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THE VARIABLE CHILL DEPTH MOULD SYSTEM

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The variable chill depth mould introduces a new concept to the semi-continuous direct chill casting process: a movable insulating sleeve within the mould permits precise control of the operating chill depth.

It has been demonstrated, in both experimental cast house and pilot scale plant trials and with moulds of aperture up to 1550 mm x 508 mm, that the system allows the casting of a wide range of aluminium alloys to yield products of improved quality under conditions of increased safety.

The simple nature of the casting relationships that exist between casting speed and mould chill length and casting speed and water flow rate make the process particularly amenable to automation without the necessity for precise control of metal flow rates.

Introduction

The metallurgical quality of rolling block that is produced with the normal semi-continuous direct chill (DC) casting process is frequently inconsistent and generally at a lower level than the optimum. In the vertical 'DC' casting process, as commonly used, the operating mould chill depth that is of vital importance to the metallurgical control of the surface and subsurface cast quality of all DC cast products is synonymous with the metal level in the mould. It is apparent, therefore, that a pre-requisite for consistent quality is precise control over the effective mould chill depth and/or strict control over the metal level in the mould. Moreover, to produce material that is consistently of optimum metallurgical quality additionally requires the adoption of a shallow metal level in the mould or a very short effective mould chill depth must be employed. Paradoxically, the low operating metal level, and/or short effective mould chill length, brings with its benefits several operational problems that generate working tolerances that exceed the practical performance of the casting equipment and the operative's capability. Safety hazards accompany the operating procedures particularly at the start of the cast.

To overcome some or all of these problems, different casting systems and methods have been devised. Of these(1) the most simple method is that where ceramic paper is used for providing an insulating liner to mask a large part of the mould face. By this technique the effective metal depth in the mould is kept constant, but only some of the operating problems are avoided and defective products can result due to the very limited and unpredictable useful paper life. An approach to overcoming the conflicting requirements of a safe and easy start-up without large compromise to product quality is the ISOCAST system. The principle of this system employs the rising mould table by which, without changing the absolute level of the metal surface, the metal level in the mould can be decreased shortly after the start of casting. However, optimum use of this method suffers from practical limitation by variations in metal temperature, as well as by level fluctuations, and it is essential to set the feed metal equipment so that the metal level in each mould is substantially the same.

In the more sophisticated methods, on-line-control using a micro-processor is employed to control the total casting process(2). With this method programmable and automatic feed back control loops are applied to exert control over all casting parameters and the microprocessor supervises the interaction of the control loops to correct for any disturbances which occur in the parameters. In such systems most of the operational problems are eliminated, although optimum product quality requires that a low operating metal level be employed in the mould. Correspondingly, a higher casting speed is essential to obtain satisfactory thermal stability within the low intrinsic heat content system. However, many of the wider freezing range alloys require a low casting speed to avoid difficulties in cast-ability.

To overcome all of these problems The British Aluminium Company plc has successfully developed the novel procedure of varying the effective mould chill depth during the course of the casting operation, making un-necessary special concern for the metal level in the mould.

This novel casting arrangement is called The Variable Chill Depth Mould (VCDM) System, (which is the subject of various patents and patent applications) and the advantages it brings in improving operational safety, in consistently producing high metallurgical quality and in rendering the

DC process amenable to automation with use of only very simple methods of control are discussed in this paper. Essentially the system comprises a refractory sleeve capable of movement within the mould aperture in such a way as to vary, at will, the exposed length of mould face. By this means the same good surface quality and narrow chill zones can be obtained as with very shallow open head moulds but without the need for skill on the part of the operator or for very expensive control equipment. Thus with the sleeve in the raised position (Figure 1a) it is possible to start the cast with the ease and safety of a deep mould and with the minimum of ingot base distortion. Subsequently, the ideal exposed mould chill depth is selected (Figure 1b) until, on termination of the casting operation the refractory sleeve is returned to its raised position where it is remote to the solidifying top of the ingot which is stationary within the mould. The high thermal insulating properties of the refractory sleeve will prevent premature solidification of the metal within the casting head and affords a safe guard against over filling of the mould with liquid metal.

