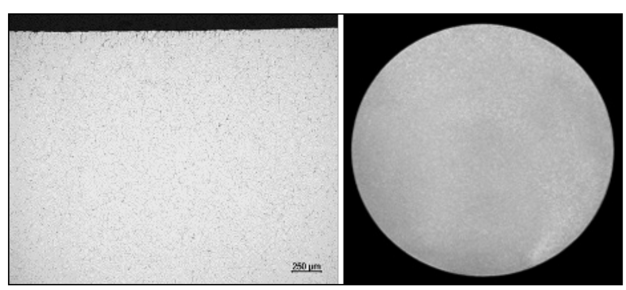


Figure 6. Micrograph of a typical surface region of the LPC 90 mm diameter cast forging ingots in alloy AA6082 (left). Macro grain structure of an as-cast AA6082 forging ingot (right).

Forging Experiments: In order to test how the grain structure develops and how the mechanical properties may vary with different processing conditions, forging trials were performed in an 800 tonne laboratory-scale forging press at Sintef in Trondheim, Norway.[7] Because of the limited size of the forging press, the samples used for the experiments had to be machined down to round bars of 40 mm in diameter and 180 mm length. The forging die and the forging sample are shown in Figure 7.

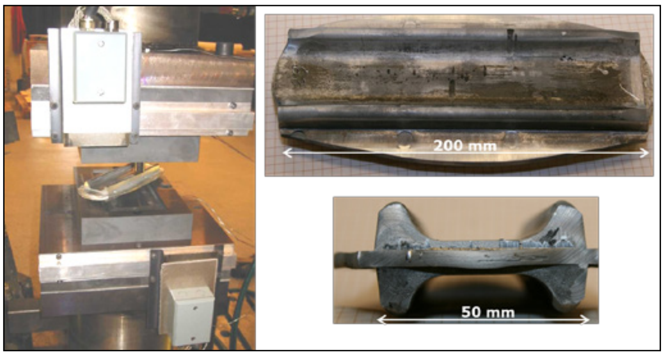


Figure 7. Forging die used on the laboratory-scale forging press (left) and detailed pictures of a forged piece (right).

For the test series, the samples were preheated in a chamber oven to a temperature between 490 and 500°C for about 45 minutes prior to forging. The forging die was preheated to 430°C and the forging stroke was performed at 20 mm/sec.

After forging, the parts were solutionized in an air circulating furnace at 560°C for 20 minutes with a heating time of approximately 15 minutes. The grain structure of solutionized samples produced from both as-cast and homogenized (2 hours soaking time at 540°C) materials is shown in Figure 8. The amount of deformation is highest in the region closest to the middle of the cross section. In the transition between the thin and thick part, there seems to have been some frictional forces near the forging die, as this area is the only place in the cross section where some recrystallization can be seen. The amount of recrystallization is low in both cases, but the unhomogenized material showed the least amount.

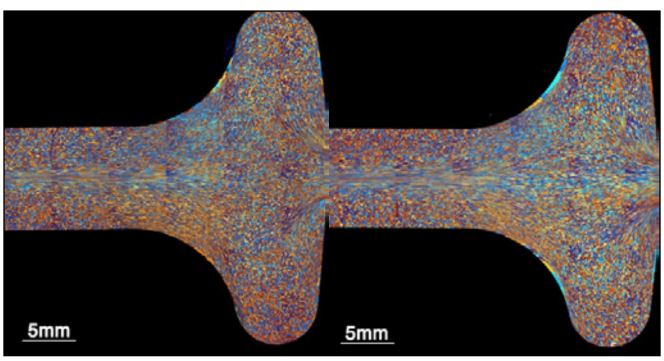


Figure 8. Light optical micrographs showing the grain structures in forged and solutionized samples (560°C/20 min). Unhomogenized material (left) and homogenized material (right).

The reason for this is probably that the unhomogenized material contains a lot of Mn and Cr in solid solution during the forging process. Therefore, it is likely that new dispersoids are precipitated at dislocations and shear bands during the forging process and the separate solutionizing process. By pinning the dislocations, they will be a very effective barrier against new recrystallization. For the homogenized material where the dispersoid particles already have precipitated during the homogenizing process, they will be more randomly distributed in the deformed material and may not be as effective in preventing new recrystallization.

From the forged samples that were solutionized at 560°C for 20 minutes followed by water quenching and aging, tensile samples were taken out from different positions and different directions (Figure 9). The tensile results show that the strength levels for the unhomogenized material are always higher than for the homogenized material.

