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Coordinated control of the composition of 01YUT steel and deformation processing modes to achieve specified mechanical properties

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Узгоджений контроль складу сталі 01ЮТ та режимів деформаційної обробки для досягнення заданих механічних властивостей

Purpose: *to investigate the influence of the chemical composition of steel on the output from the chipboard and to establish rational parameters of deoxidation and deformation to ensure the specified values of mechanical properties.* ***Methods:*** *physicochemical modeling, thermodynamic calculations, experimental studies.* ***Results:*** *the carbon content and the degree of oxidation of the semi-finished product from the electric furnace for further vacuum treatment to obtain low-carbon steel were determined. With an increase in the oxygen flow rate supplied to the chipboard and exceeding the value required for the stoichiometry of fuel combustion reactions, the oxidation of the semi-finished product increases. To avoid the formation of calcium silicates, it is necessary to have an active oxygen content below 2.5 ppm, which is ensured by the residual content of dissolved aluminum in steel of 0.025-0.027%.* ***Scientific novelty:*** *The use of complex deoxidizers in steel production allows using the synergistic effect of the joint deoxidizing action of deoxidizing elements. The use of the methodology of physicochemical modeling made it possible to effectively solve the problem of predicting the properties of steel. To study the influence of modifier elements, as well as the main alloying components, a number of parameters characterizing the state of the alloy as a whole (Zy, d) were calculated. Based on information on the significant influence of the chemical composition of the steel on its properties, a database of 150 compositions was prepared to determine the optimal composition of ultra-low-carbon steels of the 01YUT, 01YUTA type by the method of physicochemical modeling. Based on the calculations, the concentrations of elements for steels of the 01YUT and 01YUTA grades were selected.*
Key words: *YUT low-carbon steel, nitrogen, nitrides, vacuuming, oxidation, method of physicochemical modeling.*

Мета*: дослідити вплив хімічного складу сталі на випуску з ДСП та встановити раціональні параметри розкислення та деформації для забезпечення заданих значень механічних властивостей.* ***Методи****: фізико-хімічне модлювання, термодинамічні розрахунки, експериментальні дослідження.* ***Результати****: визначено вміст вуглецю та ступінь окислення напівфабрикату з електропечі для подальшої вакуумної обробки з метою отримання низьковуглецевої сталі. При збільшенні споживання кисню, який подається в ДСП і перевищує величину, необхідну для стехіометрії реакцій горіння палива, відбувається підвищення окислення напівпродукту. Для уникнення утворення силікатів кальцію необхідно мати вміст активного кисню нижче 2,5 ppm, що забезпечується залишковим вмістом розчиненого алюмінію в сталі 0,025-0,027%.* ***Наукова новизна****: Використання комплексних розкислювачів у виробництві сталі дозволяє використовувати синергетичний ефект спільної розкислювальної дії елементів-розкислювачів. Залучення фізико-хімічної методології моделювання дозволило ефективно вирішити задачу прогнозування властивостей сталі. Для дослідження впливу елементів-модифікаторів, а також основних легуючих компонентів розраховано ряд параметрів, що характеризують стан сплаву в цілому (Zy, d). На основі інформації про істотний вплив хімічного складу сталі на її властивості підготовлено базу даних із 150 складів для визначення оптимального складу ультранизьковуглецевих сталей типу 01ЮТ, 01ЮТА методом фізико-хімічного моделювання. На основі розрахунків обрані концентрації елементів для сталей типу 01 ЮТ та 01 ЮТА.*
Ключові слова: YUT низьковуглецева сталь, азот, нітриди, вакуумування, оксидування, метод фізико-хімічне моделювання.

Introduction

In recent years, the requirements for the main service characteristics (stampability, strength, corrosion resistance) of steels have increased several times, which indicates the need to find new, fundamentally different ways to achieve a given level of properties.

The physical and chemical properties of the metal are formed throughout the entire production cycle, however, post-bake processing has the greatest impact on the quality and properties of the finished metal, which necessitates the selection of its rational parameters depending on the characteristics of the target product. In a number of works [1-4] much attention is paid to the issues of developing low-carbon steel production technology, especially the influence of the formed structure of the metal on the mechanical properties of the metal is studied in detail. Thus, at present relevant for metallurgical enterprises the task is to develop production technology pure steels with the use of modern complex “arc steel melting furnace – installation ladle furnace - Vacuum treatment - continuous

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machine billet casting, which is especially important for the release low carbon steels.

