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Polishko S.

EFFECT OF PROCESSING AT THE STEEL VACUUM PROCESSING UNIT (SVPU) ON DESULFURIZATION OF UNMODIFIED AND MODIFIED KP-2 STEEL

Об'єктом дослідження є процес позапічної обробки колісної сталі КП-2. Одним з найбільш проблемних місць при виплавці сучасних сталей є стабільність хімічного складу через використання неконтрольованих за змістом ломів, шихти і стандартних модифікаторів, які виготовляються плавленим способом.

Для усунення цієї проблеми в ході дослідження використовувалися багатофункціональні модифікатори. Це пов'язано з тим, що запропонований в даній роботі метод модифікування сталі КП-2 має ряд особливостей. В даному випадку встановлено вплив модифікаторів багатофункціональної дії на установці вакуумної обробки сталі на десульфурацію колісної сталі марки КП-2, отриманої в умовах відкритого акціонерного товариства «Інтерпайп НТЗ» (м. Дніпро, Україна). Зокрема, при обробці сталевого розплаву багатофункціональними модифікаторами відбувається не тільки рафінуюча дія, але також підвищення стабільності хімічного складу і рівня механічних характеристик колісної сталі марки КП-2. Це підтверджено представленими в роботі коефіцієнтами варіації і межплавочної різниці (розмахом), отриманими методами статистичної обробки великого масиву даних – 442 серійних плавок і 1 модифікованої (6 коліс).

Завдяки багатофункціональній модифікації дійсно підвищується рівень механічних характеристик і якості готових коліс. У порівнянні з подібними серійними матеріалами, такими як FeSi, FeCa, FeMn, SiCa, застосування нових модифікаторів багатофункціональної дії в колісній сталі КП-2 забезпечує значне зниження масової частки сірки, ніж в тому ж металі, який обробляють традиційним способом. Встановлено, що при застосуванні багатофункціональних модифікаторів змінюється форма неметалевих включень на глобулярну і знижується їх кількість, що також підвищує рівень механічних властивостей колісної сталі КП-2. Отримані коефіцієнти варіації доводять, що механічні характеристики модифікованої сталі КП-2 стабільніші, ніж в серійних плавках тієї ж сталі. Це підвищить попит і якість на ці залізничні колеса.

Ключові слова: *багатофункціональні модифікатори, хімічний склад сталі, механічні властивості сталі, неметалеві включення.*

1. Introduction

The use of rail transport for railway wheel steels is a scientific and practical interest because of the fact that this – multicomponent systems that have a significant variation of the chemical composition [1]. This is happening because during the smelting of the wheel metal, due to the non-controlled chemical composition of scrap and serial modifiers, unfavorable chemical compounds get into the wheel steel. At as a result, this leads to a significant variation in the mechanical characteristics of the transport metal, it can lead to extremely negative consequences – loss crack resistance and railway wheels and the qualities of a finished products in general. This proves the relevance of these studies.

2. The object of research and its technological audit

The object of this researches is process of secondary treatment of wheel steel KP-2.

Today it is very important is the question of raising the quality of wheels for railway cars, where the alloy steel is used. In our time serial wheels are used. For example, in the conditions of open joint stock company (JSC) «Interpipe NTRP» (Dnipro, Ukraine) make wheels from steel KP-2 according to DSTU GOST 10791-2016, which are characterized by an unstable chemical composition, have an increased number of nonmetallic inclusions, but the person of acute and n faceted shape. There are stress concentrators, which leads to a decrease in strength, crack resistance, a short service life and insufficient stability of characteristics during operation.

Among the main directions of solving this problem is the modification of steel with multifunctional modifiers. To enhance the mechanical characteristics of the metal in terms of «Interpipe NTRP» multifunctional modifiers have been successfully applied [2]. They were introduced into the melt after the applied ligatures of ferrosilicon, ferromanganese, ferrotitanium, silicomanganese, silicocalcium, CaO, CaF_2.

3. The aim and objectives of research

The aim of research is establishing the effect of multifunctional modifiers on desulfurization of unmodified and modified KP-2 steel.

To achieve this aim, it is necessary to perform the following objectives:

1. To determine the stability of the chemical composition in the serial and modified metal.

2. To establish the desulfurization degree of serial and modified metal.

3. To establish the effect of modification on the morphology of non-metallic inclusions and on the level and stability of mechanical characteristics.

4. Research of existing solutions to the problem

The problem of increase the quality of wheels for railway cars is very important [3]. Among the works devoted this subject, it can be isolated [4, 5]. However, in these papers, problems such as desulfurization of steel and stabilization of chemical composition weren't considered.

An alternative solution to the problem, described in [6], does not provide for the steel desulfurization. It is also important in the study of the crystallographic texture of steel of rail wheels as a result of modification and thermomechanical processing.

