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Continuous casting without secondary spray water cooling

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A slab surface without any defect is necessary in order to ensure a hot or even direct charging of slabs into the next processing step. A more even surface temperature can be obtained by continuous casting without spray water cooling, when the heat is mainly transferred by radiation and extracted by backup rolls with inner cooling. The therefore developed MW roller (i.e. a helical-roller) makes the process of the so-called „dry casting" possible. The more homogeneous and in total higher surface temperature of the strand decreases the appearance of transversal cracks on faces and edges so effectively that scarfing is no longer necessary.
Casting of peritectic steel grades turns out to be difficult as far as surface quality is concerned, because with cooling immediately after solidification L $\rightarrow \delta$ the δ/γ-transformation takes place. Nevertheless, even these critical steel grades can be processed directly without machine scarfing using suitable casting powders and by the development of continuous casting without secondary spray water cooling.

In a continuous casting machine the liquid steel is given a prepared shape in order to solidify. The heat is dissipated by the mould, the secondary spray water cooling as well as by radiation and convection. For hot or direct charging to the rolling mill the continuously cast pre-material needs surfaces without any defect, which neither needs inspection nor repair. For conventional production the yield will increase without scarfing.

Problems occurring with secondary spray water cooling

The most frequent surface defects are transversal cracks caused by deep oscillation marks. They result from tensions caused by withdrawal, bulging, bending and straightening of the strand. There is also thermal stress which results from uneven cooling of the strand shell in the secondary cooling zone. The cooling rate of the strand depends on the height of the casting machine, the spacing of the back-up rolls, the casting speed and the steel grade. In the upper section of the casting machine a direct cooling with water spray is generally used because of the high surface temperature. The strands and the back-up rolls are both cooled in this section [1].

Steel changes its material properties according to the temperature. The ductility of microalloyed carbon steels with 1.3 % Mn, for example, will decrease from 100 % to 30 % if the temperature changes from 1000 °C to 800 °C [2]. Precipitates at the grain boundary weaken the structure stability at this <???worauf bezieht sich this???> second ductility minimum. At temperatures below 950 °C cracks can easily occur as a result of bending or of temperature stresses. The thermal stresses are caused by an uneven surface temperature, which cannot be completely eliminated by normal cooling practice. For the design of a slab casting machine and the metallurgical process engineering it is necessary that the secondary cooling zone is adjusted to the steel grade thus ensuring a cooling rate of such uniformity and intensity that no cracks will form. Low carbon steels which are not sensitive to crack formation can be cooled sharply in order to increase the strand shell thickness and decrease the liquid pool length. At the same time the strand bulging between the back up rolls is limited. This is absolutely necessary to prevent the shell deformation causing internal and surface cracking. Microalloyed steels are sensitive to crack formation, so they have to be cooled very softly. Losses in productivity have to be accepted.

Dry casting operation

Development of air-mist cooling. For these reasons Hüttenwerke Krupp Mannesmann (HKM) has begun to especially consider strand cooling at an early stage. They have always been embarking on the strategy of working with low water rates and high strand surface temperatures. On the one hand, the amount of uncontrolled water flow <???> at the loose side of the strand should be decreased, on the other hand, temperatures below 1000 °C which would unfavourably effect the ductility of the steel grade should be avoided. Local overcooling should be as low as possible. To reduce the amount of water in a pure water cooling nozzles with a small cross-section are required which, however, can clog with normal water quality. The spray cooling with regard to amount and distribution will be uncontrollable. The surface quality decreases.

To this end HKM developed the so-called air-mist cooling for soft cooling applications. It employs a mixture of water and compressed air. **Fig. 1** shows two different nozzle arrangements [1]. Water and air are supplied in different pipes <sind die üblichen Gasflaschen gemeint?, dann gas bottles, oder ist das ein Spezialausdruck???> and mixed in front of the nozzle. With this „two-finger nozzle" the water is distributed on the slab surface in the form of fine mist.

Surplus not evaporated water is pressed over the edges of the slab by the jet stream. This nozzle arrangement is difficult to control and sensitive with regard to its adjustment.

The block nozzle is situated above the narrow gap of the rollers. The cooling, however, is limited to a small strip, because the biggest part of the slab surface is shadowed by the rolls. An uneven temperature profile and uncontrolled water flow <?> which accumulates at the next roll cannot be avoided completely.

