INITIATION AND DIFFUSION OF MAGISTRAL FRACTURES IN ION NITRIDING SPECIMENS SUBJECT TO POLYCYCLIC FATIGUE

ЗАРАЖДЕНИЕ И РАСПРОСТРАНЕНИЕ МАГИСТРАЛНЫХ ТРЕЩИН ПРИ МНОГОЦИКЛОВОЙ УСТАЛОСТИ ЙОННО АЗОТИРОВОНЫХ ОБРАЗЦЫ

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Abstract: *Fractographic and x-ray microanalyses (EPMA) of the surface have been carried out after the fatigue destruction. The results have been examined in order to be explained the impact of non-metallic inclusions as initiators of fracture. The non-metallic inclusions have been determined. Some peculiarities concerning the process of initiation and diffusion of magistral fractures originated as a result of polycyclic fatigue in nitriding specimens made of steel 40X have been shown.*

Introduction

The behavior of steel 40X (C 0,42%; Cr 0,98%; Mn 0,67%; Si 0,37%; P 0,017%; S 0,016%) subject to polycyclic fatigue loading has been examined. The tested specimens' shape and size correspond to the Bulgarian National Standards-5297-83. The specimen strengthening has been conducted after the following order: improvement, hardening, and high-temperature tempering at respectively 850ºC and 580ºC, ion nitriding at 540ºC, 60hours, 3mbar, NH_3. The tested set includes16 specimens.

Polycyclic fatigue tests have been carried out using electromagnetic resonance stand. The type of loading is a console bend. The specimen has been loaded with variable strength according to the resonance frequency of the system 28-30Hz. Nominal amplitudes of stresses are between 920-1060MPa.

Results and discussion

As a result of the polycyclic fatigue tests, carried out under console bend, has been defined the fatigue limit of 860MPa [1,2]. The metalographic analysis has shown: surface hardness-615-640HV_5, effective depth of the nitriding layer – 0.55mm.

Table 1

Depth of the nitriding layer µm	Quality phase analysis	Nitride quantity %	Residual pressures MPa
0	ε+γ	6	-
50	Nitriding solid sol. of αFe+γ	0,30	-430
200	Nitriding solid sol. of αFe+γ	0,31	-630
400	Nitriding solid sol. of αFe	0,15	-520
600	Nitriding solid sol. of αFe	-	-50
800	Solid sol. of αFe	-	+40

The microstructure observation of the nitriding layers demonstrates phase composition ε→γ→nitriding α solution. The internal stresses of the nitriding layer have been measured by X-ray diffraction analysis. The results are shown in Table1. Using X-ray microanalysis the quantity of nitride in the layer has been determined.

In depth up to 200µm inside the nitriding layer are registered nitride phases γ-Fe_4N, which are detached from the satiated α-solid Fe_4N nitride solution. The residual stresses in the nitriding layer are compressive; in depth of 200µm they are (-630) MPa (see fig.1) [2,3]. In depth over 600µm residual stresses turn to tensile (+40) MPa.

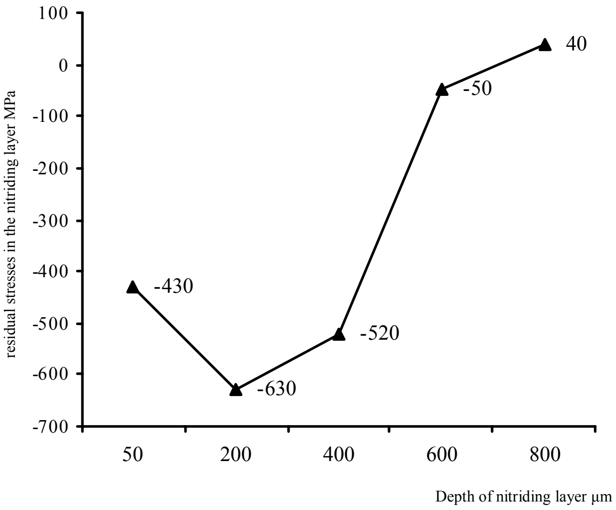
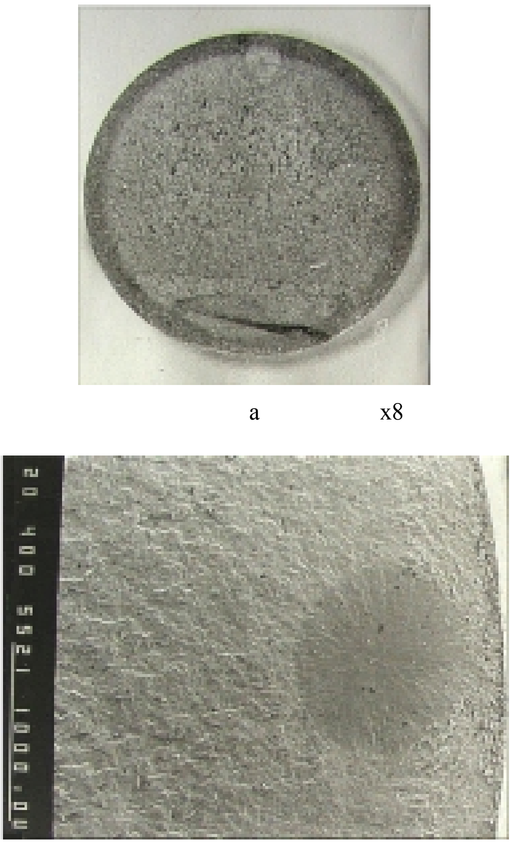


