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TRANSITION PHENOMENA IN TUNDISH DURING GRADE CHANGE OF CC-STEEL – PART 2

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ABSTRACT:
The paper deals with the possibilities and results of the transition processes modelling in a four-strand billet caster tundish with a change in the chemical composition of the continuously cast steel during sequence casting. The simulations were done using both *numerical modelling* (CFD Fluent programme) and *physical modelling* (1:3 length scale tundish model). This paper presents the data obtained on the extent of the transition zone for various non-standard boundary conditions of steel casting. The conclusion compares the data obtained from numerical modelling with the operational experiment.

KEY WORDS:
steel, continuous casting, grade change, tundish, modelling, plant experiment.

INTRODUCTION

When casting two different steel grades in a sequence, the steels tend to get mixed in the tundish and, in certain cases, also in the liquid cores of the solidifying blanks. That leads to the emergence of chemistries that correspond neither to the previous nor to the following steel grade cast. A so-called mixed or transition zone occurs in the continuously cast blanks as a results, with the chemical composition out of the tolerance specified for either of the steel grades cast. Verification and minimisation of these transition zones is an important pre-requisite to increasing the productivity of CCMs.

In order to verify the extent of the transition zone, both direct operational measurements and results obtained from physical or numerical modelling tools may be considered. On one previous occasion, when addressing a project assigned by the Grant Agency of the Czech Republic, a numerical simulation was undertaken to establish the extent of a transition zone in continuously cast 108x108mm billets related to the particular conditions provided by the billet caster no. 2 at TŽ, a.s. using a CFD Fluent software package. The results of this simulation, which are given in papers [1-3], have for instance proved a very significant effect of the weight of steel in the tundish and the flow pattern conditions on the extent of the transition zone and led to more accurate data on the number of emerging transition billets.

As the CCM no. 2 at TŽ, a.s. has practically moved to the casting of 150x150mm billets only it was necessary to adapt the simulations to these conditions, too. Special attention was devoted to the evaluation of

- tundish steel weight at ladle change,
- the effects of the temperature difference between the steel present in the tundish and newly supplied steel,
- the effects of stoppage of some casting strands,
- the effects of weight steel flow into the tundish being refilled.

1. Modelling of transition zone extent with a closed casting strand

The fundamental technological methods of minimising the extent of transition zones, the main factors affecting the transition zone extent, conditions applying to the numerical and physical modelling and these experiment's results for standard casting conditions were discussed in previous paper (part 1). This second part is mainly devoted to the simulations of non-standard casting conditions.

1. 1. Obstruction of a casting strand

Intended obstructions of one of the casting strands may exceptionally take place in an attempt to allow for a controlled extension of the casting time, e.g. due to a delayed ladle change. Forced closures of one the casting strands in the course of the casting may for instance occur due to emergency situations, e.g. a break-out at any of the casting strands. The obstruction of the casting strand naturally leads to a change in the extent of the transition zone in the remaining casting strands, to which the automated control system must react by making corresponding adjustments in the marking and tracing of the transition blooms.

The emergence of the transition zone was traced for CCM 2, tundish steel weight of 8 to 15 t, isothermal and non-isothermal flow and four possible versions of the closure of one of the casting strands. The data on the extent of the transition zone in these strands, summarised in table I, were deducted from the transition curves obtained for the three functional casting strands.

The table clearly shows that for isothermal flow conditions and the "stricter" dimensionless specification {0,1; 0,9}, there is a marked difference between the extents of the transition zones obtained from the individual variants as per the type of casting strand closure. The biggest transition zone was obtained with the instant involving a closure of the casting strand no. 8 (and with a simultaneous closure of the corresponding casting strand no. 1 at the other tundish), where up to 36.9 t of transition steel could be expected to emerge at the 6 functional casting strands, which is more by approx. 6 t compared to the situation, where all casting strands were functional. On the contrary, with the variant involving a closure of the casting strand no. 7 (and, correspondingly, casting strand no. 2), the total transition zone weight was reduced to 31.2 t, which is practically the same value as that observed for the situation with all strands in operation.

