INFLUENCE OF MULTIFUNCTIONAL MODIFICATION ON STABILIZATION OF CHEMICAL COMPOSITION OF WHEEL STEELS

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Abstract
This article deals with the impact of the chemical elements of the multifunctional modifier on the stabilization of chemical composition of the wheel steels KP-2 and KP-T. Increasing of the level of mechanical characteristics of such steels have been considered. Also, the causes of instability of the chemical composition of the wheel steel for locomotives of the class «C» have been studied. It has been established, that the injection of the multifunctional modifiers into the steel melt caused the increasing of the stability of chemical composition and the level of mechanical characteristics of steel. The systematic thermodynamic investigations of the probable influence of the components of specific modifiers on the melt have been carried out. The basic thermodynamic parameters of compounds, formed in the melt of steels after the injection of special modifiers have been determined. It has been established, that modification contributes to the improvement of the morphology of nonmetallic inclusions in the investigated steels, which-causes the increasing of the mechanical characteristics of the ones.

Key words: chemical composition; stabilization; wheeled steels; non-metallic inclusions; thermodynamic and mechanical characteristics.
ВЛИЯНИЕ МНОГОФУНКЦИОНАЛЬНОГО МОДИФИЦИРОВАНИЯ НА СТАБИЛИЗАЦИЮ ХИМИЧЕСКОГО СОСТАВА КОЛЕСНЫХ СТАЛЕЙ

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Аннотация
В данной статье рассматривается влияние многофункционального модификатора на стабильность химического состава колесных сталей КП-2 и КП-Т. Рассмотрено повышение уровня механических характеристик таких сталей. Также были выявлены причины нестабильности химического состава колесной стали для колес для локомотивов класса «С». Установлено, что введение многофункциональных модификаторов в стальной расплав приводило к повышению стабильности химического состава и уровня механических характеристик стали. Проведены систематические термодинамические исследования вероятного влияния компонентов специфических модификаторов на расплав. Определены основные термодинамические параметры соединений, образующихся в расплаве сталей после введения специальных модификаторов. Установлено, что модифицирование способствует улучшению морфологии неметаллических включений в исследуемых сталях, что также приводит к повышению их механических характеристик.

Ключевые слова: химический состав, стабилизация, колесные стали, неметаллические включения, термодинамические и механические характеристики.

Introduction
Wheel steel in the modern conditions of production is a multicomponent system. But to date, many problems of transporting the metal have not been solved. Studies of the measurement of the crystallographic texture of a set of rail wheel steel samples with different regimes of thermo-mechanical treatment and with and without modification by system Al-Mg-Si-Fe-Ca-Ti-Ce for improving the quality of finished products have been carried out [1]. Also, such tasks as significant interlacing and in-situ spread (within the same fusion without any violation of normative documentation) of the chemical composition remain unresolved. This leads to a decreasing of the dispersion of the structure, the coarsening of the morphology of nonmetallic inclusions, the destabilization of mechanical characteristics and the not predictable decreasing of performance of the wheel steels. Despite the use of technologies for evacuation of alloys in the liquid state, the using of continuous casting, the processing of melts by aluminum rod of various ligatures such as FeSi, FeMn, SiMn, FeV, FeMo, SiCa, Al, CaO, CaF2 and others, the problem of stabilizing of the chemical composition and improving the quality of the finished wheels remains relevant [2-4].

Results and its discussion
Improving the characteristics and the structure is possible by using deoxidation, modification, microalloying and refining of the steel melt in the liquid state and heat treatment in the solid state. However, the most progressive way to improve the quality of carbon steels is to treat them in a liquid state [5–10].

In recent years the multifunctional modification has been actively used in the industry. As a result of this process, the level of mechanical characteristics of various materials has been increased. To solve the problem of the instability of the chemical composition of various alloys it was proposed to modify the melts of low-alloyed alloys with nanodispersed compositions obtained by plasma-chemical synthesis. In the same time a significant (in 2 ... 3.5 times) grain refinement and stabilization of the alloy structure as a result of nanopowder modification of titanium carbonitride has been achieved [8–16].

In connection with the above, pilot-industrial smelting with the use of multifunctional modifiers was carried out in "INTERPIPE NTZ" [17]. Wheel steels of grades KP-T, KP-2 and class «С» were smelted in the 100 ton unit of a ladle furnace. After this, the array of data from the chemical composition and mechanical characteristics of these brands of wheel steels of the open-hearth and electric steelmaking modes was collected and systematized to determine the degree of instability of each of the characteristics of the transported metal. To do this, the coefficients of variation in the chemical composition of the steels were determined (Table 1). As is known, the lower is the coefficient of variation, the more stable is the system.

