Essential Readings in Light Metals: Cast Shop for Aluminum Production.
Edited by John F. Grandfield and Dmitry G. Eskin.

INVESTIGATIONS ABOUT STARTING CRACKS IN DC CASTING OF 6063 TYPE BILLETS. PART I: EXPERIMENTAL RESULTS

W. Schneider
Vereinigte Aluminium-Werke AG, Bonn (West Germany)
E. K. Jensen
Elkem Aluminium Lista, Farsund (Norway)

Influence on starting crack tendency (hot cracks in billet center) of varying a number of casting parameters was studied by experiments (Part I) and by model calculations (Part II). Effects of varying the following factors were examined in detail: casting conditions, starting block material, insulating various parts of the starting block, starting block shape. Both experiments and calculations pointed to starting block shape as a most important single factor controlling starting cracks. By using the in experiments determined and calculated depth of the liquid sump as a criterion, a proper shape was found that practically eliminates the starting crack problems in billets of the AA 6063 type alloys.

INTRODUCTION

The use of hot top molds with short mold lengths for the dc casting of billets leads to an improvement of the surface and sub surface quality and also an increase of the casting rate [1-7]. For the casting of billets of 6000 series there is a limit in the reduction of the mold length, since at high casting rates there is a tendency to hot cracks in the center of the billets. A short mold length is also more critical during starting process. In order to achieve a safe starting process and good billet butt surface quality a rapid mold filling and higher casting rates must be used. With the high casting rates during starting process the formation of so called starting cracks are formed. Figure 1 shows an example of such a starting crack of an AA 6063-billet, which is also a hot crack. The length of these cracks depends upon casting conditions as well as the billet diameter. This means, the crack length increases with increasing billet diameter. The presence of the cracks results in an increase of the billet butt cut off length. Presently the cut off length is approximately equivalent to the billet diameter. This results in an increase of butt scrap in the cast shops, which has to be remelted. A further complication is, that not all billets of a multiple casting unit have cracks and those billets with starting cracks have a wide range of crack lengths. In other cases the crack can be extend over the full length of the billet. This leads to a rejection of the billet. The aim of the investigations was, to examine the causes of the starting cracks and the factors which influence the length of the cracks. From the results of the investigations, measures for the elimination of the crack or the reduction of the crack length were to be found. This would lead to a reduction of the cut off length of the billet butt.

INVESTIGATION PROGRAMME

For the investigation of the starting crack formation the following programme was performed:

A - Influence of starting conditions (starting rate, cooling water volume, mold inlet temperature, mould filling time, addition of grain refiner).

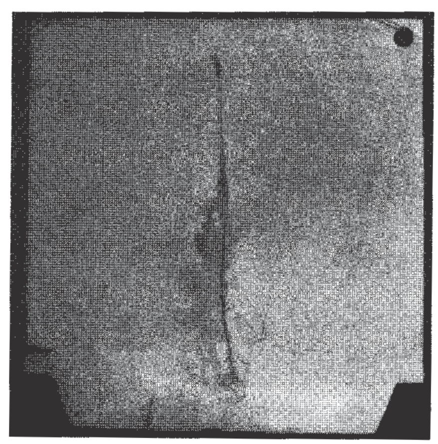

Figure 1: Starting crack of 6063 type billet.

B - Influence of starting block shape and material
C - Investigation of the liquid sump in the instationary casting phase.
D - Temperature measurements in billet butt and starting block.
E - Modelling of the instationary casting phase.

Part I of the paper deals with topic A-C of

Alloy	AA 6063 0,46 - 0,52 % Si; 0,19 - 0,23 % Fe; 0,45 - 0,49 % Mg; 0,006 - 0,008 % Ti; 0,001 - 0,0013 % B
Mold diameter in mm	204
Mold length in mm	30
Water cooling	swell cooling
Starting position of the starting block in the mold in mm	(Distance between top edge starting block and bottom edge of the hot top)
Cooling water temperature in °C	11-13
Mold inlet temperature in °C	690-715
Mold filling time until the start of the lowering in sec	23-30 (block shape D) 12-18 (block shape F)
Hot top height in mm	75

Table 1: Mold and casting data

the above mentioned investigation programme and topics D and E will be dealt with in part II.

