Effect of secondary cooling on the position of the solidification front in continuous casting of steel

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Introduction

The parameters effect the stability and productivity of casting and the quality of the product in a complex way of interactions. This effect can be analysed in two different ways:

with the help of production experiments,
with the help of calculations based on process simulation.

Production experiments are carried out with two objectives in mind:

fine-tuning process of control systems, during which correlation is established between the defects and the various sensor signals (e.g. temperature, eddy current) [1];
experiments for the improvement of productivity and quality.

Production experiments are very expensive, thus they have to be preceded by simulation-based analyses. Such analyses have been made possible by the rapid development and application of computer technology in the recent past.

Simulation programs

TEMPSIMU, developed by the University of Helsinki, is a program for the simulation of steady state conditions. The input data of the software (heat conductivity, specific heat, density, proportion of phases, latent heat) are generated by the IDS program as a function of temperature on the basis of chemical composition. The software is for PC platforms.

The Swiss-made CALCOM program is able to simulate transient processes, too. The input data can be freely programmed facilitating the addition of the latest discoveries on interfering factors (for instance resulting from laboratory experiments) to the simulation environment.

Thus, CALCOM offers the opportunity of a more detailed analysis, but requires a mathematical representation of boundary conditions. For example, TEMPSIMU requires the data input of the type of nozzle, the water temperature and the water distribution for the simulation of the effects of the secondary cooling zone. As opposed to this, CALCOM requires the knowledge of heat flux and the heat transfer coefficient as a function of temperature for each boundary surface. Moreover, the running of the programme requires a powerful computer as a platform.

TEMPSIMU has been used in the present analysis. The first of the input data is a user-defined finite element mesh for the representation of the crystallisation processes. The elements of the defined finite element mesh represent the temperature of the slab at given points as they pass through the entire length of the casting machine from top to bottom at casting speed as a function of time. TEMPSIMU input data include:

mesh data,
material data (IDS output),
casting machine specifications,
process tuning data.

The program calculates the temperature of the mesh points as a function of time, and is capable of displaying these data in several forms of graphical representation.

With the help of the program the change in shell thickness, the shape of the solid shell in cross section as a function of distance from the meniscus and surface temperature can be calculated directly.

The effect of the construction of secondary cooling on solidification

In this paper, we simulate a usual vertical casting machine. The required parameters of the machine were available since they had been determined by previous measurements [2]. The casting speed of 0.6 m/min and 30oC overheating were chosen for investigations. The composition of steel used in the analysis:

C %	Mn %	Si %	S %	P %
0.200	1.400	0.250	0.005	0.005

Appropriate cooling may ensure optimal liquid pool length and shape, resulting in limited macro segregation in the solidified material. Under inappropriate cooling conditions, however, crystallisation effected by excessive centre-line water cooling will be finished in the middle line of the slab with liquid steel remaining on the sides. In this double liquid pool (W shape) [3], the liquid is more prone to occlusion, which results in increased macro segregation in the solidified slab. According to the crystallisation theory, crystallisation starts on fine globulated grains on the surface of the slab, and with the decrease of the intensity of heat-removal, columnar dendritic crystals start to form gradually. If sufficient cooling intensity or overcooling is provided, these columnar crystals may even touch each other in the middle of the slab. The fast-growing columnar crystals displace liquid from among the crystals, gradually increasing the concentration of segregating elements in the decreasing amount of liquid matter. In cases of crystallisation ending in columnar dendrites or a very small zone of equiaxed dedritic zone, excessive segregation results in compromised mechanical parameters at the places that solidified last. In order to avoid this effect, crystallisation should preferably not end in columnar crystals but the equiaxed dedritic zone, where the degree of macro segregation is much less extensive.

The construction of the secondary cooling zone of the casting machine causes too strong centre-line cooling. The simulation reveals the formation of a double liquid pool.

The structure of the secondary cooling consist of 6 zones and 35 nozzle lines. From zone 4 onwards there is only one nozzle per nozzle line with double agent cooling. The water distribution of these nozzles across the cross section of the bar results in an intensive centre-line cooling. Accelerated shell formation at the centre line starts at 4-5 metres from the meniscus level. For this reason, from zone 4 onwards The nozzles have been replaced with ones offering a much more intense cooling effect at the sides of the slab. The modified nozzles provide no centre-line cooling at all.

The figure 1 shows the water distribution of the original nozzle lines, while the figure 2 represents that of the modified ones.