The results in the table 1 show the average concentrations of components and the coefficients of variation of their values. The coefficients have small values for the content of...
the main alloying elements of both the serial and modified steels. At the same time, in the serial metal these coefficients for harmful impurities (S and P) are significant and range from 0.01 to 0.30 for sulfur and from 0.01 to 0.34 for phosphorus. In the modified metal, such coefficients are lower: from 0.01 to 0.15 for sulfur and from 0.01 to 0.30 for phosphorus. These impurities occur in different amounts in almost all the materials of the charge, which was used in the process of steel smelting and its secondary processing. The impurities are caused by the dispersion of their concentrations in the smelted steel [18].

Coefficients of variation of the residual concentrations of the elements in the modifier (Al and Ti) range from 0.08 to 0.10 for titanium and from 0.02 to 0.23 for aluminum. At the same time, the variation coefficients in the modified metal are not that different, but are still lower: from 0.07 to 0.08 for titanium and from 0.05 to 0.09 for aluminum.

To determine the reasons for the stabilization of the chemical composition, systematic thermodynamic studies have been carried out on the possible influence of the components of special modifiers in their interaction with the melt [19].

The key thermodynamic parameters of the compounds which can be formed in the fusion steels after the injection of special modifiers are shown in the fig. 1 - 3. Melting temperature, enthalpy and entropy of formation of carbidés, nitrides, oxides and sulfides, which are submicroscopic compounds, arised in the fusion after the modifying with special deoxidizers is illustrated.

![Fig. 1. Melting temperatures, enthalpy and entropy of formation of nitrides (half-logarithmic scale)](image)

**Table 1**

| Steel | Parameter | Components | C | Mn | Si | S | P | Cr | Ni | Cu | Ti | V | Al |
|-------|-----------|------------|---|----|----|---|---|----|----|----|----|---|----|
| KPI-2 | Average   | Serial     | 0.60 | 0.74 | 0.34 | 0.01 | 0.01 | 0.07 | 0.05 | 0.06 | 0.01 | 0 | 0.03 |
|       |           | Modified   | 0.63 | 0.73 | 0.33 | 0.01 | 0.01 | 0.13 | 0.13 | 0.05 | 0.01 | 0.03 | 0.02 |
|       | Coefficients of variation | Serial | 0.03 | 0.01 | 0.05 | 0.27 | 0.08 | 0.17 | 0.12 | 0.14 | 0.09 | 0 | 0.10 |
|       |           | Modified   | 0.01 | 0.01 | 0.01 | 0.04 | 0.06 | 0.03 | 0.07 | 0.09 | 0.08 | 0.01 | 0.05 |
| KP-T  | Average   | Serial     | 0.66 | 0.76 | 0.31 | 0.01 | 0.01 | 0.19 | 0.13 | 0.06 | 0.01 | 0.10 | 0.02 |
|       |           | Modified   | 0.67 | 0.76 | 0.32 | 0.01 | 0.01 | 0.21 | 0.14 | 0.06 | 0.01 | 0.09 | 0.03 |
|       | Coefficients of variation | Serial | 0.02 | 0.03 | 0.05 | 0.19 | 0.34 | 0.06 | 0.09 | 0.18 | 0.10 | 0.13 | 0.23 |
|       |           | Modified   | 0.02 | 0.01 | 0.03 | 0.15 | 0.30 | 0.03 | 0.10 | 0.31 | 0.07 | 0.04 | 0.09 |
| Class «C» | Average | Serial | 0.72 | 0.76 | 0.33 | 0.01 | 0.01 | 0.15 | 0.05 | 0.06 | 0.01 | 0 | 0.02 |
|       | Coefficients of variation | 0.02 | 0.03 | 0.06 | 0.30 | 0.33 | 0.13 | 0.24 | 0.31 | 0.08 | 0 | 0.16 |
Fig. 2. Melting temperatures, enthalpy and entropy formations of oxides (half-logarithmic scale)

Fig. 3. Melting temperatures, enthalpy and entropy of formation of sulfides (half-logarithmic scale)

The red dotted line indicates the iron melting temperature - 1539 °C. If the formed compound has a higher melting temperature than the steel, it becomes the center of crystallization and could be related to the modifier of a sort II (by the inoculation mechanism). However, it is also important to know the values of enthalpy and entropy to define the stability of a compound as modifier. As it can be seen in the fig. 1-3, the following compounds have an optimum combination of three key thermodynamic parameters: TiN, VN, CeN, AlN, Mg₃N₂, CaO, MgO, Al₂O₃, TiO₂, TiO, CaS, MgS, MnS, MgS, TiS, CaS [20–27].

