PHASE TRANSFORMATIONS IN PLASTIC ZONES OF AUSTENITIC Fe-Ni AND Fe-Mn STEELS

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ABSTRACT

This paper presents of author's investigations on martensitic phase distribution in plastic zones under the fracture surface of austenitic Fe-Ni and Fe-Mn steels, tested under different types of loading conditions: static, impact, fatigue. A method for an estimate the material local temperature at the propagating crack tip is presented. It is based on determination the quantity of the martensite formed on the fracture surface.

KEYWORDS

Martensitic transformation, austenitic steel, fracture surface, plastic zone, local temperature.

INTRODUCTION

It is known that the fracture of metallic materials is accompanied with plastic zones at a growing crack tip. The depth and quantity of plastic zones is connected to the material local stress state formed during the fracture (Hellon,1984). Phase transformations take place in plastic zones during austenitic steels fracture.Moreover the plastic strain promotes to these transformations, but the local heating at the crack tip prevents from them. Finally, the structure and the local temperature behind a growing crack tip define a material fracture resistance. However the information about phase transformations in plastic zones of austenitic metastable steels tested under different types of loading conditions is absent. It make difficult to forecast steels behavior and restrict possibilities to use this type of steels.

EXPERIMENTAL RESULTS

Materials tested were austenitic Fe-Ni steels H32T3, H26T3 and Fe-Mn steels 40Г18Ф, 03Х13АГ19. The chemical composition is given in Table 1. The type of the martensitic transformation and temperatures of the martensitic transformation start are given in Table 2.

Table 1. Chemical composition

Steel	C	Ni	Mn	Cr	Ti	V	N
H32T3	0,030	32,1	-	-	3,2	-	-
H26T3	0,035	26,6	-	-	3,18	-	-
40Г18Ф	0,420	-	17,96	0,09	-	1,22	-
03Х13АГ19	0,030	0,7	18,37	12,56	-	-	0,14

Table 2. Type of martensitic transformations

Steel	M_s, °C	M_d, °C	Type of transformations
H32T3	-196	20	$\gamma \to \alpha$
H26T3	-20	50	$\gamma \to \alpha$
40Г18Ф	-196	-20	$\gamma \to \varepsilon \to \alpha$
03Х13АГ19	-196	20	$\gamma \to \varepsilon \to \alpha$

Impact tests were performed using the standard method at several temperatures ranging from -196 to 150°C. For static crack resistance tests and fatigue tests standard compact tension specimens (CT) with thickness of $t=19,5\cdot10^{-3}$m were used. Fatigue tests were conducted with stress ratio R=0,5 at temperatures -196,-80,20 and 150°C. The depth of layer of plastic zones under the fracture surface and variations of the material structure within plastic zones were measured by X-ray diffraction technique.

The fracture mode of the hardened Fe-Ni steels is independent of the impact test temperature. The fracture surface is ductile at all test temperatures. The depth of layer of plastic zones under the central part of the fracture surface decreases with the decrease of the test temperature.

Two plastic zones were found under the fracture surface of specimens tested within temperature interval ranging from -196 to 150°C. There are highly deformed micro plastic zone h_{yh} and lowly deformed macro plastic zone h_y (Fig.1). The amount of α-martensite is practically constant within plastic zones irrespective the existence of the material plastic strain gradient in plastic zones. It may be supposed that the such distribution of the martensitic phase within plastic zones is connected to the material local heating at the propagating crack tip.

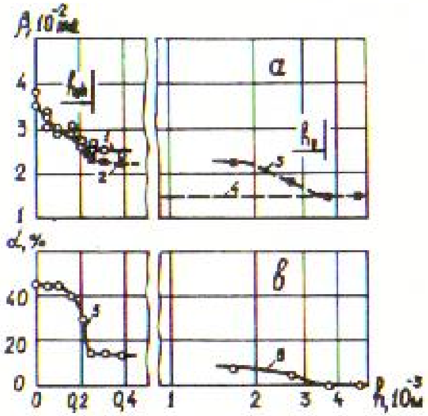

Fig.1. The relation diffraction lines width (β) $(211)K_\alpha$ of α-phase (1,2),$(311)K_\alpha$ of γ-phase (3), the amount of α-martensite (5,6) and distance from fracture surface (h) of the hardened steel H26T3 impact tested at 20°C. 4-standard width of the diffraction line $(311)K_\alpha$.

