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J. CIBULKA*,#, R. KRZOK*, R. HERMANN*, D. BOCEK*, J. CUPEK* K. MICHALEK**

IMPACT OF OSCILLATION PARAMETERS ON SURFACE QUALITY OF CAST BILLETS

The paper is focused on impact of different oscillation parameters on surface quality of peritectic steel grades cast into billets 150x150 mm. Hydraulic oscillation used for this purpose was temporarily installed on one strand of the billet caster. Hydraulic oscillation enables, in comparison to ordinary used electromechanical oscillation, flexible set-up of basic parameters of the oscillation cycle (negative strip time and its ratio). Proper oscillation mode is capable to assure regular oscillation marks development, good lubrication in the mould and adequate compression of the solidifying shell. Impact of an oscillation mode providing negative strip time 0.085 s and its ratio -50 % on surface quality of cast billets is compared with standard oscillation mode applied on strands equipped with electromechanical oscillation characterized with variable negative strip time between 0.084 and 0.096 s and fixed negative strip ratio to -14 %.

Keywords: continuous casting of steel, mould oscillation, peritectic steel grades, billet surface quality

1. Introduction

Mould oscillation represents a basic instrument for surface quality control during continuous casting of steel because it is responsible for oscillation marks development, friction in the mould and compression of the solidifying steel shell. The paper is focused on impact of different oscillation modes on surface quality assurance of peritectic steel grades cast into billets 150x150 mm.

2. Basic parameters of the oscillation cycle

It is very important to set two oscillation parameters properly to assure the required conditions in the meniscus area: mould stroke and oscillation frequency. The choice of both parameters strongly relates to the produced steel grade and must be adjusted during casting in order to ensure the same oscillation marks depth, shell compression and lubrication for different casting speeds.

Oscillation marks depth, shell compression and lubrication are determined by two basic parameters of the oscillation cycle. The first one is negative strip time Tn (s) which represents the time period when mould moves downwards with a higher speed in comparison to the set casting speed. Negative strip time is given by the following relationship:

$$Tn = \frac{60}{\pi \cdot f} \cos^{-1}\left(\frac{V_c}{\pi \cdot S \cdot f}\right) \tag{1}$$

where f is oscillation frequency (cpm), V_c is casting speed (m/min) and S is mould stroke (mm). The rest of the oscillation cycle represents positive strip time Tp.

Negative strip time is a very important factor during oscillation marks development. Longer negative strip times lead to deeper oscillation marks formation due to meniscus elongation during this period. Longer meniscus is then bent towards mould wall during positive strip time, so a deeper oscillation mark can be expected as shown in Fig. 1. On the other hand, negative strip time assures defects compression in the solidifying steel shell and causes casting powder infiltration into the space between mould wall and billet surface. Therefore, longer negative strip times can be used for breakout prevention and lubrication improvement [1].

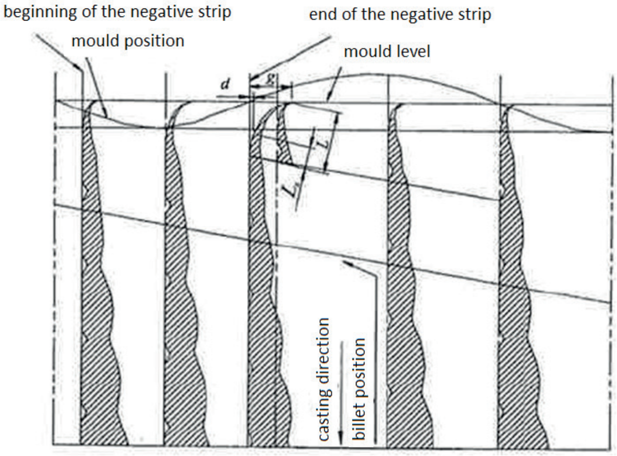

Fig. 1. Oscillation marks development [2]

The second very important parameter of the oscillation cycle is negative strip ratio *%Tn* (%). There are two different formulas for negative strip ratio but most of authors use so

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* TŘINECKÉ ŽELEZÁRNY A.S , PRŮMYSLOVÁ 1000, TŘINEC – STARÉ MĚSTO, CZECH REPUBLIC

** VŠB-TECHNICAL UNIVERSITY OF OSTRAVA, FACULTY OF METALLURGY AND MATERIALS ENGINEERING, DEPARTMENT OF METALLURGY AND FOUNDRY, AND REGIONAL MATERIALS SCIENCE AND TECHNOLOGY CENTRE, 17. LISTOPADU 15/2172, OSTRAVA-PORUBA, CZECH REPUBLIC