In spite of all efforts the portion of evaporation is low. It cannot be increased above 14 %, as shown in **fig. 2** [1; 3...4]. With this kind of air-mist cooling high amounts of water always remain accumulating at the rolls, draining being uncontrolled and leading to local overcooling below 1000 °C. The air-mist cooling does not solve the problem definitely in this respect.

Examinations have shown that the share of the spray water cooling compared to the total amount of cooling is rather low. To guarantee solidification spray water cooling is not necessary at all. However, it is required that the rolls withstand the thermal stress. This as well is true for the deflection of the rolls as for the life time of the bearings.

Heat dissipation and helical rollers. The solution of local thermal overstress was the development of a new roller type, which is characterised by heat transfer through the roller surface by indirect cooling with water. This development resulted in an international patent: the so called helical roller, which is a speciality and trade mark of slab casting in the HKM-Huckingen works (roller width: 2200 mm). **Fig. 3** shows a radiation illustration of this roller type [1].

The new design achieves its rigidity by means of a solid core, into the surface of which spiral channels have been machined. These channels are sealed by a thin sleeve which is spirally welded to the ribs. The core of this roller remains cool and thus retains its good mechanical characteristics during casting [5]. Short leakages, which are related with irregular cooling, could not occur. The cooling conditions can be controlled by the temperature and the flow velocity of the cooling water. In this dry secondary cooling system leakages will be easily detected by visual control of the machine during casting and will be repaired without any influence on the quality of continuous casting products.

If the original installation is modified to dry casting at all, the dissipated heat over the helical roller has to be increased to guarantee a sufficient strand shell growth. Due to this effect, the roller construction has to be adjusted to the casting machine layout. Liquid crater length and machine length could not be enlarged too much. In fact, a balance between roller design, casting parameters, strand surface temperature and amount of dissipated heat has to be guaranteed. This balance results in what we call the *dry-casting-operation*.

Influence of the slab thickness. The amount of dissipated heat depends on the surface temperature of the slabs as well as on the heat transfer coefficient. The main factor as far as heat transfer is concerned is the surface area which transfers the heat. Therefore, the slab width is of exceptional influence on heat transfer. With increasing slab width the direct contact surface between the strand and the rollers increases. Simultaneously, the surface area of the rollers which are affected by heat radiation is increased, **fig. 4** [1].

Influence of the roller diameter. The mechanism of the heat transfer from the strand on the roller surface is generated by direct contact and radiation transfer. The surface of direct contact is only a small line and not significantly enlarged by the roller diameter. The construction of the strand guide is compact, meaning that the gap between two rollers is in a minimum range between the roller diameters. In this closed loop, the total strand heat radiation is obviously transferred to the roller surface and to the indirect cooling media. So far, the roller diameter is only related to the proportion of strand surface to roller surface *on the* <?effective for??> heat dissipation. **Fig. 5** shows this relation for the example of two different roller diameters. The heat dissipation is proportional to the roller diameter [1].

Influence of the strand surface temperature. The heat radiation transfer increases exponentially with an increase in strand surface temperature. The strand surface temperature is continuously lowered from the mould down to the cutting area of a continuous casting machine. The strand temperature profile has to be taken into account. **Fig. 6** shows a strand surface temperature profile over the strand width [1].

The „cold“ edges of the slab are at a level of 800 to 900 °C at the end of the strand guide system. After a strong rise up to almost 1070 °C the highest surface temperature could be measured in a distance of about 400 mm from the outer edge. At the slab centre, temperature decreases again as a result of the intensive contact between strand and roller surface due to bulging. The decrease in surface temperature follows an exponential function, **fig. 7** [1].

In correlation to this effect the amount of heat dissipated by the strand guide rollers increases, as shown in **fig. 8** [1].

Influence of the roller wall thickness. The amount of heat dissipated by the rollers is finally related to the thermal conductivity and the temperature gradient of the roller material. The thermal conductivity is given by the material design. In relation to the casting parameters the strand surface temperature varies in narrow tolerances. Additionally, the water temperature is in between small ranges<???was ist gemeint? what kind of ranges? Oder vielleicht: Additionally, water temperature is also kept in a narrow range ??>. The last parameter in this system is the wall thickness of the roller surface tube <surface tube oder tube surface?>. The heat transfer increases with smaller wall thickness, as shown in **fig. 9** [1]. Wall thicknesses below a value of 15 mm will enlarge the heat dissipation but, in this case, constructional limits have to be taken into account.