The fracture mode of hardened Fe-Mn steels transite from ductile to ductile+cleavage facets when the test temperature decrease. The lowly deformed macro plastic zone h_y disappear. For example only one highly deformed micro plastic zone h_{yh} is formed under the fracture surface of specimens made from 40Г18Ф steel and tested at the temperature -196°C (Fig.2).

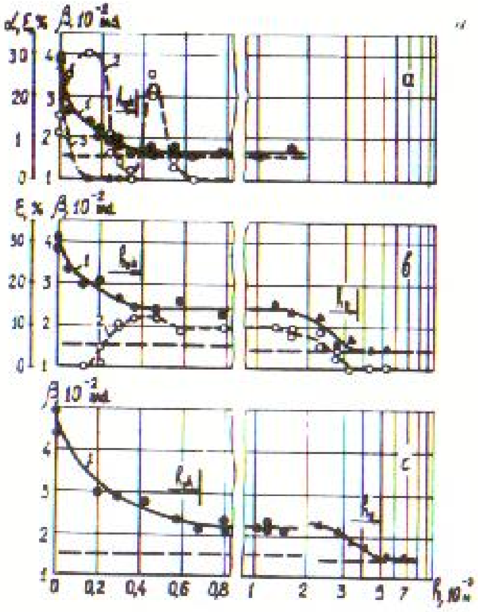

Fig.2. The relation diffraction line width (β) $(311)K_\alpha$ of γ-phase (1), the amount of ε- and α-phase (2,3) and distance from fracture surface (h) of the hardened steel 40Г18Ф impact tested at -196°C (a), 20°C (b) and 150°C (c). 4-standard width of diffraction line $(311)K_\alpha$.

The amount of α-martensite decreases with the increase the distance from fracture surface. The amount of ε-martensite increases under the fracture surface, arrives to the maximum amount under fracture surface where the plastic strain is lower then on the fracture surface and then, decreases. Similar results were obtained in investigation on the martensitic phase distribution in plastic zones of aged Fe-Ni and Fe-Mn steels. If suppose that the brittle fracture is't accompanied essential material local heating at the crack tip then the α-martensite distribution under the fracture surface will show the plastic strain change along the depth of plastic zones.

Similar regularities of plastic zones formation and martensitic phases distribution were found under static tests of specimens made from steel 03X13AГ19 and tested at the temperature interval ranging from -196 to 150°C.

Two plastic zones both cyclic h_{yh} and monotonic h_y are formed under the fracture surface of specimens manufacted from steel 03X13AГ19 and tested under fatigue loading conditions (Fig.3). The regularities of the martensitic phase are the same as in steels tested under single loading.

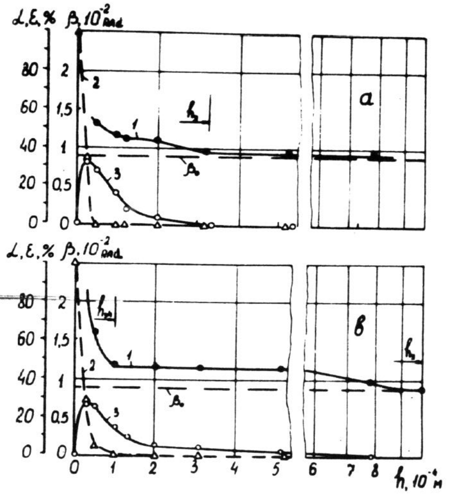

Fig.3. Variation of width of the diffraction line (311)K_α (1) and distribution of martensitic α-(2) and ε-(3) phases along plastic zones under the fatigue fracture surface of specimens made from steel 03X13AГ19 and tested at -196°C (a) and 20°C (b).

