INFLUENCE OF SHOT PEENING ON AISI 316Ti FATIGUE PROPERTIES

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Resume

This paper deals with examination of fatigue properties of AISI 316Ti stainless steel before and after shot peening including analysis of residual stress relaxation during rotating bending fatigue tests (f = 50 Hz, T = 20 ± 3 °C, R = - 1) with use of X - ray diffractometer. Obtained experimental results show increase of fatigue properties in the high – cycle region including fatigue limit and show the behavior of residual stress at cyclic loading in the region from $N = 10^3$ cycles to $N = 10^7$ cycles of loading.

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1. Introduction

Fatigue of construction materials is a phenomenon which is the centre of interest of many research laboratories for more than 170 years. Reason of this interest is the fact that more than 90 % of broken engineering components are fractures caused by fatigue of used material. Extremely dangerous are fatigue fractures in transport, for example rails, tire parts, plane wings and hulls of ships, because these are usually connected with human casualties.

Evaluation of fatigue behaviour of different materials is important for safety and reliability of a component or a construction [1-6].

Fatigue cracks initiate and propagate through the cross section of material and when the cross section reaches critical size a sudden fracture of the component appears. The initiation of fatigue damage in the field of low – cycle and high – cycle fatigue occurs mainly on an open surface of cyclic loaded component, in the place of maximal stress and cyclic loading concentration [7 - 8]. By a technological surface treatment it is possible to slow down the initial stage of fatigue crack creation, which increases fatigue properties of a component or a construction. Methods based on mechanical deformation strengthening of the surface layer are used, for example shot peening, rolling; methods based on changing the surface layer chemical composition and (or) microstructure, for example cementation, nitridation, quenching and their combinations; methods based on surface layer deposition with different properties with use of several physical and chemical – physical principles, for example PVD, CVD methods, plasma coating, ion – implantation, pre-deformation by static or repeated loading and so on [7, 9 - 11].

One of suitable surface treatments is shot peening. Shooting of hard medium (for example steel balls) on a component surface causes quantitative changes of material in surface layers (microhardness, residual stress) and characteristic surface morphology is created. Plastic deformation of the surface is connected with microstructure changes, creation of residual stress, heat effects, changes of mechanical and technological properties. Fatigue characteristics including fatigue limit can increase after application of shot peening for about 20 % [11 - 14]. However, during the fatigue loading process of a shot peened component, the compression residual stress starts to relax, what causes qualitative changes of stress distribution in the surface layers. The knowledge of the behavior of these changes is important to predict the safe operating life of a shot peened component [15].

Austenitic stainless steels are construction materials with a wide field of usage in engineering components, regarding to their mechanical and technological properties including very good resistance to corrosion degradation mechanisms. Therefore, experimental study of fatigue characteristics of these steels is very important [16].

In this work, there are listed results from experimental verification of fatigue properties before and after shot peening, including relaxation of residual stress during fatigue loading of austenitic Cr – Ni – Mo stainless steel AISI 316 Ti stabilized by titanium.