Thermal Considerations

The use of the movable sleeve makes possible several improvements in the thermal operating characteristics of open head DC casting. Control over the position at which the liquid metal is introduced to the mould chill face determines the extent of cooling that is exerted by the mould and the magnitude and position of the mould cooling domain in relation to the cooling domain that is produced by the direct quench.

Cooling domains

The concept of cooling domains is introduced to indicate those regions within the ingot shell in which the cooling influence of either the mould or the direct quench predominates.

The mould cooling domain boundary is thus the position below which the cooling effect of the mould is negligible, whilst the direct quench cooling domain boundary is the position above which there is negligible cooling as a result of the direct quench.

The relative position of these domain boundaries is thought to be a major factor influencing the coherency of the ingot shell, the depth of segregation beneath the skin and the surface quality of the emerging ingot. If casting conditions are such that a significant length of cast shell exists between the two cooling domains (Figure 2a) then reheating of that part of the ingot shell will occur and various defects can result. In conventional DC casting this can largely be overcome by the use of shallow metal heads in the mould. This automatically results in a low mould chill depth and the likelihood of some degree of overlap of the cooling domains.

When attempting to employ shallow metal depths in open head casting, problems arise especially at the start of the casting process; with large block, significant base distortion occurs, accompanied by minor face run outs and other surface defects over, perhaps, the first 300 mm; with small section ingot the components of the metal feeding systems are liable to be engulfed by the forming solid before the liquid metal sump has developed. Once casting has been successfully started, much stricter control is still required over the major casting variables. This is largely due to the change in thermal characteristics of the system, the reduced heat content making a steady state condition more difficult to achieve and maintain.