EXPERIMENTAL

For the casting trials to investigate the influence of casting conditions, starting block shape and material as well as the determination of the liquid sump during the instationary casting phase, hot top molds with 8 inch diameter were used. The majority of casting trials was performed with a mold, so designed, that the cooling water volume for direct and indirect cooling could be variied independently. Figure 2 shows schematically this mold and the starting block shape, which was used for the investigations of the influence of the starting conditions. The most important mold data and some casting data are given in Table 1. This table also contains a typical composition of the investigated alloy AA 6063 which was produced only with pot room metal. The start of the billet lowering began, when the metal level has reached the top edge of the first hot top ring situated on the mold. The lowering was triggered automatically by sensors in the mold. More details of the experiments of the above mentioned investigations are reported for reasons of clearity in the respective result sections.
The determination of starting crack length was made with a ultrasonic equipment.

RESULTS

In the following sections the achieved results of the investigation topics A-C of the above mentioned programme are reported.

Influence of the starting conditions

Within the investigations of the influence of the starting conditions on the starting crack formation and length the starting rate and the volume of cooling water for direct and indirect cooling at start of casting were variied. The preset values were kept constant for a defined billet length (500 mm). Additionally starting programmes were tested, which permitted the variation of starting rate within pre-defined billet lengths. Within these programmes the increase of the starting rate was performed step by step from a variable initial value to a constant end value.

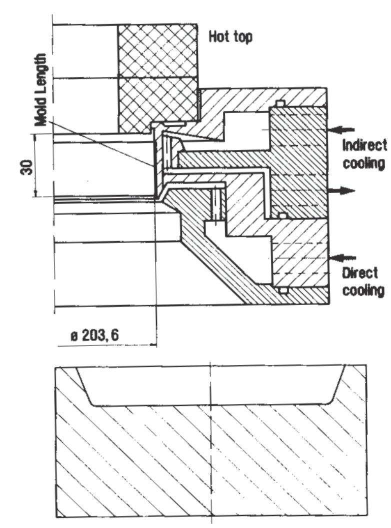

Figure 2: Schematical depiction of the test mold with starting block.

The investigations have shown, that cracks were formed under all experimental conditions. The influence of the casting (starting) rate on the starting crack length is shown in Figure 3. It is obvious, that with increasing starting rate the crack length increases.

The results show, that in order to reduce the starting cracks the starting rate must be lower in comparison to the rate in stationary casting phase (95 mm/min). But this can lead to surface defects such as cold shuts. As mentioned above, programmes were tested to balance the positive influence of low starting rates against the tendency to form surface defects. The results of these experiments are shown in Figure 4. It is to be seen, that with increasing starting lengths a continous reduction of the crack length can be achieved. Of importance is also the initial value of the starting rate (A). At the defined starting lengths the crack is shorter if lower initial values of the starting rate are used. But the use of very low starting rates leads with increasing starting lengths to the formation of surface defects of the billet butt such as cold shuts. As a result of this, to avoid the formation of surface defects, there must be a maximum in the starting length. In this case however, the reduction of the starting crack length is not significant.

The volume of cooling water has no influence on the starting crack length, as shown in Figure 5 for different ratios of cooling water volumes for direct and indirect cooling. It is to be seen, that especially with the increase of the cooling water volume for the direct cooling under the used investigation conditions, no significant reduction of the starting crack length could be achieved. Furthermore, the surface of the billet butts has shown cold shuts for water volumes higher than 7 m^3/h in direct cooling.

The mold filling time until the start of the lowering also has no influence. In opposition to this, there is an influence of the mold

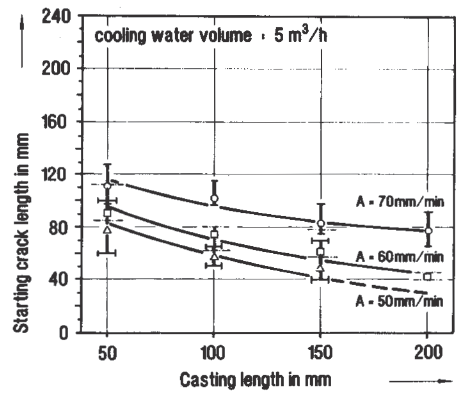

Figure 4: Influence of starting programmes/ starting rate on starting crack length.

inlet temperature of the melt during the instationary casting phase, as numerous investigations have shown. This means, that with increasing inlet temperature a small reproducible increase of the starting cracks was observed.