Unlike the oxygen-converter processes, where 60-90% metal fillings are made of liquid cast iron, with electro smelting up to 100% scrap is used in the landfill, much of which is of unknown origin. Liquid cast iron, apart from P and S, practically does not contain others admixture, therefore the converter steel have good weldability and are mainly used for sheet products. Scrap supplies in metal electric arc furnace non-ferrous metal impurities, oxide and nitride inclusions, as well as microdefects at the atomic level, characteristic of the primary metal of each scrap piece [6].

Application as part of bulk materials liquid cast iron free from harmful impurities allows to significantly increase purity and quality molten metal, however, it is optimal the amount is ≈30% [7], because on the one hand he brings an additional amount of physical and chemical heat, and this causes a reduction in consumption of electricity and increasing productivity, and with another is caused by the need for significant oxidation of the amount of carbon, which increases the duration of melting and reduces productivity [8]. Also the application of liquid cast iron in the chipboard charge leads to increase in oxygen consumption for metal purging with 35 m3/t when working without cast iron in a charge of up to 37 m3/t with iron content in the charge is 30% and up to 45 m3/t at his content of 50%.

Contamination of steel scrap with non-ferrous metals, mainly copper, which is in the process melting of steel from the metal is not removed, leads to to the reduction of plastic properties of steel and causes the formation of defects in the finished rolling stock. Yes, in foreign practice in the production of steel copper content is permissible for building structures ≤0.48%, and in steel for cold-rolled sheet ≤0.06%. Therefore, to reduce the content of copper and others non-ferrous metals in steel must be provided preparation of scrap. A feature of the electro baked semi-product is increased nitrogen content, which leads to the formation of dispersed particles of iron nitrides, which inhibit the movement of dislocations and reduce plasticity properties of steel.

According to the authors [9] nitrogen content in steels for deep drawing is not should exceed $30 \cdot 10^{-4}$%. Reducing content nitrogen is achieved through selective selection scrap metal and process management in chipboard on foamed slag [10 - 12]. For ultra of low-carbon steels is also important coordinated control of carbon and oxygen content to achieve low residual oxygen during the decarburization process, which is useful for improving the purity of steel [13, 14].

The goal of the work. To improve the quality of the received of steel and rationalization of the use of deoxidizers it is necessary to justify the optimal parameters of the semi-finished product and optimize indicators of non-baking steel processing. For this it is necessary to investigate the effect of characteristics intermediate product (oxidation, carbon content, etc harmful impurities, metal temperature at release) on the course of processes during further out-of-furnace processing to obtain steel with the specified level of mechanical properties. **Research results and discussion**. Research results and their discussion. The carbon content and degree of oxidation of the semi-finished product from the electric arc furnace were determined for further vacuum processing in order to obtain low-carbon steel (Table 1).

Table 1. Indicators of low-carbon melts produced from chipboard

Melting №	Carbon content, % (chemical analysis data/a_O)	a_O at outlet, ppm	Temperature before outlet, ℃	Coke consumption, kg/t of steel	O_2 for coke combustion, m^3/t	Oxygen for oxidation of impurities, m ^{3}/t	Duration swimming trunks, minutes
1	0,0554/0,035	1145	1653	10,22	9.54	10.18	49
2	0,0958/0,032	1299	1701	6,5	6.07	20.92	57
3	0,0765/0,038	1118	1719	5,79	5.40	21.55	49
4	0,0742/0,033	1213	1644	24,51	22.88	18.60	59
5	0,0542/0,026	1445	1703	29,76	27.78	11.62	65
6	0,0383/0,030	1316	1660	17,42	16.26	25.36	55
7	0,0293/0,025	1799	1741	8,21	7.66	27.69	73
	0,0432/0,029	1470	1694	8,73	8.15	26.81	65
	0,0508/0,025	1741	1707	13.57	12.67	15.64	61

On all swimming trunks, despite being quite large the amount of carbon-containing materials supplied on heating the metal in the furnace, received a low content carbon (values in the range of 0.03-0.096% by chemical analysis and 0.025-0.038% by oxidation). Metal oxidation at the outlet is 1118-1799 ppm, temperature - 1653 - 1741°C. Also listed the results of calculating the amount of oxygen that goes to oxidation of impurities found as the difference between by the total amount of oxygen supplied to the furnace and is spent on burning coke. There is a certain dependence between the consumption of oxygen in excess of its necessary amount to ensure the stoichiometry of the coke combustion reaction, oxidation at the outlet and the temperature of the metal. Increased oxidation of the semi-product occurs when oxygen consumption increases, which served in chipboard and exceeding the value necessary for the stoichiometry of fuel combustion reactions.