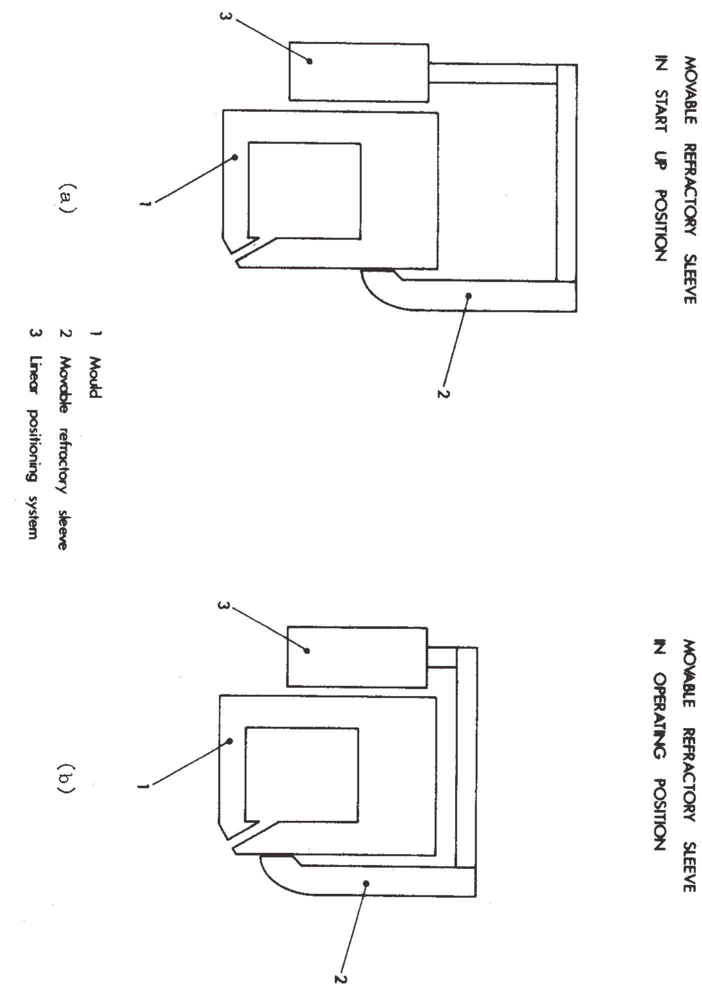

Figure 1 The principle of operation of the variable chill depth mould system

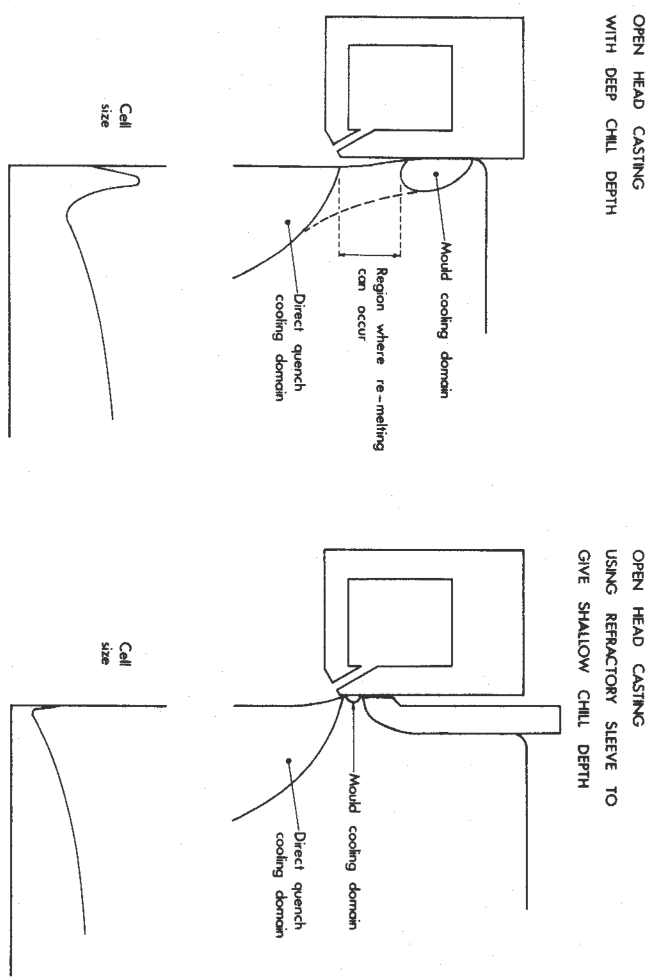

Figure 2 Conventional open head casting and VCDM casting indicating cooling domains and resultant cell size distributions under steady state running conditions

In this light a better understanding of the concept of the movable sleeve can be gained. The significance of the sleeve is that it can bring about a change in the thermal characteristics of the system such that the mould cooling domain and direct chill cooling domain within the ingot shell can meet (or overlap) (Figure 2b) without introducing the problems usually associated with low metal levels and described above.

VCDM Operating principal

The variable chill depth mould gives positive metallurgical control over the solidification behaviour. At the start of casting, with the sleeve in the raised position, significant heat is removed through the mould wall and the cooling domains are widely separated. Good penetration of the starter block is possible and the defects that result from base distortion when using a short mould are greatly reduced. Under steady running conditions thermal contact of the newly forming ingot shell with the mould is minimised by lowering the sleeve shortly after the start of the cast. The sleeve itself does not have significant thermal contact with the mould face and heat flow from the metal to the mould wall is very small. Thus the interaction of the solidifying metal with the mould face is reduced to a minimum, achieving very low forces of sliding stiction(3). By correctly positioning the sleeve so that the exposed length of mould face and casting speed are mutually balanced, the two cooling domains (Figure 2a) are brought together (Figure 2b) in order to accomplish:

i) maximum coherency within the forming ingot shell, by avoiding any reheating of the solidified metal

ii) a single mechanism of ingot shell departure from the mould face that is effected by sub-mould section shrinkage

These two phenomena result in high surface quality while enabling minimisation of peripheral segregation and avoidance of the coarse cell region and columnar structure that tend to characterise block cast through deep moulds.