A further important factor for the starting crack length is the addition rate of grain refiner rod during the starting process. Figure 6 shows the influence of different addition rates of grain refiner rod in the launder during the starting process. It is to be seen, that under the used casting conditions the crack length was reduced significantly up to an addition rate of 0,5 kg/t. With higher addition rates no further significant reduction took place. The formation of starting cracks can not be avoided only by the grain refinement.

Summarizing the above mentioned results, it can be concluded, that with the use of hot top molds having short mold lengths it is not possible to reduce the length of the starting cracks significantly respectivately to avoid starting cracks.

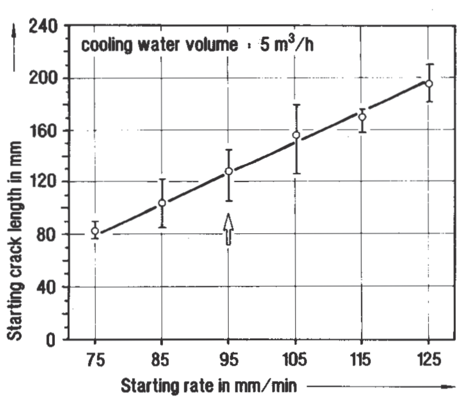

Figure 3: Influence of starting rate on starting crack length.

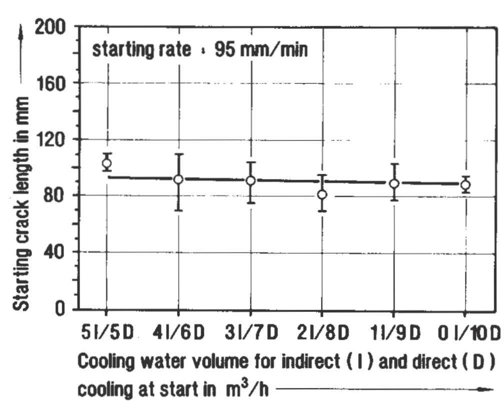

Figure 5: Influence of cooling water volume for indirect and direct cooling on starting crack length.

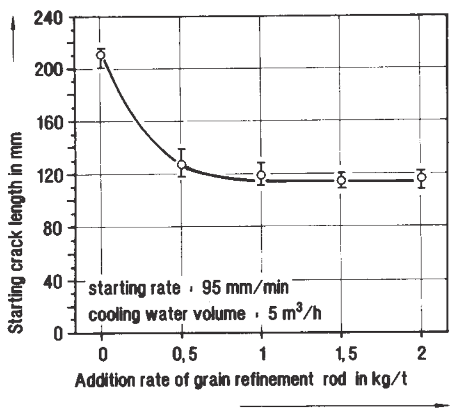

Figure 6: Influence of addition rate of grain refiner (AlTi3B1) on starting crack length.

Influence of starting block shape and material

In the above result section it has been reported, that with the starting conditions the starting crack formation can not be influenced decisively. On the basis of this fact, different starting block shapes, shown in Figure 7, have been tested to investigate their influence on crack formation. The results of the trials with these starting block shapes are given in Figure 8. It is to be seen, that the use of a completely flat starting block (shape A) leads to a difficult starting process. The same was observed using a flat starting block with partial insulation with refractory material in form of rings (shape B) and discs (shape C) of different dimensions. Additionally starting cracks were observed. No success was achieved using a starting block with a conical depression (shape E). In comparison to the above mentioned block shapes a starting block with a truncated cone in the center was sucessfully tested (shape F). With this starting block shape it was possible to cast billet butts without starting cracks. For the function of this starting block it is important, that the circumference of the

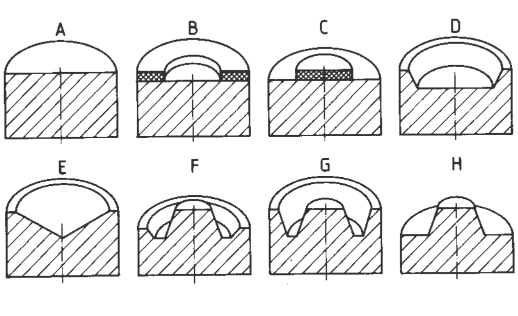

Figure 7: Tested starting block shapes.

