УДК 669.45 + 669.046.558

S. POLISHKO

EFFECT OF MODIFICATION ON THE FORMATION OF NONMETALLIC INCLUSIONS IN KP-T WHEEL STEEL

Oles Honchar Dnipro National University
Gagarina avenue, 72, 49000, Dnipro, Ukrane; e-mail: cdep@dnu.dp.ua, polishkopsa@gmail.com

У даній статті розглянуто вплив дії компонентів багатофункціонального модифікатора на формування неметалевих включень у колісній сталі марки КП-Т. Метою даної роботи було дослідження впливу модифікаторів багатофункціональної дії на морфологію і розташування неметалевих включень, а також на стабілізацію і підвищення рівня механічних характеристик. Встановлено, що в даному металі за допомогою введення багатофункціональних модифікаторів у розплав сталі підвищується стабільність хімічного складу й, як наслідок, рівень механічних характеристик. Проведено системні термодинамічні дослідження з можливого впливу компонентів спеціальних модифікаторів при їхній взаємодії з розплавом. Визначено основні термодинамічні параметри з'єднань, які можуть формуватися в розплаві сталей при введенні спеціальних модифікаторів. Доведено, що багатофункціональне модифікування поліпшує морфологію неметалічних включень, що також сприяє підвищенню рівня механічних характеристик.

В данной статье рассмотрено влияние действия компонентов многофункционального модификатора на формирование неметаллических включений в колесной стали марки КП-Т. Целью данной работы было исследование влияния модификаторов многофункционального действия на морфологию и расположение неметаллических включений, а также на стабилизацию и повышение уровня механических характеристик. Установлено, что в данном металле при помощи ввода многофункциональных модификаторов в расплав стали повышается стабильность химического состава и, как следствие, уровень механических характеристик. Проведены системные термодинамические исследования по возможному влиянию компонентов специальных модификаторов при их взаимодействии с расплавом. Определены основные термодинамические параметры соединений, которые могут формироваться в расплаве сталей при введении специальных модификаторов. Доказано, что многофункциональное модифицирование улучшает морфологию неметаллических включений, что также способствует повышению уровня механических характеристик.

This paper is concerned with the effect of the components of a multipurpose modifier on the formation of nonmetallic inclusions in KP-T wheel steel. The aim of this work is to study the effect of multipurpose modifiers on the morphology and arrangement of nonmetallic inclusions and on the stabilization and improvement of mechanical properties. It is found that doping the melt of this metal with multipurpose modifies increases the stability of its chemical composition, thus improving its mechanical properties. System thermodynamic studies are conducted into the possible effect of the components of special modifiers under their interaction with the melt. The key thermodynamic parameters of compounds that can be formed in the melt when doping it with special modifiers are determined. It is proved that multipurpose modification improves the morphology of nonmetallic inclusions, which also contributes to the improvement of mechanical properties.

Keywords: *stabilization, wheel steel KP-T, nonmetallic inclusions, thermodynamic and mechanical characteristics*

Introduction. One of important and difficult solvable problems of modern metallurgy is receiving metal of the maximum purity that certainly will lead to increase in stability and level of speed-torque characteristics of finished steel product. But, for the reason that when smelting modern metal from uncontrollable melting metal, ligatures, a blend in fusion of different detrimental impurities, such as sulfur and phosphorus, quality of a finished product considerably worsens. The same as practice, because of large volumes of fusion in a ladle, by means of use only of traditional steel smelting technologies shows, and also because of use of chemical elements of melting metal, uncontrollable on contents, it is impossible to achieve receiving improvement of quality of metallurgical products.

Therefore at the Oles Honchar Dnipro National University ways of improvement of quality of metallurgical production by multipurpose modifying are developed. In this work influence of modifying on formation of nonmetallic inclusions of a favorable form with a research of thermodynamic characteristics is presented.

The purpose of this work is the research of influence of modifiers of multipurpose action on morphology and an arrangement of nonmetallic inclusions, and also on stabilization and increase in level of mechanical characteristics.