Due to the amount of oxygen above the stoichiometric carbon and some impurities are oxidized became. At the same time, the receipt is very high oxidation is undesirable from the point of view of reduction output of suitable (iron soot), as well as from inspection on reducing the stability of the lining. Oxidation at production of especially low-carbon steel should be such as to ensure removal of carbon from the initial semi-product to the given one limits, as well as those amounts of carbon which come from deoxidation of steel from ferroalloys and electrodes when heating steel on a ladle furnace installation, as well as from a periclase-carbon lining steel ladle (carbon content in the slag area belt 10-12%, in the lining of the walls and bottom - 6%). As the results of the calculations show a minimum the necessary amount of active oxygen for obtaining a carbon content in steel of 0.005% at different initial content of it in the semi-finished product, c in most cases there is oxidation at the output sufficient, and often even excessive, for removal of carbon during subsequent out-of-furnace metal processing. At the same time, it is necessary to take into account the amount of carbon that comes in after being released metal from the furnace. Carbon can come from ferromanganese and silicomanganese. Thus, the required amount of oxygen to oxidize the carbon of the ferroalloy was calculated for ferromanganese FMn78 deoxidized with carbon, which contains up to 7% carbon, when fed to the bucket for grading and with a degree of assimilation of 35% (Table 2).

Table 2. The necessary amount of oxygen to remove carbon, which is introduced by ferromanganese

Manganese content in finished steel	FMn consumption, kg/t	Increase in carbon content, % contributed by FMn		Amount of oxygen, ppm, required for the oxidation of FMn carbon	
		100	35	100	35
0.10	3.91	0.03	0.01	365.30	127.85
0.15	5.87	0.04	0.01	547.95	191.78
0.20	7.83	0.05	0.02	730.59	255.71
0.30	11.74	0.08	0.03	1095.89	383.56
0.40	15.66	0.11	0.04	1461.19	511.42
0.50	19.57	0.14	0.05	1826.48	639.27
0.60	23.48	0.16	0.06	2191.78	767.12

Comparison of calculated and actual values of oxidation of steel at the exit from the furnace show that the smelting technology provides oxidation of the additional amount of carbon added to the metal when ferromanganese is used for all low-carbon grades of steel in which the manganese content does not exceed 0.3%. To eliminate overoxidation of the metal at the outlet, before adding deoxidizers, it is necessary to introduce a certain amount of aluminium, taking into account the different amount of aluminium that will be oxidized, and maintaining the ability of the metal to self-oxidize with carbon during vacuuming (Table 3).

Table 3. Consumption of aluminium on experimental smelters to remove overoxidation.

Smelting No	The amount of overoxidation, ppm	Consumption of aluminium at the outlet to remove overoxidation without taking into account burning, kg/melt	Consumption of aluminium at the outlet to remove overoxidation (burning 50%), kg/melt	Real consumption of aluminium for melting, kg
1	473	42.04444	84.08889	100
2	88.33333	7.851852	15.7037	100
3	164.6667	14.63704	29.27407	100
4	290.3333	25.80741	51.61481	0
5	789	70.13333	140.2667	150
6	872	77.51111	155.0222	0
7	1475	131.1111	262.2222	100
8	960.6667	85.39259	170.7852	100
9	1130.333	100.4741	200.9481	100

In real conditions, when the carbon content at the outlet is less than 0.04% for low-carbon steel grades, up to 150 kg of aluminium (120 t) is added to the ladle in flakes or shavings pressed into tablets, as a result of which the maximum reduction of oxidation (at 100% degree of assimilation aluminium) can be 1111 ppm. Given the fact that at least 50% of the aluminium is burned off due to exposure to the atmosphere and slag during production, the actual oxidation recovery does not exceed 555 ppm. A comparison of the consumption of aluminium according to the technological map and according to the calculation shows that the real value of its quantity does not correlate with the degree of re-oxidation of the metal. Excess aluminium consumption will reduce the potential for carbon removal during vacuuming (requiring additional oxygen in one form or another), while aluminium deficiency will result in excessive oxidation of manganese from ferromanganese or silicomanganese. Thus, during vacuuming, due to the high oxidizability of the metal, the carbon content can be reduced.