block is lower than the truncated cone. In the case of same heights the formation of starting cracks reoccured. However, the use of a starting block without a circumference led again to starting difficulties. The new starting block shape F is so efficient, that under certain casting conditions crack free billet butts could be cast without grain refinement. In order to recommend the use of this starting block shape in the cast shops, trials had to be done with a varified construction. This means, that in the cast shops the starting blocks are installed and centered in a way, which is shown in Figure 9a. The trials should show if there is an influence on starting crack formation. The result was, that the billets, cast with this shape, had short starting cracks in the billet butt, initiating at the screw. With

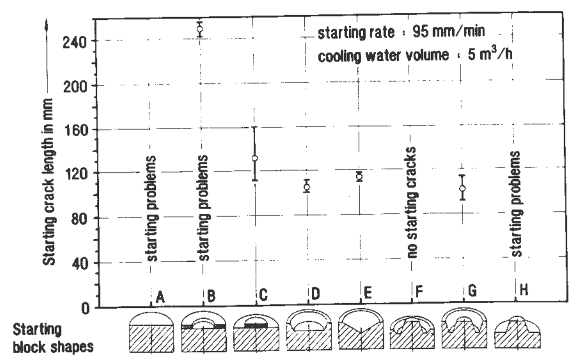

Figure 8: Influence of starting block shape on starting crack length.

the reduction of the starting rate over a short casting length, it was possible to eliminate the starting cracks without the formation of surface defects.

For the investigation of the influence of different starting block materials on starting crack formation the block shape D, shown in Figure 2 and 7, was used. The materials were aluminium, copper and grey cast iron. The results show, that with the use of copper and grey cast iron no significant change in starting crack length was achieved when compared to aluminium.

With the starting block shape F casting trials have been done, using the truncated cone as an insert, shown in Figure 9b. The material of this insert was also aluminium, copper and grey cast iron. The inserts were installed in a way, shown also in Figure 9b, to realize cast shop conditions. The results of these casting trials are shown in Figure 10. It is to be seen, that for all inserts short starting cracks were formed. There was no difference between the aluminium and copper inserts. However, the grey cast iron insert led to longer starting cracks. In the case of the aluminium and copper inserts it was possible to avoid the cracks with a reduction of the starting rate over a short casting

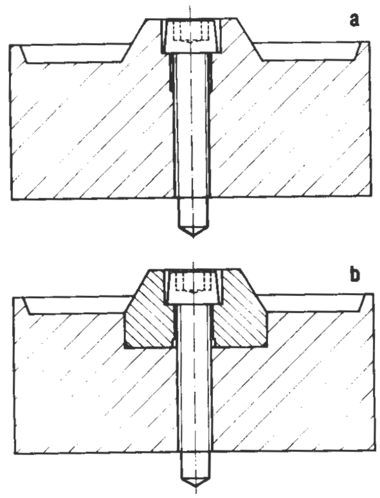

Figure 9: Starting block shape F with installation screw and the truncated cone as insert.

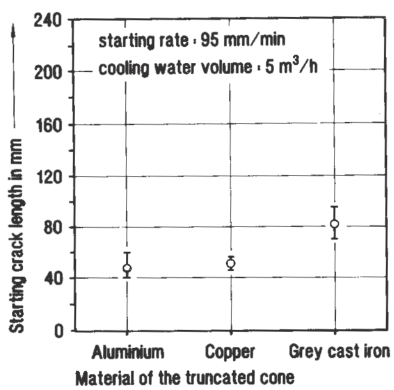

Figure 10: Influence of cone material on starting crack length.

length. This was not possible by use of the grey cast iron insert. In this case every variation of such starting conditions producing no surface defects, only a shortening of starting cracks took place.

Formation of the liquid sump during instationary casting phase

For determination of the different efficiencies of the starting block shapes D and F, shown in Figure 7, the formation of the liquid sump in the billet butt during the instationary casting phase was investigated in comparison to the modelling. A further trial parameter was the starting block material (aluminium, copper and grey cast iron), but only by using of starting block shape D.

The shape of liquid sump in the billet butt during casting using block D is shown in Figure 11. At the beginning the sump has a flat shape in the billet center. This area is narrowing with increasing billet length and sump peak will be formed. As a result of this, Figure 11 shows also the dependency of liquid sump depth of the billet length. It is to be seen, that initially the sump depth increases rapidly, decreases after passing a maximum and keeps constant after a certain billet length with the achievement of the stationary casting phase. Upon reaching the stationary casting phase curing of the starting crack take place.

