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NONMETALLIC INCLUSIONS AND SECONDARY STRUCTURE OF CONTINUOUS CASTING STEELS

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Abstract. The article presents the results of a study of the non-metallic inclusions and secondary structure of continuous casting steels It is estimate that main quantity of non-metallic inclusions (≈72%) it inputted in steel during the deoxidization and the secondary oxidation, therefore the casting processes need to be managed very well to decrease the quantity of non-metallic inclusions in liquid steel.

Reducing the secondary dendrite arms spacing for the strip casting process, in comparison with the conventional continuous casting process of thick slab, will reduce the size of non-metallic inclusion and as result could improve the mechanical properties of steel.

Content of the endogenous non-metallic inclusions in stainless steel with Ti, in carbon steel and in electrical steel grades decreases in ladle and tundish in 2.7–3.2 times in comparison with quantity of non-metallic inclusions before pouring from furnace.

The increasing of the tundish width decreases in 20 times the quantity of nonmetallic inclusions by sizes from 70 to 80 μm, and in 5–6 times by sizes 220–230 μm. Increasing of the tundish height reduces of the oxygen content in continuous casting of slab

It was development the dependence of the secondary dendrite arm spacing with cooling rate.

Analysis shown, that the secondary dendrite arms spacing for the strip casting process decreases from 5.91 to 8.31 times in comparison with the conventional continuous casting process of thick slab of thickness 220 mm. Simultaneously non-metallic inclusions sizes to decrease, too. Rapid solidification reduces the number of large non-metallic inclusions: the inclusion number larger than 1 μm is decreased by a ratio of 5 in comparison with the conventional slabs process.

It was estimated influence of main parameters on the average grain sizes and the steel microstructure for the strip and conventional casting processes.

The dependence of the grain size of carbon and low alloying steels grades (C = 0.08–0.6%, Si = 0.4–0.6%, Mn = 0.4–1.4%, P < 0.03%, S < 0.03%), (C = 0.04–0.6%, Si = 0.11–0.3%, Mn = 0.3–1.12%, P = 0.01–0.035%, S = 0.005–0.035%, Nb = 0.013%, V = 0.001%) and high chromium and stainless steels of type AISI 430 and 304 (C = 0.03–0.12%, Si = 0.83–1.0%, Mn = 0.8–1.0%, Cr =16.0–18.4%, Ni = 8.47%, N = 0.03%) from casting speed range, final thickness of slab or sheet, reduction, temperature range is estimated by a multi regression analysis.

The grain size of steel obtained by the strip casting process, in range 1300 to 1400 ºC, is 2.3 time smaller than for the slab casting processes with slab thickness from 50 to 220 mm.

Key words: steel, chemical composition, non-metallic inclusions, secondary structure, continuous casting of steels

Introduction

The use and production of sheet metal products are constantly growing, the problem of increasing the productivity of technology and equipment, improving the quality of rolling, energy saving, environmental safety is exacerbated [1].

Thin steel sheet is a type of metal that are most popular and widely used in engineering, automotive, construction, food and other industries [2].

One of the main directions of scientific and technological progress in metallurgical production is the direct production of thin sheet metal from molten steel [3]. The technological process of direct production of thin rolled products from the melt and its implementation is one of the most promising in metallurgy in recent decades [4].

Formulation of problem

Research, development, improvement and implementation in production of technologies that can significantly reduce production costs, production time and significantly reduce harmful emissions into the environment, namely the technology of continuous casting of thin sheet, is currently very relevant [5].

World leaders in this field (USA, Japan, Australia, Germany, Italy and others) have achieved significant results in the development of technological schemes and designs of casting machines and their implementation in the metallurgical industry [6]. However, due to significant technological and technical difficulties, it is not possible to establish a sustainable high-performance industrial process with operational changes in the product range today [7].

The main problem of direct production of high-quality thin steel sheet is the presence of a large number of interdependent technological parameters that affect the size and distribution of non-metallic inclusions and the secondary structure of the sheet [8].

The smallest differences in these parameters have a negative effect on surface quality and homogeneity of the rolled structure [9].

Low stability of the process does not allow to establish the production of high-quality thin rolled steel, the needs of which are constantly increasing [10].

The problem of steel sheet production in Ukraine has not been solved, so it is relevant and aimed at meeting the needs of mechanical engineering, automotive and other industries [11].

Taking into account the needs and requirements of the world consumer market of metal products, including the industry of Ukraine [12], the production of thin steel sheet will remain a promising technological process, the problems of which must be solved [13].

Solving these problems requires further in-depth study of the influence of chemical composition and technological parameters of production on the size and distribution of non-metallic inclusions and the secondary structure of the sheet [14].

Analysis of recent research results

The main advantages of the technology in comparison with traditional slab casting and subsequent rolling are the following [4]:

- significant reduction of energy consumption (3-7 times);
- shorter length of the technological line (up to 50 m, in contrast to the traditional scheme of 150-1000 m);
- the cycle of production of hire takes no more than 15 minutes; ecological purity (reduction of harmful gas emissions by 70-90%);
- opportunity to successfully integrate as an effective complement to the structural and technological changes of enterprises with a full production cycle during their modernization, which is relevant and necessary for the industry of Ukraine.

The introduction of the technology of thin steel casting-rolling in industrial production makes it possible to eliminate many technical and economic problems that existed in the traditional metallurgical production. The new method ensures high profitability of obtaining rolled metal from grades of steels and alloys that are difficult to deform, the production of which by the traditional method is difficult or impossible [4]. High rates of metal crystallization contribute to the uniform distribution of small non-metallic inclusions, obtaining a fine-grained structure and inhibiting the sequestration of impurities, which provides a new, higher level of quality and mechanical properties of metal products [11].

