

# MICROSCOPIC INVESTIGATIONS OF AXIAL ZONES OF CONTINUOUS CASTING INGOTS

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This paper presents the results of microscopic investigations of the structure and chemical composition of the axial zones of continuous casting ingots of 140 x 140 mm cross-section made of G3Si1 steel, comprising the areas of porosity and axial shrinkage defects. The occurrence of shrinkage hollows and non-metallic phase, resulting from chemical reactions of the steel components with oxygen at the solidification front, has been stated in these areas.

*Key words:* steel, ingot structure, analytical electron microscopy, continuous casting

## INTRODUCTION

The axial porosity and shrinkage porosity occurring in the axial zone of continuous casting ingots is a material discontinuity of the ingot, which can be transferred, as the internal ingot defect, to the finished products (e.g. wires), causing therefore significant rejections of finished products. Causes of formation of axial porosity and shrinkage defects in continuous casting ingots are commonly known (solidification shrinkage of steel). On the other hand the degree of such defectiveness depends in large measure on the parameters applied in the continuous steel casting process (casting speed and temperature) and intensity of ingot cooling, especially in the secondary cooling zone.

## ESTIMATION OF SOLIDIFICATION KINETICS OF 140 X 140 MM CONTINUOUSLY CAST INGOTS

Essential part of the estimation of solidification kinetics of the 140 x 140 mm ingot of G3Si1 steel (Table 1) is the determination of  $L_k$  length of solidification path in relation to the design characteristics of the used CC machine:  $L_m$  metallurgical length of the machine (a distance between steel table level in the crystallizer and the point of ingot cutting) and  $L_h$  length of the secondary cooling zone – Figure. 1.

In practice the solidification kinetics of continuously cast ingots can be expressed with use of Stefan [1, 2] formula:

$$d_i = K \cdot \sqrt{t} \quad (1)$$

where:  $d_i$  – thickness of the solidified layer of the ingot / cm

$K$  – solidification speed constant / cm/min<sup>0.5</sup>

$t$  – solidification time / min.

Table 1 **Chemical composition steel / wt. %**

Element	Min	Max
C	0,06	0,09
Mn	1,30	1,55
Si	0,75	0,95
P	-	0,02
S	-	0,02
Cr	-	0,15
Ni	-	0,10
Al(c)	-	0,02
Ca	-	0,001
O <sub>2</sub>	-	0,01
N <sub>2</sub>	-	0,01

When parameters of the continuous casting process are taken into account, the formula (1) obtains the following form:

$$d_i = K \cdot \sqrt{\frac{L_k}{V_{\text{casting}}}} \quad (2)$$

where:  $L_k$  - length of ingot solidification path / m

$V_{\text{casting}}$  - casting speed / m/min.

If we define the „ingot solidification path length” as a distance between the level of steel table in the crystallizer and the point where the ingot becomes solidified (Figure 1), then its value will be expressed by the formula:

$$L_k = \frac{D_i^2 \cdot V_{\text{casting}}}{4 \cdot K^2} \quad (3)$$

where:  $D_i$  – dimension of the square ingot side (equal to  $2d_i$ ) / m.

The CC machine used in casting of the investigated square ingots, have had the following design characteristics [3-5]:

- length of the secondary cooling zone  $L_h = 9,5$  m

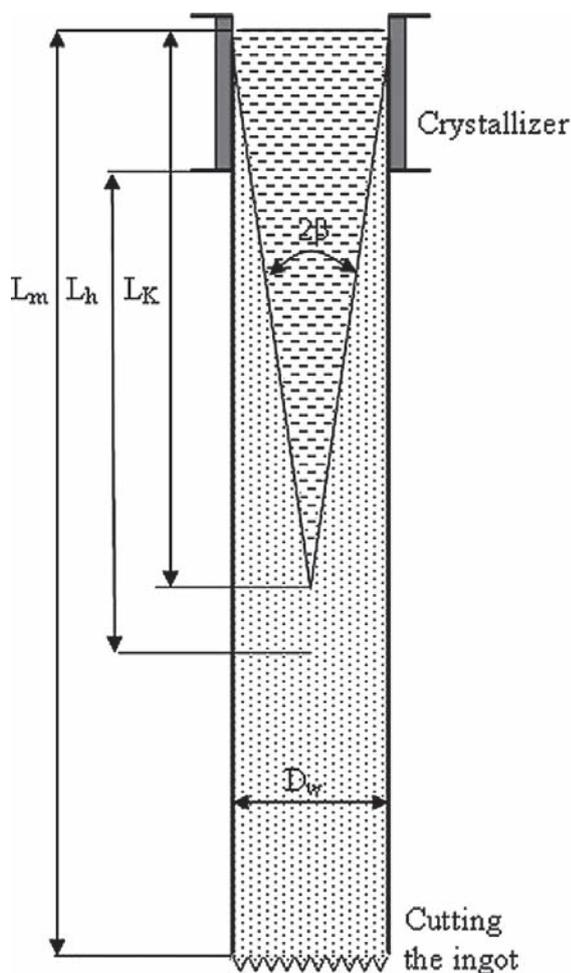


Figure 1 Illustration of solidification path of continuously cast ingot [1]

- metallurgical length  $L_m = 29,7$  m,
- distance of the ingot straightening 13,7 m from steel table in the crystallizer,
- recommended ingot casting speeds for 140x140 mm products,  $V_{casting} = 3,1 - 3,4$  m/min.

For this analysis we have assumed the values of K solidification constant and casting speed, which result from the casting technology used worldwide. The results of calculations of the solidification path length are presented in Table 2.

Table 2 Path of solidification of 140 mm square ingot

Ingot casting speeds $V_{casting}$ / m/min	The decrease in casting speed $K$ / cm/min <sup>0.5</sup>						
	1,8	2,0	2,2	2,4	2,6	2,8	3,0
Length of ingot solidification path $L_k$ / m							
2,0	30,2	24,5	20,3	17,0	14,5	12,5	10,9
2,2	32,3	27,0	22,3	18,7	16,0	13,8	12,0
2,4	26,3	29,4	24,3	20,4	17,4	15,0	13,1
2,6	39,3	31,9	26,3	22,1	18,6	16,3	14,2
2,8	42,3	34,3	28,4	23,8	20,3	17,5	15,2
3,0	45,4	36,8	30,4	25,5	21,8	18,8	16,3
3,2	48,4	39,2	32,4	27,2	23,2	20,0	17,4
3,4	51,4	41,7	34,4	28,9	24,7	21,3	18,5
3,6	54,4	44,1	36,5	30,6	26,1	22,5	19,1
3,8	57,4	46,6	38,5	32,3	27,6	23,8	20,7

where:  $L_h = 9,5$  m,  $L_m = 29,7$  m

The obtained results indicate that only in one case (for  $K = 3,0$  cm/min<sup>0.5</sup> and  $V_{casting} = 2,0$  m/min) the ingot becomes solidified in the terminal area of the secondary cooling zone. Each trial to increase casting speed causes the solidification path length to be increased. When continuously cast ingot with non-solidified internal part passes to its horizontal position then formation of axial porosity and shrinkage porosity defects will always be the result. If macrostructure of continuously cast ingots is the priority, then increasing casting speed can not be deemed as the way to increase the CC machine performance.

### RESULTS OF MICROSCOPIC INVESTIGATIONS OF AXIAL ZONES OF 140X140 MM CONTINUOUS CASTING INGOTS

Investigation of microscopic structure of axial zone of ingots (shrinkage defect and axial porosity areas) with use of X-ray analytical methods have demonstrated the presence in these areas of non-metallic phase consisting mainly of silicates and aluminates.

Figures 2, 3, 4, and 5 present examples of results of these investigations (X-ray photos confirm the chemical composition of identified products of steel).