Researchers result. In the conditions of INTERPAYP NTZ smelting of wheel steel of the KP-T brand in open 100-ton hearth furnaces has been carried out. This steel possesses the structure, properties and structure meeting requirements of DSTU 10971-2011. It was confirmed by our pilot studies [1 – 3]. Samples of ready wheels of mass production have been investigated. The analysis of 557 industrial swimming trunks (550 serials and 7 modified) of KP-T steel has shown the following.

Chemical composition of the studied metal corresponded technical documentation (tab. 1).

Table 1 – Chemical composition there were KP-T brands

Parameter	Chemical elements, %											
	C	Mn	Si	P	S	Cr	Ni	Cu	Ti	V	Al	[H]
DSTU 10791-2011	0,65 0,68	0,70 0,90	0,25 0,40	≤0,025	≤0,020	0,15 0,30	0,10 0,25	≤0,3		0,080 0,150	0,013 0,030	≤2,0 ppm
Serial steel KP-T (550 melts)												
Average value	0,67	0,78	0,33	0,013	0,012	0,19	0,12	0,05	0,006	0,094	0,023	2
Maximum value	0,69	0,88	0,4	0,025	0,017	0,23	0,15	0,11	0,011	0,12	0,03	2
Minimum value	0,65	0,7	0,27	0,006	0,005	0,16	0,1	0,03	0,005	0,08	0,015	2
Scope (max-min)	0,04	0,18	0,13	0,019	0,012	0,07	0,05	0,08	0,006	0,040	0,015	0,00
Variation coefficient	0,02	0,036	0,063	0,358	0,382	0,057	0,119	0,48	0,119	0,077	0,134	0
Modified steel KP-T (7 melts)												
Average value	0,66	0,76	0,32	0,01	0,008	0,21	0,14	0,06	0,006	0,085	0,024	1,4
Maximum value	0,68	0,77	0,34	0,012	0,015	0,21	0,15	0,08	0,006	0,09	0,028	1,6
Minimum value	0,65	0,75	0,3	0,008	0,006	0,2	0,12	0,04	0,005	0,079	0,021	1,2
Scope (max-min)	0,03	0,02	0,04	0,004	0,009	0,01	0,03	0,04	0,001	0,011	0,007	0,00
Variation coefficient	0,017	0,012	0,043	0,138	0,375	0,024	0,097	0,3	0,076	0,047	0,082	0,127

In the course of the researches it is established that for KP-T steel major factors of risk was the following.

Impurity of KP-T steel non-metallic inclusions (sulfides, silicates) – sources of emergence of microcracks in sites with microtension.

Big difference of interheat maintenance of elements (S, P, Cu, Al, Ni, V), the generating instability of indicators of impact strength and plasticity: the difference of interheat values of impact strength of a disk makes 557%, rims – 390%, relative narrowing – 383%, percentage elongation – 271%.

Forming of excess (pro-eutectoid) ferrite that does not correspond to a high carbon equivalent (from 0,856 at min contents to 0,974 at max of concentration of components on DSTU 10791-2011 and to actual data on 550 swimming trunks of

NTZ (from 0,808 to 0,852). Such discrepancy can be caused by either the non-optimal modes of heat treatment, or errors of chemical composition of the studied swimming trunks.

Presence at structure of KP-T steel of liquates which emergence is caused by uneven dissolution and distribution of a significant amount of the ligatures entered in metal melting process and impossibility of their elimination in the diffusion way in a firm state at deformation and heat treatment.

Unbalanced ratio of quantity of found by carbide and not found by carbide elements. Depending on refrigerating conditions of metal, the modes of deformation and heat treatment formation of the undesirable connections reducing the impact strength and crack resistance of wheels from KP-T steel is possible.

The non-optimal maintenance of not found by carbide elements (Cu, Ni, Si) which is negatively influencing the impact strength and crack resistance.

Due to the big defects of wheels from KP-T steel we have conducted additional researches of structure and properties of KP-T steel for the purpose of elimination of the reasons for the lowered impact strength of a disk and a rim of wheels.