Results of research

Non-metallic inclusions. Sources of non-metallic inclusions in steel are lining of smelting furnace, lining of chute of furnace, bottom-pouring refractories, lining of ladle, slag from smelting furnace, metallic scrap, products of secondary oxidation and products of deoxidization. Approximately inclusion quantity is inputted in steels are shown in Table 1.

Table 1. Sources of non-metallic inclusions in steels and approximately quantity inputted inclusions (N_{nmi}).

Name of source of non-metallic inclusions	N_{nmi}, %
Lining of smelting furnace	0.5
Lining of chute of furnace	0.5
Bottom-pouring refractories	1.0
Lining of ladle	3.0
Slag from smelting furnace	3.0
Metallic scrap	20.0
Products of secondary oxidation	32.0
Products of deoxidization	40.0
Sum	100.0

The data of Table 1 are the basis for calculating and predicting of the thickness influence on the element segregation in continuously cast steel slabs.

The above data show that the main quantity of non-metallic inclusions (72%) it inputted during the deoxidization and the secondary oxidation.

Content of the endogenous non-metallic inclusions in stainless steel with Ti, carbon steel and electrical steel grades, in furnace before pouring (1) in ladle (2) and tundish (3) are as shown in Fig. 1.

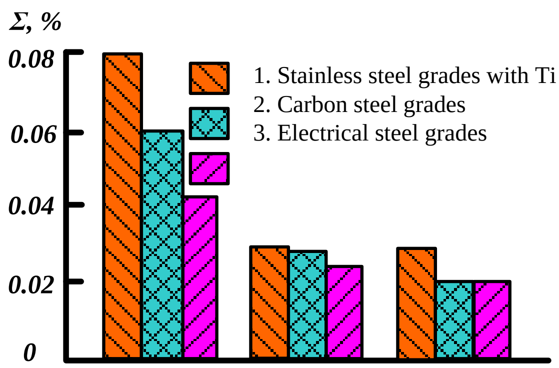


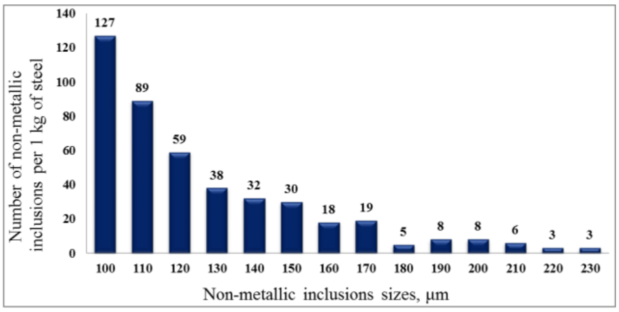
Fig. 1. Content of the endogenous non-metallic inclusions in stainless steel with Ti, in carbon steel grades and in electrical steel grade in furnace before pouring (1), in ladle (2) and tundish (3).

Data of Fig. 1. show that content of the endogenous non-metallic inclusions in stainless steel with Ti, in carbon steel grades and in electrical steel grades decreases in ladle and tundish in 2.7–3.2 times in comparison with quantity of non-metallic inclusions before pouring from furnace.

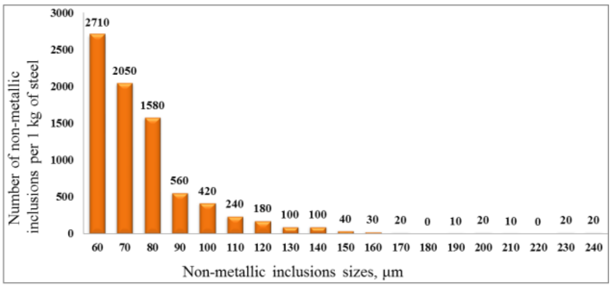
Influence of the tundish width on the quantity of non-metallic inclusions is shown in Fig. 2.

The data from Fig. 2. show that the increasing of the tundish width decreases in 20 times the quantity of nonmetallic inclusions by sizes from 70 to 80 μm, and in 5-6 times by sizes 220-230 μm.

Increasing of the tundish height reduces of the oxygen content in CC of slab (Fig. 3).



a



b

Fig. 2. Influence of the tundish width on the quantity of non-metallic inclusions [1]: a, b – tundish width is 1.08 and 0.8 m, accordingly.

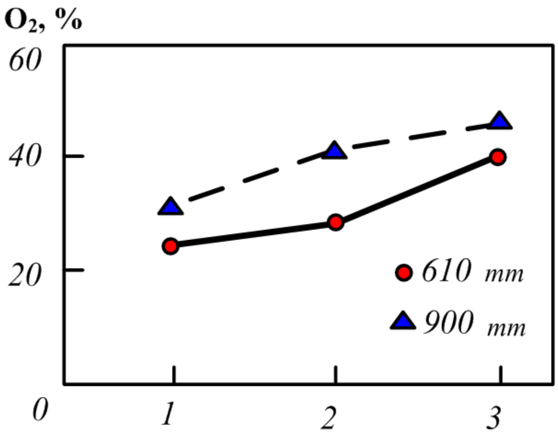


Fig. 3. Influence of the tundish height on the oxygen content in CC of slab: 1 – start; 2 – middle; 3 – finish.

