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The influence of non-metallic inclusions on the corrosion and strength properties of wheel steel

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Abstract
The influence of non-metallic inclusions on the tendency of wheel steel to the stress corrosion fracture and their fatigue resistance under the influence of corrosive medium is investigated.
Keywords: NON-METALLIC INCLUSIONS, WHEELS, CORROSION, MECHANICAL PROPERTIES

In the operation of railway wheel chemical and physic-chemical interaction of metal with aggressive components of the environment occurred and at the same time it is exposed to dynamic loads [1]. According to research results [2] non-metallic inclusions are centers of the corrosion initiation which damage the wheels during operation.

This publication presents researches data of non-metallic inclusions influence of the different chemical nature to the tendency of wheel steel to corrosion fracture and their fatigue strength in corrosive medium.

Materials and methods of researches

The properties of the steel samples contaminated by the program in special melts by different types of non-metallic inclusions were studied: in melt 1– (Fe, Mn) S, FeS-MnS, in melt 2 – Al_2O_3, MnO • Al_2O_3, in melt 3 – SiO_2, MnO • SiO_2, FeO • SiO_2, in melt 4 – TiCN. The quantitative content of inclusions in the test steel is about 0.5 % vol. The structure of the steel samples is dispersed and hypopearlitic.

Accelerated test method of the steel samples tendency to corrosion fracture was applied.

On the plant IM-12 equipped with a device for use of a liquid corrosive medium stretch of samples was carried out at the rate of 1.8 mm / min in a 5% aqueous solution of NaCl and 1% aqueous solution of H_2SO_4, which imitated the environment when operating of railway wheels under the influence of precipitation and contamination, as well as in the air.

Test of samples with a diameter of 7.62 mm on the fatigue strength was carried out on the machine of NU type with the number of loading cycles 1 • 106.

These test methods are described in work [3].

Table 1. Chemical composition of steels of the test smelts

Test Melt No	Elements content,%									
	C	Mn	Si	S	P	Cr	Ni	Cu	Al	Ti
1	0.57	0.73	0.34	0.054	0.011	0.12	0.11	0.20	–	–
2	0.59	0.73	0.35	0.024	0.012	0.12	0.12	0.18	0.14	–
3	0.58	0.75	0.67	0.025	0.012	0.14	0.12	0.15	–	–
4	0.59	0.73	0.35	0.026	0.011	0.12	0.13	0.15	–	0.15

Research results and its discussion

According to [4] it is known that the destruction of the steel due to corrosion fracturing occurs suddenly with no noticeable plastic deformation at voltages significantly lower than the tensile strength and low total corrosion. Such destruction is possible only with simultaneous exposure to the steel product of a corrosive medium or a tensile stress from external loads or the residual stress in the product.

All non-metallic inclusions in corrosive medium are stress concentrators. They have different levels of electrical conductivity and semiconductor properties that are different from those in the steel matrix and also promote the adsorption processes along interphase boundaries inclusion-matrix that together cause an increase of the steel electrochemical microheterogeneity.

The most sensitive to the effects of corrosive media are following indicators of steels: resistance to tearing-off S_k, tensile strength σ_B, percentage of elongation δ and contraction ratio ψ.

From Table 2 it implies that the mechanical properties of the wheel steel with a hypopearlitic structure and about the same content of non-metallic inclusions depend on the chemical nature of the latter.

Decreasing of the influence degree on the resistance to tearing-off $S_к$, tensile strength σ_B, percentage of elongation δ and contraction ratio ψ of the inclusions in an order is clearly visible: sulphides (Fe, Mn) S, FeS-MnS → corundum and spinel Al_2O_3, $MnO \cdot Al_2O_3$ → silicates SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$ → titanium carbonitride TiCN. This is cohering with data on the influence of the inclusions on the durability of the wheel steel at low-cycle fatigue [2].

Harmful influence of sulfide inclusions on the mechanical properties of wheel steel in corrosive medium is connected with the presence of tensile residual stresses near these inclusions; near others studied inclusions these are compressive stress [4].

The results of tests on the fatigue strength of wheel steel melts 1-4 are shown in Table 3.

