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Improvement of the extra-furnace rail steel processing on the "ladle-furnace" unit in order to increase the operational stability of railway rails

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Abstract. The article contains the results of studies of the influence of technological parameters of the extra-furnace rail steel processing in the conditions of the electric furnace shop of "EVRAZ ZSMK" JSC on the oxygen content in the finished rails and on their mechanical properties. The studies carried out using the multiple regression analysis showed that the oxygen concentration in the rail steel was reduced by 2 ppm with an increase in the duration of the inert gas blowing on the ladle-furnace unit to 100 min. At the same time, a decrease in the concentration and length of the rows of oxide brittle fracture nonmetallic inclusions, which have the most negative effect on the operational properties of the railway rails, was also recorded. In addition, the carried out experimental studies showed that the decrease in the concentration of oxygen in the rail steel by the specified amount, due to an increase in the duration of the blowing of the melt with an inert gas, makes it possible to increase the following mechanical properties of the rails: ultimate strength, elongation, relative constriction, hardness. Based on the conducted research, the technology of extra-furnace rail steel processing was developed and introduced at the electric steelmaking shop of "EVRAZ ZSMK" JSC in series on two "ladle-furnace" units, which allowed the recommended values of the duration of blowing with inert gas to be achieved without reducing the shop productivity.

1. Introduction

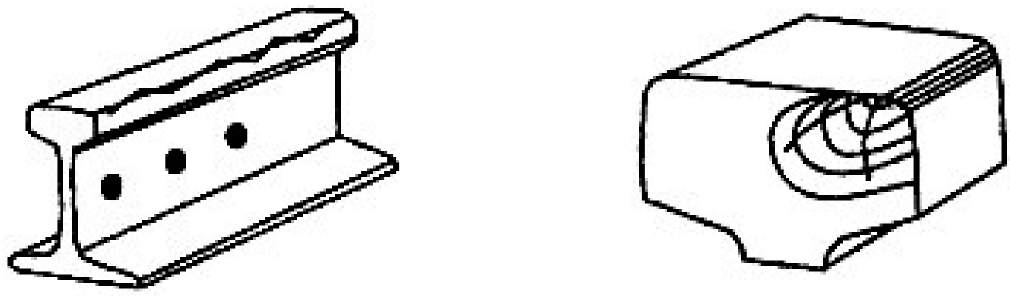
The results of comprehensive research of VNIIZhT and IMET RAS named after A.A. Baykov [1-4] testify that the main reason for the premature decommissioning of rails is the formation of contact fatigue defects in the working fillet of the rail head, the emergence of which is associated with the accumulation of nonmetallic inclusions, namely, brittle-decomposed oxide inclusions.

The brittle decomposed oxide inclusions in the degree of plasticity during deformation occupy an intermediate position between the so-called "plastic" inclusions, which change their shape and stretch into the rows during rolling (sulfide inclusions, plastic silicates) and "brittle" inclusions, which, during the similar treatment do not stretch, but are crushed (alumina, silica).

The fragile oxide inclusions, which are mainly complex oxides (aluminates, silicates, spinels), can stretch in the rows during deformation, but when a certain limiting value is achieved, the degrees of deformation get destroyed. The bulk of brittle-grained oxide inclusions in rail steel, in particular calcium aluminates (figure 1) are formed when it is deoxidized. And this fact takes place, despite the refusal to use aluminum as a deoxidizer for rail steels – aluminum as a by-product is introduced by ferroalloys (ferrovanadium, silicomanganese).

Figure 1. Calcium aluminates in the rail electric steel.

The formation of these defects occurs according to the following scheme (figure 2): at the initial moment a longitudinal inclined crack appears in the zone of accumulation of brittle fractured oxide inclusions, the development of which leads to the metal delamination – the metal spalling on the side fillet head (figure 2 a); then this defect is converted into transverse cracks (figure 2 b).