Fig.1 Diffusion of residual stresses in depth of nitriding layer

The fracture morphology analysis has been made by using light (LM) and scanning electron microscopy (SEM). Typical view of a fracture destructed as a result of polyciclic fatigue under console bend has been shown on fig.2. The point where the fracture had been initiated can be clearly seen, that is the round spot under the nitriding layer. As shown on fig.1 the zone under the layer is exactly where compressive stresses turn to tensile ones. The fracture inside the round spot is propagated radially from the centre where it has initiated. This is also observed in the further diffusion inside the specimen, in the nitriding layer as in the core of the specimen. The round spot diameter initiator of destruction is ∅1mm.



a x8

b x40

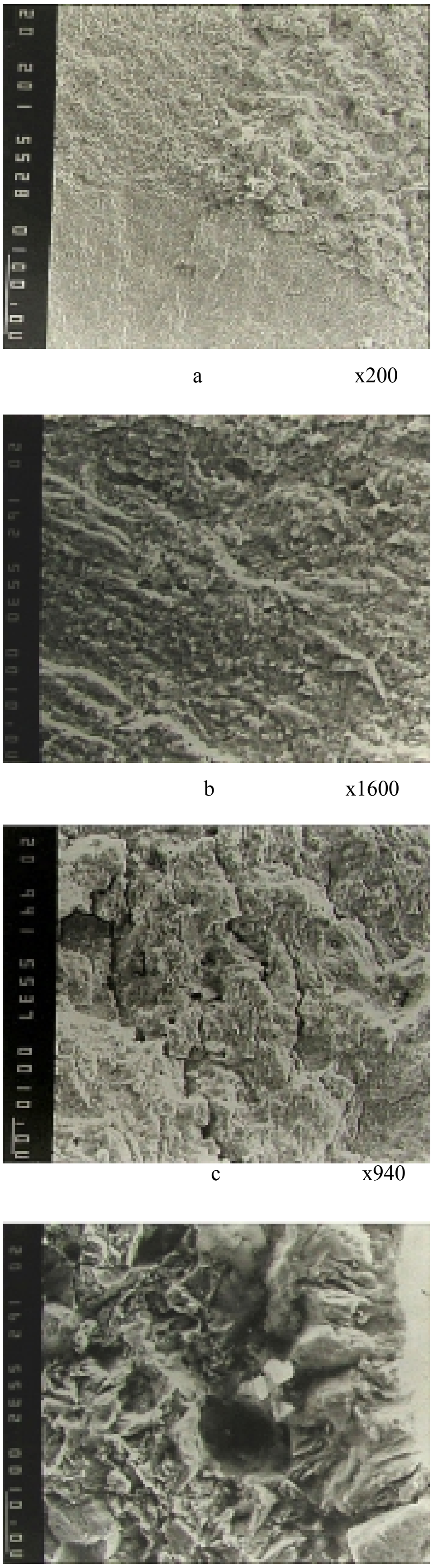
Fig.2 Morphology of fracture after fatigue destruction of ion nitriding specimen, steel 40X, depth 0.55mm
a) light microscopy (LM); b) scanning microscopy (SEM)

On the surface of the specimen fracture typical fatigue zones appear, fig.3. At the moment of the fracture initiation in the zone of the initiator the crack propagates with low velocity. The fracture is brittle with small facets, fig.3. Regardless of the outlined radial ridges, the general aspect of the fracture is flat.