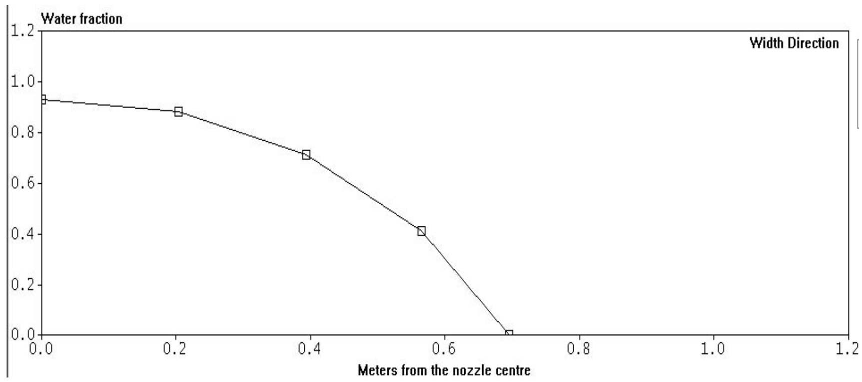

Figure 1: Spraying pattern of the original nozzle lines

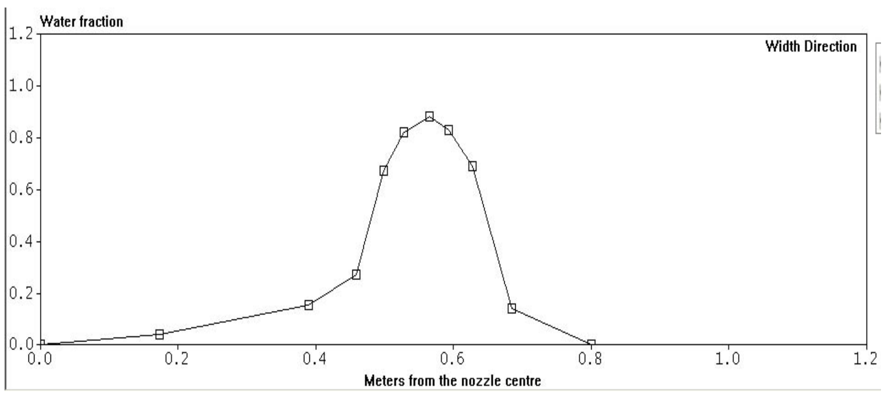

Figure 2: Spraying pattern of the modified nozzle lines

Using of new nozzles in the secondary cooling zone, the solidification would have had to be finished in the center of slab. However, the investigation showed a double liquid pool – altough with 6 % lesser depth – if the liquidus temperature was used for indication of pool border. But the solidification was finished in the center with 8 % larger depth (see Table 1.)

	Original cooling conditions	Modified cooling conditions
Liquid pool length for liquidus	8.70 m	8.17 m
Liquid pool length for solidus	10.72 m	11.75 m

Table 1: Calculated liquid pool length.

Figure 3. shows the increasing of shell thickness using different cooling conditions. The vertical arrows indicate the characteristic shell thickness in the figures 4.-7.b.

