EFFECT OF NON-METALLIC INCLUSIONS ON CRACK PROPAGATION AND FATIGUE LIFE OF STEEL

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ABSTRACT

Using the methods of quantitative optical metallography, the attempt to get evidence for the micromechanism of non-metallic inclusions effect on processes of fatigue microcracks initiation and growth in cast steel under low-cycle and high-cycle loading was made. Non-metallic inclusions are non-coherent with metallic matrix, they prevent dislocation migration and serve as stress concentrators. Due to this reason, 70...100 % primary microcracks were initiated on non-metallic inclusions, inspite of only 0.1-0.2 volume percent of inclusions existing in steel. It was established that microcracks contours were often faithful copies of inclusion contours, contributing greatly to crack formation in steel in process of cyclic loading.

Influence of non-metallic inclusions on mechanical properties and resistance to low cycle and high cycle fracture was studied on mid-carbon and chromium steels. There were sufficiently strict dependencies observed between inclusion index I, relative elongation δ, effective surface energy γ, quantity of cycles before fracture N and fatigue strength σ_{-1}.

The results of investigation have shown that non-metallic inclusions influence significantly on steel resistance to fatigue fracture. The globularization of inclusions would increase endurance 1.4-1.6 times for low cycle loading and 1.15-1.25 times for high cycle loading.

INTRODUCTION

The main factors, determining the resistance of steel to fatigue fracture, are: grain size, strain, solution and precipitation hardening; dispersion and shape of structural components. Within structural fracture mechanics the influence of these factors on fatigue strength is studied rather well. It is considered that there is a directly proportional dependence between strength limit and fatigue life. At the same time, non-metallic inclusions influence over steel resistance to fatigue fracture is studied less, probably due to insufficient content of inclusions in metal (0.1…0.3 vol. %). It is known that large inclusions located near surface of specimen (part of machine) promote fatigue fracture. Due to non-coherent bonding of non-metallic inclusions with metallic matrix they prevent dislocation migration and serve as stress concentrators, it is possible to anticipate their great influence on fatigue crack initiation and propagation processes.

GENERAL INFORMATION

Using methods of quantitative optical metallography, the attempt was made to study the micromechanisms of differently shaped inclusion influence on fatigue microcrack initiation and propagation in cast steel under low cycle and high cycle loading. The testing was carried out using flat specimens – polished sections – under tensile and bending loads. The polished surfaces of specimens were periodically studied with an optical microscopy. There were the following destruction characteristics determined by calculation method of optical metallography with 10% accuracy:

- the index of relationship between the microcracks and inclusions, equal to relative quantity of microcracks, initiated in inclusions and extending through them, A_C;
- the index of inclusions contribution to fracture, equal to fraction of inclusions which caused the initiation of microcracks and promoting their propagation, A_i,

First index (A_C) has characterized the role of inclusions in microcracks initiation, the second one (A_i) – in their propagation. As a characteristic of inclusions index I was used, that is ratio of a maximum dimensions sum of inclusions to a length of a random straight line intersecting them. The more inclusions in steel and the closer their shape to a film one, the larger index I value.

In conditions of a fraction deoxidizing of mid-carbon steel of the same initial composition (0.45 %C, 0.76%Mn, 0.38 % Si, 0.05 % S, 0.041 %P) there were 6 fractions received with 3 types of inclusions: globular (type one), film (type two), and acute-angled (type three) (table 1). With amount of inclusions being constant (0.10…0.12 vol. %), their index changed between 0.0023 and 0.0063.

TABLE 1
INFLUENCE OF DEOXIDATION ON NON-METALLIC INCLUSIONS AND AUSTENITE GRAIN SIZE OF MID-CARBON STEEL

Variant	Deoxidizers, %			Inclusions		Austenite grain size, μm
	Al	SiCa	FeCe	type	index	
1	-	-	-	I	0.0046	52.6
2	0.02	-	-	II	0.0063	18.4
3	0.1	-	-	III	0.0053	10.7
4	0.1	0.15	-	I, III	0.0034	10.2
5	0.1	-	0.15	I	0.0041	9.9
6	0.1	0.15	0.15	I	0.0023	8.7

There observed sufficiently strict dependencies between inclusion index I and relative elongation δ, effective surface energy γ and fatigue life σ_{-1} (fig.1). The point corresponding to the first variant of table 1 does not fit into curve $\sigma_{-1}=f(I)$. One may suppose that in this case the drop in σ_{-1} with I value increase happened due to large size of austenite grain (see table 1). There's no correlation found between index I and strength limit σ_u values, and, respectively, drop in σ_{-1} during I rise can be explained by the influence of shape (type) of inclusions on steel resistance to fatigue fracture.