Corresponding author: Jiri.Cibulka@trz.cz

called alpha version which provides a better description of shell defects compression [3]. Alpha formula is given by the following relationship:

$$\%Tn = \frac{V_c - 2 \cdot S \cdot f}{V_c} \cdot 100 \qquad (2)$$

Negative strip time ratio is mostly used for the control between shell compression and proper lubrication. Demands for both features assurance go against each other. If the negative strip ratio is increased (i. e. it is more below zero), shell compression is improved but the lubrication is worsen. In order to ensure good lubrication it is necessary to set lower negative strip ratios when the relative speed between mould wall and billet surface is decreased. Maximum of the relative speed is a key factor from the point of lubrication view because it defends casting powder infiltration between mould wall and billets surface.

Choice of the basic parameters of the oscillation cycle (i. e. *Tn* and *%Tn*) for the given conditions depends on produced steel grade and cast section. Ferrite potential *FP* is widely used as a criterion of the chemical composition impact on steel behaviour during continuous casting. Ferrite potential is given by the following formula for low alloyed steel grades:

$$FP = 2.5\,(0.5 - Cp) \qquad (3)$$

where Cp is so called carbon equivalent and it is given by chemical composition of the steel grade according to the following relationship: Cp = [%C] + 0.02 [%Mn] + 0.04 [%Ni] – 0.1 [%Si] – 0.04 [%Cr] – 0.1 [%Mo].

It is possible to determine steel grade susceptibility either to defects formation or to sticking to the mould wall according to ferrite potential (see Fig. 2). Parameters of the oscillation cycle have to be chosen according to the steel grade characteristics in order to minimize undesirable events during continuous casting of steel like shell sticking on the mould wall and deep oscillation marks formation, which enables improvement of billets surface quality. However, mould oscillation is not the only factor responsible for the final surface quality. Therefore, it is necessary to control many other parameters like casting powder properties, powder melting and heat extraction in the mould.

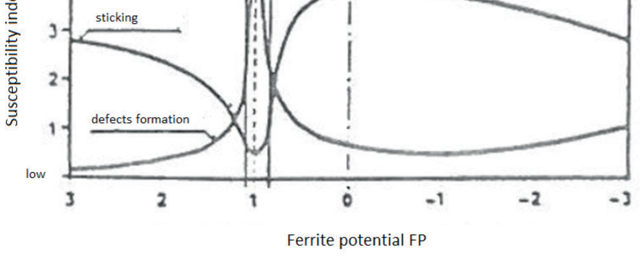

Fig. 2. Steel susceptibility to sticking and defects development depending on ferrite potential [1]

3. Experimental procedure

The present research is based on results published in [4] where the impact of both negative strip time and negative strip ratio on surface quality of peritectic steel grades was already discussed. Hydraulic oscillation was used for this purpose which was temporarily installed on one strand of the billet continuous casting machine in Třinec Steelworks. The remaining caster strands were equipped with ordinary electromechanical oscillation. The basic advantage of the hydraulic oscillation is that it enables flexible stroke and oscillation frequency adjustment during steel casting. Therefore, any both negative strip time and negative strip ratio can be applied and kept on a required level for different casting speeds. Contrary to that, possibilities of the electromechanical oscillation are slightly limited because it is possible to change just oscillation frequency whilst the stroke must be kept on a certain level all the time. This disadvantage leads to changes in negative strip time or its ratio when casting speed is increased or decreased.

Results published in [4] showed that it is very important to use short negative strip time and high negative strip ratio during continuous casting of peritectic steel grades because their ferrite potential is around 1, which indicates that such steel grades tend more to defects formation than to sticking (Fig. 2). Oscillation mode characterized with negative strip time 0..088 s and negative strip ratio -37 % was proven as a very convenient one for the given casting conditions. However, an idea of negative strip ratio increasing up to -50 % was declared as having a potential for further surface quality improvement because shell compression will be additionally increased.

The current paper presents results obtained during trials with the oscillation mode including short negative strip time (0.088 s) and negative strip ratio increased up to -50 %. This oscillation mode was applied just on the strand equipped with hydraulic oscillation whereas the standard oscillation pattern with variable negative strip time and negative strip ratio fixed on -14 % for different casting speeds was used on strands equipped with electromechanical oscillation. A set of representative samples was gathered from different billets surface positions for both oscillation modes having different settings of basic oscillation cycle parameters. The samples were processed by etching in nital. Observed microstructures and measured oscillation marks depths were compared for tested oscillation patterns. The results were also given into context with surface quality of wires rolled from the tested billets.

