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The Complex Influence of Chemical Modifier Elements on Improving the Quality of Wheel Steel by Out-of-Furnace Processing of Their Melts

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This article presents the effect of multifunctional modification on reducing the content of harmful impurities, stabilizing the chemical composition, and improving the morphology of non-metallic inclusions. As determined, modifier elements increase the level of mechanical characteristics of КП-Т wheel steel used in railway vehicles in Ukraine and other countries. The results of the influence of modifier elements on the total activity of harmful impurities of sulphur and phosphorus are presented. The thermodynamic characteristics of compounds formed under the influence of multifunctional modifiers on the melt are given. As shown, during modification, crystallization centres are formed due to the interaction of special multicomponent deoxidizers-modifiers with steel melt. They are quite evenly distributed in the bulk of the metal due to the special physical and chemical properties, the composition of modifier-deoxidizers, the constancy of their geometric shape and mass. Studies of the structures of serial and modified with multifunctional modifier steel КП-Т are carried out. As established, in unmodified serial steel of this grade, excess ferrite (about 5–7%) is released outside the former austenite grains, which decorates them. As determined, due to the action of modifier elements in the modified steel, highly dispersed fine-grained pearlite is formed with single ferrite precipitates outside the grains in the modified steel of the КП-Т grade. As proved, modifiers improve the mechanical characteristics of КП-Т grade steel. This is because, during the curing of the modified ingot, mainly volumetric, rather than oriented, heat-removing crystallization takes place, as for serial

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metal. As proved, after modification, the morphology of non-metallic inclusions is significantly improved. As determined, thanks to the modifier elements, this problem is levelled, since, due to them, the globulization of non-metallic inclusions occurs. As a result, the quality of finished wheels is significantly improved.

Key words: multifunctional modifiers, chemical composition of steel, non-metallic inclusions, mechanical properties of steel.

Розглянуто вплив багатофункціонального модифікування на пониження хемічного вмісту шкідливих домішок, стабілізацію хемічного складу, поліпшення морфології неметалевих включень і підвищення рівня механічних характеристик колісної криці КП-Т, що застосовується у залізничних вагонах як України, так і закордоном. Представлено результати впливу елементів-модифікаторів на сукупну діяльність шкідливих домішок Сульфуру та Фосфору. Наведено термодинамічні характеристики сполук, що формуються через вплив на розтоп багатофункціональних модифікаторів. Показано, що за модифікування центри кристалізації утворюються внаслідок взаємодії спеціяльних багатокомпонентних розкиснювачів-модифікаторів із крицевим розтопом. Вони достатньо рівномірно розподілені в об'ємі металу завдяки особливим фізико-хемічним властивостям, складу розкиснювачів-модифікаторів, сталості їхньої геометричної форми та маси. Досліджено структури серійної криці КП-Т та модифікованої багатофункціональними модифікаторами. Встановлено, що у немодифікованій серійній криці за межами колишніх аустенітних зерен виділяється надлишковий ферит (близько 5–7%), який декорує їх. Визначено, що завдяки дії елементів-модифікаторів у модифікованій криці утворюється високодисперсний перліт дрібнозернистої структури з одиничними виділеннями фериту за межами зерен у модифікованій криці марки КП-Т. Доведено, що модифікування сприяє підвищенню механічних властивостей сталі марки КП-Т. Це відбувається завдяки тому, що під час затвердіння модифікованого зливка має місце в основному об'ємна, а не орієнтована тепловідведенням кристалізація, як для серійного металу. Доведено, що після модифікування істотно поліпшується морфологія неметалевих включень. Визначено, що модифікування допомагає нейтралізувати цю проблему, оскільки завдяки йому відбувається їхня ґлобуляризація. Внаслідок цього значно підвищується якість готових коліс.

Ключові слова: багатофункціональні модифікатори, хемічний склад криці, неметалеві включення, механічні властивості криці.

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1. INTRODUCTION

Reducing the content of harmful impurities, stabilizing the chemical composition, as well as the optimal level of mechanical characteristics are among the main tasks of modern metallurgy to improve the quality of finished railway wheels that are used in electric railway transport.

The most effective way to achieve this goal is the treatment of steels in the liquid state with multifunctional modifiers [1, 2].