Surface quality of continuously cast products

Slabs. Surface cracks can be avoided even with sensitive steel grades if thermal stresses are eliminated by even cooling and strand temperatures remaining above the second ductility minimum. <?? sind das 2 Gründe -1) cooling und 2) temp higher than 2nd minimum- oder is folgendes gemeint: ...by even cooling provided that strand temperature always remains above the second ductility minimum??> So the surface temperature of the strand at the end of the withdrawal machine should be higher than 1000 °C. Cooling without spray water is expected to avoid local overcooling caused by uncontrolled water flow. In pilot trials surface temperatures of slabs were measured at casting machines with different cooling techniques. The results in surface temperature are compared after 20 min of casting time in **fig. 10** [1]. With normal spray water cooling a strand temperature of almost 970 °C can be achieved. With air-mist cooling a surface temperature of 1030 °C is measured, which is more convenient for the surface quality. Even better surface quality is expected with slab temperatures of 1080 °C which are achieved in the dry casting technique with pure roller cooling.

Pipes. Fig. 11 shows some results of UOE pipes [1]. With the development of the air mist cooling it becomes possible to reduce the scarfing loss from 3.3 to 2.8 %. Introduction of the dry casting technique allows the production without any scarfing. Start and end slabs result in the remaining loss of 0.3 %. In a similar way the pipe quality has been improved. The amount of pipes with surface defects has been reduced from 33 to 10 and finally to 1 %.

Peritectic steel grades. Casting of peritectic steel grades with a carbon mass content between 0.09 % and 0.12 % turns out to be difficult regarding surface quality because with cooling immediately after solidification $L \rightarrow \delta$ the δ/γ-transformation takes place. The phase diagram Fe-C for high temperatures is shown in **fig. 12** [6].

This transformation is connected with a physical shrinkage. At the point of solidification the strand shell shrinks in the mould and may locally take off from the mould wall. The following heating up of the strand shell due to the liquid steel from inside causes a new push to the mould wall. The sudden cooling makes the strand shell shrink again. This permanent change of local take-off and push-on can first lead to internal cracks at the solidification front which cannot be cured by the liquid steel. In case of further strains, i.e. bad lubrication or unfavourable mould oscillation, these internal cracks burst up to the surface and may cause strand breakouts. **Fig. 13** [7] shows a graphical representation of these processes.

Tensions caused by frictions based on transversal contraction of the strand shell build up linearly starting from the narrow side of the strand and proceeding to the centre of the slab, **fig. 14**. In this area the highest tension rate can be observed. Consequently, longitudinal cracks will build up in the centre of the slab thus resulting in strand breakouts of worst case [8].

To improve the surface quality of peritectic steel grades, a reduction of the heat extraction in the mould is necessary. The heat flux in the mould can be influenced by different casting parameters like casting speed, stroke length, stroke frequency and negative strip time. Low casting speed reduces the heat extraction and thereby improves the surface structure of the casting material. The longitudinal crack index as a function of the casting speed is shown in **fig. 15** [9].

It is also possible to influence the local heat flux by employing suitable casting powders. The following characteristics have proven favourable:

- ♦ high cristallisation temperature,
- ♦ low viscosity,
- ♦ high basicity (i.e. high CaO/SiO_2-ratio),
- ♦ high content of Na_2O,
- ♦ high content of F,
- ♦ high content of Li_2O.

Conclusion

The development of continuous casting without secondary spray water cooling guarantees the direct charge of slabs to the next processing stage. Also the critical peritectic steel grades with carbon mass contents between 0.09 and 0.12 % C can be processed directly wíthout machine scarfing using suitable casting powders.

References

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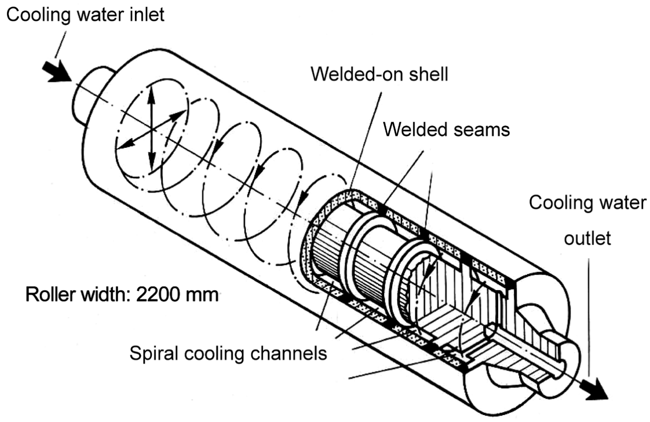