According to the formation of a large number of stable submicroscopic compounds, it is possible to expect the increasing of chemical uniformity of the metal. Usually, the crystallization expands from a mold wall in an ingot by the growth of dendrites, the great bulk of which sprout deeply into in the direction of an axis of the ingot where there is a significant amount of non-metallic inclusions where the steel crystallizes. There is the homogeneous grain here, as shown on the scheme. After the modifying there are formed the centers of crystallization as a result of interaction of special multicomponent deoxidizing modifiers with the steel fusion. They are proportionally distributed in the metal because of the special physical and chemical characteristics, structure of deoxidizing modifiers, constancy of their geometrical form and weight. When an ingot hardens, it generally takes place the volume crystallization, not oriented on the heat sink. The dominance of the volume mechanism of crystallization is one of the basic reasons of stabilization of chemical
composition of the steels, modified by special deoxidizing modifiers [28-31].

Modifying has led to improvement of morphology of non-metallic inclusions. The structure and morphology of non-metallic inclusions were investigated on the scanning JEOL JSN-6360LA electron microscope equipped with the JED-2300 system. The results are represented on fig. 4 (table 2, 3).

![Fig. 4. Non-metallic inclusions in the serial and modified KP-T steel, h3000](image)

**Table 2**

| № point | Si | S  | Ca | Mn | Fe | Amount,% |
|---------|----|----|----|----|----|----------|
| 015     | 0  | 0  | 31.2| 6.3| 62.5| 0        |
| 016     | 0  | 0  | 33.6| 2.8| 63.7| 0        |

**Table 3**

| № point | S     | Mn  | Fe  | Amount,% |
|---------|-------|-----|-----|----------|
| 007     | 29.84 | 61.79| 8.38| 100      |
| 008     | 28.67 | 57.41| 13.93| 100      |
| 009     | 26.26 | 57.72| 16.03| 100      |

The data obtained confirm that the non-metallic inclusions in the modified steel even after magnification have the globular structure and do not act as the concentrators of tension. Also, the modification caused the increasing of the mechanical characteristics of modified steels of grades KP-2 and KP-T, as can be seen on the tables 4 and 5.

It was determined that the obtained characteristics of the modified KP-T steel are higher than the characteristics of the serial steel of the same grade: in 1.02 times in the tensile strength $\sigma_b$, in 1.14 times in the KCU toughness, in 1.02 times in the relative elongation $\delta$, $\psi$ (?), and in 1.06 times (what exactly number?) and in 1,006 times in hardness.

The mechanical characteristics of the low-carbon constant, both serial and modified, are given in Table 4, 5.

The value of the mechanical characteristics of modified steels is higher than their value in the serial metal. This ensures a higher reliability of reinforced concrete and wheels, being used in construction of vehicles due to the increasing of the level of mechanical characteristics.
Table 4

| Type       | ̄\(\sigma\), MPa | ̄\(\delta\), % | ̄\(\psi\), % | ̄\(HB\), Mlata | KCU, Dzh m /cm² |
|------------|-----------------|---------------|--------------|----------------|-----------------|
| Requirements | 1020-1180       | ≥9            | ≥16          | 3200-3600      | ≥18 ≥20          |
| Serial     | Average         | 1000          | 11,5         | 21              | 2910            | - 25            |
|            | Coefficients of variation | 0,02          | 0,07         | 0,1            | 0,03            | - 0,15          |
| Modified   | Average         | 1052          | 11,5         | 22,9           | 2982            | - 29            |
|            | Coefficients of variation | 0,01          | 0,02         | 0,08           | 0,03            | - 0,11          |

Table 5

| Type       | ̄\(\sigma\), MPa | ̄\(\delta\), % | ̄\(\psi\), % | ̄\(HB\), Mlata | KCU, Dzh m /cm² |
|------------|-----------------|---------------|--------------|----------------|-----------------|
| Requirements | 1020-1180       | ≥9            | ≥16          | 3200-3600      | ≥18 ≥20          |
| Serial     | Average         | 1132          | 11,1         | 22,9           | 3254            | 23 20           |
|            | Coefficients of variation | 0,02          | 0,14         | 0,15           | 0,05            | 0,15 0,34       |
| Modified   | Average         | 1153          | 11,2         | 26,2           | 3273            | 27 24           |
|            | Coefficients of variation | 0,01          | 0,08         | 0,11           | 0,03            | 0,15 0,28       |

Conclusions

It was set that the effect of multifunctional modifiers provides a reduction of the content of non-metallic inclusions and stabilization of both the chemical composition and the level of mechanical characteristics of the KP-T wheel steel. The results prove that modifying is the most effective way of eliminating such essential drawbacks as instability of the chemical composition. The reduction of the content of harmful impurities such as phosphorus and sulfur, undoubtedly leads to the improvement of the quality of the finished wheels. Stabilized chemical composition and mechanical characteristics play an important role in the usage of the ready-made wheels. Modification without significant additional costs ensures the stabilization of the chemical composition and characteristics of steel and is possible by the implementation of the mechanism of bulk crystallization of the melt, reduction of liquation, grinding of structural components.
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