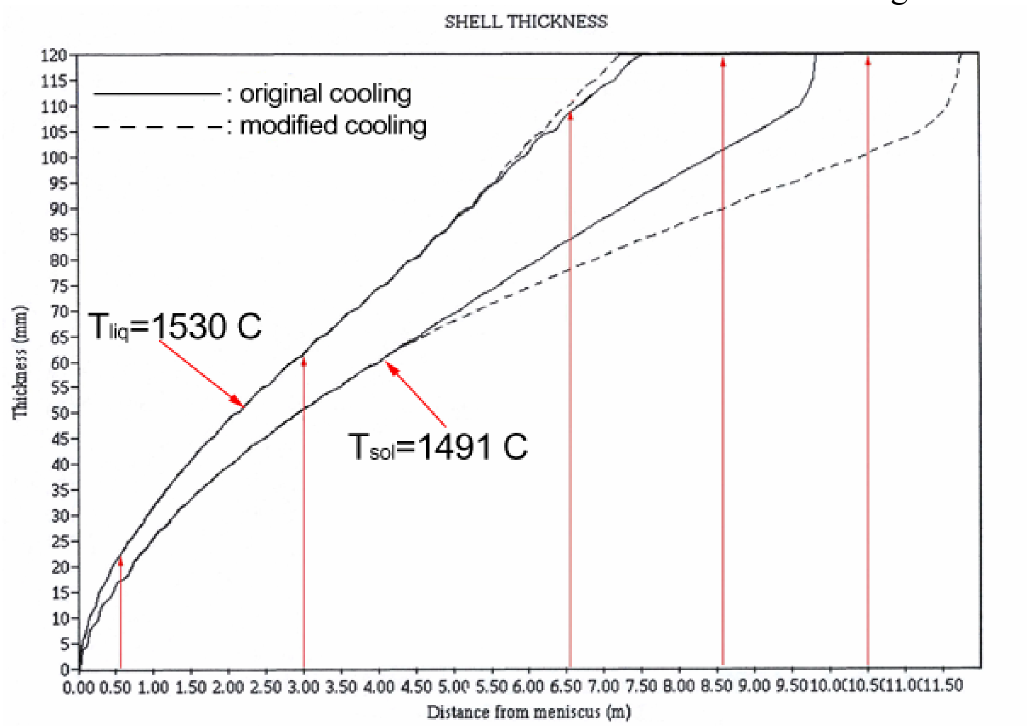

Figure 3: Shell expansion graph.

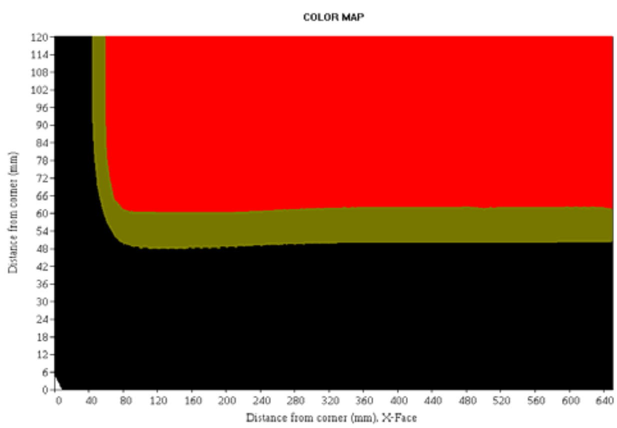

Fig.4: liquid pool shape in the quarter of cross section 3 meters from the mold.

Figure 4. shows the shell contours below 4. cooling zone. The contours separate the picture into two parts. The light area indicates the liquid metal and the dark area indicates the solid metal. Figure 4. corresponds to both cooling systems. Figs. 5.a-7.a corresponds to original cooling, figs. 5.b-7.b are valid for modified cooling.

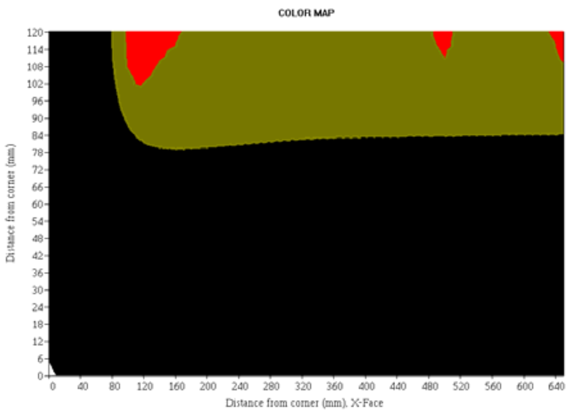

Fig.5.a

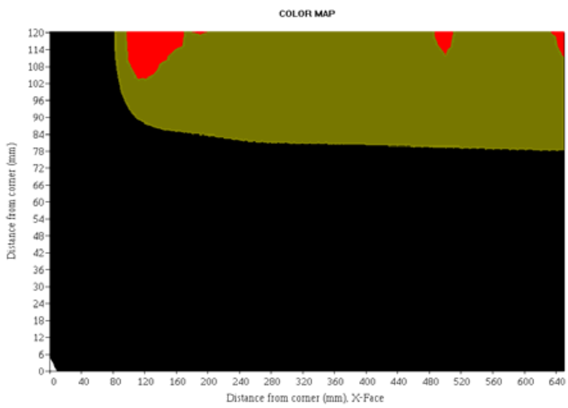

Fig.5.b

Fig5: Liquid pool shape in the quarter of cross section, at 6.6 meter distance from the mold with original cooling (Fig.5.a) and with modified cooling (Fig.5.b).