The values given in table I also attest to the beneficial effect of non-isothermal flow on the extent of the transition zone. The weight of the transition steel for the stricter dimensionless specification was found to range from 28,25 t to 31,55 t, and thus did not differ largely from the value of 29,01 t which was the case with all casting strands functional.

When introducing the simulation results in real operation, an account needs to be taken of the fact that the weight of steel pertaining to the transition zone, when one of the casting strands is closed at each tundish, is divided among three functional strands of the given tundish only (and six strands for two tundishes, respectively), which ultimately leads to an increase in the length of the transition blooms at each of these casting strands.

Table I: Results of simulation of the extent of transition zone in 150x150mm CC-billets using CFD Fluent (8 t weight steel in tundish, one strand is stopped)

Conditions			Transition Zone Extent						
Weight of steel in tundish, t	Casting speed, $m.min^{-1}$	Temperature difference, °C	$\widetilde{c}_{old}$	$\widetilde{c}_{new}$	Units	Stopped casting strand	min/max	Max. ref. length at 1 casting strand, m	Total weight at 6 casting strands, t
8	2,7	0	0,1	0,9	s	CS5	82/826		35,0
					m		3,69/37,17	33,48	
			0,3	0,7	s		118/436		14,9
					m		5,31/19,62	14,31	
		30	0,1	0,9	s	CS5	120/720		28,25
					m		5,4/32,4	27,0	
			0,3	0,7	s		128/432		14,31
					m		5,76/19,44	13,68	
8	2,7	0	0,1	0,9	s	CS6	84/762		31,9
					m		3,78/34,29	30,51	
			0,3	0,7	s		120/466		16,2
					m		5,4/20,97	15,57	
		30	0,1	0,9	s	CS6	118/788		31,55
					m		5,31/35,46	30,15	
			0,3	0,7	s		126/460		15,73
					m		5,67/20,7	15,03	
8	2,7	0	0,1	0,9	s	CS7	80/744		31,2
					m		3,6/33,48	29,88	
			0,3	0,7	s		128/468		16,0
					m		5,76/21,06	15,3	
		30	0,1	0,9	s	CS7	124/770		30,42
					m		5,58/34,65	29,07	
			0,3	0,7	s		130/444		14,79
					m		5,85/19,98	14,13	
8	2,7	0	0,1	0,9	s	CS8	78/862		36,9
					m		3,51/38,79	35,28	
			0,3	0,7	s		122/400		13,09
					m		5,49/18	12,51	
		30	0,1	0,9	s	CS8	136/752		29,01
					m		6,12/33,84	27,72	
			0,3	0,7	s		162/438		13,00
					m		7,29/19,71	12,42	

This is apparent in the graphical comparison of the extent of the transition zone in figure 1, where the simulation results for isothermal flow conditions were processed. The figures clearly show that with steel weight of 8 t in the tundish and closed casting strand no. 8, the emergent transition zone reached as far as the fourth bloom of the casting strand no. 7, provided bloom sizing to 11,9 m lengths and dimensionless specification {0,1; 0,9} are considered. For the "milder" specification {0,3; 0,7}, however, the transition zone for all four variants only interferes with up to two 11,9 m-long blooms. As shown in table I, more favourable distribution of the transition zone may be observed for blooms cast under the conditions of non-isothermal flow.