Steels used in wheels for locomotives and passenger cars experience constant cyclic loads, because of which it is necessary to ensure high quality in their manufacture. Despite the use of technologies for evacuation of alloys in the liquid state, the using of continuous casting, the processing of melts by aluminium rod of various ligatures such as FeSi, FeMn, SiMn, FeV, FeMo, SiCa, Al, CaO, CaF_2 and others, the problem of stabilizing of the chemical composition and improving the quality of the finished wheels remains relevant [3]. Ferroalloys, deoxidizers and modifiers are added to the melt in the specified sequence. The introduction of each of them reduces the temperature of the metal in the ladle, cooling it down, which often leads to underdissolution of refractory ferroalloys and the formation of microliquates. In addition, many enterprises manage to obtain metal with characteristics that meet the standards, but with various non-metallic inclusions of various types and rough shapes, which does not guarantee the quality of the finished product. Even though research in the field of modification of steels and alloys is carried out today by many specialists, this topic remains relevant [4–9].

In this regard, the purpose of this article is to analyse the effect of multifunctional wheel steel modifiers on their characteristics for their use in locomotives for trains and passenger cars.

2. EXPERIMENTAL/THEORETICAL DETAILS

Wheel steels are multicomponent systems that consist of 12 or more chemical elements. Therefore, their smelting and manufacturing is a laborious process, as it requires high energy costs due to the use of the above ligatures.

In connection with the foregoing, Interpipe NTRP carried out a pilot-industrial melting with the use of multifunctional modifiers. Wheel steel grade КП-Т was smelted in a 100-ton ladle furnace. After that, data on the chemical composition, structure, mechanical characteristics and non-metallic inclusions of this grade of wheel steel were obtained and processed. Thanks to them, it was possible to determine why serial steel is of insufficient quality. Its chemical composition is presented in Table 1.

3. RESULTS AND DISCUSSION

3.1. Study of the Chemical Composition of Wheel Steel КП-Т

As a result of the research, a stronger effect of aluminium and titani-

TABLE 1. Chemical composition КП-Т steel from ДСТУ 10791-2016.

C	Mn	Si	Cr	Ni	Cu	V	S	P
0.62–0.70	0.50–1.00	0.22–0.65	≤ 0.40	≤ 0.30	≤ 0.30	≤ 0.15	0.005–0.025	≤ 0.030

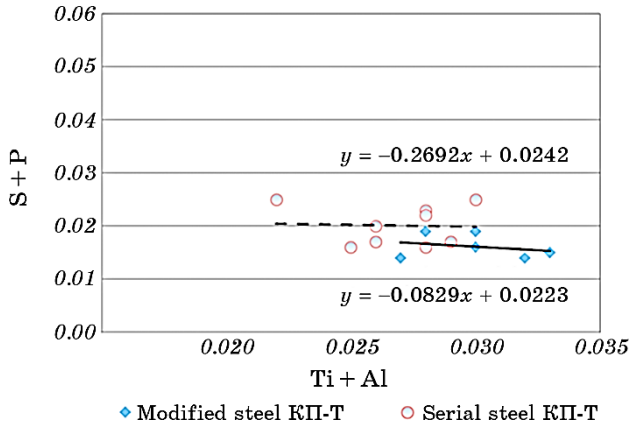


Fig. 1. Influence of modifier elements (Al + Ti) on the change in the content of harmful impurities (S + P) in serial and modified wheel steel КП-Т.

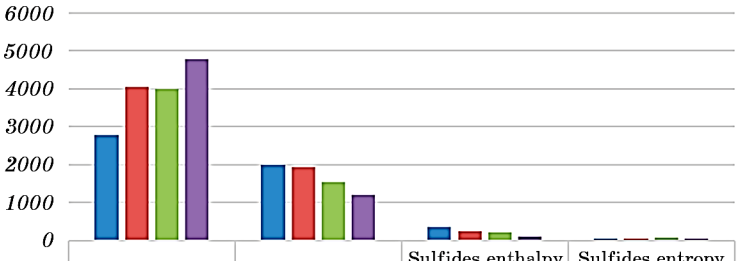
um in the modified steel on the reduction of the content of harmful impurities was established (Figs. 1, 2).

It follows from Fig. 1 that the action of modifier elements [1] in modified steel cleans the metal from harmful impurities ≈ 2 times better than in serial steel.

This is explained by the fact that in the modified metal, due to the multicomponent modifiers, there are stronger desulphurising elements (Mg , Ti) than Mn for serial steel, so they interact with sulphur in the first place [4]. Their thermodynamic characteristics are presented in Fig. 2. Manganese in unmodified serial steel actively interacts with sulphur, so a significant amount of it is spent on desulphurization.