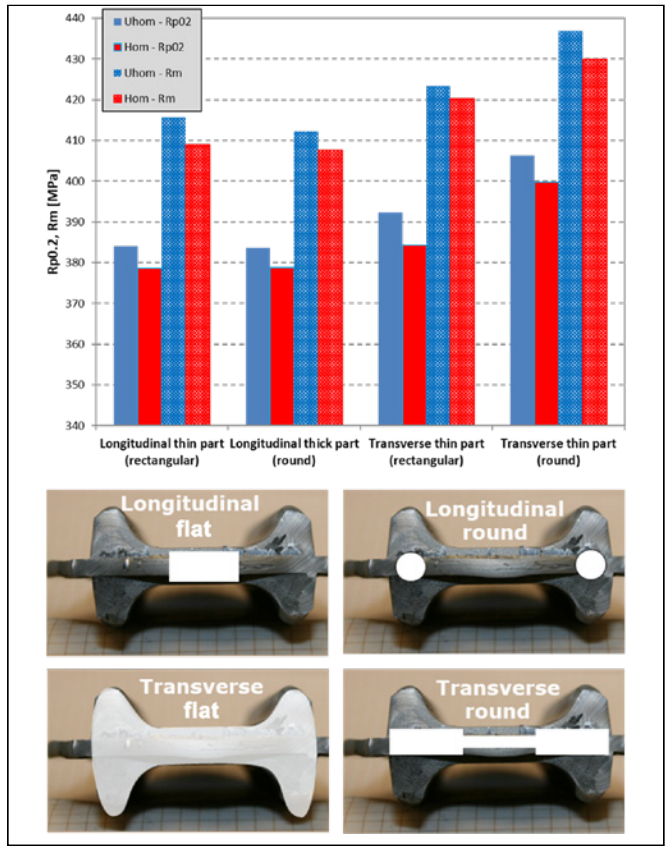


Figure 9. Tensile results from samples taken from different positions and directions of forged pieces. Results from unhomogenized material is represented by the blue bars and homogenized by the red bars.

Since the grain structures in the areas where the tensile samples are taken from are basically the same, this difference must come from some other effect. One explanation could be some form of contribution from the dispersoid particles, which may be more effectively distributed in the unhomogenized material.

As expected, the strength level seems to be highest in the part of the forged sample where the amount of deformation has been highest. By looking at the grain structure of the forged sample in Figure 8, this is clearly the center part of the cross section, the area where the transverse round tensile sample has been taken from.

High Temperature Preheating Versus Separate Solutionizing: The results from the forging trial (Figure 8) show that the grain structure is very robust upon separate solutionizing after hot forging, especially for unhomogenized materials. As a result, various robust process windows applicable for successful forging with LPC material in terms of temperature time with and without homogenizing have been developed. In cooperation with forging processors, it has been found that most 6xxx alloys used in automotive forging today can obtain high mechanical properties and controlled recrystallization without the use of separate homogenizing. This also includes the 6110 range of alloys with significant amounts of Cu that require specific treatments.

It has become more common to preheat the forging ingot to a relatively high temperature prior to forging and skip the separate solutionizing operation afterwards. The main driver for this has probably been extruded forging bars, which are much less resistant against recrystallization upon forging and a subsequent separate solutionizing process. By performing the solutionizing step prior to forging, the chance for getting detrimental recrystallization is considerably reduced.

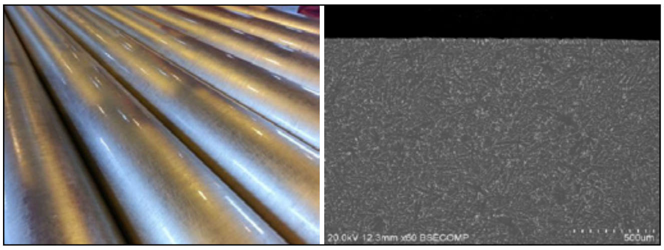


Figure 10. Billet surface and sub-surface structure of an AA7075 alloy cast with the LPC technology in 152 mm diameter.

Performing the solutionizing step prior to forging with unhomogenized material requires that the combination of temperature and time is enough to dissolve the eutectic phases from the casting process and to distribute the Mg and Si well enough. Doing the solutionizing prior to forging also requires that there are lubrications that can tolerate such high temperatures, and that the forging process itself is fast enough to avoid extensive precipitation of non-hardening Mg_2Si particles during the forging operation. Lab trials (with 40 mm diameter ingots) and industrial trials (with 90 mm diameter forging ingots) have shown that this is possible without major changes in the processing conditions.

Other Alloys: With the LPC technology it is possible to cast almost any alloy in a quality that can be forged without any prior scalping of the surface. Figure 10 shows an example of AA7075 that has been cast with the LPC technology in a 152 mm diameter.

Summary

The LPC technology is capable of casting small diameter billets with a superior surface quality. This has been demonstrated by both lab and industrial scale trials, showing that the process of making wheel suspension parts can be shortened both by eliminating the need for scalping of the surface as well as the need for homogenization prior to forging. With the start-up of large-scale production of HyForge ingots at Husnes, it is expected that material costs for a forged part will be reduced by about 20%, which would make forged aluminum suspension parts much more competitive.

References

1. Jensrud, Ola and Ketill Pedersen, "Castforge: The synthesis for development of new technologies for manufacturing of aluminum automotive parts," 2nd International Conference & Exhibition on New Developments in Metallurgical Process Technology, September 2004.

2. *Forged Components, 2nd edition*, Hirschvogel Automotive Group, 2014, p. 39.

3. Wiel, Robert and Dr. Michael Muckelbauer, "Potentials in Aluminum Forging for Passenger Car Chassis Parts by Using Alternative Prematerial, or: Forging without Scrap," NEMU 2019, pp. 55-64.

4. Håkonsen, A., J.E. Hafsås, and R. Ledal, "A New DC Casting Technology for Extrusion Billets with Improved Surface Quality," *Light Metals 2014*, pp. 873-878.

5. "SIR Inline Melt Refining," Hycast, www.hycast.no/products/sir.

6. Mortensen, D., "A mathematical model of the heat and fluid flows in direct-chill casting of aluminum sheet ingots and billets," *Metallurgical and Materials Trans.*, Vol. 30B, 1999, pp. 119-133.

7. Sintef, www.sintef.no. ■