For binary systems, the calculated deoxidizing capacity of carbon with a content of 0.55-0.62% is higher than that of silicon with a content of 0.25-0.45%. Manganese is a relatively weak deoxidizer and does not ensure reduction of metal oxidation to the required limits. However, manganese is used in the smelting of many grades of steel. The positive effect of manganese on the properties of steel is associated with a decrease in the sulphur content, an improvement in the removal of formed MnO inclusions due to a low interphase tension at the "metal-MnO inclusion" separation boundary. The deoxidizing effect of manganese in the presence of carbon can be manifested when it is introduced into the metal together with other stronger deoxidizers - silicon, aluminium. The influence of manganese and silicon as weaker deoxidizers on the deoxidizing capacity of carbon for ternary systems is taken into account through interaction parameters, the values of which are given in [16]. In view of this, the equilibrium content of oxygen in the metal before vacuuming was a maximum of 31.4 ppm (at the content, %: carbon 0.55, silicon 0.25, manganese 0.56); minimum 27.0 ppm (at the content,%: carbon 0.61, silicon 0.42, manganese 0.85). A comparison of the obtained calculated values of oxygen content with the results of direct determination of oxidation by CELOX sensors showed their good agreement (minimum 28 ppm, maximum 43 ppm) at a temperature of 1610-1630°C.

In the practice of steel production, the use of complex deoxidizers has a number of advantages. When they are used, the thermodynamic conditions of deoxidation are significantly improved. It is known that manganese increases the deoxidizing capacity of silicon. Manganese and silicon individually and together increase the deoxidizing capacity of aluminium. This is due to a decrease in the thermodynamic activity of the formed oxide in complex deoxidation products, which differ from the composition of the products during separate deoxidation. When using silicocalcium to modify steel, the silicon included in the composition of silicocalcium can have a deoxidizing effect under the condition of the formation of an oxide phase (calcium silicates), in which the activity of SiO_2 will be less than one. When the activity of silica decreases, the effect of silicon in silicocalcium increases. According to the literature, the minimum activity of SiO_2 is 0.024 in dicalcium silicate. Therefore, the calculations were performed for the formation of $2CaO{\cdot}SiO_2$.

The results of the calculation of the equilibrium oxygen content at different concentrations of deoxidizer elements and temperatures are shown in Table 1 (deoxidizers are Al_2O_3, SiO_2, and $2CaO{\cdot}SiO_2$).

Table 4. Equilibrium content of oxygen during deoxidation with aluminum and silicon

Deoxidizer element	Deoxidation product	Concentration of deoxidizer, %	Oxygen activity, ppm at temperature (°C)		
			1500	1550	1600
Aluminum	Al_2O_3	0,015	1,26	2,68	6,1
		0,020	1,05	2,24	5,2
		0,025	0,92	1,96	4,6
		0,030	0,825	1,75	4,1
Silicon	SiO_2	0,25	28,7	48,5	81,0
		0,30	26,0	44,0	74,5
		0,35	24,0	41,0	69,0
		0,40	22,6	39,0	65,0
Silicocalcium	$2CaO{\cdot}SiO_2$	0,25	4,35	7,5	12,6
		0,30	4,0	6,9	11,5
		0,35	3,7	6,45	10,7
		0,40	3,4	6,0	10,0

As the results of the calculations show, in the concentration range corresponding to the grade composition of the steel, aluminium has the greatest deoxidizing capacity. However, during the formation of dicalcium silicate, silicon silicocalcium is able to have a deoxidizing effect, forming silicate non-metallic inclusions. In order to avoid the formation of calcium silicates, it is necessary to have an active oxygen content below 2.5 ppm, which is provided by a residual content of dissolved aluminium in the steel of 0.025-0.027% (determined by the CELOX sensor). The high chemical activity of pure calcium and the high elasticity of its vapors at the temperature of steelmaking lead to the need to use in metallurgical technology not pure calcium, but its alloys. Silicocalcium of various brands, alloys with aluminium, magnesium are most widely used. Aluminium is the most widely used deoxidizer and element that grinds the grain, but causes the formation of refractory inclusions capable of agglomeration. During rolling, they form chains of alumina and the mechanical properties of steel. If calcium is used at the same time as aluminium, then the resulting inclusions are low-melting calcium aluminates. They are in a liquid state and can quickly float in steel. The inclusions remaining in the steel are small in size and spherical in shape and do not reduce the mechanical properties of the steel. During the deoxidation of steel with aluminocalcium, the composition of the deoxidation products is determined by the FeO-CaO-$A1_2O_3$ state diagram. Analysis of this diagram shows the possibility of the formation of the following non-metallic phases: calcium mono-, bi- and hexaaluminates, calcium and aluminum oxides, hercynite, oxide melt (FeO, CaO, Al_2O_3), as well as gaseous calcium. The main thing is the formation in liquid steel of low-melting products with high fluidity of deoxidation reactions to ensure their assimilation by slag. Modern processes of steel modification are blowing the metal in a ladle with a powdered form of calcium or its alloys at a great depth with submerged lances; shooting a container with calcium into a bucket;