4. Discussion of the obtained results

Very interesting results were obtained during samples investigation of the steel grade with the following chemical composition: C 0.2 %, Mn 1.3 %, Si 0.1 %, P 0.015 %, S 0.025 % and Cr 1.15 % having ferrite potential approximately 0.8 %. Typical oscillation marks observed on billets surface of this grade for low casting speeds are shown in Fig. 3. Low casting speeds are typical with significant difference in negative strip times between hydraulic and electromechanical oscillation (see Table 1). Metallography investigation of the taken samples shown in Fig. 4 confirms that short negative strip time achieved by hydraulic oscillation application assures shallow oscillation marks development. This fact is not surprising at all but more interesting is to compare structures observed under oscillation marks with different depths. It is clear from Fig. 4 that deeper oscillation marks developed owing to longer negative strip time applied on strands equipped with electromechanical oscillation are characterized by columnar crystals growth in subsurface billet area. Presence of columnar crystals is a sign of a higher heat extraction, which is strange because deeper oscillation marks filled with mould flux should block the heat flow from billet into mould wall. However, there is a possible explanation in the paper [5]. The authors observed presence of columnar crystals under both shallow and deep oscillation marks but there was a clear difference in their appearance. Columnar crystals under shallow oscillation marks were connected to each other more closely to the bloom surface so it was possible to see a pattern which looked like fine grained structure.

TABLE 1

Oscillation parameters set on strands equipped with hydraulic and electromechanical oscillation at casting speed 2.2 m/min

Oscillation mechanism	Casting speed, m/min	T_n, s	%T_n, %	Marks depth, mm
Electromechanical	2.2	0.100	-14	0.28
Hydraulic	2.2	0.088	-50	0.13

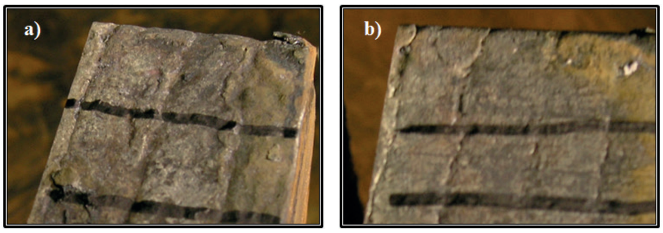

Fig. 3. Typical oscillation marks for: a) electromechanical oscillation (Vc = 2.2 m/min, Tn = 0.100 s, %Tn = -14 %); b) hydraulic oscillation (Vc = 2.2 m/min, Tn = 0.088 s, %Tn = -50 %)

Based on this information, the present observations can be explained so that columnar crystals were probably connected together so close to the billet surface that their presence is not clear on metallography pictures (except for short local columnar crystals) in case of shallow oscillation marks. Literature explains this phenomenon by chill zone existence immediately under the surface [7] [8] but current results show that chill zone can be omitted under certain conditions and so columnar structure is present exactly under the billet surface in such a case.

Fig. 4 provides one more observation. Columnar crystals start growing in positions of billet surface bending and then tend to grow together as written above. Areas developed by enclosed columnar crystals really look like grains as observed in [5,6]. It is clear that columnar crystals are not suitable in subsurface area because they are usually responsible for cracking during rolling process.

Similar samples were also taken from billets produced with higher casting speeds where the difference in negative strip times between hydraulic and electromechanical oscillation is not so striking (see Table 2). The most interesting finding of these examinations was that it is possible to observe very emphatic (looking like more stretched) oscillation marks even with short negative strip time assured by hydraulic oscillation. Such marks were situated mostly in corner areas – see Fig. 5. Structure analysis revealed (Fig. 6) that these oscillation marks are very deep so that they correspond to the longer negative strip time provided with electromechanical oscillation at a lower casting speed. Subsurface area was also covered with columnar crystals connecting together in a certain depth so that the material reminds coarse grained structure again.