Article [7] is devoted and impact modifier which contains rare earth elements (RE) on the characteristics of the alloy with a melting point or viscous (Al-Bi-Sb) and Si-Ca alloys to high-carbon steel containing 1.9 % C. But in this work, the question of reducing the sulfur concentration and the number of non-metallic inclusions in steel remains unresolved.

The modification described in detail in [8]. However, this source does not fully disclose the description of the process of stabilization of the chemical composition and improvement of the morphology of nonmetallic inclusions.

In [9, 10] it is illustrated that metal modification process is a one of the second main smelting operations in steel wheel. This process consists in reducing the amount of non-metallic inclusions from the liquid metal, which is present in the form of various metal compounds with harmful impurities. But it wasn't proved that to improve the morphology of non-metallic inclusions and reducing the amount of sulfur, it is necessary to introduce modifying elements – substances that have a special feature for combining with sulfur.

The authors of [7, 11] shows that the steel quality is largely dependent on melt processing of multifunctional modifiers. This is an essential process for obtaining quality steel. Depending on the situation, the molten steel is introduced soluble scavengers modifier-ligatures (FeMn, FeSi, FeTi, FeNb, SiMn, SiCa, C, Al) in the form of ingots. As a result of the multifunctional action, iron is reduced to a free state and the formation of oxides of modifiers of the multifunctional action, which due to a less specific weight, float to the surface as slags. However, the problem of improving the quality of the metal remains important, as part of the non-metallic inclusions still remains in the steel, despite the use of the above modifiers of multifunctional action. Introduction of each metal reduces the temperature of the ladle cooling it, which often leads to undissolved ferroalloys and refractory to the formation of microsegregates. Thus, the results lead to the conclusion that the most progressive way to improve the quality and grained carbon steels is handling them in the liquid state multifunctional modifiers as briquettes (Fig. 1).

The above statement, as proved in [12, 13], is justified by the fact that the modifiers in the form of briquettes are completely absorbed by the steel melt. As a result, non-metallic inclusions of a globular form are formed, which leads to the formation of additional crystallization centers. This, in turn, contributes to the stability of the properties and quality of the finished metal.

Fig. 1. Reducing the sulfur content in the processing of unmodified standard steel KP-2

5. Methods of research

In the study of the stability of the chemical composition of multifunctional modifiers, statistical processing methods were used. The use of statistical processing methods is convenient technically, since all the necessary features were available in Microsoft Office.

Analysis of the chemical composition of the KP-2 series steel by statistical processing methods showed the following:

– low degree of desulfurization of KP-2 steel;

– the unstable chemical composition of KP-2steel, processed in the traditional way with serial deoxidizers.

To obtain accurate and reliable results, a complex of modern methods for determining the properties of the materials under study has been used. The chemical composition of steel without modification and after modification was determined on high-precision instruments: Polivak E-600 and LECO (England). Microstructure studies were performed on a NEOPHOT 32 microscope (Germany) at magnifications up to 900 short. Mechanical properties were determined on standard discontinuous samples on an MUP-20 tensile testing machine and pendulum shock machine MK-30 (Russia). Experimental data processing was performed using modern computer programs Microsoft Excel 2016.

The smelting of KP-2 wheeled steel was carried out on an open-hearth furnace with further processing on a ladle furnace and a vacuum unit. Wheel rolling and heat treatment was carried out according to the existing production technology under the conditions of «Interpipe NTRP».

6. Research results

The chemical composition of steel KP-2 complies with the requirements of DSTU GOST 10791-2016 according to statistical research data 442 serial heats produced by «Interpipe NTRP» of unmodified and modified second melt (6 wheels) of steel KP-2 steel (Table 1) [14].

From the data presented in Table 1 it follows that the maximum values for harmful impurities of sulfur and phosphorus in unmodified KP-2 steel are higher than in a modified metal of the same grade. At the same time, the minimum values are the same, but at the same time the interfusion difference (span) between the maximum and minimum values in the serial metal is also larger than in

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the modified one. This leads to instability of the chemical composition of the wheel steel KP-2, and, as a result, to the instability of the mechanical characteristics. This causes a reduction in the quality of the finished wheels.

Table 1

Chemical composition of KP-2 steel

Options	Chemical composition data				
	C	Mn	Si	P	S
KP-2 unmodified steel					
Maximum	0.62	0.74	0.36	0.015	0.009
Minimum	0.58	0.70	0.29	0.008	0.005
Range	0.04	0.04	0.07	0.007	0.004
Average value	0.60	0.72	0.31	0.012	0.007
Variation coefficient	0.02	0.02	0.09	0.21	0.24
KP-2 modified steel					
Maximum	0.63	0.73	0.33	0.013	0.006
Minimum	0.62	0.72	0.32	0.012	0.005
Range	0.01	0.01	0.01	0.001	0.001
Average value	0.63	0.73	0.33	0.012	0.006
Variation coefficient	0.01	0.01	0.01	0.04	0.08

In order to confirm the above, a study was conducted of the effect of modification on a SVPU (steel vacuum processing unit) for desulfurization of unmodified and modified KP-2 steel.