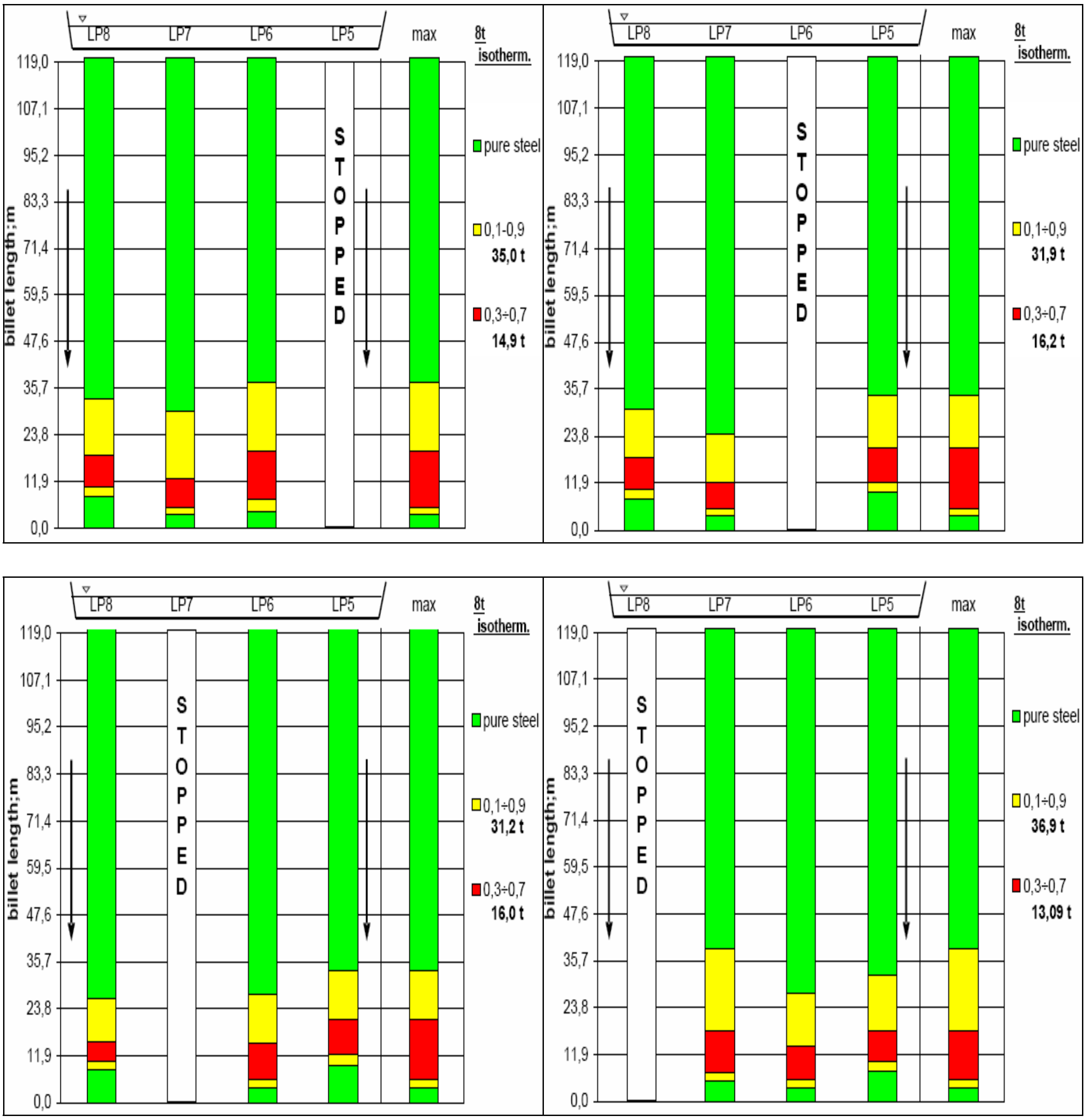

Figure 1: Graphical representation of the transition zone extent in 150x150 mm billets under *isothermal* bath flow, at the tundish steel weight 8t and with one stopped casting strand

1. 2. Obstruction of two casting strands

Numerical simulations of a casting strand closure were also done for those situations, where, for any reasons, two casting strands were obstructed at a single tundish. The results of these simulations showed even more marked displacements in the locations of the transition zones at the functional casting strands. Although this particular casting variant is unsuitable from the operational point of view, the results obtained from numerical simulations may, even in these extreme instances, yield the required data on the real extent of the transition zone in the cast blooms.

2. Modelling of tundish refilling mode with increased flow rate

In sequence casting at CCM 2, for various reasons, the mode of rapid tundish filling up to the nominal weight is usually used during the ladle change, i.e. during a certain period of time when the steel flows into the tundish at increased mass flow to ensure an increase in weight during 2 to 3 minutes. The increased flow into the tundish leads to substantial changes in the flow characteristics and, in addition, to an increase in the volume of turbulences, which may adversely affect the steel cleanliness. The increased flow rate may also lead to a reduction in retention times as a result of a growth of the fraction of stirred volume in the tundish. The change in tundish flow dynamics during the overfilling period quite logically results in a change in the transition curve trends. The objective of the modelling simulations was to specify the effect of the increased flow rate into the tundish upon the character of the transition curves and hence even the potential drift in the extent and location of the transition zone under the conditions prevailing at CCM no. 2.