Influence of the slag thickness in tundish and the tundish barriers on the quantity of non-metallic inclusions is shown in Fig. 4.

The data from Fig. 4 show that by decreasing the slag thickness and by using barriers in tundish the quantity of non-metallic inclusions decreases too.

Independently from forming shape process of non-metallic inclusions, they are concentrated between dendrites arms and on the surface of boundary primary grains.

The dependence of the secondary dendrite arm spacing (λ_{II}, μm) with cooling rate (R, °C/s) is as follow:

$$\lambda_{II} = 96 \cdot R^{-0,42}, \quad (1)$$

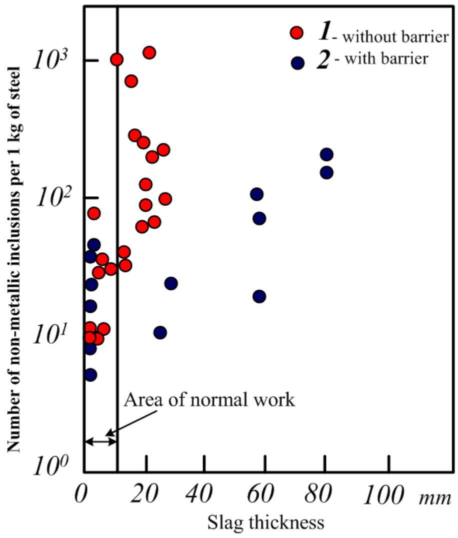


Fig. 4. Influence of the slag thickness and the tundish barriers on the quantity of non-metallic inclusions.

The secondary dendrite arm spacing (λ_{II}, μm) for thick slab and strip casting processes, is as in following Table 2.

Table 2. Влияние параметров затвердевания на размеры дендритов и расстояние между осями дендритов 2 порядка.

Parameter	Strip		Thick slab
Thickness, mm	1.2	1.8	220
Casting speed, m/min	131	59	2
Total solidification time, s	0.116	0.258	1070
Average speed of crystallization, mm/s	5.172	3.488	0.103
Average shell cooling rate in mould, °C/s	1853	826	12
Average size of dendrites (x^p), mm	0.6 - 0.7	1.0 - 1.2	12.0 – 20.0
Secondary dendrite arms spacing (λ_{II}, μm)	4.07	5.72	33.81

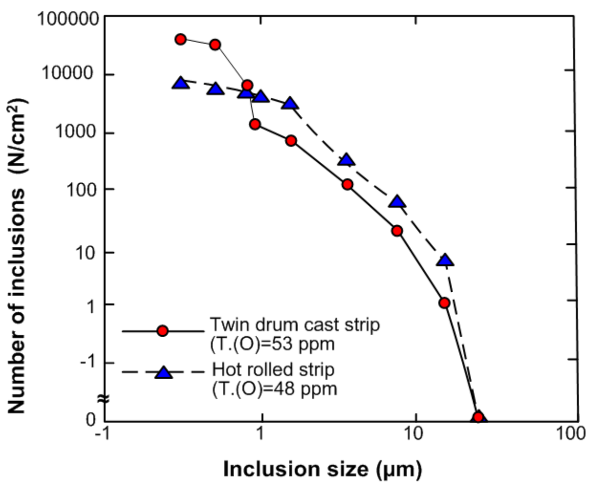


Fig. 5. Size distribution of non-metallic inclusions.

The data of Table 2 show that the secondary dendrite arms spacing for the strip casting process decreases from 5.91 to 8.31 times in comparison with the conventional continuous casting process of thick slab of thickness 220 mm. This means that for the strip casting process the sizes of non-metallic inclusions will be decreased from 5.91 to 8.31 times, too. Rapid solidification reduces the number of large non-metallic inclusions: the inclusion number larger than 1 μm is decreased by a ratio of 5 in comparison with the conventional slabs process, as presented in Fig. 5.

Experimental data show that the reduction of size of non-metallic inclusions improves the properties of steel, for example the critical cracks (Fig. 6).

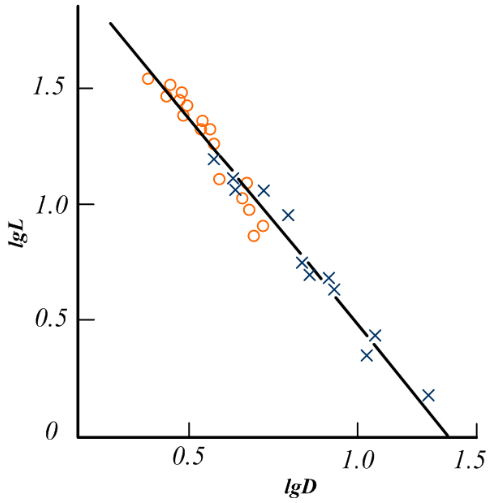


Fig. 6. Influence of the size of manganese (MnS) sulfides (lg D) on critical crack length (lg L).

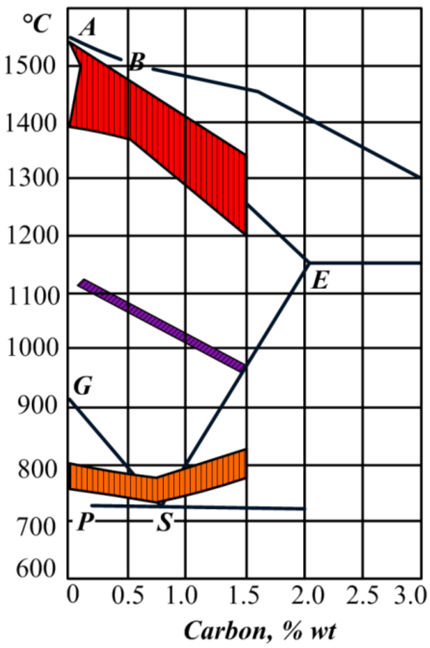


Fig. 7. Influence of carbon content on position of brittleness fields.