The decrease in sulfur content according to the results of research as a result of technological operations on SVPU is presented in graphs (Fig. 2, 3). All data in Fig. 2, 3 comply with the requirements of regulatory documents (GOST).

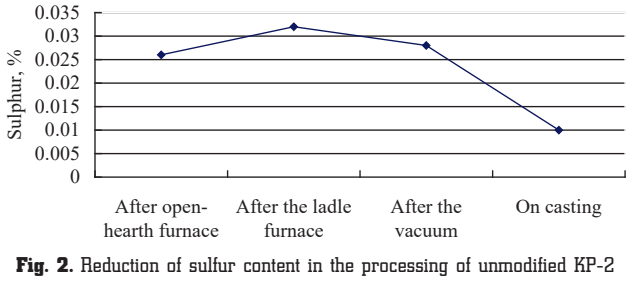


Fig. 2. Reduction of sulfur content in the processing of unmodified KP-2 serial steel on the installation of vacuum steel processing

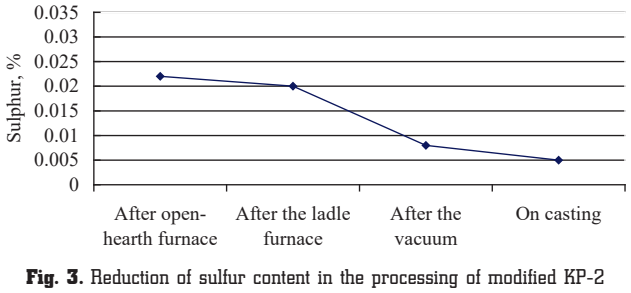


Fig. 3. Reduction of sulfur content in the processing of modified KP-2 standard steel at the vacuum processing facility for steel

From the analysis of the data presented in Fig. 2, 3, it is possible to draw the following conclusions.

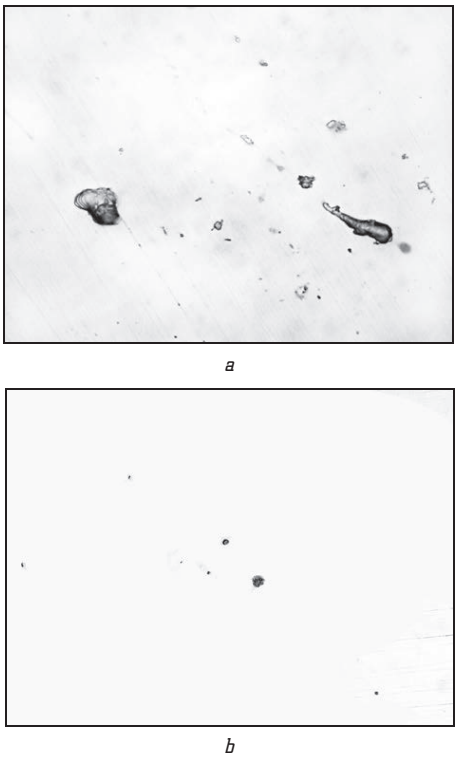
Desulfurization of industrial melts on SVPU does not depend on the sulfur concentration after open-hearth: for example, the degree of desulfurization with high sulfur content (S=0.026 %) after marten on casting is 2.9 (S=0.010 % wt.), Fig. 2.

Processing of modifiers multifunctional action of KP-2 steel on SVPU sulfur content reduced to 0.005 %. It's at 7 times lower compared with the requirements of DSTU GOST 10791 and from 40 % up to 60 % less than 442 KP-2 unmodified steel melting (Fig. 3).

Since the sulfur content largely determines the risk of microcracks and the destruction of the wheels, it is necessary to strive for their optimal content from 0.005 % to 0.006 % wt. sulfur.

In unmodified melting, even after processing on SVPU, the interfusion sulfur content is very unstable. Only modification allows to reduce on a constant basis both the sulfur content and stabilize its intermelting and interfusion concentration.

According to the results of studies of non-metallic inclusions, it was found that in the modified steel they have a globular shape, in contrast to the commercial metal, which has non-metallic inclusions of elongated faceted shape (Fig. 4).



a

b

Fig. 4. Appearance of non-metallic inclusions in KP-2 steel grade, h900: *a* – serial; *b* – modified

From the photos in Fig. 4, it can be seen that the number of non-metallic inclusions themselves also in the modified metal is less than in the serial one. This is due to the fact that the components of the modifier contribute to the formation of stable compounds, which are additional centers of crystallization. At the same time, excess sulfur is also formed into compounds that float to the slag.