Casting Relationships

The VCDM has been used to establish a number of basic casting relationships. The most important of these is the relationship between casting speed and exposed mould chill length. From experience with normal casting it is well known that for a given metal level there is an optimum casting speed at which best block quality is achieved.

Using the VCDM it is readily possible to vary the operating mould chill depth over a wide range and to adjust casting speed to give optimum surface quality for each exposed length. This operation can be repeated for a range of different alloys. The resulting relationships are shown in Figure 3 from which it can be seen that as the mould chill length is decreased the casting speed must be increased in order to maintain optimum metallurgical quality. The curve represents the mutually corresponding values of these two parameters at which the cooling domains are brought together.

Any deviation from the optimum speed will result in reduced metallurgical quality. Either too slow or too fast a speed could lead to surface folds and increased sub-surface segregation. While, for any composition, a

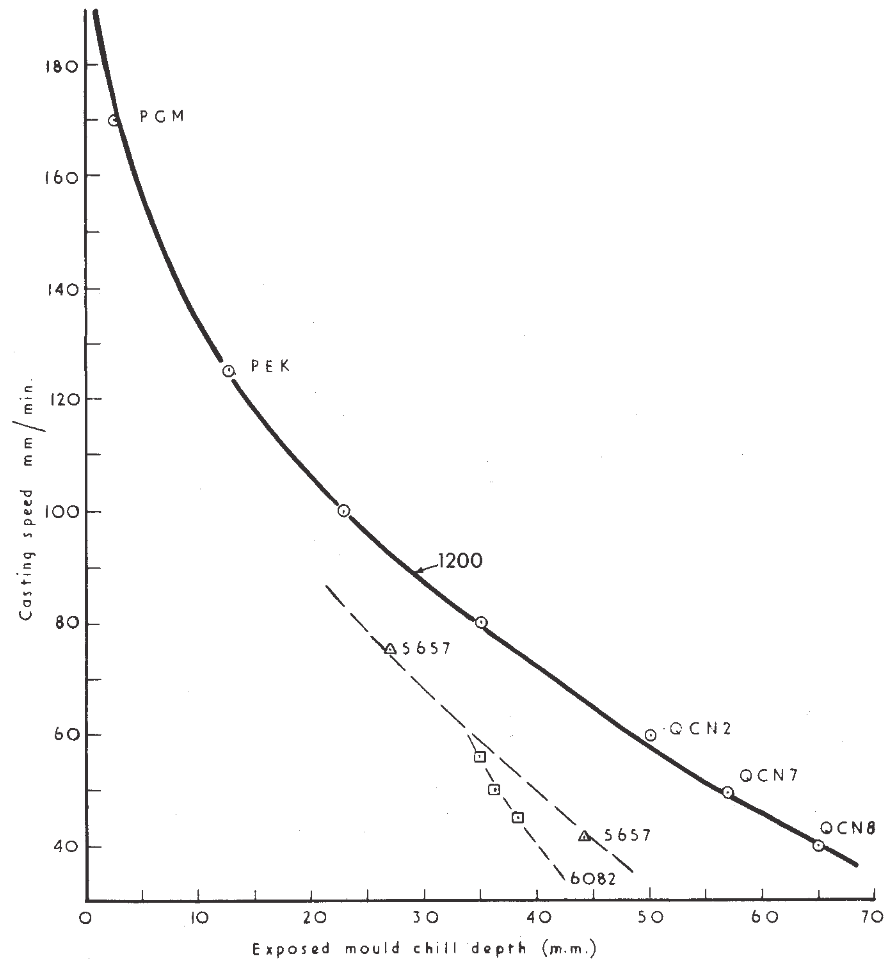

Figure 3 The relationship between casting speed and exposed mould chill depth for alloys 1200, 5657 and 6082

fixed relationship between optimum speed and exposed chill depth exists, the relationship is different for different alloys. The casting functions for the more alloyed materials are displaced towards the origin. This characteristic indicates the castability limitations that appear with wider freezing range alloys. The other important consequence of altering the exposed length of mould is in its effect upon the width of the peripheral zones. Thus, Figure 4 shows the progressive decrease in zone width that accompanies decrease in exposed chill depth. This relationship was, of course, obtained by varying the casting speed so that optimum surface quality was maintained at each exposed mould depth and the cooling domains remained mated throughout.

