Research of non-metallic inclusions of E90KhAF rail steel

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Abstract: This article is devoted to the research of the non-metallic inclusions of the E90KhAF rail steel in different zones of continuous cast billets. It is established that in the rim zone the main non-metallic inclusions are silicates of iron and aluminosilicates. Aluminosilicates and silicates of iron are identified in the zone of columnar crystals. Sulfides of manganese (MnS), silicates of manganese, aluminum and iron are found in the central zone of the billet.

1. Introduction
The quantity, composition and distribution of non-metallic inclusions are important indicators of the steels quality that determine their mechanical properties and service characteristics. Among all possible ways of classifying inclusions, their separation by origin and time of formation is generally recognized. Endogenous inclusions are formed during phase-structural transformations in liquid and solid steel, and exogenous inclusions are introduced into the liquid from the outside as a result of the destruction of steelmaking and casting equipment lining, capture of charge particles, exothermic mixtures and slags [1-3].

2. Results and discussion
The authors of [4-6] previously studied the role of nonmetallic inclusions in rail steels of grades E76 and E76F in the process of hot plastic deformation. The purpose of these studies was to obtain information on non-metallic inclusions in the areas of continuous cast billet (CCB) of E90KhAF rail steel, which will be further used in the search for new technologies and improving the existing technology for the production of rail products.

When studying the CCB rim zone of E90KhAF steel, the presence of iron silicates (FeO·SiO₂), as well as the inclusion of aluminosilicates, were revealed by X-ray diffraction after high-temperature torsion (figures 1-3).

In the zone of CCB columnar crystals of E90KhAF steel, aluminosilicates were identified by X-ray diffraction after high-temperature torsion (figure 4). Metallographic studies, in addition to aluminosilicates (figure 5), revealed the presence of iron silicates (figure 6).

The manganese sulfides (MnS), manganese, aluminum and iron silicates (figures 7-9) were revealed by X-ray and metallography in the CCB central zone of E90KhAF steel after high-temperature torsion.
Figure 1. The fragment of diffraction pattern of CCB rim zone of E90KhAF steel.

Figure 2. Iron silicates of CCB rim zone of E90KhAF steel after high temperature torsion.

Figure 3. Aluminosilicates of the CCB rim zone of E90KhAF steel after high temperature torsion.

Figure 4. The fragment of diffraction pattern of the zone of CCB columnar crystals of E90KhAF steel.
Figure 5. Aluminosilicates in the CCB zone of columnar crystals of E90KhAF steel after high temperature torsion.

Figure 6. Iron silicates in the CCB zone of columnar crystals of E90KhAF after high temperature torsion.

Figure 7. The fragment of diffraction pattern of CCB central zone of E90KhAF steel.

The presence of non-deformable aluminum silicates ($\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$), iron silicates ($\text{FeO} \cdot \text{SiO}_2$) and manganese ($\text{MnO} \cdot \text{SiO}_2$), in the locations of which the integrity violations of metal may be formed (figures 2, 3, 5, 6, 8, 9), will contribute to the localization of deformation and reduction of the shear deformation degree.

Non-metallic inclusions contained in steel are a set of stress concentrators, the value of which depends on the type and size of the inclusion, temperature and deformation conditions, the ratio of the physico-mechanical properties of the inclusion and the steel matrix.

The heterogeneity of the mechanical properties of steel can be caused not only by a change in the number of inclusions, but also by a change in their shape. During pressure treatment, plastic silicate and sulfide inclusions are stretched in the direction of deformation, and non-deforming inclusions of oxides; silicates and complex spinels are redistributed and form stitching clusters, which contributes to anisotropy of mechanical properties, which manifests itself mainly in ductility indicators.

Two-phase inclusions consisting of silicate and oxide or spinel exhibit inhomogeneous deformability. The silicate phase is well deformed, elongating in the direction of deformation (figures 3, 5), and corundum or spinel, being in the silicate matrix, is not deformed.

Inclusions of most oxides and spinels during high-temperature torsion are brittle. During deformation, the resulting fragments of inclusions rotate along the torsion axis, while being smoothed as a result of friction forces at the interface.
Multiphase inclusions exhibit inhomogeneous deformability depending on the nature of the phases. They are particles of oxides or spinels enclosed in a silicate matrix (figures 3, 5). The latter is plastically deformed with the metal matrix of steel, and the oxide particles are not deformed (particles of destroyed refractories that got into the steel during smelting), rotate in the silicate matrix in the direction of its flow, being destroyed during high-temperature deformation.

The observation data on the distribution and behavior of non-metallic inclusions during high-temperature plastic deformation do not contradict the studies of non-metallic inclusions in steels performed by Gubenko S.I., Starov R.V., Parusov V.V., Derevyanchenko I.V. [1, 6-9].

**Figure 8.** Manganese sulfides in the CCB central zone of E90KhAF steel after high temperature torsion.

**Figure 9.** Non-metallic inclusions of the CCB central zone of E90KhAF steel after high temperature torsion: a, b – silicates of aluminum and manganese; c, d – iron silicates;
It should be noted that during plastic deformation at the “inclusion-matrix” interfaces, deformation and contact stresses arise due to the different deformability of the inclusions and the steel matrix. The inclusion and matrix constitute a system of a stressed (inclusion) and plastic (matrix) layer with dislocations at the interface [9].

3. Conclusion
Thus, the presence of various types and forms of non-metallic inclusions in steels allows the technological plasticity and mechanical properties of steels to be predicted as a whole.

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References
[1] Gubenko S I 1991 Transformation of Non-Metallic Inclusions (Moscow: Metallurgy) 225
[2] Starov R V, Parusov V V and Nesterenko A M 2000 Int. Scientific-Technical Conference on Steel Production in the 21st Century. Forecast, Processes, Technology, Ecology (Kiev) pp 167–168
[3] Starov R V, Litvinov L F and Derevyanchenko I V 2003 Metallurgical and Mining Industry 8 25–27
[4] Simachev A S, Temlyantsev M V and Oskolkova T N 2016 Steel in Translation 2 112–14
[5] Simachev A S 2014 IV Intern. Scientific-Practical Conf. on Modern Innovations in Science and Technology (Kursk) vol 4 pp 101–103
[6] Simachev A S 2014 Int. Research Journal 3-2 63–64
[7] Starov R V, Derevyanchenko I V, Parusov V V and Sychkov A B 2005 Steel 1 79–82
[8] Dobuzhskaya A B, Smirnov L A et al 2015 Steel 7 82–6
[9] Gubenko S I, Parusov V V and Derevyanchenko I V 2005 Non-Metallic Inclusions in Steel (ART-PRESS) p 536