inserting into the metal at high speed a wire containing calcium compounds clad with steel. As noted in [4], the efficiency of calcium alloys increases when they are used together with aluminium. In this case, the negative influence of sulphide inclusions is reduced and the accumulation of particles (clusters) of oxysulfide inclusions characteristic of alumina do not appear. The use of complex deoxidizers in the production of steel allows you to use the synergistic effect of the joint deoxidizing action of the deoxidizing elements. The use of calcium allows you to significantly improve the quality of steel by controlling the morphology of non-metallic inclusions, increasing the degree of deoxidation and desulfurization.

Physic-chemical modelling for forecasting and management properties of steel. Involvement of physic-chemical methodology modelling made it possible to solve the task of predicting steel properties quite effectively. The theory of physicochemical modelling is based on a single metallochemical interpretation of the elementary act of interatomic interaction. The physic-chemical model of the alloy structure by E.V. Prikhodko [17] is based on the use of the equations of the system of non-polarized ionic radii (SNIR) to calculate parameters, the combination of which can characterize the properties of the melt as a chemically unified whole with any number of components in the system and different ratios between their concentrations.

The main parameters of SNIR include: Zy - the number of electrons involved in the formation of an average acceptor bond; this value is an integral characteristic of interatomic interaction in a multicomponent system and can be interpreted as the chemical equivalent of a given composition; d is the corresponding Zy internuclear distance. Depending on the chemical characteristics of the components of metal melts, first of all, their position in the Periodic Table and the electronic configuration corresponding to these positions, the role of the main parameter that controls changes in one or another property can be performed by either Zy or d. The mentioned parameters are determined on the basis of the accepted assumption that that the probability of the formation of double bonds in the AXBYCZ melt ...namely A-A. A-B, A-C,..., B- B. B-C. ..., C-C ... are proportional to the product of the corresponding molar concentrations. At the same time, any deviation from the statistical definition can be taken into account by varying the possibilities of the occurrence of connections of various types.

To study the influence of modifier elements, as well as the main alloying components, a number of parameters characterizing the state of the alloy as a whole (Zy, d) were calculated. These parameters are calculated for fifteen alloys while varying a single element in order to assess the influence of the concentration of alloying and modifying elements on the steel properties. Based on information about the significant influence of the chemical composition of steel on its properties, a database containing 150 compositions was prepared for determining the optimal composition of ultra-low-carbon steels of the 01YUT, 01YUTA type by the method of physicochemical modelling. The typical composition of the investigated steels 01YUTA and 01YUT has the following content of components, % by mass:

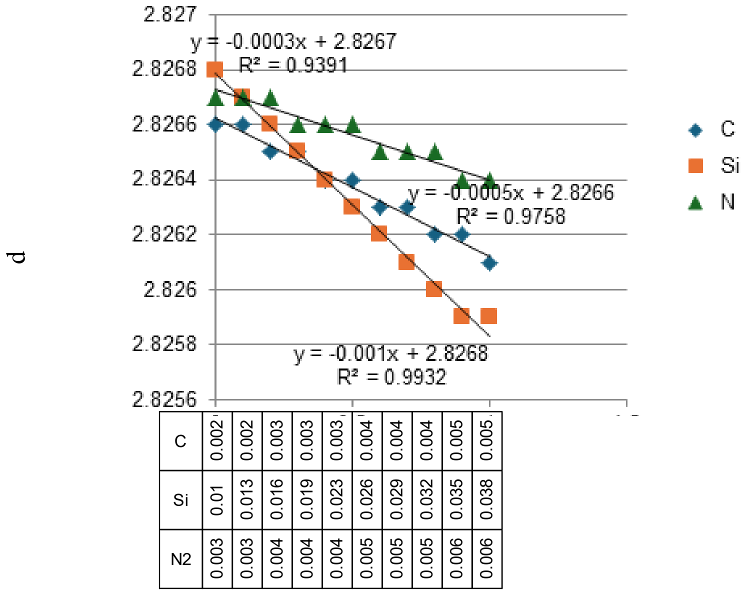
Steel brand	C	Mn	Si	P	S	Cr	Ni	Cu	Al	Ti	N2	Ca
01YUT	0.003	0.13	0.02	0.008	0.012	0.01	0.01	0.02	0.041	0.056	0.004	-
01YUTA	0.002	0.12	0.01	0.006	0.011	0.01	0.01	0.02	0.05	0.062	0.005	0.0002