Fig. 3: Diagramme of a spiral-welded roller and cooling circuit [1]

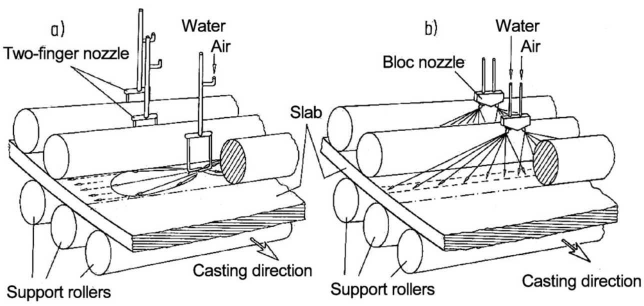

Fig. 1: Air mist cooling using two-finger nozzles (a) or bloc nozzles (b) [1]

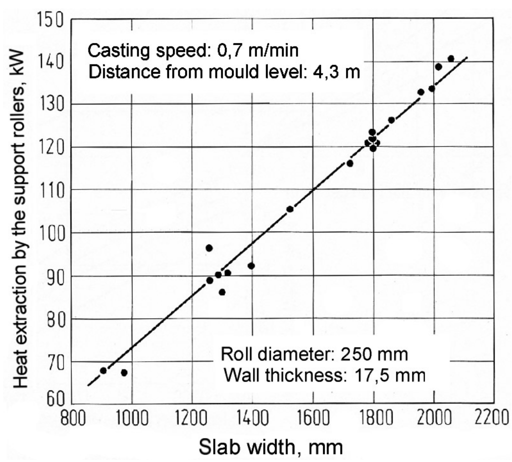

Fig. 4: Heat extraction by the support rollers as function of slab width [1]

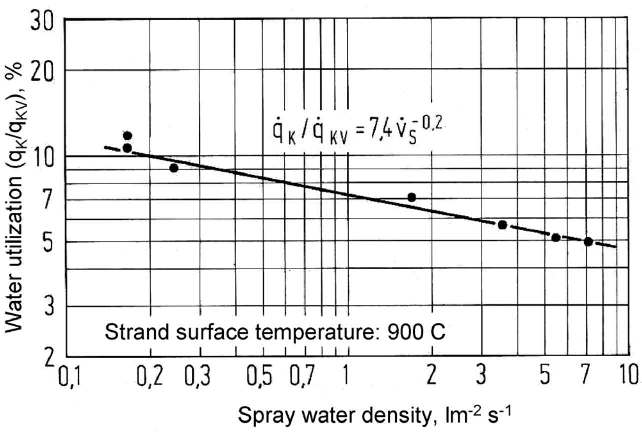

Fig. 2: Spray water utilisation versus water density [1]

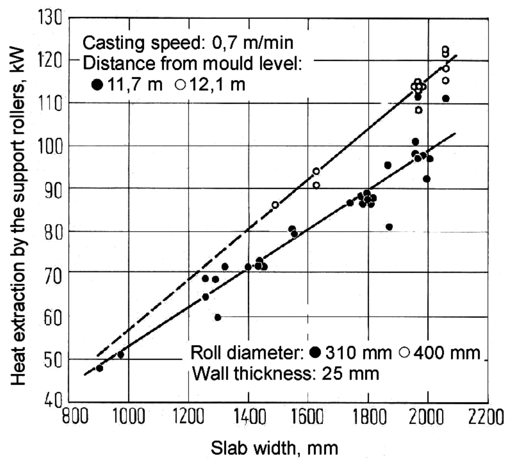

Fig. 5: Influence of the roll diameter on the heat extraction by the support rollers [1]

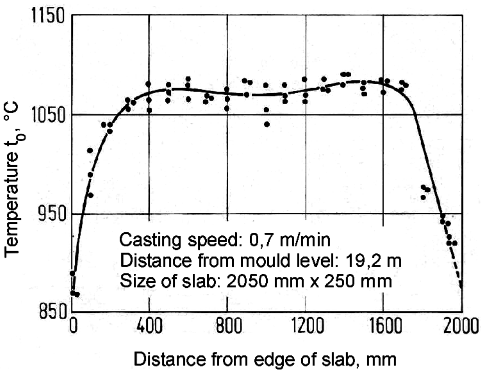

Fig. 6: Profile of surface temperature as function of the slab width for spray water cooling [1]

