INFLUENCE OF MISALIGNMENT LADLE SHROUD ON TUNDISH RESIDENCE TIME

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Abstract
An idea that the ladle shroud under operation conditions can be misaligned towards an impact point on basis of used shroud feeding and holding technology was developed. That means that the stream of incoming liquid steel is not always directed vertically or to the center of impact point of tundish. Different residence times in particular streams at the continuous casting can occur consequently. In case that the tundish is replenished from ladle with different steel quality after previous tundish level decrease, that asymmetry can show in various length of the transition regions of slabs on particular streams of continuously casted steel.

Keywords: tundish, continuous casting, water model, ladle shroud

1. Introduction

At continuous casting of steel tundish is positioned between the ladle and the mold. One of its purposes is to ensure even distribution of steel to all casting streams. Modern tundish is inter alia designed for inclusion absorption, flotation, thermal and chemical homogenization of steel [1,2]. Effort in about last decade was aim into maximize potential of tundish in way of refining, alloying possibility and also in view of transition regions in transient way of casting [3].
Research model allows relatively quick and safe acquisition of information for the design and development facilities at relatively low financial cost. In this case is constantly growing use of physical and mathematical models. In the case of physical models are used mostly in equipment designed to work in a reduced scale, using the theory of physical similarity and modelling [4]. An important fact is that in case of equipment for continuous casting of steel, there is no simple in isothermal flow. For flow simulation of liquid steel by water is very difficult, even impossible to meet all conditions of similarity. The complexity of processes occurring in the real tundish not allows imitate all the processes if such processes are. In modelling we focus on sub-processes, which are suspected of neglecting a significant impact on non-essential variables and processes. We receive approximate similarity, applicable in the case of a water model to simulate the flow of steel in the tundish.
For the flow visualization method uses a tinted liquid. This method uses the already Reynolds in 1883 for determining the transition between laminar and turbulent flow [5].This method allows to obtain a good understanding of the flow in tundish, such as the creation of dead zones or short cutting on the flow [6]. The disadvantage of this method is that after staining the entire volume

of the tundish we cannot make further observation of flow. Along with the visual evaluation of flow is applied water conductivity measuring with equipment from the company Moravian Instruments, utilizing saline injection of KCl to water.

One of the former purposes of using of impact pads besides decreasing of sole erosion was to decrease pressure of molten steel on weirs and dams during replenishing of tundish. During using of first impact pads of simply shapes massive splash was recognized during tundish loading and at the same time breaking of slag level around shroud by reflected stream of steel from impact pad was detected. Therefore further development and improvement of impact pads which eliminate turbulent flow of steel continue [7]. In these days there are highly sophisticated shapes which function strongly depends on precision of impact point of liquid steel which is given mainly by shroud mounting.

All steel flow modifiers in tundish are designed to ideal state [8-10]. Ladle shroud in practice can be often misaligned towards impact point due to used shroud feeding and holding technology. As a result there is a considerable difference in retention time in particular continuous casting streams. In case that tundish is replenished from ladle with different steel quality after previous tundish level decrease, that asymmetry can show in various length of transition regions of slabs on particular streams [11].

2. Material and experimental methods

For comparison of shroud misalignment influence on retention time there was 6 speeds of casting (0.8, 1, 1.2, 1.6, 1.8 and 2m.min^{-1}), whereby one measurement for correct shroud alignment (0°) and one measurement for misalignment shroud. Misalignment of ladle shroud was adjusted by using laser builder’s level and it was 3° in the direction to right casting stream and in another series it was 3° directed to the rear side of tundish **Fig.1**. Measurements were visually interpreted by using $KMnO_4$ indicator and also by water conductivity measuring at tundish inlets and outlets [12,13]. Emplacement of conductivity sensors and tundish layout are in **Fig 2**.