It is probably worth pointing out that in conventionally cast DC block there is frequently a region of coarse cells beneath the block surface and a typical cell size plot is indicated in Figure 2a. This band of coarse cells results from the reheating of the forming shell as a result of the mis-match of the mould and direct chill cooling domains. By maintaining the mating of the cooling domains the region of coarse cells can be avoided. Figure 2b indicates a cell size plot for VCDM cast material cast under these conditions. Incidentally the cell size in the core of the block is finer than that for the open head cast block of Figure 2a because the casting speed in the VCDM block was much higher in order to take advantage of the short chill depth.

A second important relationship has been identified which relates direct chill water flow rate and the casting speed. This relationship is not of the precise form of that between chill depth and speed but really indicates levels of water flow. Thus, during start up water flow rates must exceed a minimum value while not exceeding a defined maximum. When casting under steady state conditions at speeds as high as 170 mm/minute it was found that the sump depth grew excessively (to about 700 mm) and the cooling water boiled off the surface. Additional secondary cooling water had, therefore, to be applied. The general form of the water flow casting speed relationship can be assessed from Figure 5.

The VCDM Casting Operation

As outlined above, basic casting relationships exist between exposed chill depth and casting speed and between water flow rate and casting speed. These relationships are combined into a single graph in Figure 5 (which illustrates the relationships for 6082) where the necessary values for casting speed, exposed mould length and water flow are plotted against cast length. In any cast, providing that the three variables adhere throughout to these ideal relationships, a block of high surface quality requiring minimal scalping will result. The high intrinsic heat content of the system gives a thermal stability that renders it relatively insensitive to normal variations in metal flow rate, to reasonable fluctuations in metal temperature and to wider fluctuations in ambient temperature. Hence operation of the VCDM system can be simply accomplished either with manual control or, more easily, with automatic control. Both methods of operation follow the above simple basic programme of casting events that are executed sequentially in the manual mode but virtually simultaneously by automatic scheduling. A typical VCDM operating cycle is outlined below:

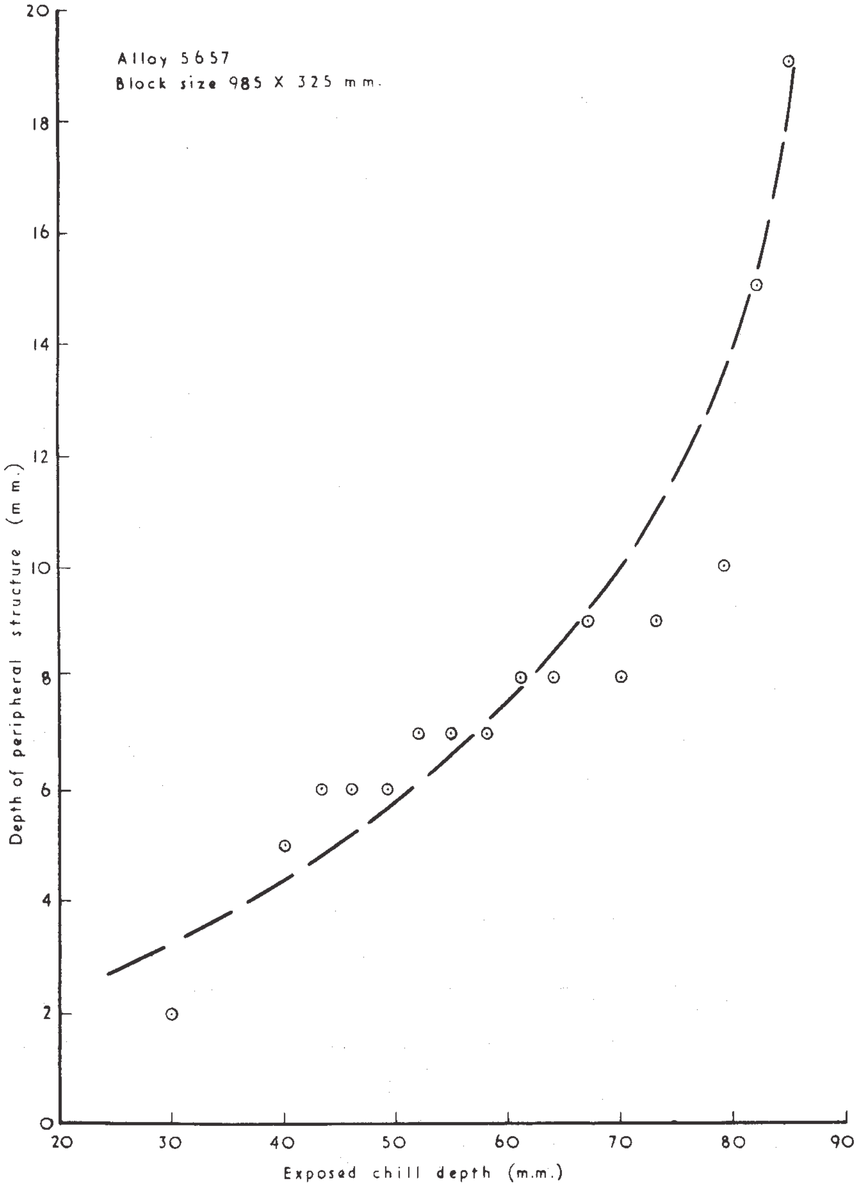

Figure 4 Peripheral zone width as a function of exposed mould chill depth at optimum casting speeds

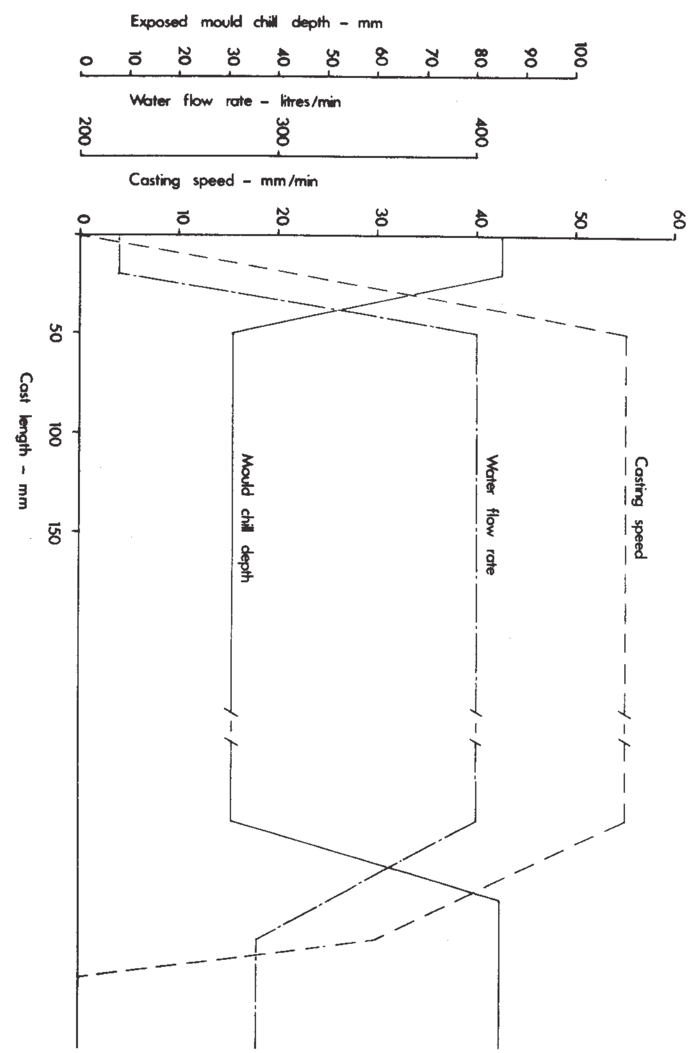

Figure 5 Typical programme for VCDM casting (Alloy 6082 in 985 mm x 325 mm section block)