The data from Fig. 6 show that in case of decreasing the size of non-metallic inclusion in range from 5.91 to 8.31 times it is possible to increase the crack resistance in range from 1.87 to 2.64 times.

Secondary structure. During solidification the steel has a few temperature intervals of brittleness, where plastic properties are drooped:

1. High temperature brittleness from solidus temperature (t_s) to 1200 – 1340 ºC (as result of impurities accumulation and elements segregation on grain boundaries);

2. Medium temperature brittleness – from 1150 till 950 ºC (as result of sulfides accumulation on grain boundaries, with Mn/S > 60 the brittleness is absented);

Low temperature brittleness – from 850 till 700 ºC (as result AlN precipitation on grain boundaries).The influence of carbon content on brittleness fields is shown on Fig. 7.

In these intervals, as consequence of element segregation on the austenite grain boundary, increases the probability of crack appearance.

The element segregation to the austenite grain boundary depended strongly on the grain size of structure.

In Fig. 8 is shown the grain sizes evolution of the steel grade St 14 (C < 0.08, Mn < 0.40, P < 0.03, S < 0.03) relatively for conditions of casting, pressing, rolling and coiling.

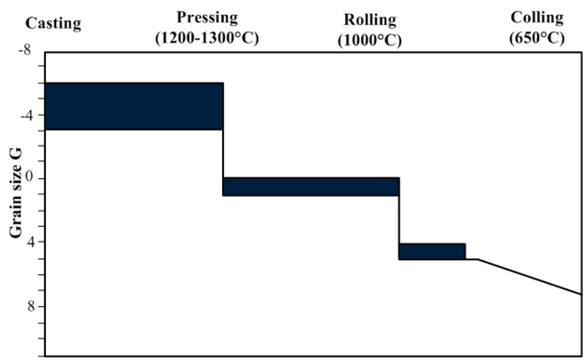


Fig. 8. Grain size evolution for a strip of thickness of 12 mm.

In research was shown the austenite and ferrite grain characteristics as a function of the amount of hot deformation (Fig. 9).

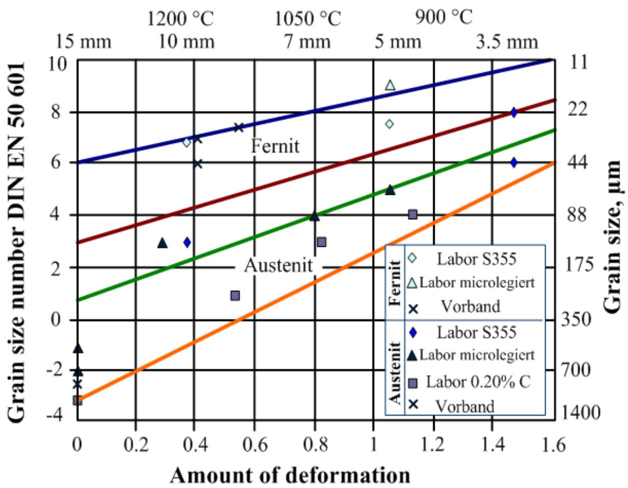
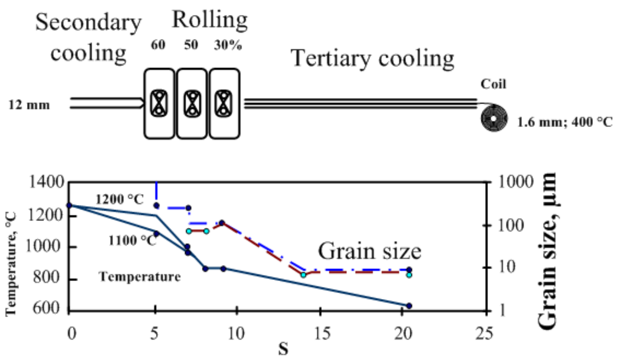


Fig. 9. Austenite and ferrite grain characteristics as a function of the amount of hot deformation.



$R_o$mm	R_m mm	% C	% Si	% Mn	% Nb	% Ti	% V
465	671	0.17	0.11	1.12	0.013	0.000	0.001

Fig. 10. The grain size of steel S355, featuring two initial-pass temperatures for in – line rolling.

Modeling of the grain size of steel grade S355, featuring two initial-pass temperatures for in – line rolling, is shown in Fig. 10.

In according with results of research the microstructure of electric steel grade, produced by strip casting is shown in Fig. 11.

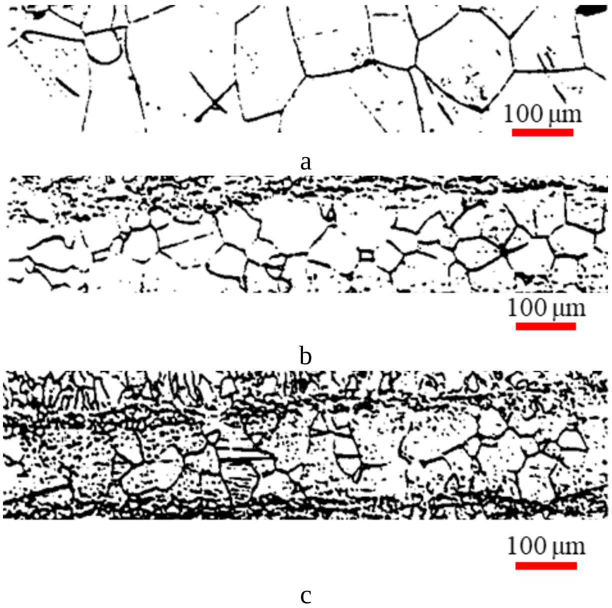


Fig. 11. Microstructure of a strip transversal section of electric steel grade in temperature range from 1000 (a) to 800 (b) and 600 (c) °C.