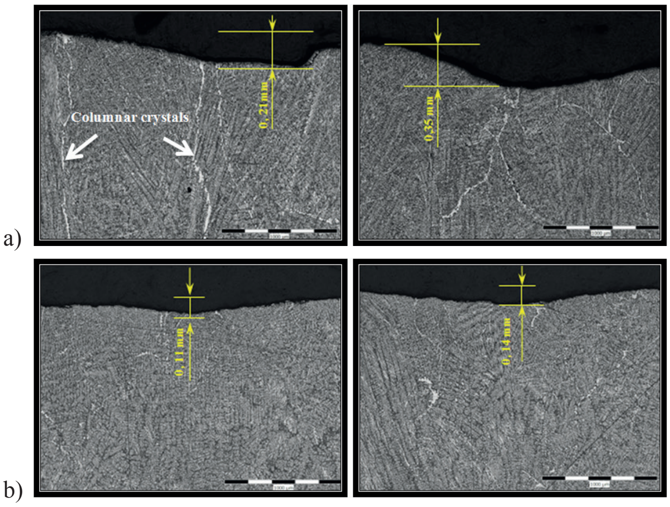

Fig. 4. Microstructures under oscillation marks for: a) electromech. oscillation (Vc = 2.2 m/min, Tn = 0.100 s, %Tn = -14 %); b) hydraulic oscillation (Vc = 2.2 m/min, Tn = 0.088 s, %Tn = -50 %)

The found oscillation marks do not conform to the set oscillation parameters and their development had to be seriously influenced by some other casting parameters. Because the marks were situated in corner areas where the heat flow from the solidifying shell into the mould wall is higher, it can be supposed that the used mould powder was probably more rigid in corner region than in the remaining mould area. The result was that a bigger amount of powder was entrapped during meniscus bending because of its worse melting.

TABLE 2

Oscillation parameters set on strands equipped with hydraulic and electromechanical oscillation at casting speed 2.4 m/min

Oscillation mechanism	Casting speed, m/min	T_n, s	%T_n,%
Electromechanical	2.4	0.092	-14
Hydraulic	2.4	0.088	-50

As written above, the abnormal oscillation marks were observed just for higher casting speeds specified with increased heat removal in the mould (i. e. delta T is increased – see Fig. 7). Mould flux is then more undercooled and so more rigid. In order to understand the whole process, it is necessary to measure liquid flux thickness in different mould positions, which is very difficult to assure for such a small cast section as examined in the paper. The thicker liquid flux layer is measured in the mould the lower tendency to abnormal oscillation marks development can be expected because liquid powder will be available in meniscus area. Mould powder thickness was not measured during the trials described in the paper, so this parameter should be included in the next analysis.

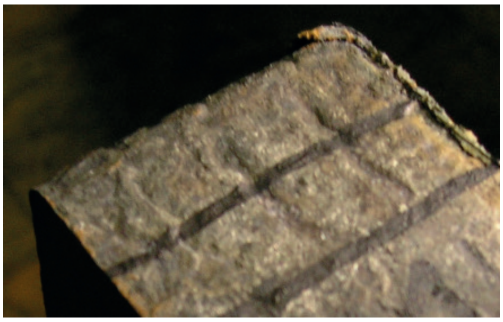

Fig. 5. Abnormal oscillation marks observed in corner areas of billets surface cast with short negative strip time and a higher casting speed (Vc = 2.4 m/min, Tn = 0.088 s, %Tn = -50 %)

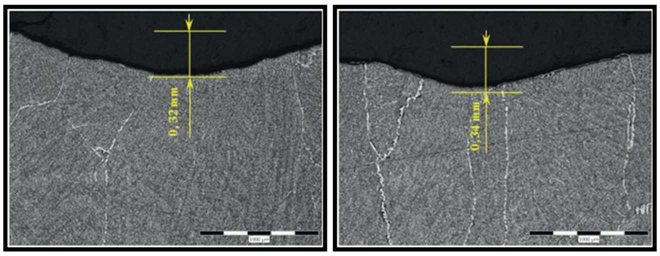

Fig. 6. Microstructure under abnormal oscillation marks observed at short negative strip time and a higher casting speed (Vc = 2.4 m/min, Tn = 0.088 s, %Tn = -50 %)

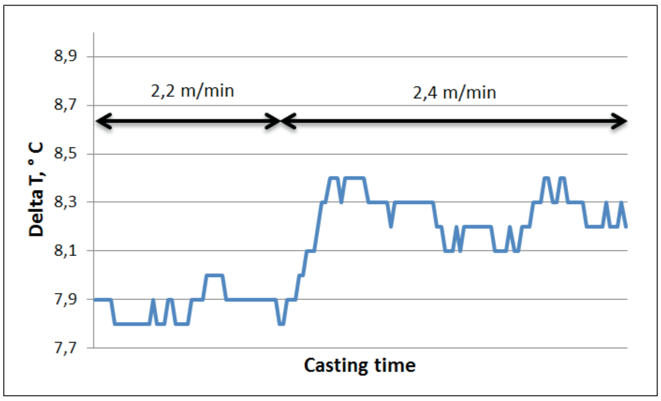

Fig. 7. Impact of casting speed on heat removal in the mould

The paper discussion has been just about the impact of the negative strip time on surface and subsurface billets quality up to now. However, very important is to set negative strip ratio properly as well because it controls demands between shell compression and lubrication in the mould. Consequences of the wrong negative strip ratio set-up are more difficult to estimate on cast steel in comparison to negative strip time. For example, low negative strip ratio (e. g. +10 %) can assure very regular oscillation marks development because of good lubrication. On the other hand, it is not capable to assure proper shell compression, so a lot of micro depressions can be situated in the shell. The result is that quite poor surface quality of final rolled products can be expected even though cast billets seemed to be of high quality.