Preparation of casting cycle

With the sleeve in its raised position (see Figure 1) a safer and easier cast start is made possible by permitting the following conditions to be readily fulfilled before starting the cast:

i) a deep mould chill face is exposed for contact with liquid metal to occur

ii) deep starter block penetration into the mould cavity

iii) a safe low flow rate of cooling water is preselected (Figure 5)

iv) a large clearance exists between the liquid-metal-floating distributor and the top surface of the starter block.

Start-up procedure

Employing either a fixed hearth furnace, tilting furnace or even transfer ladles, the VCDM system is ideally suited to operate because of its insensitivity to relatively large fluctuations in metal flow rate during the course of the cast. The system is supplied with liquid metal and subsequent to the floating valve operating in the mould, the liquid metal level in the feed launder rises to the reference height.

With the casting head filled with metal the time dependent conditions effecting ease of start-up (and termination) are more tolerant to delays than systems of lower intrinsic heat contents.

Once filled with molten metal the starter block begins to descend at a relatively slow speed. There is within the system an adequate reservoir of hot liquid metal that avoids hazards of metal starvation while the height of the sleeve provides a safeguard against metal overfilling the mould that can arise from sticking valves. Once the ingot base enters the direct water chill the water flow rate is increased toward the steady state condition and the movable sleeve begins to descend progressively to reduce the exposed mould chill depth at a rate that is less than the speed of descent of the solidifying metal within the mould.

Using automatic control, steady state casting speed is attained after minimum cast length, and with freedom from bottom end casting defects. At a similar cast length the steady running conditions of the direct chill flow rate and the exposed mould chill depth arrive at their mutually optimum operating levels to produce optimum cast quality throughout the steady state casting operation. Under manual control it will not, of course, be possible to achieve such close adherence to the desired starting conditions and the transition to steady state is, inevitably, more protracted with a likely reduction in the yield of highest quality block.

Steady state casting

The relatively high metal level is thermally insulated by the movable sleeve and under optimum casting conditions only the minimum of metal contact takes place with the mould chill face. However, the metallostatic pressure head positively supplies metal to the mould chill face, making it a simple matter to maintain high quality when casting at very high speeds.

Termination of casting operation

With accumulation of the required cast length the liquid metal supply is interrupted and the residual metal in the feed launder is consumed by the casting operation before the movable sleeve returns slowly to its original raised position.

When the solidifying top of the descending block is remote to the underside of the movable sleeve the casting speed is slowed and stopped, and the water flow rate is reduced to its initial low level. The feed launder is raised and the liquid metal level valves are retrieved.

Pilot Scale Plant Trials

Having gained extensive experience with the VCDM system within the British Aluminium Technical Department using a wide range of mould sizes and alloy types, the decision was taken to carry out pilot scale trials in a plant. The particular factory chosen employs twin casting machines in which, under normal circumstances, identical casting operations are carried out alternately on each of the two machines. Thus, by using the VCDM on one of the machines a good comparison of its performance relative to a conventional system could be obtained. The factory produces relatively small rolling blocks (two blocks per drop) but high demands for block quality are made and the nature of the operation allows minimum time for maintenance between casts.

The system was commissioned early in 1982. At the same time all production casters were introduced to the simple operating procedures of the movable sleeve and showed ready acceptance of the new casting system. After one week of operating experience the casting squads demonstrated considerable confidence in the system and were adept in taking full advantage of the casting benefits provided by the movable sleeves. Preference was always given to the VCDM system for the first drop because of its capability of casting metal of low super heat without freezing the floating metal distributor into the block.