The mode involving tundish refilling with increased flow rate may be relatively well simulated using the method of physical modelling, where the corresponding trends of changes in mass flow into the tundish model may be established using the control elements of the model fluid flow. Besides the physical simulations, we also focused our attention to the numerical simulations of these phenomena. It needs to be noted that solving tasks of this type using the CFD programmes is characteristic for being rather complicated.

Modelling of the transition mode determined by the dropping melt level down to the low level and its subsequent rise to the usual level height calls for a use of a multi-phase melt-gas flow model, i.e. a model that allows for an interaction of the two phases as well as to solve the respective equations of conservation of mass, momentum and energy for each individual phase. The multi-phase Volume of Fluid (VOF) model is the most suited one to the conditions defined in this way. The tasks addressed by the VOF multiphase model are sensitive in terms of the time step length; here, the selected time step length amounted to 0,01 s based on the results of the testing tasks, which logically leads to substantial simulations times despite using high-performance computers.

The variant briefly characterised below was modelled using the CFD Fluent programme: the tundish level drops from 15 to 8 t with stopped tundish inlet (ladle change); when the weight of 8 t is achieved the tundish is refilled at a mass flow rate of 5 $t.min^{-1}$; once the weight of 15 t is obtained, the mass flow rate is reduced to 2,31 $t.min^{-1}$. The simulations were performed for both isothermal and non-isothermal flow conditions.

The characters of transition curves for the selected casting strand no. 7 are reciprocally compared in figure 2. The figure shows clearly that the transition curve for the filling of the tundish with increased flow rate shows an earlier and steeper concentration growth compared to the curve for the stable level at 8 t, which results in an earlier detection of the transition zone in the cast blooms as well as in an emergence of a sharper interface. At approximately 200 s after the start of the refilling process, after the weight of 15 t has been achieved, the flow rate is reduced, which results in a change in the character of the transition curve. The concentration growth is already less steep and, at approx. 300 s, the curve already interferes with another curve for the stable 8 t steel level in the tundish. From the practical point of view, this means, besides other, that in order to adhere to the dimensionless specification of 0,1 ÷ 0,9, the extent of the transition zone will be even larger than was the case with the stable weight of 8 t. The dimensionless specification which such an extent of strictness, however, tend to be very rare in real operations; much more frequently, they range between 0,3 ÷ 0,7. For these values, the mode with increased flow rate is, on the contrary, ***more suitable***. The above example conclusion, however, does not apply generally – the extent of the transition zone depends on the weight of steel in the tundish achieved after the filling process (which mostly tends to range between 11-14 tonnes) and, in addition, on the time curve of the refilling process.

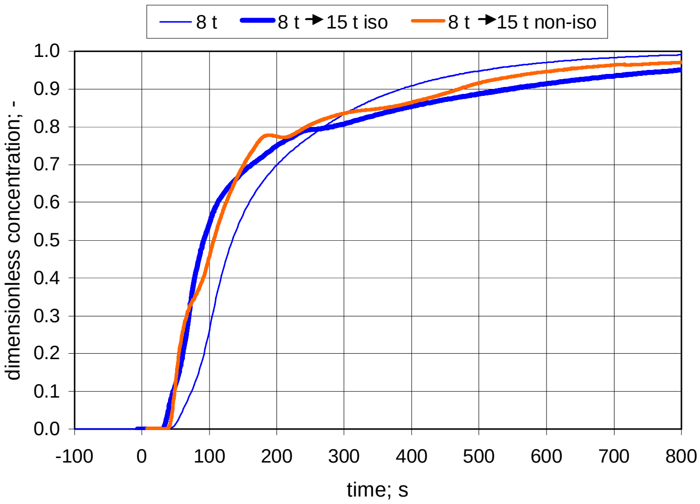

Figure 2: Comparison of transition curves for casting strand 7 for 8 t of steel in the tundish and tundish refilling from 8 to 15 t through an increased flow rate under *isothermal* and *non-isothermal* conditions

Figure 2 also clearly shows that the increased flow rate nullifies the difference between the isothermal and non-isothermal flow conditions. The character of the two curves is very similar in the ascending and the descending part – a similar character was found out for the other casting strands, too. The factor causing this phenomenon apparently relates to the generation of pronouncedly higher inertial forces in the course of the tundish filling with increased flow rate, suppressing the effect of natural convection as a consequence of varying temperatures of the steel in the tundish and the steel being fed into the tundish.