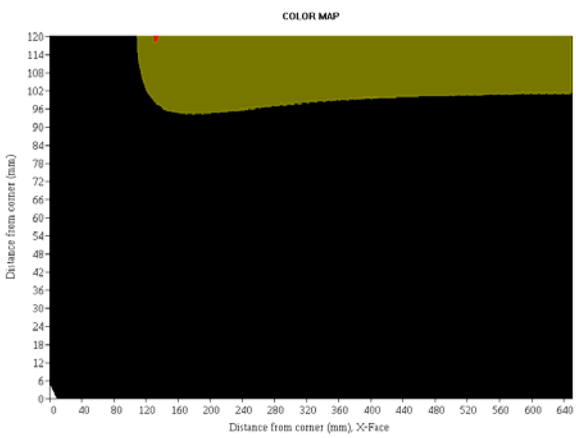

Fig.6.a

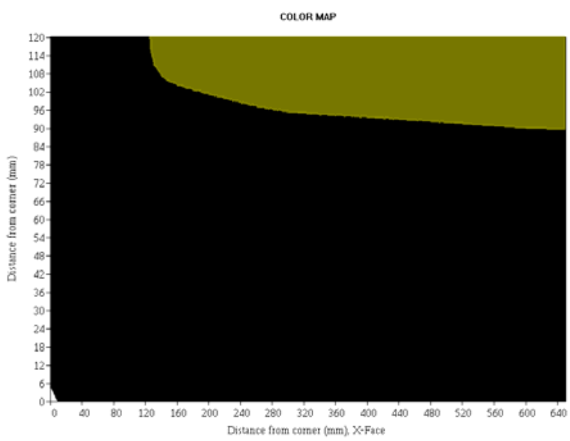

Fig.6.b

Fig.6: Liquid pool shape in the quarter of cross section, at 8.6 meter distance from the mold with original cooling (Fig.6.a) and with modified cooling (Fig.6.b).

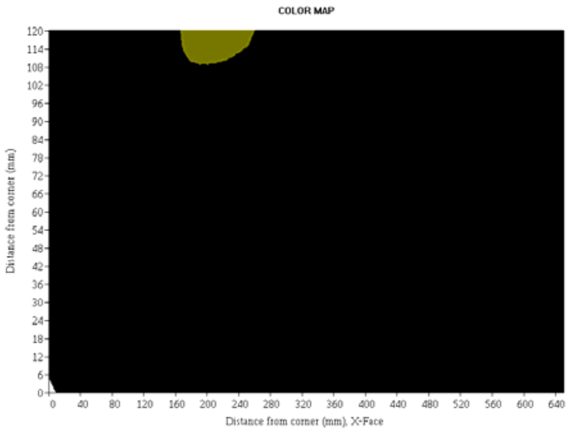

Fig.7.a

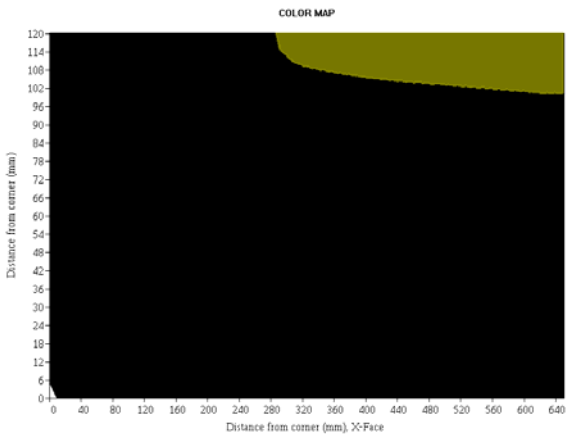

Fig.7.b

Fig.7: Liquid pool shape in the quarter of cross section, at 10.6 meter distance from the mold with original cooling (Fig.7.a) and with modified cooling (Fig.7.b).

Conclusion, further investigations

The TEMPSIMU program is very useful for evaluation of the effect of casting parameters, and by this way gives a tool for development of technology. Nevertheless, a lot of functions are supposed by the program, thus a control based on own experiments seems to be required.

With the aim of control, the testing of a 100 mm section i.e. because of symmetries a quarter of the section is planned. The characteristic points of crystallization can be determined by the program. The chemical analysis of carbon and sulfur content, as well as the evaulation of metallographic structure and mechanical properties (by tensile and impact testing) in these points would be done for verification of the program.

References

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