As can be seen, Mn and Fe have a lower enthalpy compared to Mg and Ti when interacting with sulphur; therefore, it can be expected that the sequence of interaction of desulphurising elements in a liquid melt will be as follows: Mg → Ti → Mn → Fe.

In connection with the foregoing, it can be expected that based on the possible formation of stable submicroscopic compounds in a sufficiently large amount, it can be expected that this will affect the increase in the homogeneity of the metal in chemical composition in the modified steel (Fig. 3). The smaller the coefficient of variation, the



	Density of sulfides, kg/m³	Sulfides melting point, °C	Sulfides enthalpy formation, $-\Delta H$ kJ/mol	Sulfides entropy formation, $-\Delta H$ kJ/mol
Mg MgS Mg+S=MgS	2790	2000	348	50.3
Ti TiS Ti+S=TiS	4060	1927	238	50.3
Mn MnS Mn+S=MnS	3990	1530	214.35	80.75
Fe FeS Fe+S=FeS	4790	1193	100.4	50.54

Fig. 2. Thermodynamic characteristics of sulphides.

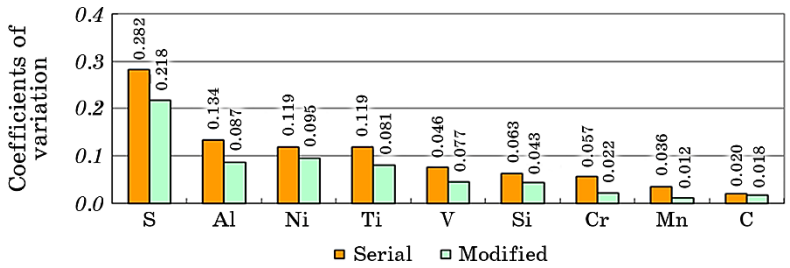


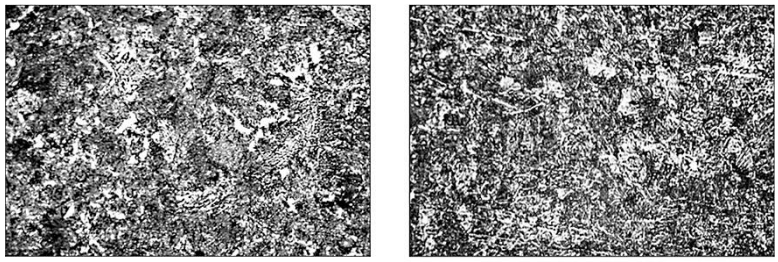
Fig. 3. Reducing the coefficients of variation of each of the elements of the chemical composition of КП-Т after modification with multifunctional modifiers in comparison with the data for serial metal treated in the traditional way.

more stable the system and the more homogeneous the chemical composition.

3.2. Study of the Structure of Wheel Steel КП-Т

Ordinary crystallization develops from the wall of the mould inside the ingot by the growth of dendrites, which partially 'wedged out', and their main mass grows deep into the direction of the axis of the ingot, where there is a significant amount of non-metallic inclusions, on which, as on finished surfaces, steel crystallizes. In addition, an inequigranular structure is obtained (Fig. 4, *a*).

During modification, crystallization centres are formed because of the interaction of special multicomponent deoxidizers-modifiers with steel melt (Fig. 4, *b*). They are quite evenly distributed in the volume of



a *b*

Fig. 4. The structure of the wheel steel КП-Т (serial) (*a*) and modified (*b*), ×600.

the metal due to the special physical and chemical properties, the composition of deoxidizers-modifiers, the constancy of their geometric shape and mass.

Also, studies of the structures of serial steel КП-Т and modified with multifunctional modifiers found that in serial unmodified steel, excess ferrite (about 5–7%) is released along the boundaries of the former austenitic grains, which decorates them. By comparison (Fig. 4, *a*, *b*), we can conclude that after the modification, the grain structure was crushed. One can see highly dispersed fine-grained pearlite with single ferrite precipitates along the grain boundaries in the modified КП-Т grade steel.

3.3. Study of the Mechanical Characteristics of Wheel Steel КП-Т

During the solidification of the modified ingot, there is mainly volumetric crystallization, rather than heat sink-oriented crystallization, as for serial metal. The predominant mechanism of bulk crystallization is one of the main reasons for the stabilization of the chemical composition and the increase in the level of mechanical properties of steels modified with multifunctional modifiers (Figs. 5, 6).