The above shows that one possibility to gain information on the extent of the transition zone in continuously cast blooms involves a use of the modelling methods. The results may further be processed using a fitting mathematical/statistic procedure in such a way as to obtain applicable relation for direct implementation in the operational automated system of control and tracing of transition blooms.

3. Comparison with operational experiment

An important part in solving the issue of transition zones was the mutual comparison of the results obtained form numerical modelling and those obtained from the operational experiment. The principle of the operational experiment involved cross alloying of two sequential heats with nickel and copper and subsequently determining the concentrations of the two elements along the length of the cooled billets using a mobile spectrometer [4,5].

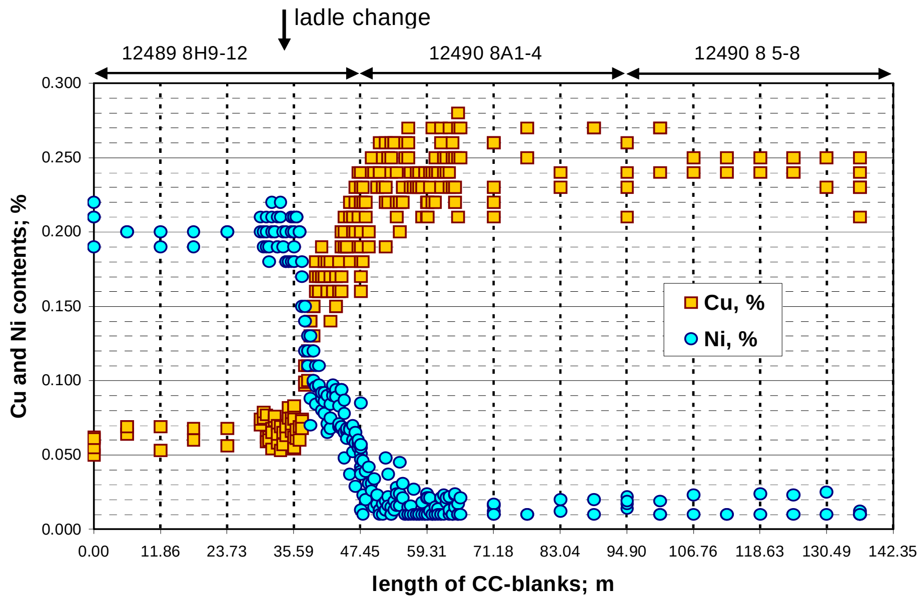

Figure 3: Graphic illustration of the course of variations in the content of nickel and copper in blanks of no. 8 casting stream at transition from heat No. 12489 to heat No. 12490

Figure 3 then shows the results of the analyses for a single casting strand. The vertical chart grating strokes represent the boundaries of the average bloom lengths. The figure clearly shows growth in the concentration of copper, which corresponds to the simultaneous decrease in nickel content in the as-cast blooms. The length of the actual transition zone for this particular casting strand is approx 27 m and the zone interferes with the mere three blooms.