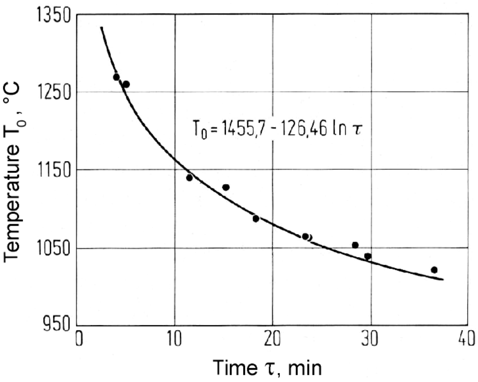

Fig. 7: Surface temperature as function of time [1]

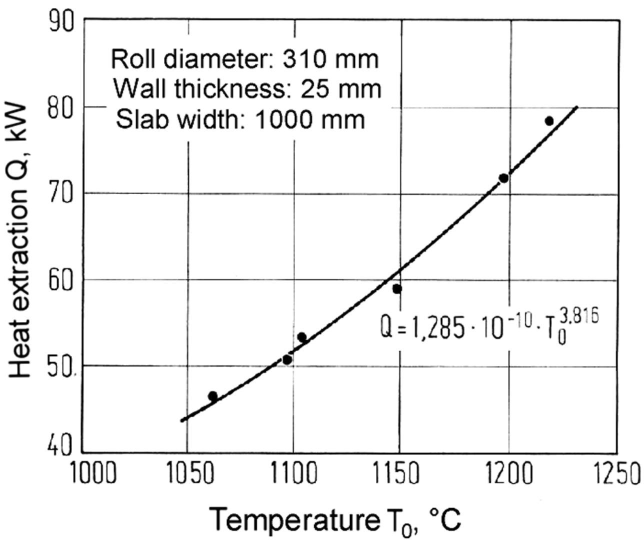

Fig. 8: Heat extraction by the support rollers as function of the surface temperature of the strand [1]

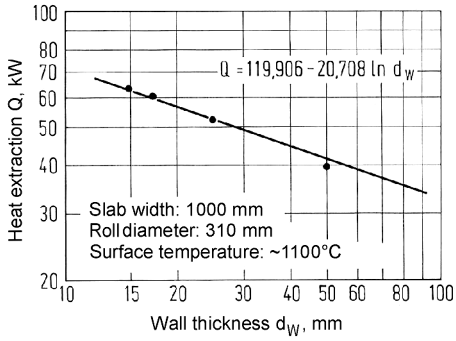

Fig. 9: Heat extraction by the support rollers as function of wall thickness [1]

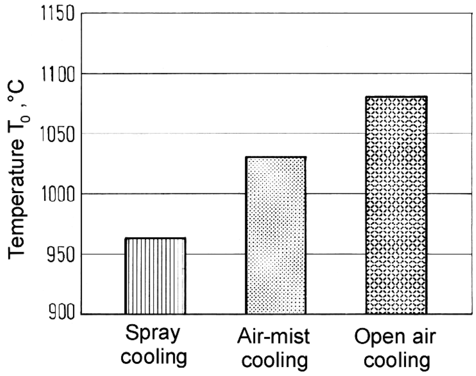

Fig. 10: Surface temperature after 20 min for the different cooling techniques [1]

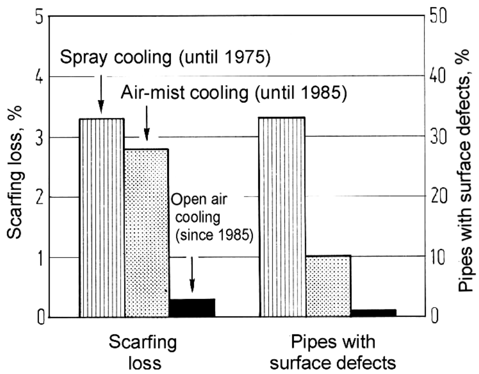

Fig. 11: Surface quality for the different cooling techniques [1]

