Billet sump modification of Al-Billets for the Prevention of Starting Cracks
BILLET SUMP MODIFICATION OF AL-BILLETS FOR THE PREVENTION OF STARTING CRACKS

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Abstract
Depending on the cast alloy, starting cracks are a common problem while casting aluminium extrusion billets. The hot crack formation is well investigated in theory as well as the formation of the sump shape using different casting technologies. Nevertheless, starting cracks are a problem in DC casting.

Because TRIMET ALUMINIUM AG Essen uses the spout and float technology for DC-casting of aluminium this paper presents an investigation into methods for the prevention of starting cracks in Al-billets using float and spout DC-casting and covers the research methods, the results of crack prevention and the real implementation in practice. The main topics are the control of the sump formation and the correlations between sump geometry and hot cracks in the billet.

The experimental research covers the DC-casting with varied casting parameters (stop-and-go-casting, casting speed etc.), sump depth measurements, ultra-sonic tests and the metallographic examinations. In the analysis and interpretation the crack prevention is discussed considering the sump depth measurements. On the basis of these measurements the effect of the different casting technologies and parameters are shown.

Finally, the methods have to be implemented in production. The essential points are the upscaling and the automation of the casting process, especially the start-up phase.

The results of this investigation provide excellent possibilities for crack prevention for the DC-casting.

Introduction
Starting cracks make up a substantial part of the scrap rate during DC-casting and therefore generate substantial cost. Thus investigations on crack prevention were started based on the paper of W. Schneider, [1] to [3].

In [1] and [2] W. Schneider describes some correlations between sump formation, sump depth and starting cracks. Due to the hot crack character of the starting cracks, Figure 1, varying and controlling the billet sump is an excellent possibility to avoid starting cracks. Amongst others a new geometry like pictured in Figure 2 b) was used. The corresponding sump formation showed no local maximum at the start-up phase, Figure 3. As a result no starting cracks could be found in any billet. So lowering the residual stresses in the solidifying billet butt and a homogeneous temperature distribution support starting crack prevention, [4].

Therefore an easy way was developed to influence the sump formation in billets and especially in billet butts. Because TRIMET ALUMINIUM AG Essen uses the float and spout DC-casting technology for Al-billet production, the focus was to apply the examined technologies to the casting implements in Essen. The main objective was to eliminate starting cracks by influencing the sump formation at the start-up phase of the casting.

Figure 1. Typical dendritic surface of a starting crack.

Figure 2. a) Standard starting block geometry and b) new geometry compared by W. Schneider, [1].
Experimental research

The DC-casting technology used in these investigations is the float and spout technology. The castings were carried out on an R&D casting machine with the following data:

- 2 casting furnaces (2.5t)
- 7 m casting length
- Fully automated casting process
- Stop-and-go-casting
- Pulsation water cooling
- Impeller cleaning (argon/nitrogen/chlorine)
- CF-filter with pore burner

The data for all castings are:

- Casting alloy: AlMgSi1Cu (EN AW –6013)
- Mould diameter: 381mm
- Mould material EN AW-6082
- Starting block material: EN AW-6082
- Starting block geometry: see Figure 2a)

Reference data based on the typical production parameters especially concerning the casting speed in the starting phase were determined to enable an exact comparison. For this purpose starting cracks with lengths between 150mm and 300mm were generated systematically by lowering the grain refiner content, [3]. Shorter starting cracks are difficult to detect with ultra-sonic tests, because of cold shuts or inclusions in the billet butt. If the cracks are longer the cracks do not anneal and the billet will crack over the whole length. For the reference data the grain refiner content was varied between 0 and 5 kg/t AlTi3B1. A content of 1.8 kg/t AlTi3B1 yields reliable crack lengths of around 200 mm to 300 mm when using the standard casting technology and parameters. These starting cracks are easy to detect due to their dimensions, Figure 4. All further castings were carried out with this reference grain refiner content of 1.8 kg/t AlTi3B1 for perfect comparability.

The investigated test parameters of the casting technology are:

- Stop-and-go-casting in the start-up phase
- Variations of the casting speed in the start-up phase

All other casting parameters like temperatures, water flow etc. were kept constant for all castings. The stop-and-go-casting principle means that the table is stopped repeatedly for a short time during the start of casting, see Figure 5. The disadvantage of the stop-and-go-technology is the tendency to float or mould overflow. If the stopping times are too long the melt level increases and the float or even the mould will overflow. To avoid this, it is possible to shorten the stopping times or to avoid a complete stop. Instead of a stopping phase, a very slow table speed is used as shown in Figure 5. Three different variations of the stop-and-go-technology were tried to optimise the start of casting without overflowing of the float.

a) V1
- Stop time: 5s
- Go time: 32,5s
- Stop-and-go start: 0mm
- Stop-and-go end: 400mm

(see Figure 5)

b) V2
- Stop time: 5s
- Go time: 180s
- Stop-and-go start: 0mm
- Stop-and-go end: 400mm

c) V3
- Stop time: 5s
- Go time: 32,5s
- Stop-and-go start: 150mm
- Stop-and-go end: 350mm

Figure 3. Sump depth formation in billet butts by the use of the starting blocks a) and b), [1].

Figure 4. Slice of a reference billet with a starting crack.
The intention of the stop-and-go-technology is to re-melt the top of the starting crack and to influence the sump formation. First experiments with this technology showed that it is very effective against starting cracks. At the same time measurements showed that the sump depth is decreased significantly. Thus it is obvious to test the effect of lowering the casting speed at the starting phase without any stop, because a lower casting speed yields directly to a decreased sump depth.