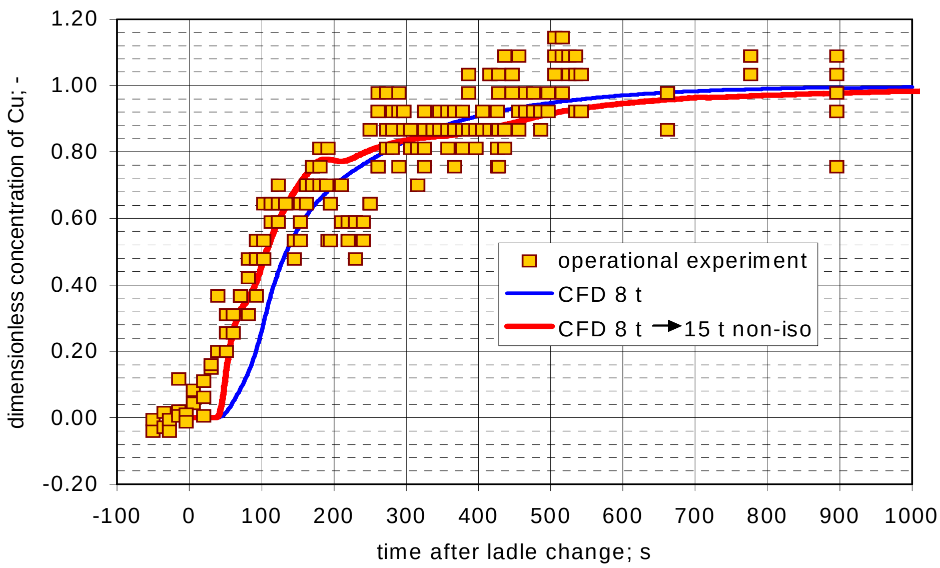

Figure 4: Graphical comparison of operational results with those obtained from CFD simulation of transition zone origination for the casting stream no.7

Figure 4 graphically compares the operational results with those obtained from a numerical simulation for the constant tundish steel weight of 8t for the mode involving tundish refilling with increased flow rate. The chart clearly shows the relatively good correlation of the numerical simulations with the operational experiment. A minor disagreement may be observed in the rise phase, where the curves from the numerical simulations show a delay compared to the experimental data, which may relate to the somewhat different conditions of the operational experiment and the numerical simulations compared to it. Considering that these results are not very important in terms of the operational determination of the size of the transition zone, the results obtained from the numerical simulations that were, in addition, verified using physical modelling, are acceptable from the operational point of view.

4. Conclusion

The physical and mathematical modelling of bath flow in a four-strand tundish at CCM no. 2 at TŽ, a.s. was primarily focused upon the simulation of the transition zone extent in finished billets originating as a result of sequence casting of two different steel grades. Results of these simulations also led to the draft of the so-called transition curves applying to individual casting strands, on the basis of which the extent of the transition zones may be predicted for a range of verifying casting conditions and dimensionless specifications of chemical composition of steels. The results obtained from the simulations imply that the transition zone is much smaller than that inherent in past practice applied for CCM 2. This conclusion had been previously confirmed by results obtained from extensive operational measurements of the transition zone.

Presently, all data obtained from numerical and physical modelling were treated using approximation and regression methods the aim of which was to obtain mathematical relations accounting for the effect of boundary casting conditions. Results of these mathematical relations were implemented to the control system of CCM 2.

REFERENCES

[1.] Michalek, K.,Troszok, V., Pindor, J. , Střasák, P.: Numerická simulace rozsahu směsné oblasti v plynule litých sochorech 108x108 mm. Hutnické listy, 2002, č.6-8, s.38-45. ISSN 0018-8069.

[2.] Michalek, K., Pindor, J. and Střasák, P.: Numerical simulation of transition zone extent in continuously cast steel. Acta metallurgica Slovaca, 2001,č.2/3, s.419-424. ISSN-1335-1532.

[3.] Michalek, K., Střasák, P., Pindor, J.: Modelování vzájemného smíchávání dvou značek ocelí v podmínkách mezipánve. In Teorie a praxe výroby a zpracování oceli. Rožnov pod Radhoštěm, 2002, s.102-108. ISBN 80-85988-69-0.

[4.] Michalek, K., Pindor, J., Lasota, R., Szymanik, M. and Bednarz, V.: Verification of transition zone extent in continuously cast billets under conditions of the No. 2 CC-machine at Třinec Ironworks, a.s. Acta metallurgica Slovaca, 2002, č.4, s.423-430. ISSN-1335-1532.

[5.] Michalek, K., Pindor, J., Plura, J., Sawová, M., Gryc, K., Češek, M., Pieprzyca, J.: Operational verification of transition zone extent in continuously část billets of 150 x 150 mm in size under conditions of the No. 2 CC-machine at TŽ, a.s. In 5th international metallurgical conference Continuous Casting of Billets and Modelling of Steelmaking Processes, Třinec, Czech Republic, 2003, s.321-332. ISBN 80-239-0861-8.