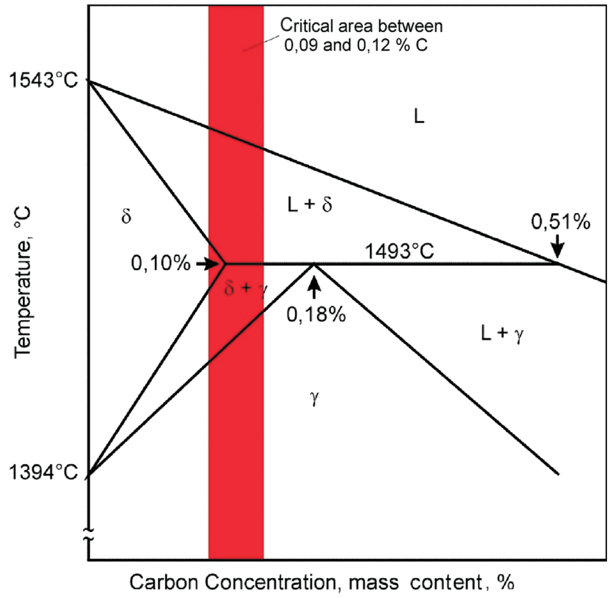

Fig. 12: Phase diagramme Fe-C for high temperatures [6]

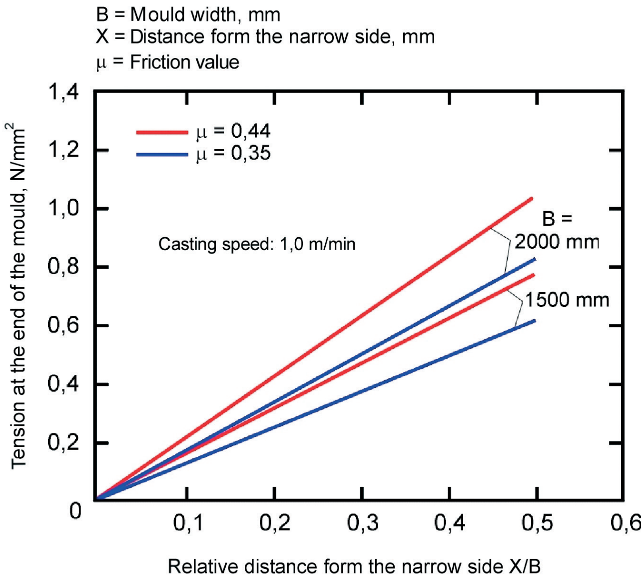

Fig. 14: Strand tension as function of the distance from the narrow side of the slab [8]

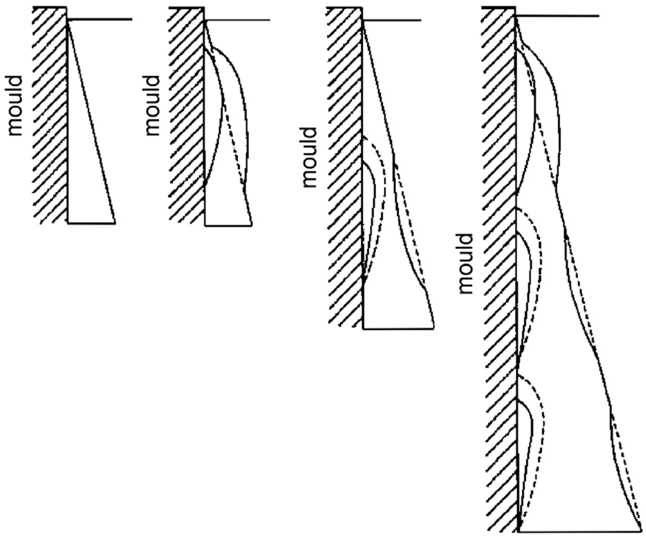

Fig. 13: Diagrammatic representation of gap formation in the mould as a result of the δ to γ phase transformation [7]

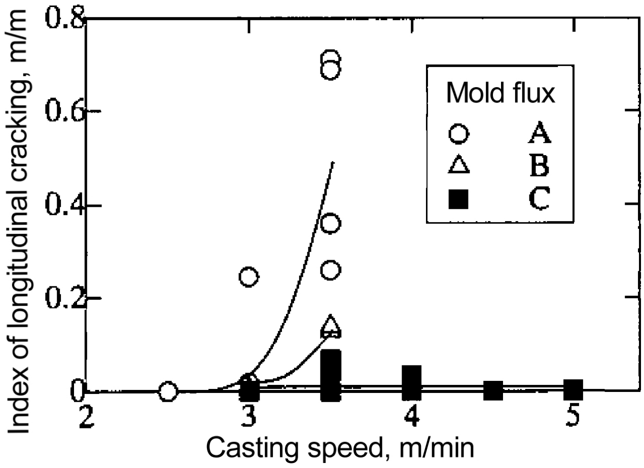

Fig. 15: Surface quality as function of casting speed [9]

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