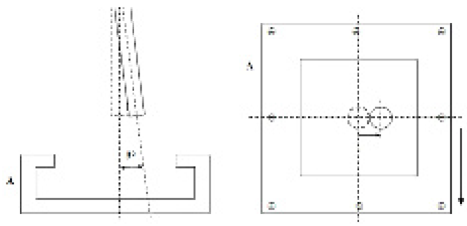

Fig.1 Setting of ladle shroud to 3° directed to the right casting stream

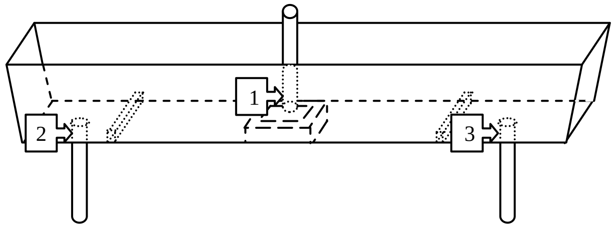

Fig.2 Scheme of tundish layout and conductivity sensors emplacement

3. Results and Discussion

In **Table 1** are minimum and maximum residence time values of model for correctly aligned shroud and misaligned shroud into right direction.

Table 1 Measured residence times for model

Shroud devitation	[°]	0°	3°	0°	3°	0°	3°	0°	3°	0°	3°	0°	3°
Casting speed	[m.min^{-1}]	0.8		1		1.2		1.6		1.8		2	
Left stream	τ_{min} [s]	61.5	79.5	69.5	67	69	66	63.5	51.5	56	49.5	41.5	31
	τ_{max} [s]	81	110.5	108.5	81	110	110.5	141.5	80.5	118.5	48	154.5	55
Right stream	τ_{min} [s]	63	73	67.5	69.5	66.5	83	65	62	63	69	51.5	47
	τ_{max} [s]	87	102.5	99.5	92	116	118.5	130	101	110	126.5	152	129

Based on the measured residence times were calculated the differences of corresponding residence times between left and right casting stream according to current relationships:

$$\Delta\tau_{\min} = 100 - \frac{\tau_{\min rightstream}}{\tau_{\min leftstream}} * 100\% \tag{1}$$

$$\Delta\tau_{\max} = 100 - \frac{\tau_{\max rightstream}}{\tau_{\max leftstream}} * 100\% \tag{2}$$

Where:

$\Delta\tau_{\min}$ is the percentage difference between the minimum residence time of the right stream compared with the left casting stream

$\Delta\tau_{\max}$ is the percentage difference between the maximum residence time of the right stream compared with the left casting stream

A negative value means that the residence time in the right stream is longer than the residence time of the left stream.

Table 2 Percentage difference between left and right stream residence time for correct aligned ladle shroud and misaligned shroud into the right direction

	Correct set ladle shroud 0°		Misalignment ladle shroud 3°	
Casting speed [m.min^{-1}]	Difference of minimal residence time [%]	Difference of maximal residence time [%]	Difference of minimal residence time [%]	Difference of maximal residence time [%]
0.8	-2.4	-7.4	8.2	7.2
1	2.9	8.3	-3.7	-13.6
1.2	3.6	-5.5	-25.8	-7.2
1.6	-2.4	8.1	-20.4	-25.5
1.8	-12.5	7.2	-39.4	-163.5
2	-24.1	1.6	-51.6	-134.5

On **Fig.3** and **Fig.4** is a visual comparison of the water flow in the tundish. In the case of Fig.2 it can be concluded that the redistribution of influent water is symmetrical for left and right side flow. The residence times of the two streams should be the same. If the ladle shroud was offset towards the right casting stream of 3°, it caused the asymmetrical distribution of influent water for both casting streams [14].