Table 2. Mechanical properties of wheel steel with non-metallic inclusions after the tensile testing in different media

Medium	Number of melt - inclusions	Properties parameters			
		S_k, MPa	σ_B, MPa	δ, %	ψ, %
Air	1 – sulfides (Fe, Mn)S, FeS-MnS	1105	1124	13.2	32.2
	2 – Al_2O_3, $MnO \cdot Al_2O_3$	1053	1025	11.8	29.6
	3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	1109	1084	11.4	33.4
	4 – TiCN	1071	1048	12.3	30.2
5 % aqueous solution of NaCl	1 – sulfides (Fe, Mn)S, FeS-MnS	975	1015	10.1	27.4
	2 – Al_2O_3, $MnO \cdot Al_2O_3$	1025	1018	10.8	28.2
	3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	1040	1075	11.1	28.5
	4 – TiCN	1044	1040	11.1	28.9
1 % aqueous solution of H_2SO_4	1 – sulfides (Fe, Mn)S, FeS-MnS	834	960	8.9	24.2
	2 – Al_2O_3, $MnO \cdot Al_2O_3$	906	988	9.1	26.3
	3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	945	997	10.2	27.1
	4 – TiCN	962	1005	10.4	27.4

Table 3. Amount of fatigue limit σ_{-1} and fatigue strength coefficient β of wheel steel with different types of inclusions

Medium	Number of melt-inclusions	Indicators of environment influence on strength	
		σ_{-1}, MPa	β
Air	1 – sulfides (Fe, Mn)S, FeS-MnS	370	1
	2 – Al_2O_3, $MnO \cdot Al_2O_3$	324	1
	3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	355	1
	4 – TiCN	367	1
5 % aqueous solution of NaCl	1 – sulfides (Fe, Mn)S, FeS-MnS	292	0.79
	2 – Al_2O_3, $MnO \cdot Al_2O_3$	295	0.91
	3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	334	0.94
	4 – TiCN	356	0.97
1 % aqueous solution of H_2SO_4	1 – sulfides (Fe, Mn)S, FeS-MnS	237	0.64
	2 – Al_2O_3, $MnO \cdot Al_2O_3$	275	0.85
	3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	312	0.88
	4 – TiCN	345	0.94

The main criterion of the environment influence on the fatigue strength of steel is an indicator of fatigue limit σ-1. As another indicator characterizing the influence of the environment fatigue strength coefficient is accepted β. That is the ratio of fatigue limit σ-1 in corrosive media to the fatigue limit σ-1 when tested in air [3]. The value of this ratio is usually less than 1 because the fatigue strength of steel in corrosive media is lower for steels with non-metallic inclusions. The larger the value of this ratio differs from 1, the stronger the influence of the medium and non-metallic inclusions on the fatigue strength of the wheel steel.

According to the data in Table 3 the value of the fatigue limit σ-1 in air depends on the chemical nature of the non-metallic inclusions. The highest fatigue limit σ-1 is in the air at the steel with sulfides (melt 1). This indicator decreases in the order: steel, titanium carbonitride (melt 4) → steel with silicates (melt 3) → steel with aluminum oxide (melt 2).

When tested in a 5% aqueous solution of NaCl the strongest decline in the fatigue limit σ-1 was observed and the reduction factor β fatigue strength of steel with sulfide inclusions (melt 1) was seen.There is a decreasing influence of nonmetallic inclusions on the fatigue limit σ-1 in the order: sulphides (Fe, Mn) S, FeS-MnS → corundum and spinel Al_2O_3, MnO • Al_2O_3 → silicates SiO_2, MnO • SiO_2, FeO • SiO_2→ titanium carbonitride TiCN.

Even more clearly defined were regularities in testing samples of steels in 1% aqueous solution of H_2SO_4.

Conclusion

1. Non-metallic inclusions in the wheel steel began to influence significantly on their tendency to corrosion fracture and reduction the tensile strength in corrosive media.

2. According to the influence degree of the chemical nature of the non-metallic inclusions on the mechanical properties of wheel steel in corrosive media following decreasing order is set: sulphides (Fe, Mn) S, FeS-MnS → corundum and spinel Al_2O_3, MnO • Al_2O_3 → silicates SiO_2, MnO • SiO_2, FeO • SiO_2 → titanium carbonitride TiCN.

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