Table 3. Influence of main parameters on the average grain sizes for the strip and conventional casting processes.

N	Chemical composition, %wt.	Sizes of slab or thickness of strip, mm	Speed of casting, m/min	Superheat, °C	Reduction at pressing, %/t,°C	Hot reduction at rolling, %/t,°C	Rolling	Temperature, °C	Grain size, µm (γ phase, α phase) Surf.	Grain size, µm (γ phase, α phase) Cent.	Source
1	Low – C = 0.04% (Si=0.15–0.30; Mn=0.50–0.80; P<0.01;S <0.005; Al<0.005; N<0.01) (AISI 1005)	22.6 – 3.1	35 - 45	50 - 60	-	30/-	-	as-cast	100 (γ)	300 (γ)	13
2	Peritectic – C= 0.1%	2.8 – 3.0	65	45 – 60			-		100 (γ)	400 (γ)	
3	Medium – C =0.45%	3.0	40	70			-		80 (γ)	200 (γ)	
6.1	C<0.007, Si=4.5, P<0.01, Ni<0.07, Ti<0.02, Co<0.02, Al<0.01. electric steel	0.1 – 0.3	360	30	Force, kN 30 - 300	-	* t of coil	1000*	α phase -	89.6	12
6.2								800*	14.7	81.6	
6.3								600*	14.6	40.2	
6.4								400*	14.6	9.1	
6.5								as cast	11.5	8.6	
7.1	C < 0.08,	50 →		Casting – to 1200 – 1300 °C					1000-2828		
7.2	Mn <		4		25/	-			250 – 354		

7.3	0.40, P < 0.03, S < 0.03 (St14)	squeezing rolling to 25-30 mm	- 6.5		1200 - 1300	35/ 1000			62.5–88.4	10
7.4		50 ...→ 12						coiling to 650 ºC	31.2	
7.5		50 …→ 6				60/1000			15.6	
8.1	C = 0.17, Si = 0.11, Mn = 1.12, Nb = 0.013, V = 0.001 (S355)	12…→ 1.6	50 – 60	As cast – 1400					1000	11
					1-rolling 60% / 1200-1050				500	
						2-rolling 50% / 1050-900			100	
							3-rolling 30% / 900-850	coiling to 400 ºC	10	
8.2	S355 (C = 0.15 - 0.2, Si < 0.3, Mn= 0.3 - 0.6, P<0.035, S<0.035,)	15	50 – 60	Strip					γ	α
				As - cast – 1350 ºC					865	44
				15 mm → 10 mm at 1200 ºC					-	33
				15 mm → 10 mm at 1200 ºC → 9 mm at 1150 ºC					-	27
9.1	C = 0.03; Si=0.83; Mn=0.80; Cr = 18.4; Ni = 8.47; N = 0.03 (AISI 304)	3	100	As – cast → hot coil					28 – 34	14
9.2		3 → 0.9		Cold rolling (Z-mill) 70% → annealing (cal) 1150 ºC, 1.6 min → skin pass–0.3 %					24 - 27	
9.3		3 → 1.5		Cold rolling (tandem mill) 50% → annealing (cal) 1150 ºC, 1.6 min					13 – 16	
9.4		3 → 0.9		Cold rolling (tandem mill) 50% → annealing (cal) 1150 ºC, 1.6 min → Cold rolling (tandem mill) 40% → annealing (cal) 1150 ºC, 1.6 min					12.5 - 18	
10.1	C < 0.12; Si < 1.0; Mn < 1.0; Cr=16.0-18.0 (AISI 430)	(50–60)→ 5	3 – 4.4	20 - 40	Rolling at 960–970 ºC + annealing at 740–780 ºC + coiling at 850 – 860 ºC				31.2	15
10.2		(50–60)→ 3			Rolling at 960–970 ºC + annealing at 740–780 ºC + coiling at 850 – 860 ºC				22.1	
11	St 17GS (C = 0.14 - 0.20,	13 ton ingot		As – cast				1400	647	8
								1300	493	

	Si = 0.4 - 0.60, Mn = 1.0 – 1.4)				1200	147		
12	St 3 (C = 0.14 - 0.22, Si = 0.12 - 0.30, Mn = 0.4 – 0.65)		As – cast		1300	250		18
					1250	32		
13	(C=0.95-.05,Si=0.17-0.37,Mn=0.2–0.4, Cr=1.3-1.65) ShKh 15		As – cast		1200	250		
					1100	94		
14	C=0.38, Si=0.21, Mn=0.53, P=0.02, S=0.009, Cr=0.28		After rolling at 930 °C, with reduction of thickness on 45 %,		20	100 - 200		4, 17
15	St 17GS (C = 0.14 - 0.20, Si = 0.4 - 0.60, Mn = 1.0 – 1.4)	30 → 7.4	Speed of crystallization ≈ 2.6 mm/s.	Finish rolling at 850 °C	20	Surf.	Cent.	18
						48	63	
		30 → 2.0			20	32	48	

Technological parameters of the above structure, presented in Fig. 11, are as follow:

1. Chemical composition (% wt.): C < 0.007, Si = 4.5, P < 0.01, Ni < 0.07, Ti < 0.02, Co < 0.02, Al < 0.01.
2. Superheat – 30 °C.
3. Roll diameter – from 300 to 400 mm.
4. Roll length – 150 mm.
5. Casting speed – 6 m/s.
6. Cast strip thickness – from 0.1 to 0.3 mm.
7. Separation force per unit length of the roll ranged from 0.2 to 2.0 kN/mm.
8. Strip tension between the twin–roll and caster and the coiler ranged from 11 to 44 N/mm^2.