In this second test run the casting speeds at the starting phase were varied, Figure 6. Slower casting speeds yield a decreased sump depth. A lower sump depth is synonymous with a lower temperature gradient, which leads to lower residual stresses. Four different variations were tested:

a) V4
Original casting speed

b) V5
Slower casting speed at the start-up phase with the same average casting speed like the stop-and-Go method V1 (-3mm/min in the start-up phase)

c) V6
Slower casting speed at the start-up phase (-6mm/min in the start-up phase)

d) V7
Slower casting speed at the start-up phase (first two steps –0mm/min, then –6mm/min)

For all casting experiments the following measurements were carried out:
- Sump depth measurements
- Ultra-sonic measurements of the billet butts
- Metallographic analysis of billets slices
- Metallographic analysis of polished specimen (microscopy)
- SEM analysis of specimen
Results

The results of the investigated modifications in the start-up phase are very promising. Particularly the results of the castings with stop-and-go (Version V1) during the casting start are outstanding. For all billets cast with the stop-and-go-technology and with the reference grain refiner content (1,8 kg/t AlTi3B1) no cracks could be detected with ultra-sonic methods nor with metallographic specimens respectively.

To explore the efficiency of the stop-and-go method V1 further tests were carried out. The grain refiner content was gradually lowered below 1.8 kg/t AlTi3B1. When using the stop-and-go-technology with a grain refiner content down to 1.4 kg/t AlTi3B1 the billets are free from cracks. Using the standard aluminium starting blocks without the stop-and-go-casting this grain refiner content yields completely cracked billets.

All other variations (V2, V3, V5 – V7) were tested only with a grain refiner content of 1.8 kg/t AlTi3B1. The crack prevention was only a little bit inferior to the method V1. But there are clear differences in the practical casting process especially concerning the overflow of float and mould. Summarising these results can be seen in Figure 7. All these results correlate excellently with the sump measurements. As expected a low sump depth and consequential low residual stresses work well preventing starting cracks. This requirement is achieved perfectly when using the stop-and-go-technology (V1). Less stop phases (V2) yield an increased sump depth and a later start of the stop-and-go-phase (V3) yields a significant increased sump depth at the beginning of the start-up phase, Figure 8. The advantage of the stop-and-go variations V2 and V3 is the easier casting start, because the risk of float overflow is minimized to an insignificant level.

A reduced casting speed in the start-up phase without stop-and-go results in another development of the sump depth. Following the main points are visible, Figure 9:

- If the average casting speed is equal to the stop-and-go method V1 (like V5) the sump depth is much higher
- For a low sump depth a significantly decreased casting speed is necessary
- The sump depth has a local maximum in the very start of the start-up phase.

The decreased casting speed increases the risk of float overflow clearly, while the increased sump depth at the first start-up phase raises the risk of starting cracks.

Figure 10 sums up the developments of the sump depth for the most important methods. It is very clear that all tested methods are helpful for lowering the sump depth and the residual stresses respectively. The most effective method in this comparison is the stop-and-go method V1. It is exceedingly efficient especially from the very start of the cast.

![Figure 7. Schematic classification of the investigated technologies regarding handling (float or mould overflow, float freeze-off) and starting crack suppression.](image)

![Figure 8. Sump depths in the start-up phase for the casting variations V1 – V3 (stop-and-go-casting).](image)
Further measurements showed that there is a second effect of the stop-and-go method. It influences the shape of the sump positively. Caused by the table speed changes the sump has not only a lower depth, but the shape is additionally flattened in the middle of the billet, Figure 11. This is due to the different solidification progress at the billet surface and in the middle of the billet respectively while stopping the table. The stopping phase influences the solidification speed at the billet surface immediately, while the solidification in the billet is influenced decelerated and damped. This sump geometry can additionally reduce the temperature gradient and the residual stresses respectively in the area of the starting crack formation.

Figure 9. Sump depths in the start-up phase for the casting variations V1, V5 – V7 (stop-and-go-casting)

Figure 10. Sump depths in the start-up phase for the casting variations V1, V3, V4 and V7 (stop-and-go-casting)

Conclusions

Considering other publications these investigations showed clearly that a very important parameter for starting crack formation is the sump depth and the shape of the sump. Decreasing the sump depth helps to prevent starting cracks as well as a more flat sump geometry with a low temperature gradient in the middle of the billet. Accordingly it is recommended to influence the sump for starting crack prevention. With each of the methods analysed for this paper starting cracks can be prevented. But there are significant differences in efficiency and feasibility in practice.

Technologically the best version is the stop-and-go method with a multitude of stops. It results in a low sump depth and a flat sump geometry that means a significant decreased probability of starting cracks. But a higher casting speed, fewer and later stop phases are much simpler to handle. Thus a compromise between these objectives must be made. This area of conflict, Figure 7, is best solved by the stop-and-go versions V1 or especially V3. The stop-and-go technology is relatively easy to implement. It requires only some changes in the controlling software and an adequate, quick hydraulic system for the casting table. Therefore TRIMET utilises the Stop-And-Go method at the production plants. Provided that the starting conditions (especially the casting speed and the stop-and-go-times) are adjusted properly, this technology can be easily applied in production at TRIMET ALUMINIUM AG Essen. Additionally the computer-controlled guidance gives perfect reproducibility and can be automated. If there is really no possibility to implement the stop-and-go method, decreasing the table speed in the start-up phase is a less efficient, alternative solution.

Summing up it can be said that there are excellent and easy possibilities for starting crack prevention, which are applicable for nearly all DC-casting technologies.
References