2. Experimental

Experimental examination was done on austenitic Cr – Ni – Mo stainless steel

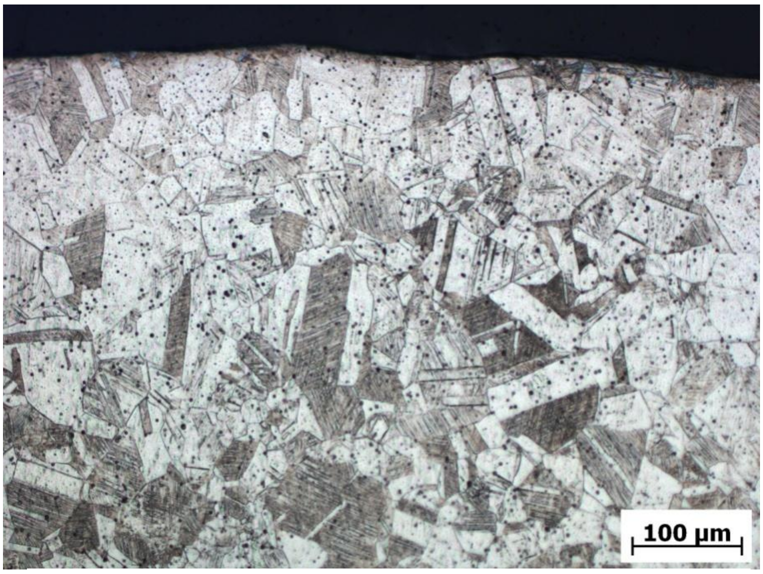

Fig. 1. Microstructure of AISI 316Ti steel, electrolytic etching

Table 1

Results of quantitative chemical analysis of AISI 316 Ti steel (in weight %)

Cr	Ni	Mo	Mn	Ti	C	Si	P	S	Fe
17.55	12.96	2.54	1.63	0.37	0.058	0.81	0.033	0.037	rest

(commercially referred to AISI 316Ti, STN 41 7348), stabilized by titanium. This steel is nonmagnetic with very good resistance to acids. Quantitative chemical analysis of AISI 316Ti steel is listed in Tab. 1. The microstructure of this steel (Fig. 1) is formed by austenitic grains with a great number of deformation twins.

From a rod of 14 mm in diameter were machined round specimens for tensile and fatigue tests, both with 8 mm in diameter. Specimens for tensile tests (3 pcs) and specimens for fatigue tests (19 pcs) were ground. Final surface roughness was: arithmetical mean roughness Ra = 1.1 μm and roughness height Rz = 7.35 μm. Part of specimens (7 pcs) were shot peened with quenched steel ball shots with hardness of 40 ÷ 50 HRC, Almen intensity [13] was 8 A with 100 % coverage. The roughness in the middle part of specimens after shot peening was Ra = 1.75 μm and Rz = 9.40 μm.

Microhardness measurement HV 0.1 (Fig. 2) has shown a deformation strengthening in the surface layers induced by shot peening (Fig. 3). Tensile test results (Tab. 2) shown a 124 % increase of yield strength, however, no increase of tensile strength was observed.

Rotating bending fatigue tests (Rotoflex equipment, frequency of loading f = 50 Hz, temperature T = 20 ± 3 °C, ratio of cycle asymmetry R = - 1) to evaluate the influence of shot peening was done on 12 machined specimens and 7 shot peened specimens and the run – out number of cycles for fatigue limit σ_{oC} determination was defined for $N = 10^7$ cycles. The dependence of bending

Table 2

Results of tensile tests on specimens before and after shot peening

	Tensile strength R_m (MPa)	Yield strength $R_{p0,2}$ (MPa)	Elongation A (%)
Before shot peening	778	287	54
After shot peening	752	643	40