Metallographic examinaton of wheels universal allocation of threadlike educations (moustaches) on non-metallic inclusions is revealed. And the greatest density of such defective educations takes place on sites with the increased

Fig. 1 – Disclosure of the microcrack formed on non-metallic inclusions with allocation products of atmospheric corrosion in KP-T steel. Allocations are from right to left visible products of atmospheric corrosion. White points in a crack - nonmetallic inclusions., x1000

microtension - lengthways рисок after grinding on a surface of samples. Non-metallic inclusions are highlighted in the form of white islands. In fig. 1 it is shown that thin threadlike educations regenerate in wide "channel" defects. On it the white shining non-metallic inclusions are also visible (below at the left), and a part of a cover from globular sulfide is found at the upper right.

In fig. 2 the beginning of disclosure of the cracks formed on threadlike allocations of products of atmospheric corrosion on a KP-T steel sample surface which form as have shown our researches is presented on non-metallic inclusions in places with the increased tension.

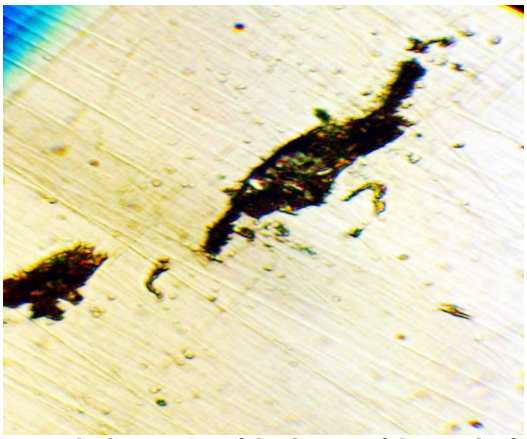


Figure 2 – The beginning of disclosure of the cracks formed in the form of microcracks on non-metallic inclusions with allocations of products of atmospheric corrosion on them, in KP-T steel. In the field of a shlif and a crack light are visible non-metallic inclusions, x1000

The revealed unusual sites of defeat of a surface of samples of the thermo-processed KP-T steel wheels given above can be the cause of the lowered impact strength of serial metal. It occurs because the defects connected with atmospheric corrosion appeared in the locations of non-metallic inclusions and the localized microtension.

Due to the above-stated researches, swimming trunks using multifunction modifiers (fig. 3) have been carried out.

Fig. 3 – Appearance of multifunction modifiers of brand of one size
Apparently from tab. 1, after modifying chemical composition of KP-T steel was stabilized. For establishment of the reasons of stabilization of chemical composition system thermodynamic researches on possible influence of components of special modifiers at their interaction with fusion are conducted.

The key thermodynamic parameters of connections which can form in fusion steels at introduction of special modifiers are given in fig. 4 – 6. Considered melting temperature, an enthalpy and entropy of formation of carbides, nitrides, oxides and sulfides, that is those submicroscopic connections which arise in fusion when modifying by special deoxidizers modifiers.

The red dotted line has noted iron melting temperature – 1539 °C. If the formed connection has higher melting temperature, than at steel, it can become the center of crystallization and to be the sort modifier II (on the inoculation mecha-

nism). However, it is important to know also sizes of an enthalpy and entropy to define "survivability" of connection as modifier. Apparently from the data below, connections have an optimum combination of three key thermodynamic parameters: TiN, VN, CeN, AlN, Mg3N2, CaO, MgO, Al2O3, TiO2, TiO, CaS, TiS2, MnS, MgS, TiS, CaS.

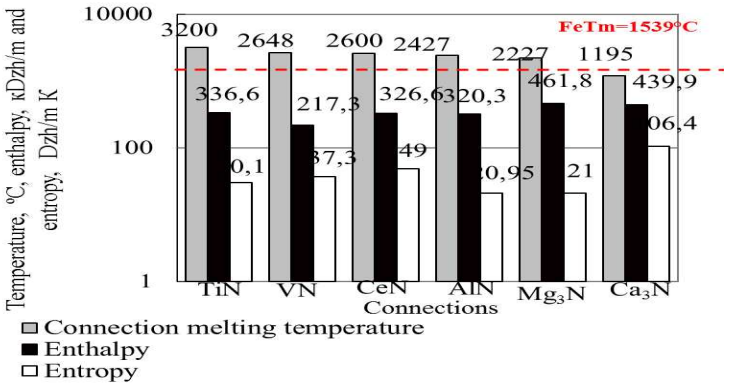


Fig. 4 – Melting temperatures, enthalpy and entropy of formation of nitrides (half-logarithmic scale)