The photos shown in fig.2 that demonstrate how inclusions take part in crack initiation prove this conclusion. Fatigue microcracks often repeat outlines of inclusions (type two), promoting the steel fracture while cyclic loading to a greatest extent. Acute-angled inclusions (type three) promoted fatigue crack initiation and propagation to a lower degree. Globular inclusions (type one) either took no part in crack initiation process or inhibited formation of the rounded cavities that least contributed to a matrix integrity violation and its fatigue fracture promotion.

Influence of non-metallic inclusions on steel 40XJI resistance to low cycle destruction was studied on steel (table 2). As it may be seen from fig.3, irrespective to from residual deformation value (for flat bending) steel with globular inclusions possessed the highest fracture resistance (variants 5 and 6), and in case of film inclusions the fracture resistance was the lowest (variant 2).

TABLE 2
INFLUENCE OF DEOXIDATION ON NON-METALLIC INCLUSIONS AND AUSTENITE GRAIN SIZE OF STEEL 40XЛ

Variant	Deoxidizers, %				Inclusions			Austenite grain size, μm
	Al	Ti	SiCa	FeCe	type	index	quantity, vol. %	
1	-	-	-	-	I	0.0030	0.101	61.4
2	0.03	-	-	-	II	0.0067	0.089	16.2
3	0.15	-	-	-	III	0.0037	0.084	12.4
4	0.10	0.05	0.15	-	I, II	0.0032	0.089	10.7
5	0.10	0.05	-	0.15	I	0.0027	0.078	9.6
6	0.10	0.05	0.15	0.15	I	0.0024	0.074	9.8

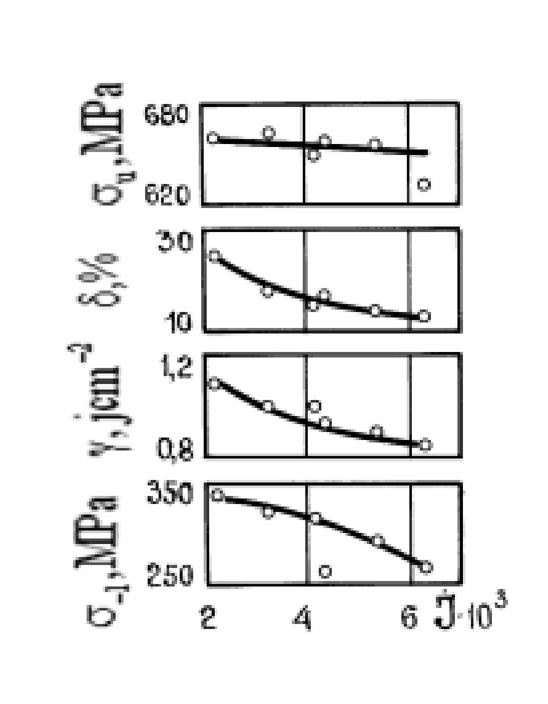

Figure1: Influence of index I on σ_u, δ,γ and σ_{-1} of mid-carbon steel.

Figure 2: Microcracks initiation near inclusions of type two (a), type three (b) and type one (c).

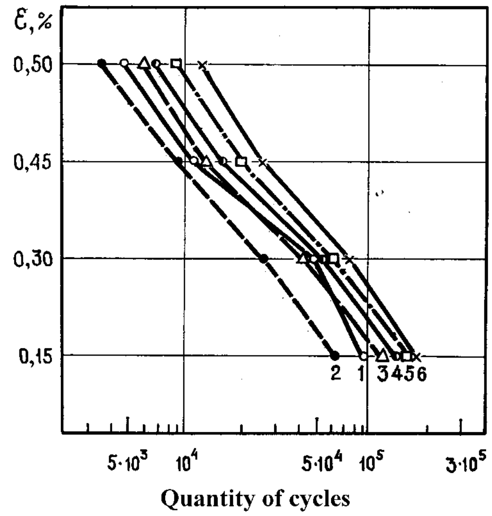

Figure 3: Steel 40ХЛ life at low cycle loading dependencies on deoxidization variant (see table 2).

Metallographical analysis has proved the data shown in fig.3 and gave the following evidence. Shape (type) of non-metallic inclusions was the decisive factor for crack initiation intensity. Globular and rounded non-metallic inclusions to a minor extent inhibited microcrack initiation and propagation calling the small cavities initiation (fig. 4a,b). Film inclusions of type two inhibited the elongated crack initiation (fig. 4c,d). Inclusions of type three were the ones of intermediate type; intensive crack initiation close to them was observed in a case of their disposition either in-groups or on grain boundaries (fig. 4e,f).

