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Investigation of Non-Metallic Inclusion Effect on Corrosion Behavior of Wheel Steel

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The function of non-metallic inclusion activity in the nucleation and propagation of corrosive damage in wheel steel is investigated, the consequent set of inclusions according to their harmful effect is established, and the extent of non-metallic inclusion effect on low-cycle durability of wheel steel is defined. The function of inclusive-matrix interphase boundaries in wheel steel microchemical heterogeneity in the propagation of adsorptive and corrosive processes during wheel operation is investigated.

Keywords: RAILROAD WHEEL, NON-METALLIC INCLUSIONS, CORROSION, LOW-CYCLE STEEL FATIGUE, VALVE ACTION, ELECTRODE POTENTIAL

Introduction

Corrosion damage of steel during wheel operation occurs as a result of effect of environmental aggressive components and static and dynamic load stress. However, operation of wheels is usually realized without a reliable anticorrosive protection. The study of non-metallic inclusion effect on the wheel steel corrosion as well as on the structural changes in wheels during operation is particularly important. The increase of railroad wheel reliability and durability demands improving wheel steel quality, developing perspective steel composition, using the opportunities of tread area thermal strengthening. The investigation of worn-out railroad wheels [1, 2] showed that non-metallic inclusions were the centres of corrosion damage nucleation. However, the mechanism of non-metallic inclusion effect needs special investigation.

The task of present research is study of non-metallic inclusion effect on corrosion damages occurrence and propagation during wheel operation.

Methodology

The investigation is carried out on steel samples with various non-metallic inclusions according to the plan accepted by the authors.

Wheel steel scrap is remelted in the laboratory electric furnace using different deoxidizing agents (aluminium, silicocalcium, titanium) and also addition of sulphur powder. The material composition of inclusions is as follows: in steel melted 1 – sulphides (Fe, Mn)S Fe-S MnS; in steel melted 2 – Al_2O_3, $MnO \cdot Al_2O_3$; in steel melted 3 – SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$; in steel melted 4 – TiCN. There were identical, approximately 0.5% volume content of each type non-metallic inclusions in order to compare data about effect of different kinds of non-metallic inclusions on steel corrosive properties **(Table 1)**.

The volume content of inclusions is evaluated using instrument “Kvantimet”. Non-metallic inclusions are identified in steel by metallographic and micro X-ray spectrum methods using Neophot-21 and MS-46 Cameca, and also by petrographic method.

According the recommendations [3, 4], the samples are low-cycle fatique tested on the air and two different corrosive environments: 5% water solution of NaCl and 1% water solution of H_2SO_4, which imitated probable environmental content during the railroad wheel operation including that during the atmospheric precipitations and different contamination influence.

Results and Discussion

Non-metallic inclusions have an impact on low-cycle fatigue (index N) of steel. It follows from the data given in **Table 2** that at every investigated kind of non-metallic inclusion the effect of corrosion environment is revealed in reduction of steel durability and low-cycle fatigue. The lowest value of index N is featured for sulphide-contaminated steel. N value grows in the presence of corundum, spinel, silicates and titanium carbonitride in steel. The coefficients of environmental influence β_e are defined by method similar to that described in works [4, 5]. These coefficients are the ratio of wheel steel durability in the air to similar index in the appropriate corrosive environment. The more this coefficient value, the more non-metallic inclusions reduce low-cycle durability of steel. Data given in **Table 1** differ from the results of work [4], in which the effect of non-metallic inclusion type on durability of steel 20 is investigated.

Table 1. Chemical composition of experimentally melted steel

Experimental melting operation No.	Element content, % mass									
	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

Table 2. Index N and coefficients of environment influence β_e on low-cycle durability of steel with various non-metallic inclusions

Experimental environment	Experimental melting operation No.	Inclusion type	$N^{*)}$, cycle	β_e
Air	1	(Fe,Mn)S, FeS-MnS	1.2	-
	2	Al_2O_3, $MnO\cdot Al_2O_3$	1.8	-
	3	SiO_2, $MnO\cdot SiO_2$, $FeO\cdot SiO_2$	2.0	-
	4	TiCN	2.2	-
NaCl water solution	1	(Fe,Mn)S, FeS-MnS	0.6	2.0
	2	Al_2O_3, $MnO\cdot Al_2O_3$	1.2	1.5
	3	SiO_2, $MnO\cdot SiO_2$, $FeO\cdot SiO_2$	1.4	1.43
	4	TiCN	1.6	1.38
H_2SO_4 water solution	1	(Fe,Mn)S, FeS-MnS	0.5	2.4
	2	Al_2O_3, $MnO\cdot Al_2O_3$	0.8	1.78
	3	SiO_2, $MnO\cdot SiO_2$, $FeO\cdot SiO_2$	1.2	1.67
	4	TiCN	1.4	1.57

[*] Represented data are reduced in 10^4 times

According to data in [4], silicates have the lest intensive effect, and corundum, sulphides and nitrides have the most intensive effect.

The results of microelectrode potential measurement of steel 20 near non-metallic inclusions are shown in [4]. We carried out similar research on steel wheel samples melted experimentally.