The shape of liquid sump in the billet butt during casting by the use of block shape F shows Figure 12. It is to be seen, that at casting start two sump peaks exist at the level of the truncated cone, before the normal shape of the sump is formed. Figure 12 shows also the dependency of the sump depth of the billet length. It is obvious, that at first the sump depth also increases rapidly, but no maximum in the curve will be formed. This means, that the sump depth of the stationary casting phase will be achieved earlier and in the instationary casting phase a flatter sump formation exists. It is concluded, that the presence of no sump depth maximum by using starting block shape F is responsible for the absence of starting cracks.

The investigations of the starting block materials aluminium, copper and grey cast iron on sump depth formation with respect to billet length by use of block shape D, have shown only small differences in the sump depth during the instationary casting phase. The use of a cast iron block led to a longer and the copper block to a smaller sump depth maximum in the instationary phase as compared to the aluminium block. More details about this will be reported in part II of the paper.

CONCLUSIONS

The prevention of starting cracks in the butt of AA 6063 billets by use of hot top molds with short mold lengths can be achieved with a newly developed starting

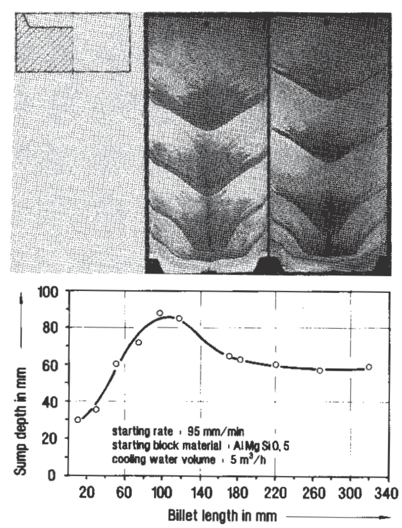

Figure 11: Sump depth formation in billet butt by use of starting block shape D.

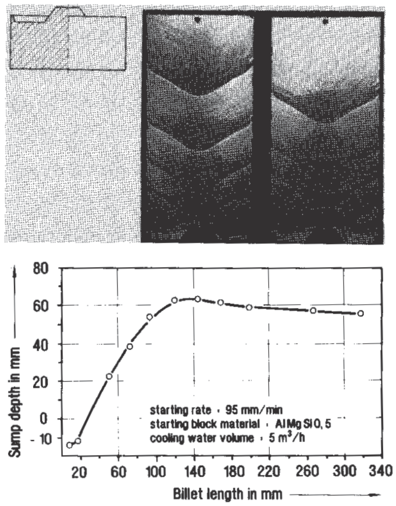

Figure 12: Sump depth formation in billet butt by use of starting block shape F.

block shape. This starting block has in the center a truncated cone, which is higher than the circumference of the block. The shape of the new block avoids the sump depth maximum during the instationary casting phase. Therefore the stationary sump depth will be achieved earlier in comparison to the bowl-shaped starting blocks used until now. The new block shape has been tested to mold diameters greater than 400 mm for casting of AA 6063 and additionally also for AA 6351 and AA 3003. The dimensions of the circumference and the truncated cone of the starting block depend upon the diameter of the mold.

The introduced new starting block shape is now used successfully for multiple casting units in cast shops of West Germany, Norway and Switzerland. Only in some cases short crack lengths have been observed. This has resulted in the reduction of the cut off length of the billet butt and also the butt scrap. The reduction of the cut off length should be limited, so that the part of the billet butt should be removed, which contains oxide pollution caused by the turbulences during the starting process.

REFERENCES

1. US-Patent Nr. 2983 972
2. E. Lossack, Light Metals, 2 (1976), 413
3. G. Moritz, Z. Metallkunde, 60 (1969), 742
4. K. Buxmann, Aluminium, 54 (1978) 11, 685
5. K. Buxmann, Metall, 31 (1977) 2, 163
6. W. Schneider, Aluminium, 61 (1985), 338
7. G. Scharf, E. Lossack, Metall, 32 (1978) 6, 555

The work was supported by the committee "Continous Casting" of the German Society for Material Science and Technoloy (Deutsche Gesellschaft für Materialkunde).