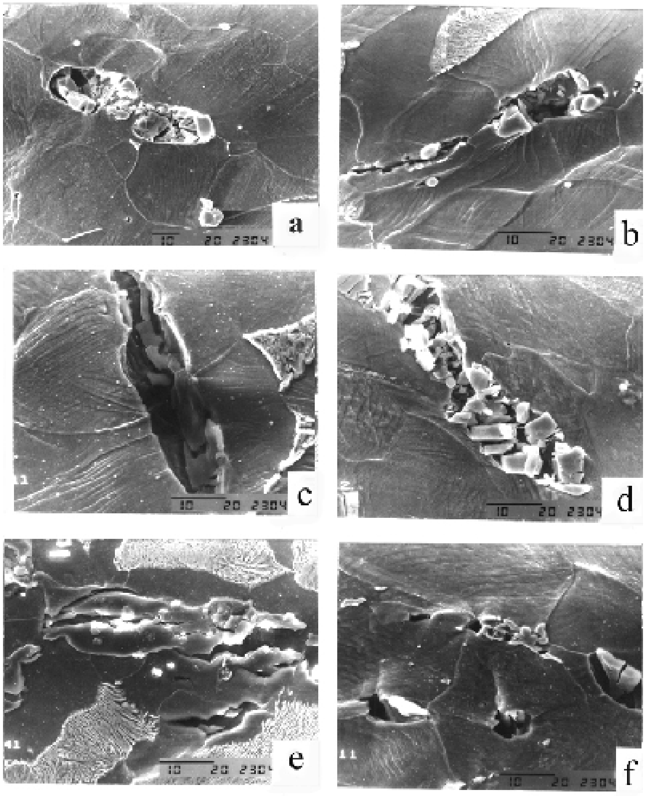

Figure 4: Involvement of non-metallic inclusions in a process of crack initiation.

Results of quantitative metallography of steel of variants 2,3 and 6 with inclusions of type two, three and one, respectively, have shown that during the first cycles of loading in variant 2 steel microcracks appeared only on non-metallic inclusions (A_C=1.0). For variants 3 and 6 index A_C was equal to 0.8 and 0.7, respectively (fig.5). The given results give the evidence of the great role of inclusions in processes of microcrack initiation and propagation.

Index A_i is numerically equal to a fraction of inclusions taking part in a fracture process. Index grows with cycle number increase being the greatest for steel with type two inclusions, and the lowest – for steel with type one inclusions (fig.5).

Experimental data evaluation has shown the existence of correlation between index I and fracture cycle number N at a studied interval of deformation degree ε. This correlation is described well with curves of a second order (fig.6). Likewise fig.1, the point corresponding to variant 1 (steel with the largest austenite grain) lies aside of three curves describing the abovementioned correlation dependence.

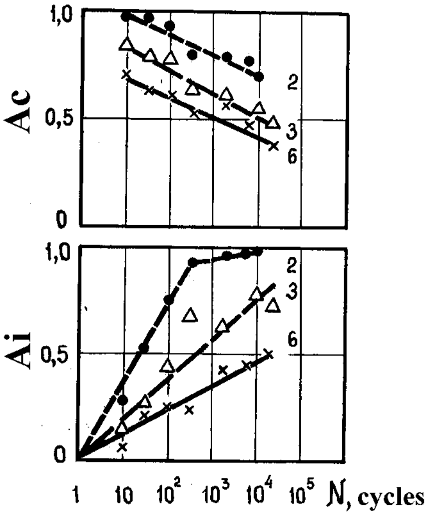

Figure 5: Influence of cycles number N on indexes A_C and A_i.

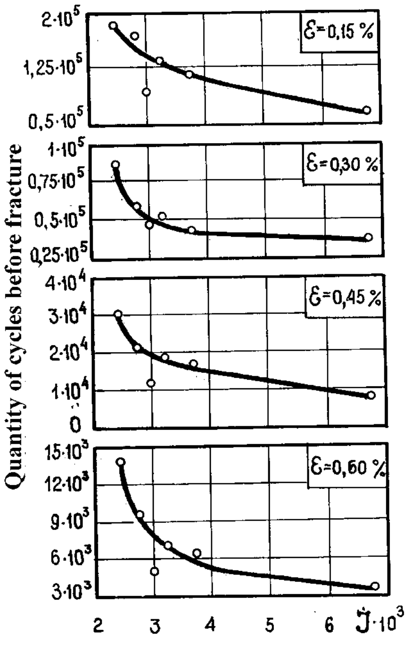

Figure 6: Dependence between cycle number N and inclusion index I.

In general, the results of investigation have shown that non-metallic inclusion influence significantly steel resistance to fatigue fracture. If a steel with a third type of inclusions (mid-scale production technology) was taken as a reference, then globularization of inclusions would increase 1.4 – 1.6 times endurance for low cycle loading, and 1.15 – 1.25 times – for high cycle loading.