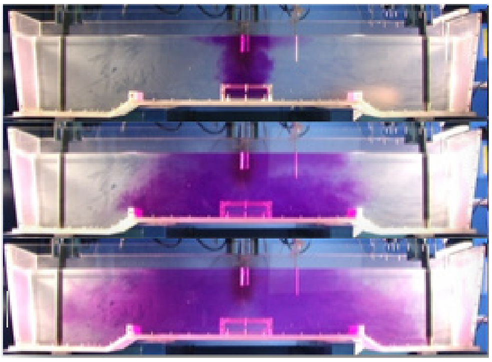

Fig.3 Correct set ladle shroud, 2m.min^{-1}, 10s, 40s, 70s

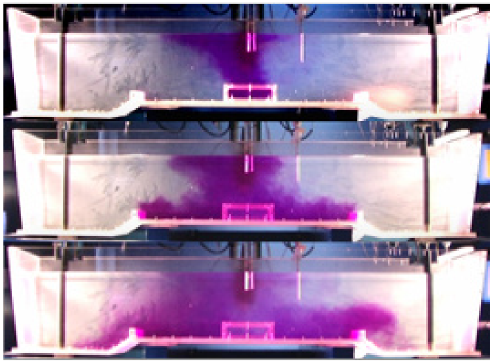

Fig.4 Misaligned ladle shroud 3° to the right side, 2m.min^{-1}, 10s, 40s, 70s

According to **Fig.5** in the case of ladle shroud misalignment is stream of influent water reflected obliquely to the slag, which explains the significant reduction in residence time of the left casting stream.

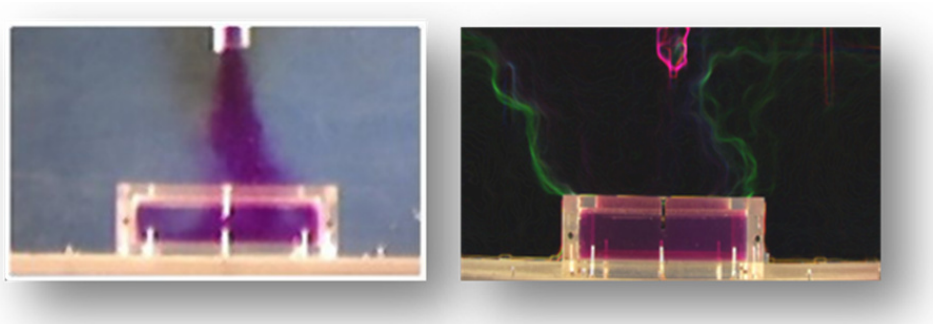

Fig.5 Pictures of vortex above the turbostop. The ladle shroud deviation of 3° to the right, 3s and 10s after injection of contrast medium

This visual comparison is confirmed by **Fig.6** and **Fig.7**. To reduce the minimum residence time occurred mainly in the left stream, and this difference was significant on the casting speed 1m.min^{-1} and achieved 20 seconds. Difference in maximum residence times also increased from casting speed 1m.min^{-1} and in the speed 2m.min^{-1} was almost the 80 seconds, which may manifest in a different length of the transitional area to the predicted length.

If the ladle shroud is tilted from the vertical axis by 3 ° towards the back side of the tundish, there were also changes of residence times compared to the correct set ladle shroud, as shown in **Table 3** and **Fig.8**. Values were calculated using relations (1) and (2). A negative value means that the residence time in the case of the tilted ladle shroud is shorter than in the correct set ladle shroud.

To apply the results on the work is necessary to use a conversion factor of 1.74 according to [6], where it is shown that the processes of the model run 1.74 times faster than on the work.

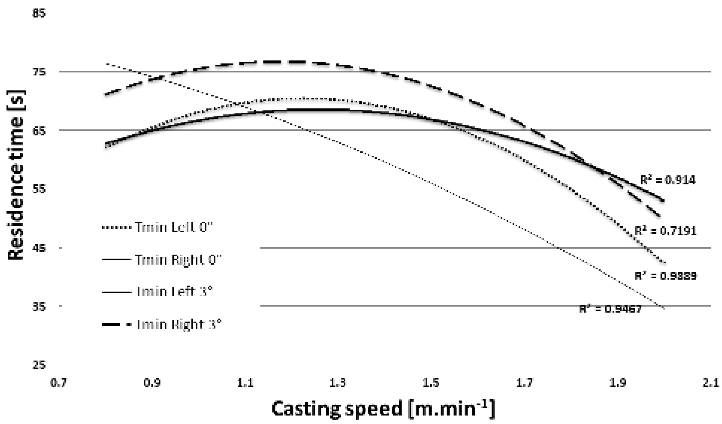

Fig.6 Comparsion of minimal residence time of correct set and misalignment ladle shroud in 3° directed to the right casting stream