(a) (b)

Figure 2. Stages of formation of contact fatigue defects in the head of rails in the process of operation: a – formation of a longitudinal inclined crack; b – formation of transverse cracks.

Due to the sharply negative influence of these nonmetallic inclusions on the operational stability of rails, the current regulatory documentation, covering the rails production of various categories, provides for a strict regulation of not only the total oxygen content in the finished rails (not more than 20 ppm), but also oxygen bound to brittle fractured oxide inclusions (no more than 10 ppm).

At “EVRAZ ZSMK” JSC, which is currently one of the leading domestic manufacturers of railroad rails [5, 6], in recent years the work has been purposefully carried out to reduce the contamination of rail steel with oxygen and oxide nonmetallic inclusions. So for the period from 2005 to 2013 due to the introduction of a complex of technical and technological measures to improve the technological modes of smelting, deoxidation, extra-furnace rail steel processing and evacuation [7-9], it became possible to reduce the total oxygen content in rails by more than 2 times – to 14 ppm (figure 3).

However, in order to ensure compliance with the requirements of standards for the concentration of oxygen bound to brittle fractured oxide inclusions (not more than 10 ppm), further reduction of the total oxygen content in the rail metal to a level not more than 12-13 ppm is necessary.

2. Methods of research

In order to determine the nature and extent of the effect of technological parameters on the concentration of oxygen in the rail steel, multiple regression analysis was performed. The object of the study was a random sample from 190 melts of rail steel E76KhF of the current production.

The influence of the following technological parameters on the content of total oxygen in rail rolling was analyzed:

- the content of silicon in steel in the first sample on the “ladle-furnace” unit;

- carbon content in the tapping;
- consumption of coke breeze during steel is deoxidation in the tapping;
- consumption of silicomanganese during the steel deoxidation in the tapping;
- duration of blowing with inert gas during processing on the “ladle-furnace” unit;
- duration of steel processing in the vacuum unit.

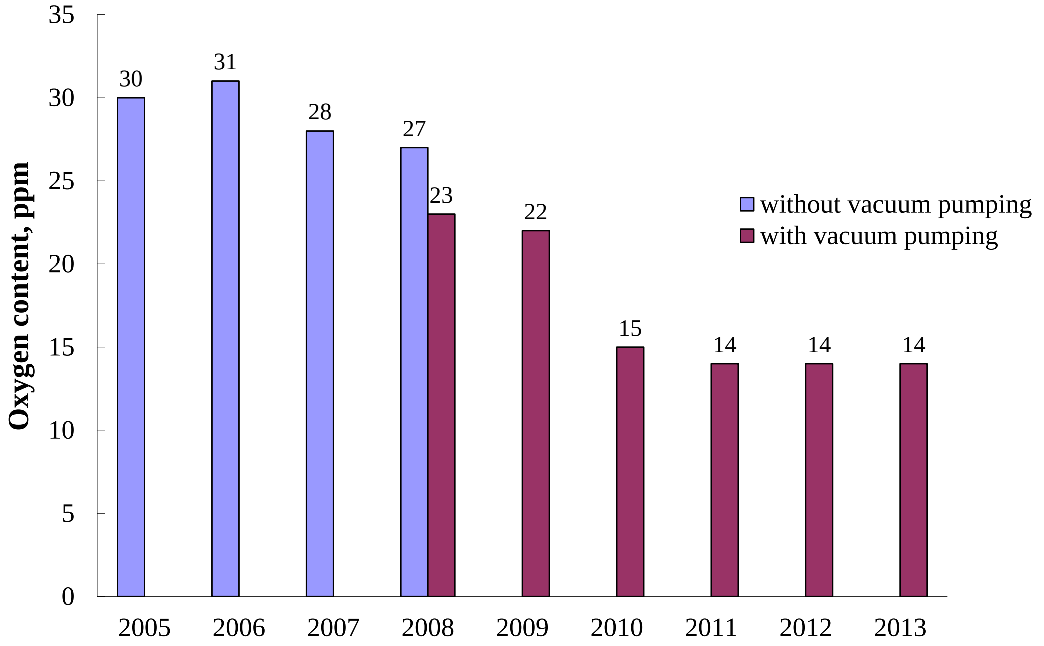


Figure 3. Dynamics of the total oxygen content in the finished rails produced by “EVRAZ ZSMK” JSC.