The fracture inside the specimen is brittle, with rougher surface, fig.3c. Sections with well-defined fine fatigue lines are visible. Many large secondary cracks are observed. Their relative arrangement is also a consequence of the cyclic character of the loading.

The type of the nitriding layer fracture is brittle, fig.3d. The grains are big with well visible boundaries. Some plastic elements are also observed. On the specimen surface, inside the nitride zone $(\varepsilon+\gamma')$ can be seen pillar-like grains of Fe_4N. From inside the nitriding layer towards the surface the brittle fracture character increases. In the same direction increases also the quantity of nitride in the layer (table1).

The surface fracture shown on fig.4 is plastic mode of typical fracture with well formed dimples.



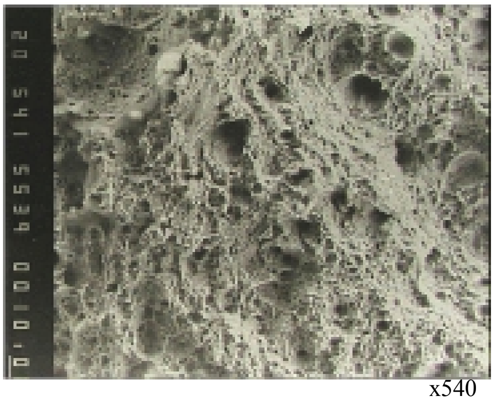
a x200

b x1600

c x940

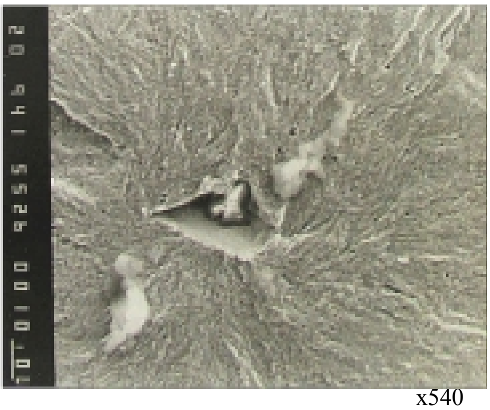
d x1600

Fig.3 Morphology of fracture after fatigue destruction of ion nitriding specimen, steel 40X, depth 0.55mm
a) common limits between nitring layer, core, initiation zone
b) initiation zone; c) core; d) nitriding layer



x540

Fig.4 Morphology of destruction in the zone of fracture



x540

Fig.5 Metallurgical defect, pore with calcium, non-metallic inclusion

Non-metallic inclusions are the main reason of initiating fractures in the examined case [4].

The metallurgical defect, which served as fracture initiator is shown on fig.5. This defect is located in the center of the round spot on fig.2.

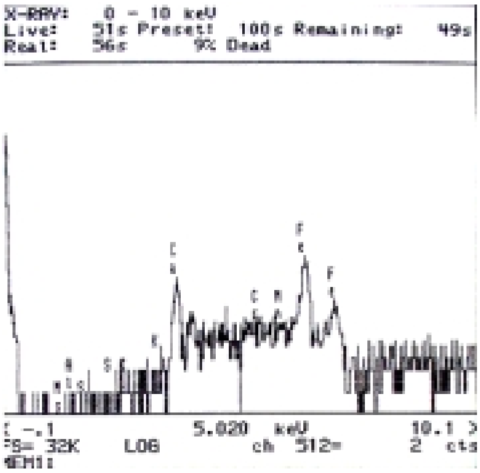


Fig.6 X-ray spectrum of calcium non-metallic inclusion from metallurgic defect

By X-ray microanalysis has been determined the type of the metallurgical defect. The X-ray spectrum shows presence of calcium non-metallic inclusion from metallurgical defect, initiator of magistral fracture (fig.6).

Conclusion

Negative influence of metallurgical defects like non-metallic inclusions and pores has been confirmed. Metallurgical defects are fracture initiators in the zone under the nitriding layer. In this zone by virtue of the equilibrium the residual stresses are tensile.

The residual compressive stresses in the nitriding layer reduce the medium tensile stresses from the loading, which increases the resistance against fatigue fracture in the nitriding layer.

The compressive stresses reduce the possibility of fracture initiation in the nitriding layer caused by non-metallic inclusions and pores.

The significant role of residual compressive stresses in nitriding layer has been confirmed, which explains the high fatigue strength after the ion nitriding process.

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