Increase of casting speed in each case has negatively affected the product rejection index. The presence of non-metallic phase in the areas of shrinkage defects and axial porosity is the result of chemical reactions at the

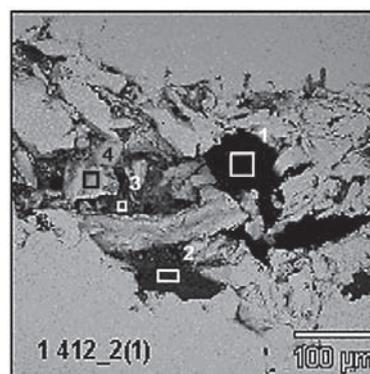
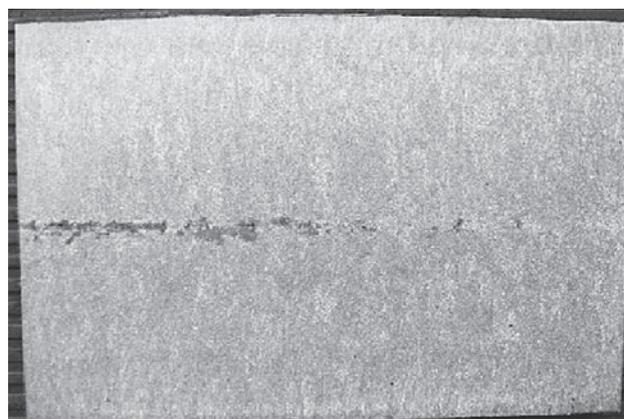
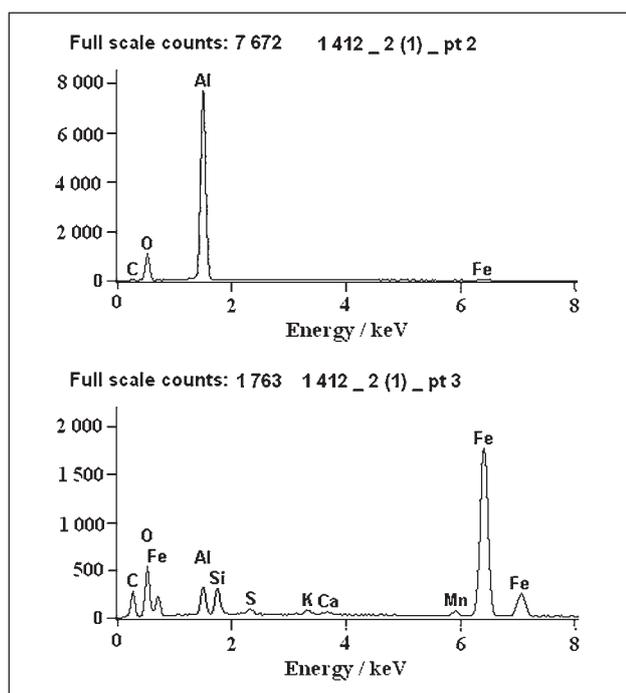
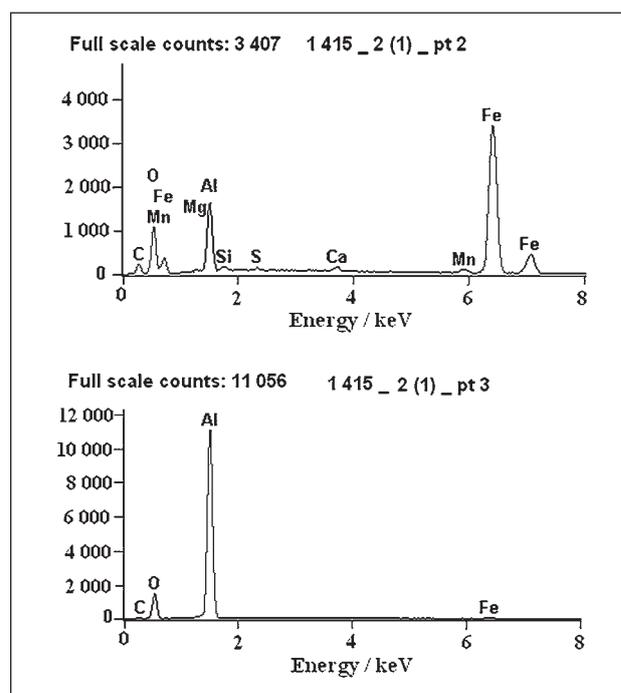