Dependence of the average grain sizes of strip with the strip coiling temperature is shown in Fig. 12.

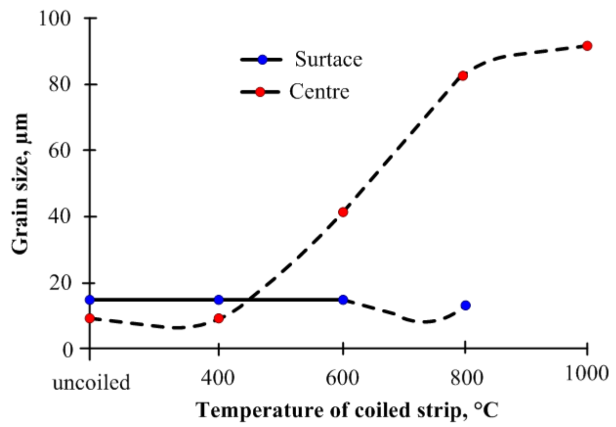


Fig. 12. Dependence of the average grain sizes of strip with the strip cooling temperature.

Table 4. Microstructure description.

N of position in tabl. 3	Description of microstructure	Source
1	Mainly acicular ferrite	13
2	Ferrite + Pearlite	
3	Fully pearlitic	

In Table 3 and Table 4 are presented respectively the influence of main parameters on the average grain sizes and the steel microstructure for the strip and conventional casting processes.

Dependence of the grain size (D_{ccc}, µm) of carbon and low alloying steels grades (C = 0.08 - 0.6%, Si = 0.4 – 0.6%, Mn = 0.4 – 1.4%, P < 0.03%, S < 0.03%) for the conventional continuous casting process with following conditions:

- casting speed range (V_{cast}) from 2 to 10 m/min;
- final thickness of slab or sheet (δ_{fin}) - 2.0 ÷ 135 mm;
- reduction (R_{sum}) - 0 ÷ 93.3 %;
- measured temperature rang of grain size (t_{gs}) - 25 ÷ 1250 °C

is estimated by a multi regression analysis with the following relation:

$$D_{ccc} = 36657 - 889.6 \cdot V_{cast} - 946.8 \cdot \delta_{fin} - 276 \cdot R_{sum} - 4.268 \cdot t_{gs} + 0.3647 \cdot t_{gs} \cdot \delta_{fin} + 2.125 \cdot \delta_{fin}^2, \quad (2)$$

Coefficient of multi correlation R = 0.999.

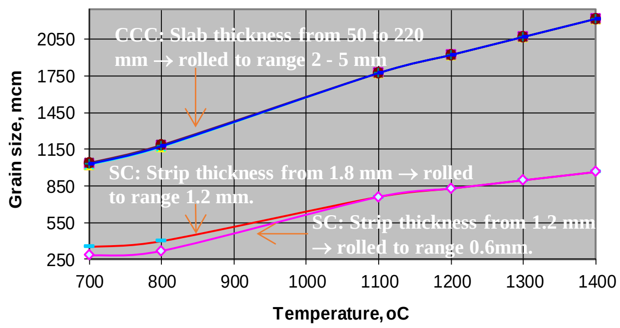


Fig. 13. Influence of temperature on grain sizes of steel manufactured by conventional continuous casting (CCC) and strip casting (SC).

Depended of the grain size (D_{str}, µm) of carbon and low alloying steels grades (C = 0.04 - 0.6%, Si = 0.11 – 0.3%, Mn = 0.3 – 1.12%, P = 0.01 – 0.035%, S = 0.005 - 0.035%, Nb = 0.013%, V = 0.001%) for the strip casting process with following conditions:

- casting speed range (V_{cast}) from 40 to 65 m/min;
- final thickness of slab or sheet (δ_{fin}) - 1.68 ÷ 12 mm;
- reduction (R_{sum}) - 0 ÷ 86 %;

- measured temperature rang of grain size (t_{gs}) - 25 ÷ 1400 °C is estimated by a multi regression analysis with the following relation:

$$D_{str} = 10.6 + 0.6806 \cdot t_{gs} - 0.005961 \cdot R_{sum} \cdot t_{gs}^2, \quad R = 0.985, \quad (3)$$

Depended of the grain size (D_{ststr}, μm) of high chromium and stainless steels of type AISI 430 and 304 (C = 0.03 - 0.12%, Si = 0.83 – 1.0%, Mn = 0.8 – 1.0%, Cr = 16.0 – 18.4%, Ni = 8.47%, N = 0.03%) for the strip casting process with following conditions:

- casting speed range (V_{cast}) from 3.7 to 100 m/min;
- final thickness of slab or sheet (δ_{fin}) - 0.9 ÷ 5 mm;
- reduction (R_{sum}) - 0 ÷ 94.5 %;
- measured temperature range of grain size – room temperature is estimated by a multi regression analysis with the following relation:

$$D_{strst} = 20.6 - 0.02008 \cdot V_{cast} - 0.1208 \cdot R_{sum} + 4.336 \cdot \delta_{fin}, \quad R = 0.908, \quad (4)$$

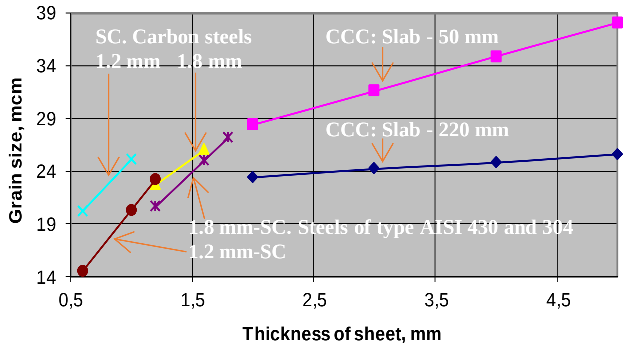


Fig. 14. Influence of the steel manufacture route on the grain size of the carbon and high alloying steels at room temperature.

In accordance with the data of Table 3, the influence of temperature and thickness on the grain sizes of steel manufactured respectively by conventional continuous casting (CCC) and strip casting (SC) are presented respectively in Figures 13 and 14.

The data of Fig. 13 show that at temperature 1300–1400 °C the grain size of strip decreases nearly 2.30 times respect to the conventional casting.

Influence of the steel manufacture route on the grain size of the carbon and high alloying steel grades, at room temperature, is shown in Fig. 14.

Conclusions

1. It is estimate that main quantity of non-metallic inclusions (≈72%) it inputted in steel during the deoxidization and the secondary oxidation, therefore the casting processes need to be managed very well to decrease the quantity of nonmetallic inclusions in liquid steel.

2. Reducing the secondary dendrite arms spacing for the strip casting process, in comparison with the conventional continuous casting process of thick slab, will reduce the size of non-metallic inclusion and as result could improve the mechanical properties of steel.

3. Content of the endogenous non-metallic inclusions in stainless steel with Ti, in carbon steel and in electrical steel grades decreases in ladle and tundish in 2.7–3.2 times in comparison with quantity of non-metallic inclusions before pouring from furnace.

4. The increasing of the tundish width decreases in 20 times the quantity of nonmetallic inclusions by sizes from 70 to 80 μm, and in 5- 6 times by sizes 220-230 μm.

5. Increasing of the tundish height reduces of the oxygen content in CC of slab.

6. It was development the dependence of the secondary dendrite arm spacing with cooling rate.

7. Analysis shown, that the secondary dendrite arms spacing for the strip casting process decreases from 5.91 to 8.31 times in comparison with the conventional continuous casting process of thick slab of thickness 220 mm. Simultaneously non-metallic inclusions sizes to decrease, too. Rapid solidification reduces the number of large non-metallic inclusions: the inclusion number larger than 1 μm is decreased by a ratio of 5 in comparison with the conventional slabs process.

8. It was estimated influence of main parameters on the average grain sizes and the steel microstructure for the strip and conventional casting processes.

9. The dependence of the grain size of carbon and low alloying steels grades (C = 0.08 - 0.6%, Si = 0.4 – 0.6%, Mn = 0.4 – 1.4%, P < 0.03%, S < 0.03%), (C = 0.04 - 0.6%, Si = 0.11 – 0.3%, Mn = 0.3 – 1.12%, P = 0.01 – 0.035%, S = 0.005 - 0.035%, Nb = 0.013%, V = 0.001%) and high chromium and stainless steels of type AISI 430 and 304 (C = 0.03 - 0.12%, Si = 0.83 – 1.0%, Mn = 0.8 – 1.0%, Cr = 16.0 – 18.4%, Ni = 8.47%, N = 0.03%), from casting speed range, final thickness of slab or sheet, reduction, temperature range is estimated by a multi regression analysis.

10. The grain size of steel obtained by the strip casting process, in range 1300 to 1400 °c, is 2.3 time smaller than for the slab casting processes with slab thickness from 50 to 220 mm. For the strip casting process the grain size decreases compared to the conventional continuous casting process, as consequence it is possible to increase of the element content in steel for the strip casting process.

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НЕМЕТАЛЛИЧЕСКИЕ ВКЛЮЧЕНИЯ И ВТОРИЧНАЯ СТРУКТУРА НЕПРЕРЫВНО ЛИТЫХ СТАЛЕЙ

Е. Г. Афтандилянц

Аннотация. В статье представлены результаты исследования неметаллических включений и вторичной структуры сталей непрерывной разливки. Подсчитано, что основное количество неметаллических включений (72%) вносится в сталь во время раскисления и вторичного окисления, поэтому необходимо целенаправленное управление процессами литья, для уменьшения количества неметаллических включений в стали.

Уменьшение расстояния между дендритными ветвями второго порядка, в случае процесса разливки ленты, по сравнению с традиционным процессом непрерывной разливки толстых слябов приводит к уменьшению размера неметаллических включений и, как результат, улучшению механических свойств стали.

Содержание эндогенных неметаллических включений в нержавеющей стали с Ti, в углеродистой стали и в электротехнических марках стали снижается в ковше и разливочном устройстве в 2,7 - 3,2 раза по сравнению с количеством неметаллических включений перед разливкой из печи.