The concentration range of elements was set based on literature data. 150 compositions of experimental steels of type 01YUTA and 01YUT were analysed. Calculated composition of alloy type 01YUT, 01YUTA for modelling interatomic interaction and integral parameters,% wt.:

C	Mn	Si	P	S	Cr	Ni	Cu	Al	Ti	N_2	Ca
0.002	0.091	0.01	0.0064	0.008	0.08	0.008	0.01	0.031	0.044	0.003	0.0001
0.0048	0.029	0.038	0.0094	0.0018	0.02	0.02	0.038	0.059	0.072	0.0058	0.0004

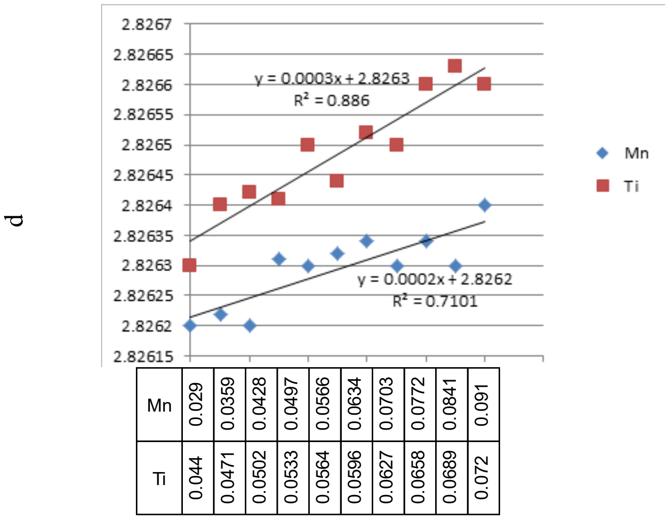
Below are the results of calculating the values of the d parameter depending on the content of carbon, manganese, silicon for the calculated alloy 01YUT.

The change in parameter d depending on the content of carbon, manganese, silicon, phosphorus, sulphur in the calculated alloy 01ЮТ was also calculated. The obtained data on the change of the parameter d depending on the composition of the alloy show that the chemical elements are different affect the distance between atoms in the melt. For 01YUTA steel, the d parameter does not change at manganese content of 0.009...0.024% and chromium 0.008...0.036% and with a nickel content of 0.009...0.023%, copper 0.008...0.036%, calcium 0.0001...0.0004%. With by increasing the silicon content, parameter d decreases, does not change with chromium content 0.02...0.08%, nickel 0.008...0.02%, copper 0.01...0.038%. For 01YUT steel, the parameter Zy increases with increasing content of silicon and manganese and chromium. Considered integral parameters characterize the state of the system and determine the change properties of steels. Based on calculations selected element concentrations for type steels 01 YUT and 01 YUTA, which are in the range: carbon 0.002...0.003%, manganese 0.12...0.13%, silicon 0.01...0.02%, phosphorus 0.006...0.008%, sulphur 0.011...0.012%, aluminium 0.04...0.05%, titanium 0.05...0.06%, nitrogen 0.004...0.005%, calcium 0.0002...0.0003%. Such a concentration interval elements will provide optimal complex of properties of steels.



C	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.004	0.005	0.005
Si	0.01	0.013	0.016	0.019	0.023	0.026	0.029	0.032	0.035	0.038
N2	0.003	0.003	0.004	0.004	0.004	0.005	0.005	0.005	0.006	0.006