The surface quality of the ingot was judged to be very good and of a surface texture that was, at minimum, at least as good as the best that could be achieved with their conventional moulds. The sub-surface structure was better than could be obtained with the usual system, due to the more shallow exposed mould chill depth that is easily attained with the VCDM. The operating range of the exposed mould chill depth initially was set at 70 mm for cast start-up and termination and at 30 mm for steady running conditions. After one week of production use the overall sleeve movement was increased to give 18 mm exposed mould chill depth. This is not practical on their normal moulds. In less than one month of production operations the cast shop had voluntarily adopted the VCDM system as routine production equipment and reported several advantages that suited their mode of operation.

Advantages reported by the factory

1 Safer start-up with reduced tendency for run-outs since it was possible to commence casting with a deep exposed mould face.

2 The mould liquid depth at start-up was greater than traditionally employed, reducing the required precision of distributory/dummy

clearance and hence preventing freezing in of the float as a consequence of too little clearance.

3 The refractory movable sleeve could be lowered approximately 50 mm after start-up to a depth consistent with optimum surface quality and internal structure to suit end product requirements. Therefore, reduced scalping was possible.

4 During the drop there was an increased operating tolerance on the casting parameters, particularly with regard to metal temperature variations and the metal level in the mould.

In February at the end of one drop the cast blocks were accidentally driven upwards into the underside of the sleeves. This resulted in the complete casting head, which weighs several hundred weights, being raised from the machine, supported only by the two sleeves. In spite of this harsh treatment, the casting system had continued to work satisfactorily and produced a further 260 high quality rolling blocks without any special attention or the need for repair.

Overall, in the course of the pilot trial, some 826 tonnes of high quality rolling block was cast through the VCDM. The rejection rate, for physical reasons, was 5.5% better than that with the conventional systems.

Conclusions

The VCDM casting system has been shown to be a process innovation of major importance to the semi-continuous direct chill casting of aluminium and its alloys. At the present stage of the development, which has included extensive experimental cast house operation and pilot plant factory use, the major benefits that it offers seem to lie in:

1 Improved operational safety in a potentially hazardous process.

2 Capability of consistently producing improved product quality in terms of surface, of peripheral zone widths, of sub-surface segregation and uniformity of core structure.

3 Rendering the process amenable to automation by relatively simple means.

Acknowledgements

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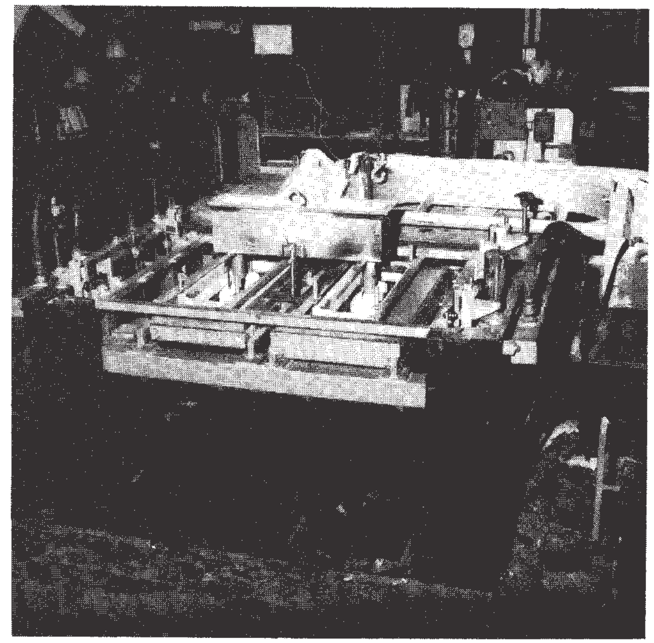

Figure 6 Twin head experimental VCDM casting rig

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