In order to quantify the contribution of the negative strip ratio increased up to -50 %, results from rolled wires were used for this purpose. Wires surface quality was quantified by so called RQI coefficient determined by detection system called Defectomat HotRod. RQI values are above one and a higher value indicates worse wire surface quality.

Results of wire surface quality for the steel grade with C 0.1 %, Mn 0.4 %, Si 0.1 %, P 0.015 % and S 0.015 % having ferrite potential approximately 1 (i. e. the most susceptible steel grade for defects formation) are depicted in Fig. 8. It is clear that negative strip ratio increased up to -50 % generates visible deterioration in wire surface quality, which is caused by insufficient lubrication in the mould. Negative strip ratio increased to -50 % is so too high for casting of peritectic steel grades into billets 150x150 mm and it is necessary to set it on a lower level. Former results published in [4] showed that negative strip ratio around -37 % seems to be a good compromise between demands for sufficient shell compression and proper lubrication in the mould for casting of peritectic steel grades into billets 150x150 mm. This conclusion can be proved by Fig. 9.

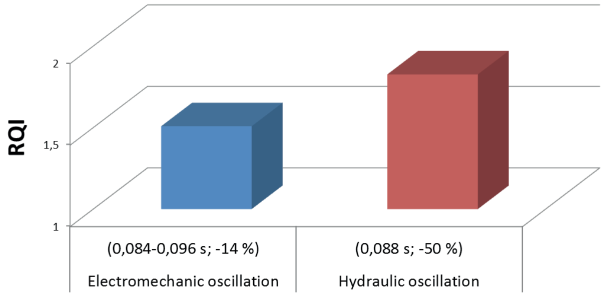

Fig. 8. Wires surface quality of peritectic steel grades cast with negative strip ratios -14 and -50 %

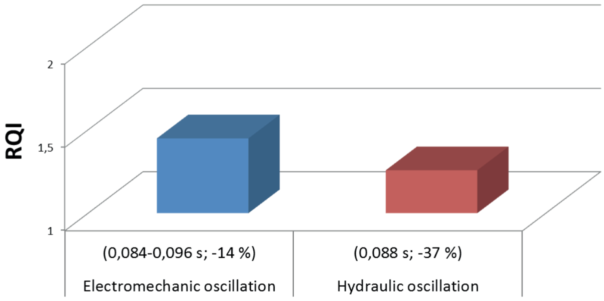

Fig. 9. Wires surface quality of peritectic steel grades cast with negative strip ratios -14 and -37 %

5. Conclusions

Impact of oscillation parameters on surface quality of peritectic steel grades cast into billets 150x150 mm was discussed. It is very important to assure short negative strip time providing shallow oscillation marks development. Shallow oscillation marks are very important because columnar crystals are present under deep oscillation marks.

Columnar crystals usually start growing in positions of billets surface bending and they usually join together in a certain depth so that they create structure pattern looking like coarse grained material. Columnar crystals are generally considered as undesirable in subsurface layers because they are responsible for steel cracking during rolling process. Further observation was that negative strip time is not the only parameter responsible for oscillation marks depth. Mould flux melting is a very important factor as well and can seriously differ in certain mould positions. The corner area seems to be a critical zone in this matter because it is characterized with a higher heat removal. The result is that the flux is more rigid in corner areas, which leads to deep oscillation marks development (they appear like more stretched marks). The phenomenon of the abnormal oscillation marks development is visible mostly at higher casting speeds when the heat removal in the mould is increased.

In order to assure maximum surface quality of peritectic steel grades cast into billets 150 x 150 mm, it is necessary to use proper negative strip ratio as well. Negative strip ratio increased to -37 % seems to be very convenient because it is capable to assure a good compromise between shell compression and lubrication in the mould. Negative strip ratio increased up to -50 % is already too high because of poor lubrication causing worse quality of final products.

The described results showed that it is necessary to control even flux melting process in order to understand oscillation marks development completely. The performed work should be therefore supplied with knowledge in the field of mould flux melting, which will be included in the next research.

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