Figure 2 Microscopic image of ingot axial zone (2/2). Melt 739

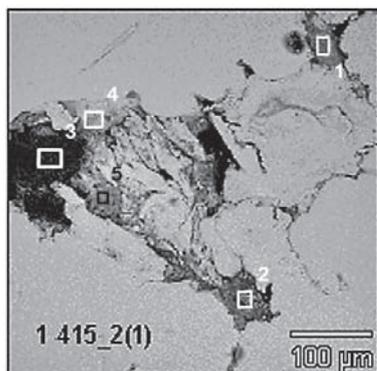
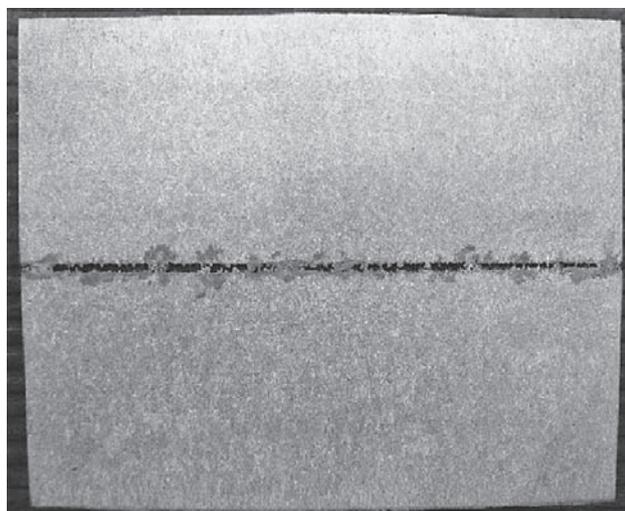


**Figure 3** X-ray photograph of non metallic inclusions chemical composition identified on the axial zones of continuous casting ingots



**Figure 5** X-ray photograph of non metallic inclusions chemical composition identified on the axial zones of continuous casting ingots

solidification front between elements, especially oxygen, emanating from the steel due to variable solubility in solid and liquid metallic phase.



**Figure 4** Microscopic image of ingot axial zone (1/9). Melt 244

The presence of non-metallic phase in the areas of shrinkage defects and axial porosity is the result of chemical reactions at the solidification front between elements, especially oxygen, emanating from the steel due to variable solubility in solid and liquid metallic phase.

The use of additional filtration of steel before casting it could reduce the likelihood of non-metallic phases, as presented in the publications [6, 7]. Positive impact on the solution of the problem will have to perform the test model, similar to the ongoing work by the authors (among others [8-9]).

## SUMMARY AND CONCLUSIONS

Following conclusions can be drawn on the basis of the performed investigations:

- microscopic investigations of axial ingot zones, areas of shrinkage defects and axial porosity, have demonstrated that the non-metallic phase (silicates and aluminates) presented there stands in the way of welding during the process of rolling of continuously cast ingots,
- the preliminary steel deoxidizing with use of aluminium, introduced to the steelmaking process of G3Si1 steel, have caused significant reductions in non-metallic phase formation (at the solidification front) during solidification of the continuously cast ingots, what is proved by microscopic X-ray investigations of ingot axial structure. At the same time a decrease has been observed in per-unit consumption of ferroalloys (FeMn, FeSi, FeMnSi).

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**Note:** The responsible translator for English language is A. Matuga, Katowice, Poland