By virtue of the analysis of martensitic phases distribution within plastic zones under the fracture surface of specimens made from austenitic Fe-Ni and Fe-Mn steels and tested under different types of loading conditions we have proposed a method for determination of the material local temperature at the crack tip (Klevtsov at al.,1991). For example the hardened austenitic steel H26T3 was used. Suppose it is necessary to determine the material local temperature at the crack tip of impact specimens tested at temperatures 20 and 50°C(Fig.4);

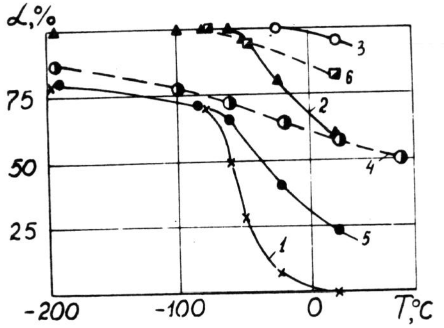

Fig.4. Temperature dependence of the amount of α-martensite in the hardened steel H26T3. 1-cooling martensite; 2-martensite on the fracture surface of impact specimens; 3-5-on the fracture surface of static specimens tested at 40,70 and 100°C and cooled to different temperatures; 6-on the fracture surface of static specimens cooled to -50°C tested at 20°C and again cooled to different temperatures.

The cooling martensite is absent at the temperature 20°C. The amount of the cooling martensite at the temperature -50°C is equal to 30% (Fig.4,curve 1). In order to solve the problem static tests were performed on bend notched specimens within temperature interval ranging from 40 to 100°C. We used loading rate $V_{load.} \leq 3\cdot10^{-6}$ m/sec in fact excluded the material local heating. Then we determined the amount of α-martensite on the fracture surface, after that fractures were cooled to temperatures 20°C,-20°C etc., and again the amount of α-martensite on these fracture surfaces was determined. The amount of α-martensite on the fracture surface of specimens tested at 40°C (curve 3), 70°C (curve 4) and 100°C (curve 5) and cooled to different temperatures is presented in Fig.4. The amount of α-martensite on the fracture surface of specimens tested at the temperature 70°C and cooled to 20°C as shown in Fig.4, is equal to the amount of α-martensite on the fracture surface of the specimen tested at the temperature 20°C. Thus the material local temperature at the crack tip of the impact specimen tested at 20°C was equal to 70°C and the amount of α-martensite formed during the test was equal 50% (Fig.4,curve 4). The material local temperature at the crack tip of the impact specimen tested at -50°C was determined in a similar way (Fig.4,curve 6). The material local temperature was equal to 20°C and the amount of α-martensite formed during the test was equal 82%. The proposed technique may be used only for metastable austenitic steels in which both strain-induced martensite and cooling martensite are formed at temperatures below the test temperature.

CONCLUSIONS

1. Distribution of martensitic phases within plastic zones under the fracture surface of austenitic steels is independent from types of loading conditions but is connected to the fracture micromechanism. The amount of α-martensite is constant within the micro plastic zone under the ductile fracture surface of steels. The amount of α-martensite decrease along the depth of the plastic zone under the brittle fracture surface of steels.
2. The maximum amount of ε-martensite form under the fracture surface where the plastic strain is lower then on the fracture surface. The maximum amount of α-martensite form on the fracture surface.
3. The increase of the single loading rate lead to the decrease of the amount of martensitic phases in plastic zones under the fracture surface. The most of the martensite was found in plastic zones under the fracture surface of specimens tested under fatigue loading conditions.
4. A method for estimation of the material local temperature at the propagating crack tip based on determination of the amount of martensitic phases formed on the fracture surface is proposed.

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