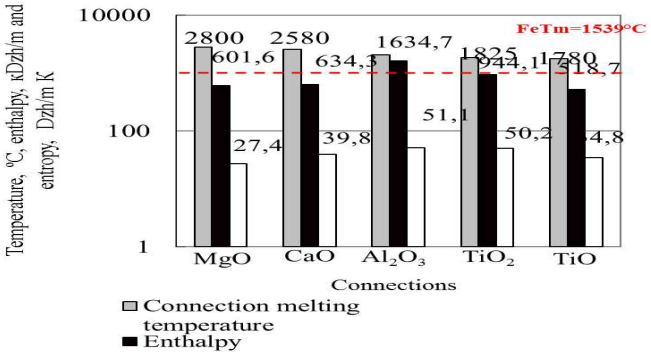


Fig. 5 – Melting temperatures, enthalpy and entropy formations of oxides (half-logarithmic scale)

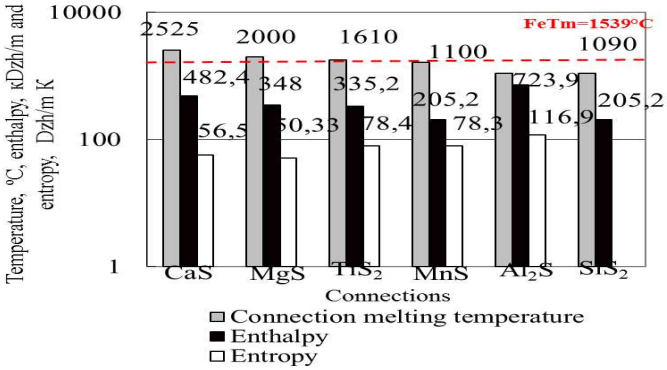


Fig. 6 – Melting temperatures, enthalpy and entropy of formation of sulfides (half-logarithmic scale)

Proceeding from possible formation of permanent submicroscopic connections in rather large number, it is possible to expect that it will influence increase in uniformity of metal on chemical composition. Normal crystallization develops from a mold wall in an ingot by growth of dendrites which "are partially pinched out", and their main weight sprouts deep into in the direction of an ingot axis where there is a significant amount of non-metallic inclusions on which as on ready surfaces steel crystallizes. Here homogeneous grain, as shown in the scheme forms. When modifying the centers of crystallization are formed as a result of interaction of special multicomponent deoxidizers modifiers with steel fusion. They are rather evenly distributed in volume of metal thanks to special physical and chemical characteristics, structure of deoxidizers modifiers, constancy of their geometrical form and weight. When hardening an ingot the volume, but not oriented on the heat sink crystallization takes place, generally. The preferential mechanism of volume crystallization is one of basic reasons of stabilization of chemical composition steels, modified by special deoxidizers modifiers.

Modifying has led respectively to improvement of morphology of non-metallic inclusions. Their structure and morphology of non-metallic inclusions were investigated on the scanning JEOL JSN-6360LA electron microscope equipped with the JED-2300 system. Which these results are represented in fig. 7 and table 2, 3.