3. Results and discussions

The analysis established a significant effect on the content of total oxygen in the metal for the duration of metal blowing in the ladle furnace. According to the data obtained, with an increase in the duration of steel blowing on the “ladle-furnace” unit in the range 40-128 minutes, a decrease in the concentration of total oxygen in the metal is observed (figure 4). At the same time, a decrease in the content of total oxygen is achieved due to the decrease in the oxygen content bound to nonmetallic inclusions.

The dependence obtained is explained by the well-known phenomenon of intensification of nonmetallic inclusions transfer processes to the slag with increasing blowing duration. Since the inclusions transfer process by gas bubbles is due to the general capacity of non-wettable solids to adhere to the gas bubbles in the liquid – flotation, the adhesion forces exert a significant influence on the degree of melt refining, which in turn are determined by the dimensions of non-metallic inclusions and their composition.

Thus, the choice of the optimum blowing duration depends on the parameters influencing the composition of the resulting non-metallic inclusions, in particular on the steel grade, the deoxidizers used and the alloying additives. So, in relation to the conditions for the production of E76KhF rail steel be the electric steelmaking shop of “EVRAZ ZSMK” JSC, a significant decrease in the concentration of brittle fractured oxide inclusions is observed with an increase in the blowing duration more than 100 min.

The absence of a relation between the oxygen content in the steel and the parameters characterizing the oxidation of the melt (the carbon content at the furnace outlet and the silicon content in the first ladle sample at the ladle-furnace unit) is due to the order of addition of the deoxidants used. At present the small coke additive is carried out after the addition of silicomanganese, that is, in the deoxidized metal. The absence of the dependence of oxygen content in the steel on the slag basicity during the processing in the ladle-furnace unit is due to a rather narrow interval of values variation of this parameter (2.2-2.8).

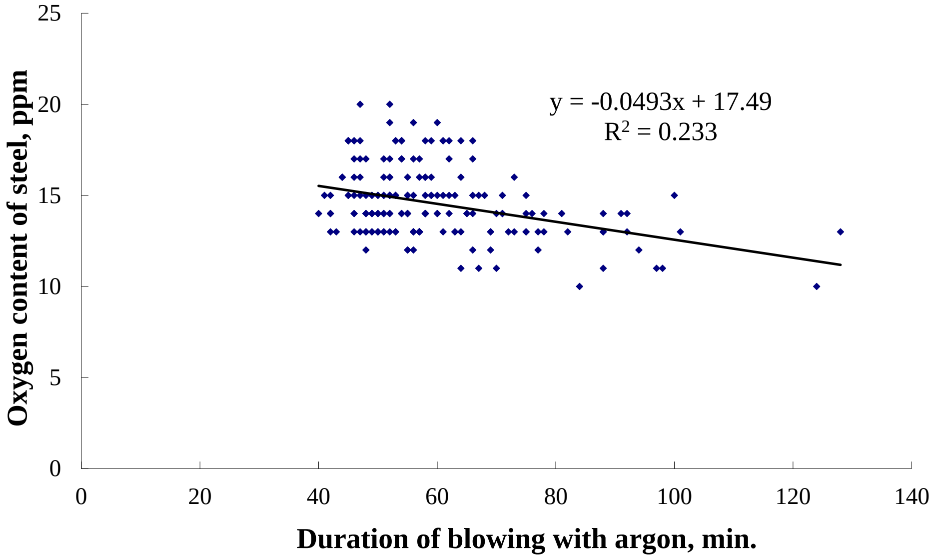


Figure 4. Dependence of oxygen content in the rail steel on the duration of blowing with inert gas during extra-furnace rail steel processing.