Thus, it has been proven that the modification reduces the concentration of harmful impurities and stabilizes the chemical composition with a simultaneous increase in the mechanical properties of steel grades Ст1кп and КП-Т.

Studies of non-metallic inclusions in КП-Т steel proved that their morphology significantly improves after modification. After all, elongated non-metallic inclusions found in serial steel are internal stress concentrators that contribute to faster destruction of the metal (Fig. 7). Modification helps to neutralize this problem, since thanks to it their globularization occurs. As a result, the quality of the finished wheels is significantly improved (Fig. 8).

The data below confirm that non-metallic inclusions in the modified

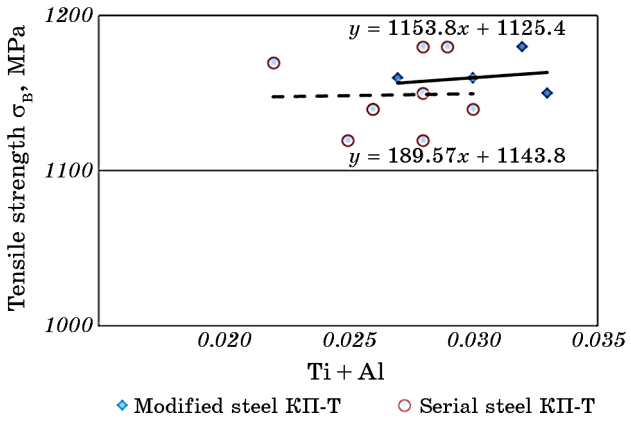


Fig. 5. Influence of modifier elements on the mechanical characteristics of wheel steel КП-Т.

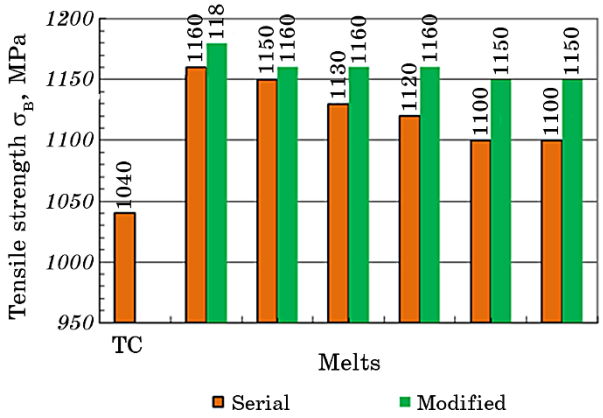


Fig. 6. Change in mechanical characteristics in wheel steel КП-Т under the influence of modification.

steel, even at high magnifications, have a globular shape. Their composition is always complex—these are iron and silicon oxides together with manganese and iron sulphides, silicates, manganese and iron oxides together with cementite.

We would also like to note that non-metallic inclusions in serial heats of КП-Т steel are elongated along the direction of deformation and their total length in the field of view is quite large from 7 to 57 μm. In modified steels, on the contrary, non-metallic inclusions, even in the places of accumulations, had a globular shape so small that they are not significant obstacles to the movement of dislocations and cannot be stress concentrators due to their rounded shape.

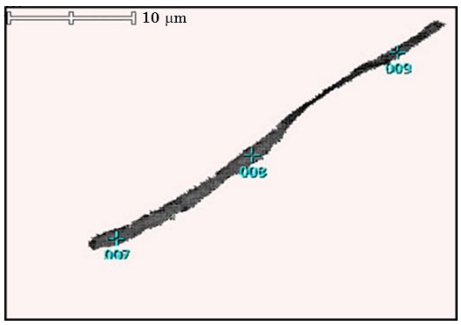


Fig. 7. Non-metallic inclusions in serial steel КП-Т, ×3000.

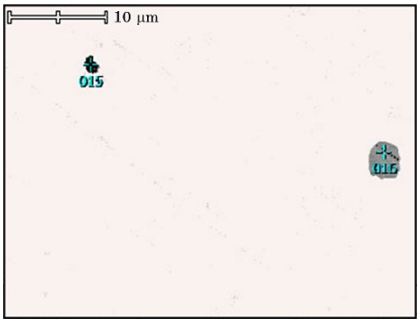


Fig. 8. Non-metallic inclusions in modified steel КП-Т, ×3000.

4. CONCLUSION

Thus, it has been proven that the modification reduces the concentration of harmful impurities and stabilizes the chemical composition with a simultaneous increase in the mechanical properties of the КП-Т wheel steel.

Further work will be devoted to improving the composition of modifiers and modernizing its composition to obtain high-quality transport metal.

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