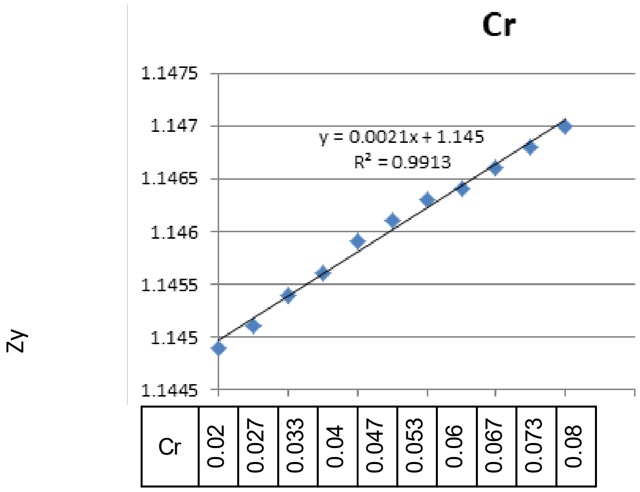
Fig 1. Change in parameter d depending on the content of carbon, silicon, and nitrogen in 01YUTA steel



Mn	0.029	0.0359	0.0428	0.0497	0.0566	0.0634	0.0703	0.0772	0.0841	0.091
Ti	0.044	0.0471	0.0502	0.0533	0.0564	0.0596	0.0627	0.0658	0.0689	0.072

Fig 2. Change in parameter d depending on the content of manganese and titanium in 01YUTA steel

For the calculated alloy 01YUT, the change in the Zy parameter was determined depending on the content of chromium.