The level of mechanical characteristics in the KP-2 wheel steel is presented in Table 2.

Table 2

Mechanical characteristics of KP-2 steel

Options	Tensile strength, $\sigma_в$, MPa	Relative elongation, δ, %	Relative narrowing, ψ, %	Hardness, HB_{30}, MP	Impact toughness KCU, J/m^2
Unmodified steel KP-2					
Maximum	1030	16.5	35	306	33
Minimum	980	13	26	278	20
Range	50	3.5	9	28	13
Average value	1005	14.81	31.5	291.4	25
Variation coefficient	0.03	0.07	0.10	0.03	0.15
Modified steel KP-2					
Maximum	1060	13	28	3020	31
Minimum	1020	11	21	2900	24
Range	40	20	7	120	7
Average value	1052	11.5	22.9	2982	28
Variation coefficient	0.02	0.07	0.13	0.02	0.11

From the data presented in Table 2 it follows that the level of mechanical characteristics in the modified steel also turned out to be higher than that of the standard unmodified steel of the same grade. The level of mechanical characteristics of KP-2 steel after modification has increased on average by 5 % strength, 1 % of plasticity, 11 % impact toughness. The coefficients of variation show that the mechanical characteristics of KP-2 modified steel are more stable than in serial melts of the same steel. This is very important, since it is thankful the stability that the level of various characteristics can be predicted, which will increase the demand and quality of these railway wheels.

7. SWOT analysis of research results

Strengths. Modification of multifunctional modifiers has a positive effect on the formation of non-metallic inclusions. This leads to a higher level of mechanical characteristics and an increase in the quality of finished wheels made of KP-2 steel.

The positive aspects of the study also include the fact that:

– the time costs are reduced due to the fact that the modifiers of the multifunctional action are manufactured in a melting-free manner for several tens of minutes per piece. While serial deoxidizers are manufactured in a melted manner, requiring an average time to 1.5 hours apiece;

– increases the efficiency and productivity of steel products in general;

– increases the speed of production of finished wheels without loss of quality;

– production of modifiers of multifunctional action is environmentally friendly due to the complete assimilation of their p ac by steel melt.

Weaknesses. Minor increase in the cost of production for 1 briquette modifier that is leveled by the need for their smaller number in steelmaking in comparison with serial analogues, which are needed more, and also they are more expensive.

Opportunities. The use of multifunctional modification in the production of KP-2 steel thereby reducing energy consumption and increasing the level of mechanical characteristics while reducing the cost of finished production wheels. The estimated economic effect of the introduction of multifunctional modifiers is approximately 30 euros per 1 smelting.

Threats. The need buying of material (chips) for the manufacture of briquettes, but this is offset by the fact that the multifunctional modifiers are environmentally safe and do not need the ground for disposal of industrial wastes.

There are analogues similar to these modifiers, but they are manufactured using the fused method with significant energy consumption [15].

8. Conclusions

1. As a result of the research, it is found that through the use of multifunctional modifiers, the stability of the chemical composition in the serial and modified metal is increased. By the method of statistical processing, it is established that the coefficients of variation and range in the modified steel are lower than in the standard metal.

2. It is proven that the desulfurization of KP-2 steel has increased under the influence of the modification. When introduced into the melt multifunctional modifiers average sulfur concentration decreased from 0.007 to 0.006 g %. The maximum value at the same time decreased even more – from 0.009 to 0.006 %, and the minimum remains the same – 0.005 % for serial and modified steel. This confirms the conclusions of paragraph 1 – a decrease in scope in the modified metal. It is recommended to tighten the technological regimes along the entire production chain, from smelting to deformation and heat treatment.

3. It is established that the effect of modification improves the morphology of non-metallic inclusions. The use of multifunctional modification at the company «Interpipe NTRP» in the smelting of KP-2 steel allows to increase the level of mechanical properties of KP-2 steel 2 on average by 5 % tensile strength, 1 % of plasticity and 11 % impact toughness. Based on the obtained coefficients of variation, it can be argued that the mechanical characteristics of KP-2 modified steel are more stable than in serial melts of the same steel. This is very important, since it is thanks to the stability that the level of various characteristics can be predicted, which will increase the demand and quality of these railway wheels.

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Polishko Serhii, *PhD, Senior Researcher, Associate Professor, Department of Production Technology, Oles Honchar Dnipro National University, Ukraine, e-mail: polishkopsa@gmail.com, ORCID: http://orcid.org/0000-0003-4388-2317*