According to the concepts in [4, 6], electrochemical heterogeneity of surface in the contact with corrosive environment is one of the basic factors of steel corrosion behaviour in the process of wheel operation. Under these conditions the presence of non-metallic inclusions, which physical-chemical properties are unlike steel matrix properties, near the wheel surface causes electrochemical heterogeneity of railroad surface when contacting with electrolytic environment. The author [4] explains the different effect of non-metallic inclusion on corrosion damage propagation by different semiconductor properties of inclusions, which causes dissimilar valve action on the boundary “inclusion-steel matrix” in the electrolyte. Non-metallic inclusions – catodes related to steel matrix – form descending series according to φ value: 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. Non-metallic inclusions form ascending series according to value of specific electrical resistivity in the same order.

In present work similar to research [4], electrolyte containing H_2SO_4 (1 %), H_2O_2 (0.14 %), $K_2Cr_2O_7$ (0.0005 %) is used for investigation of surface microelectrical heterogeneity of trial steel samples. The electrode potentials of steel matrix and non-metallic inclusions are measured on laboratory-scale plant (**Table 3**). Obtained results indicate the considerable potential difference on interphase boundaries “inclusion-steel matrix”, which results in appearance of heavy density currents on these boundaries. Corrosion current densities differ in value depending on inclusion type. According to our information, sulphide inclusions are the least favourable regarding to effect on wheel steel corrosion behavior during operation.

According to data given in **Table 3**, corrosion damages near sulphide inclusions are expected to be the most considerable during operation, and damages near titanium carbonitride will be less intensive. These conclusions are in agreement with data in **Table 2**.

Some differences in estimation of extent of non-metallic inclusions effect on possible steel corrosion damages under wheel operation compared to data in [4] can be connected with various degree of steel 20 sample impurity intensity as compared to content of non-metallic inclusions in our test steel samples.

To analyse the effect of distortional stresses that can take place on the tread area and on other stressed elements of railroad wheels under operation on the electrode potential difference of Δφ, a part of steel samples with various inclusions are subjected to cold deformation (deformation ratio 45 – 55 %) on the laboratory mill. Deformation stresses sharply reduce the electrode potential value. Thus, more considerable corrosion damages during wheel operation are observed when investigating the tread area state of worn-out railroad wheels [7].

Data given in **Table 3** also allow a descending series of non-metallic inclusion harmful effect on steel tendency to corrode under operation conditions, i.e.: 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.

Table 3. Potential difference Δφ on inclusive-steel matrix interphase boundaries (electrolyte H_2O)

Experimental smelting operation No.	Inclusion type	Potential difference - Δφ, mV	
		Before deformation	After deformation
1	(Fe,Mn)S, FeS-MnS	29.3	45.40
2	Al_2O_3, $MnO \cdot Al_2O_3$	19.1	42.90
3	SiO_2, $MnO \cdot SiO_2$, $FeO \cdot SiO_2$	10.7	24.93
4	titanium TiCN	6.3	14.55

Plastic properties of non-metallic inclusions under cold deformation affect the relation of $\Delta\varphi$ values estimated before and after plastic deformation of samples. However, all non-metallic inclusion types considered in this work are deformation stress concentrators, which caused the increase of $\Delta\varphi$ potential difference as a result of plastic deformation, relation of $\Delta\varphi$ values is 1.55, and at other non-deforming inclusions relation of $\Delta\varphi$ values is 2.25 – for corundum and spinel, 2.33 – for silicates, 2.31 – for titanium carbonitride.

Conclusions

Represented data show that non-deforming inclusions behave almost the same as stress concentrators under large deformation. And ductile sulphides deforming together with steel matrix promote to partial relaxation of distortional stress. The latter is in agreement with data in [8].

References

1. S. I. Gubenko, S. I. Pinchuk, Ye. V Belaya. *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2009, No. 2, pp. 69-73.*
2. A. V. Kushnarev, A. A. Bagatov, S. I. Gubenko, et al. *Sovremennyye Tekhnologii Proizvodstva Transportnogo Metalla.* Monograph, Nizhny Tagil, NTMK, 2008, 394 p.*
3. M. L. Bernstein, A. G. Rakhstadt. *Metallovedeniye i Termicheskaya Obrabotka Stali*. Guidebook in 3 vol., Moscow, Metallurgiya, 1991, 462 p.*
4. A. B. Kuslitskiiy. *Nemetallicheskie Vklyucheniya i Ustalost Stali*, Kyiv, Tehnika, 1976, 128 p. *
5. V. I. Lihtman, Ye. D. Shchukin, P. A. Rebinder. *Fiziko-Khimicheskaya Mehanika Materialov*, Moscow, AN SSSR, 1962, 303 p. *
6. A. B. Kuslitskiiy, A. K. Mindyuk, V. P. Rudenko, B. F. Ryabov. *Fiziko-Khimicheskaya Mehanika Materialov*, 1965, No. 1, pp. 76-84. *
7. S. I. Gubenko, S. I. Pinchuk, Ye. V. Belaya. *Metallurgicheskaya i Gornorudnaya Promyshlennost*, 2010, No. 1, pp. 80-84.*
8. S. I. Gubenko, V. V. Parusov, I. V. Derevyanchenko. *Nemetallicheskie Vklyucheniya v Stali*, Dnepropetrovsk, ART-PRESS, 2005, 536 p.*

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Исследование влияния неметаллических включений на коррозионное поведение колесной стали

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Исследована роль активности неметаллических включений в зарождении и развитии коррозионных повреждений в колесной стали, установлен последовательный ряд включений по степени их вредного влияния, определена степень влияния неметаллических включений на малоцикловую долговечность колесной стали в разных средах. Исследована роль межфазных границ включение-матрица в микрохимической гетерогенности колесной стали, в развитии адсорбционных и коррозионных процессов при эксплуатации колес.