При увеличении ширины промежуточного ковша количество неметаллических включений размером от 70 до 80 мкм уменьшается в 20 раз, а размером 220 - 230 мкм - в 5-6 раз. Увеличение высоты разливочного ковша снижает содержание кислорода в непрерывно литом слябе.

В статье установлена зависимость расстояния между вторичными ветвями дендритов от скорости охлаждения.

Анализ показал, что расстояние между ветвями второго порядка дендритов в процессе разливки ленты уменьшается в 5,91 - 8,31 раза по сравнению с традиционным процессом непрерывной разливки толстых слябов толщиной 220 мм.

Одновременно уменьшаются и размеры неметаллических включений. Быстрое затвердевание снижает количество крупных неметаллических включений: количество включений размером более 1 мкм уменьшается в 5 раз по сравнению с традиционным процессом изготовления слябов.

Установлено влияние основных технологических параметров процесса непрерывного литья на средний размер зерна и микроструктуру стали для ленточного и традиционного процессов литья.

В результате множественного регрессионного анализа установлена зависимость размера зерна углеродистых и низколегированных марок сталей, содержащих, C = 0,08 - 0,6%, Si = 0,4 - 0,6%, Mn = 0,4 - 1,4%, P <0,03%, S <0,03%, а также C = 0,04 - 0,6%, Si = 0,11 - 0,3%, Mn = 0,3 - 1,12%, P = 0,01 - 0,035%, S = 0,005 - 0,035%, Nb = 0,013%, V = 0,001% и высокохромистых и нержавеющих сталей типа AISI 430 и 304 (C = 0,03 - 0,12%, Si = 0,83 - 1,0%, Mn = 0,8 - 1,0%, Cr = 16,0 - 18,4%, Ni = 8,47%, N = 0,03%) от скорости литья, конечной толщины полосы или листа, величины обжатия и температуры.

Размер зерна стали, полученной в процессе разливки полосы, в диапазоне от 1300 до 1400 °C, в 2,3 раза меньше, чем для процессов разливки слябов с толщиной от 50 до 220 мм.

Ключевые слова: сталь, химический состав, неметаллические включения, вторичная структура, непрерывное литье сталей

НЕМЕТАЛЕВІ ВКЛЮЧЕННЯ І ВТОРИННА СТРУКТУРА БЕЗПЕРЕРВНО ЛИТИХ СТАЛЕЙ

Є. Г. Афтанділянц

Анотація. У статті представлені результати дослідження неметалічних включень і вторинної структури сталей безперервного розливання. Підраховано, що основна кількість неметалічних включень (72%) вноситься в сталь під час розкислення і вторинного окислення, тому необхідно цілеспрямоване управління процесами лиття, для зменшення кількості неметалевих включень в сталі.

Зменшення відстані між дендритними гілками другого порядку, в разі процесу розливання стрічки, в порівнянні з традиційним процесом безперервного розливання товстих слябів призводить до зменшення розміру неметалічних включень і, як результат, поліпшенню механічних властивостей стали.

Зміст ендогенних неметалевих включень в неіржавіючої сталі з Ti, в вуглецевої сталі і в електротехнічних марках стали знижується в ковші і розливному пристрої в 2,7 - 3,2 рази в порівнянні з кількістю неметалевих включень перед розливанням з печі.

При збільшенні ширини проміжного ковшу кількість неметалічних включень розміром від 70 до 80 мкм зменшується в 20 разів, а розміром 220-230 мкм – в 5-6 разів. Збільшення висоти розливного ковша знижує вміст кисню в безперервно литим слябів.

У статті встановлено залежність відстані між вторинними гілками дендритів від швидкості охолодження.

Аналіз показав, що відстань між гілками другого порядку дендритів в процесі розливання стрічки зменшується в 5,91-8,31 рази в порівнянні з традиційним процесом безперервного розливання товстих слябів товщиною 220 мм. Одночасно зменшуються і розміри неметалічних включень. Швидке затвердіння знижує кількість великих неметалевих включень. Наприклад, кількість включень розміром понад 1 мкм зменшується в 5 разів у порівнянні з традиційним процесом виготовлення слябів.

Встановлено вплив основних технологічних параметрів процесу безперервного лиття на середній розмір зерна і мікроструктуру сталі для стрічкового і традиційного процесів лиття.

В результаті множинного регресійного аналізу встановлено залежність розміру зерна вуглецевих і низьколегованих марок сталей, що містять, C = 0,08 - 0,6%, Si = 0,4 - 0,6%, Mn = 0,4 - 1,4%, P <0,03%, S <0,03%, а також C = 0,04 - 0,6%, Si = 0,11 - 0,3%, Mn = 0,3 - 1,12%, P = 0,01 - 0,035%, S = 0,005 - 0,035%, Nb = 0,013%, V = 0,001% і високо хромистих і неіржавіючих сталей типу AISI 430 і 304 (C = 0,03 - 0,12%, Si = 0, 83 - 1,0%, Mn = 0,8 - 1,0%, Cr = 16,0 - 18,4%, Ni = 8,47%, N = 0,03%) від швидкості лиття, кінцевої товщини смуги або листа, величини обтиску і температури.

Розмір зерна стали, отриманої в процесі розливання смуги, в діапазоні від 1300 до 1400 °C, в 2,3 рази менше, ніж для процесів розливання слябів з товщиною від 50 до 220 мм.

Ключові слова: сталь, хімічний склад, неметалеві включення, вторинна структура, безперервне лиття сталей.

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