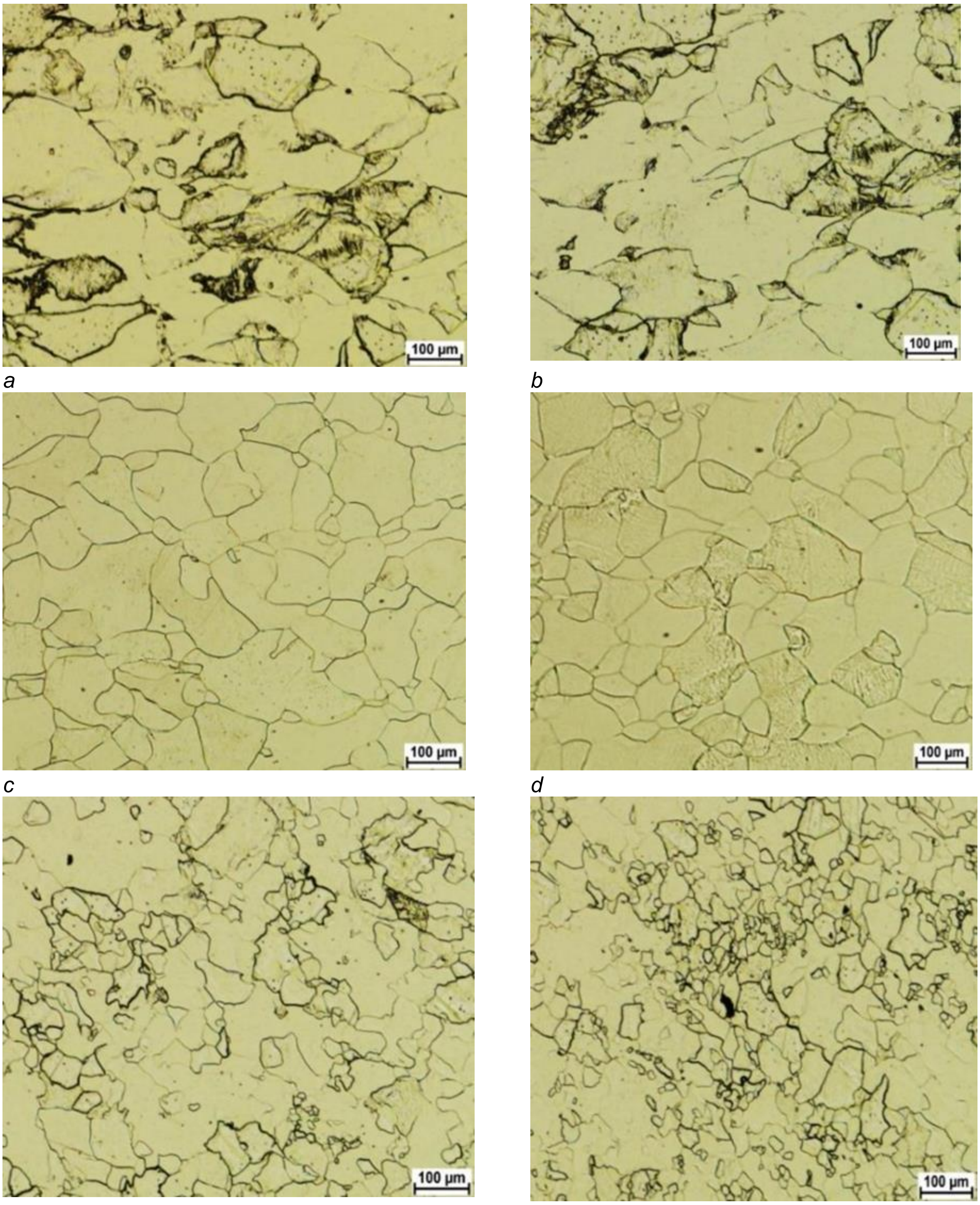


Cr	0.02	0.027	0.033	0.04	0.047	0.053	0.06	0.067	0.073	0.08

Fig. 3. Change of the Zy parameter depending on the chromium content in 01YUTA steel

The results of the rolling of test samples. Heating the metal before rolling was carried out in an electric furnace with at a speed of 3°C/s, rolling was carried out at laboratory one cell condition for one and for two passes, the rolling speed was 1.4 m/m, the duration of the pause between passes is 13-15 seconds. After rolling, the samples were cooled in air from temperature of the end of rolling to the temperature environment, speed cooling 5-8°C/s, or for simulation purposes sheet winding was loaded into an electric furnace, the temperature of which corresponds to the temperature winding into a roll, and cooled together with the furnace to ambient temperature with a cooling rate of 0.05°C/s.

Microstructures of hot-rolled ultra-low-carbon steels are shown in Figure 1.



a *b*

c *d*

e *f*

Fig 4. - Microstructure of hot-rolled ultra-low-carbon steels: a, b – 01YUT; c, d – 01YUT; e, f – 01YUT(Ca)

The microstructure of 01YUTA steel (Fig. 1, a, b), which was rolled in two passes: the first – in the austenitic region, the second – in the ferritic region of the temper tour with a degree of deformation of 60.0% and cooled in air (Fig. 1 , a, b) is characterized by the presence of a fine-grained layer in the surface zone of the sheet with a thickness of 150-200 microns. The size of the ferrite grain in this layer is 10-20 µm. The grain size in the central zone is 20-130 µm. Thus, zonal heterogeneity is observed.

Microstructure of steel 01YUT (Fig. 1, c, d), rolled in two passes: the first – in the austenitic region, the second – in the ferritic temperature region with a degree of deformation of 60.0% and cooled in air (Fig. 1, c, d) , is characterized by the presence of a fine-grained layer 150-200 microns thick in some areas of the headquarters. The size of the ferrite grain in the surface layer is 10-20 µm, in the central layer 15-130 µm.

The microstructure of steel 01YUT(Ca) (Fig. 1, d, e) rolled in two passes: the first – in the austenitic region, the second – in the ferritic region at temperatures with a degree of deformation of 60.0% and cooled in air (Fig. 1, d, e), is characterized by the presence of a fine-grained layer 100-200 µm thick in some areas of the headquarters. The size of the ferrite grain in the surface layer is 5-20 microns, in the central layer the cores are 15-130 microns.

Conclusions

Based on the performed analysis of indicators existing technology of smelting and out-of-furnace processing low-carbon steel established factors that contribute to reducing the carbon content in the finished steel: high oxidation of steel at the melting point; relatively low carbon content at the melting point; high metal temperature at the outlet.

Shown is the possibility of receiving at the release of Semi-finished chipboard with a carbon content of less than 0.03% and high oxidation, which creates prerequisites to obtain especially low-carbon steel during its subsequent out-of-furnace processing. Thermodynamic calculations and on the basis analysis of the results of previous ice melts of low-carbon steel, it is shown that the activity oxygen in the semi-product to obtain especially of low-carbon steel should be such that ensure the removal of carbon from it to of the given limit, as well as those amounts of carbon which come from deoxidation of steel from ferroalloys and electrodes when heating steel in a ladle-furnace, a also from the periclase-carbon lining of the steel ladle (carbon content in the area of the slag belt is 10-12%, c wall and floor linings - 6%); metal on release from Chipboard is oxidized. Consumption of aluminium on release does not correlate with the degree of overoxidation metal, which would be desirable for stabilization and reduction of silicomanganese carbon monoxide; pressure reduction in a vacuum chamber up to 100 mbar is theoretically enough for the predominant oxidation of carbon in comparable to manganese and silicon in everything temperature range of the technological process.

The results of physicochemical modelling for determining the optimal composition of low-carbon steel are presented. Modes of deformation treatment of experimental steel samples have been established.

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