To analyze the changes in the technical and economic parameters of steel production, using a technology of secondary treatment with an extended duration of blowing with inert gas, a series of 15 experimental meltings was carried out, for which blowing duration was at least 100 minutes. As a basis for the comparative analysis, 19 smelting of the current production, produced in the same period, were used.

According to the data obtained (table 1), an increase in the average duration of metal blowing on the "ladle-furnace" unit from 63 min up to 122 min led to an increase in the specific electricity consumption by an average of 27.3 kW×h/t (from 64.9 kW×h/t to 92.2 kW×h/t steel); the specific consumption of argon increased by 0.32 m^3/t (from 0.24 m^3/t to 0.46 m^3/t).

At the same time, the content of total oxygen and oxygen bound into brittle fractured nonmetallic inclusions in rails obtained from the steel of experimental melts is lower by 2 ppm in comparison with rails from melts of current production. The length of the lines of nonmetallic inclusions on rails obtained from the steel of experimental meltings is lower by 0.004 mm.

Table 1. Analysis of changes in technical and economic indicators of the technology with increased blowing duration.

Indicator name	Mean values of the indicators	
	experimental melts	melts of the current production
Duration of blowing on LFU, min.	126.4	63.0
Argon consumption for blowing, m^3/t	0.46	0.24
Temperature, °C:		
- at the beginning of processing on the "ladle-furnace" unit	1549	1545
- at the end of processing on the "ladle-furnace" unit	1620	1620
Specific power consumption for automatic transmission, kW·h/t	92.2	64.9
Consumption of nitrated ferrovanadium, kg/t	1.44	1.44

Total oxygen content in rolled rail stock, ppm	12	14
The content of oxygen bound in brittle fractured nonmetallic inclusions, in rolled rail stock, ppm	8	10
Length of a line of brittle fractured oxide inclusions, mm	0.008	0.012

An analysis was also performed concerning the effect of the new technology on the mechanical properties of the rails after rolling (before hardening) with an extended duration of blowing with inert gas. As a result, it was established (table 2) that the rails obtained from the steel of experimental smelting have slightly better results compared to the rails obtained from the smelting of current production (an increase in such indicators as the ultimate strength, yield strength, relative contraction, elongation, hardness).

Table 2. Analysis of the influence of new technology of extra-furnace steel processing on the mechanical properties of the rails after rolling (before hardening).

Indicator name	Average values of the indicator		Requirements of GOST (not less than)
	experiment al melts	melts of the current production	
1. Yield strength (σ_t), N/mm^2	700	620	–
2. Strength limit (σ_v), Н/мм^2	1150	1130	1111
3. Specific elongation (δ), %	11.5	10.5	8.1
4. Contraction ratio, %	18.3	14.5	–
5. Hardness, HB	339	333	–

Increase in the duration of blowing with an inert gas up to 100 min and more, as was shown above, contributes to the decrease in the concentration of brittle fractured oxides in steel, which leads to an increase in the strength and plastic characteristics of rail products.

4. Conclusion

The experiments conducted in the conditions of the electric steelmaking shop of “EVRAZ ZSMK” JSC shows that when the blowing duration of the melt with an inert gas is increased during the processing on the “ladle-furnace” unit to 100 min, there is a decrease in the oxygen concentration in the rail steel grade E76KhF by 2 ppm, including oxygen, bound in the oxide brittle fractured nonmetallic inclusions, by the same amount. In this case, an improvement in the mechanical properties of the rails is achieved. Based on the obtained results, the technology of out-of-furnace processing of rail steel was developed and implemented in series on two “ladle-furnace” units, which allows the recommended values of the duration of blowing with inert gas to be achieved without reducing the productivity of the shop.

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