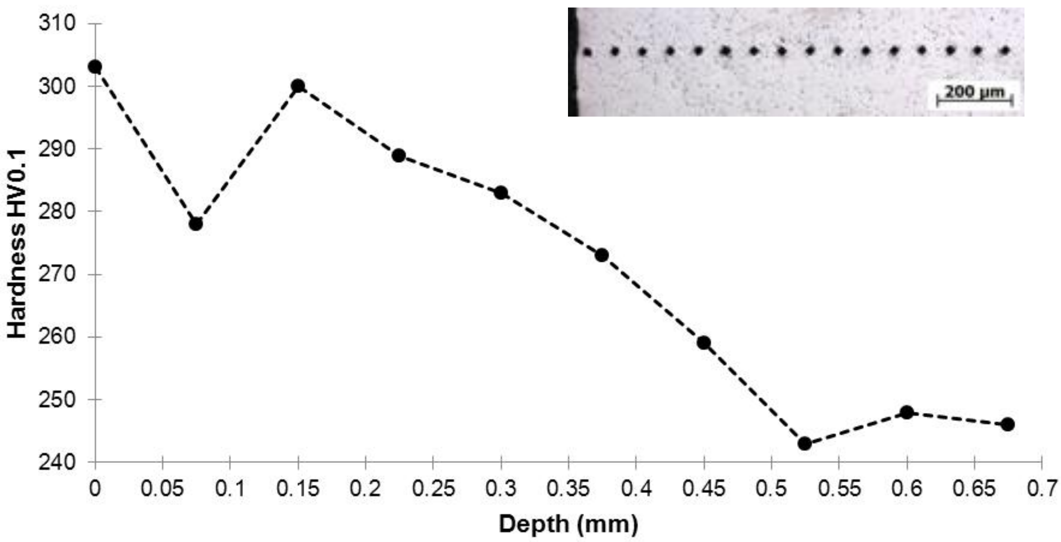

Fig. 2. The dependence of hardness on the distance from shot peened surface of the specimen

stress σ_o vs. number of cycles to failure (or run – out) N_f is shown in Fig. 3 and the fatigue limit for machined specimens was determined σ_{oC} = 320 MPa and after shot peening σ_{oC} = 420 MPa.

The values of residual stress of shot peened specimens were measured by X – ray diffraction. To obtain dependence of residual stress on the distance from the shot peened surface, small layers of material were systematically removed by electro-polishing and each time the value of residual stress was measured. With the use of X – ray diffractometer was also measured the FWHM (Full Width at Half Maximum) parameter, which is expressing the distortion of the atomic lattice caused by defects in lattice.

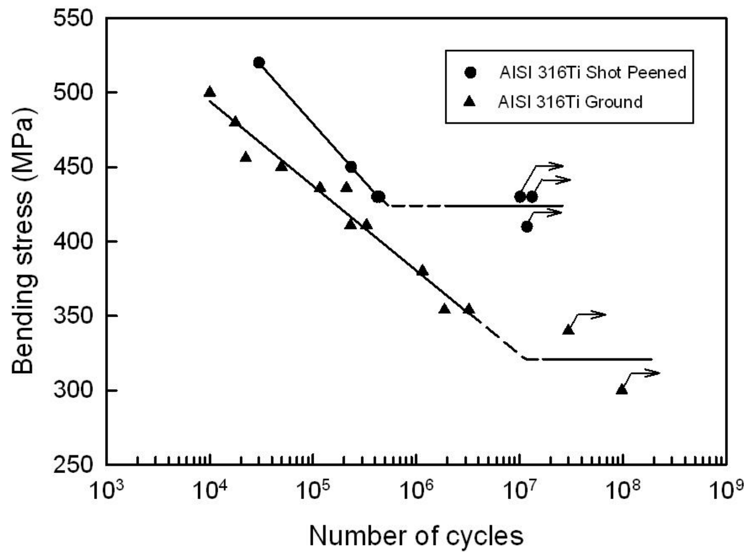

Fig. 3. The dependence of bending stress σ_o vs. number of cycles to failure N_f, steel AISI 316Ti