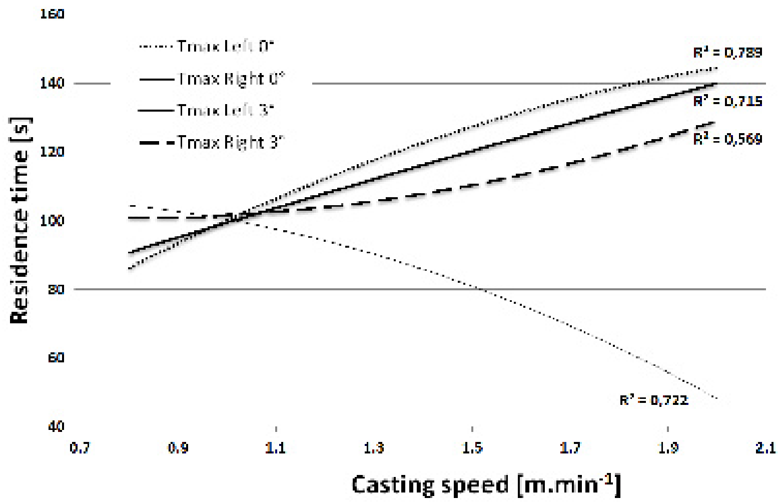

Fig.7 Comparsion of maximal residence time of correct set and misalignment ladle shroud in 3° directed to the right casting stream

Table 3 Percentual average difference between left and right stream residence time for correct set ladle shroud and misaligned ladle shroud directed into the back side of the tundish in 3°

Casting speed [$m.min^{-1}$]	Percentual average difference of minimal residence times $\Delta\tau min$[%]	Percentual average difference of maximal residence times $\Delta\tau_{max}$[%]
0.8	-10.7	-4.3
1	-35.6	-6.1
1.2	-61.3	-59.7
1.6	-43.6	-69.6
1.8	-25.2	-82.8
2	-32.8	-181.2

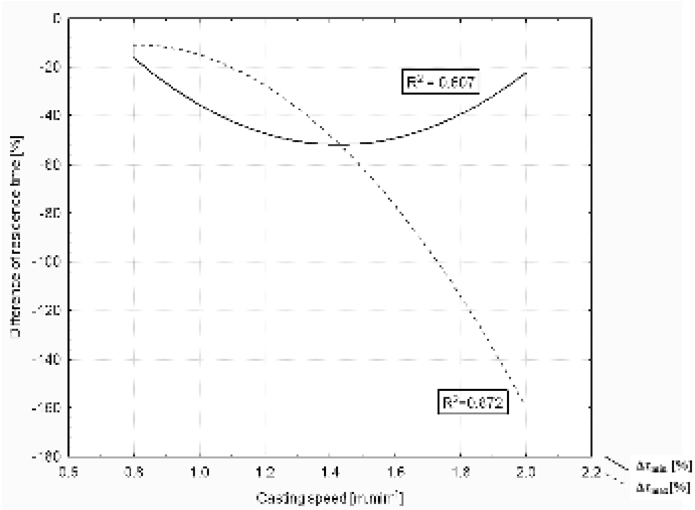

Fig.8 Graphical expression of percentual difference of average residence times for correct set ladle shroud and misaligned ladle shroud directed into the back side of the tundish in 3°

4. Conclusions

Every steel flow modifier as dam, weir and impact pad is designed for operation in ideal location with exactly set point and angle of steel impact [15]. From the measurements results that any deviation of ladle shroud from the vertical axis in combination with turbostop causes asymmetry and shorten of retention times on both streams, depending on the casting speed and the ladle shroud deviation. In practice during casting is very important to ensure and monitor correct position of the ladle shroud.

Acknowledgements

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