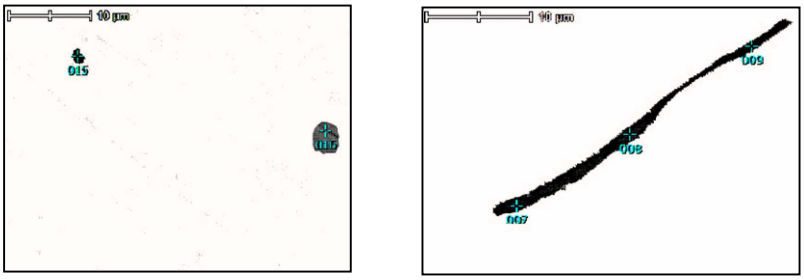


Fig. 7 – Non-metallic inclusions in the serial and modified KP-T steel, x3000

Table 2 – Structure of non-metallic inclusions of the modified KP-T steel

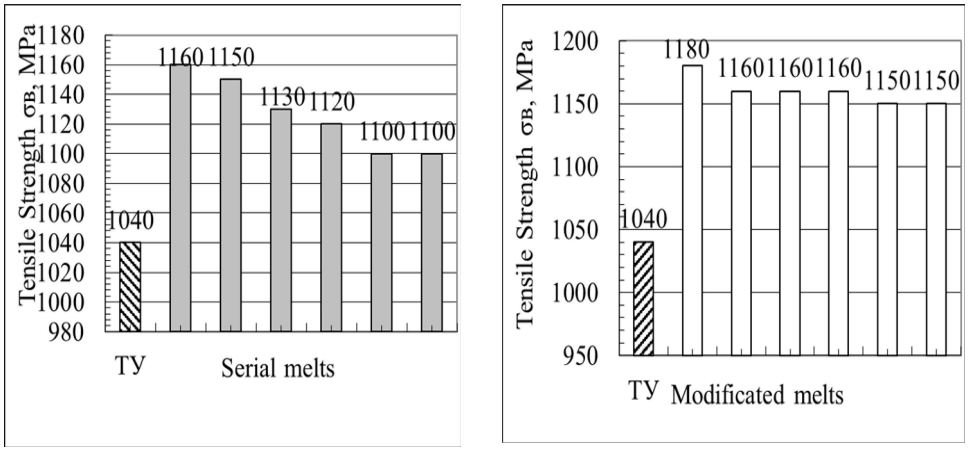
№ точки	O	Si	S	Ca	Mn	Fe	Всего,%
015	0	0	31,2	6,3	62,5	0	100
016	0	0	33,6	2,8	63,7	0	100

Table 3 – Structure of non-metallic inclusions of the KP-T serial steel

№ точки	S	Mn	Fe	Всего,%
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 above-stated data confirm that in the modified steel non-metallic inclusions even at big increases have the globular form and are not concentrators of tension.

Under influence of modifying there was also an increase in mechanical properties of the modified KP-T brand steel that is visible from fig. 8.



a) b)

Fig. 8 – The histogram of a mean of mechanical properties of the serial (a) and modified (b) wheel steel of the KP-T brand

It is revealed that the received properties of the modified KP-T steel are higher than properties of serial steel of the same brand: on strength $\sigma_в$ by 1,02 times, on the impact strength of KCU by 1,14 times, on percentage elongation δ by 1,02 times, to relative narrowing ψ by 1,06 times, and on hardness by 1,006 times.

The below-stated results prove that modifying – the most effective way of elimination of such essential shortcomings as instability of chemical composition, decrease in maintenance of detrimental impurities, such as phosphorus and sulfur what will undoubtedly lead to improvement of quality of ready wheels.

Conclusions. It is established that influence of multipurpose modifiers provides to decrease in content of nonmetallic inclusions and stabilization of both the chemical composition, and level of mechanical characteristics of wheel steel of the KP-T brand.

Stabilization of the chemical composition and mechanical characteristics plays one of the major roles as ready wheels. Thanks to use of multipurpose modifiers crack resistance of transport metal increases.

1. *Polishko S. A.* Effect of multifunctional deoxidizing modifiers on the stabilization of the chemical composition and increase in the mechanical characteristics of St1kp and KP-T steels. Noví materíali í tekhnologíí˙ u metalurgíí˙ta mashinobuduvanní. Sb. nauchn. trudov. 2012. №.2. P. 32–37
2. *Markova Í. A., Ívchenko T. Í., Tatarko YU. V., Polishko S. O.* Investigation of the stability of the chemical composition and mechanical properties of mass produced steel./ Í.A. Markova. Metallurgicheskaya i gornorudnaya promyshlennost'. 2013. № 6. P . 64–67.
3. Composite deoxidizer for the treatment of steels. Patent for Invention 85254 Ukraína: Int. Cl.[7] S22S 35/00, S22S 38/06, S21S 7/04, S21S 7/06 / *Shapovalova O. M., Shapovalov V. P., Shapovalov O. V., Políshko S. O.* Applicant and Patent Attorney Dnipropetrovsk National University. № a200700858; filed. 26.01.2007; published 12.01.2009. Bul. № 1.

Received 20.11.2017,
in final form 12.12.2017