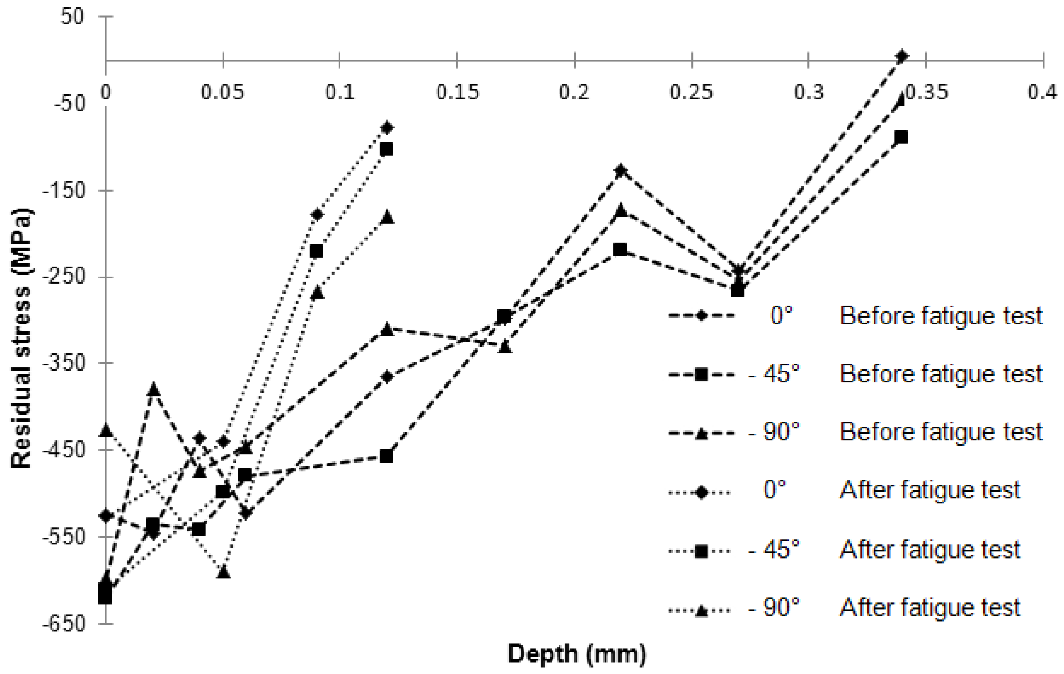

Fig. 4. The dependence of residual stress on the distance from the shot peened surface, steel AISI 316Ti

3. Results and discussion

Obtained results of fatigue properties of AISI 316Ti steel after shot peening application proved higher resistance against fatigue loading in the area of $N_f = 2 \times 10^4$ cycles up to $N_f = 10^7$ cycles, Fig. 3. The lean line of S – N diagram is shifted to higher values of number of cycles and fatigue limit σ_{oC} is for AISI 316Ti steel, before shot peening and for N = 10^7 cycles σ_{oC} = 320 MPa, after application of shot peening the fatigue limit reaches value σ_{oC} = 420 MPa; so the increase of fatigue limit is almost 24 %. These conclusions correspond with works [11 - 14].

The results of FWHM parameter and residual stress before and after the fatigue test, or more precisely, the relaxation of residual stress during the rotating bending fatigue test (after N = 10^3; 10^4; 5×10^4 and 2×10^6 cycles) are involved in Fig. 4 up – to Fig. 7.

Obtained results, Fig. 2 (dependence of hardness on the distance from shot peened surface), Fig. 4 (dependence of residual stress on the distance from the shot peened surface), Fig. 5 (dependence of FWHM parameter on the distance from the shot peened surface) have good correlation. Decrease of compressive residual stress and decrease of FWHM parameter corresponds with decrease of HV0.1 hardness with increasing distance from the shot peened surface of the specimen towards the core of the specimen [9, 14, 17]. The behavior of residual stress is a function of multiple factors, which can also have influence on each other, for example heating of experimental material during the fatigue test (which results from the austenitic microstructure of the material) [18], deformation strengthening [13, 19], surface roughness after shot peening [15], angle of measuring (angular rotation of the specimen) [20], amplitude of applied cyclic loading etc [6, 20, 21]. Influence of the mentioned factors is also visible from the curves in Fig. 6 and Fig. 7. Generally, it can be asserted that values of compressive residual stress decrease with increasing number of applied cycles of loading.

4. Conclusions

Based on results obtained from AISI 316Ti rotating bending fatigue tests (f = 50 Hz, T = 20 ± 3 °C, R = - 1) can be considered:

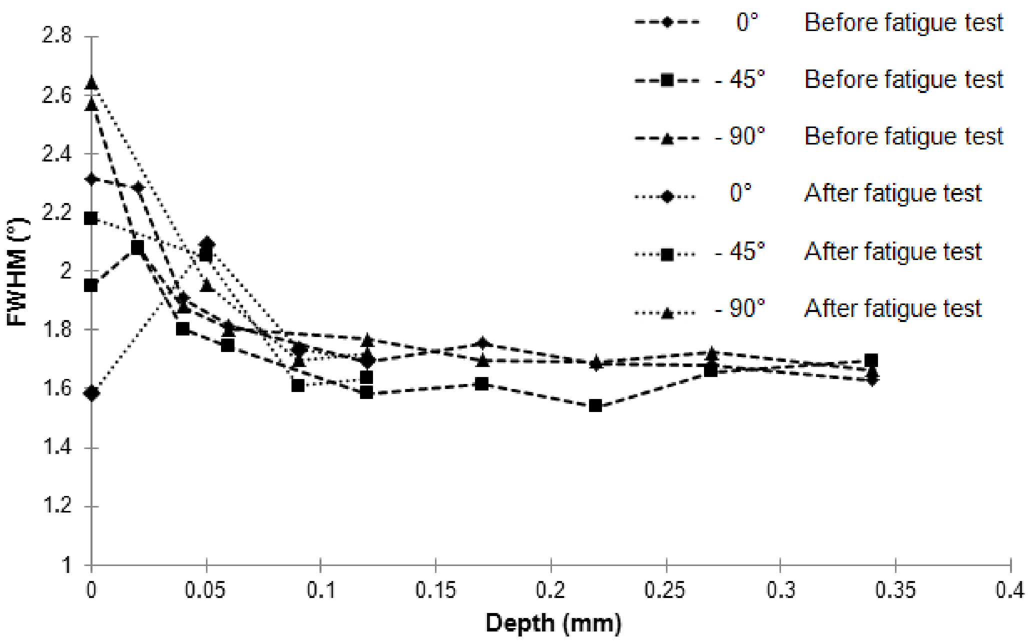

Fig. 5. The dependence of FWHM parameter on the distance from the surface, steel AISI 316Ti

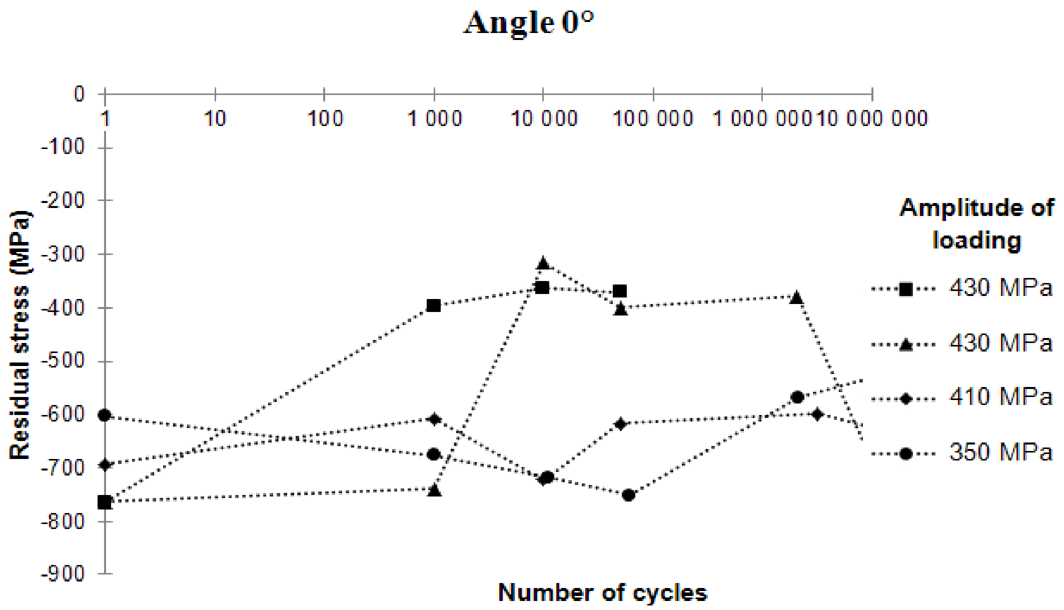

Fig. 6. Behavior of residual stress during fatigue test, steel AISI 316Ti, measured under angle 0° - direction of maximal loading stress

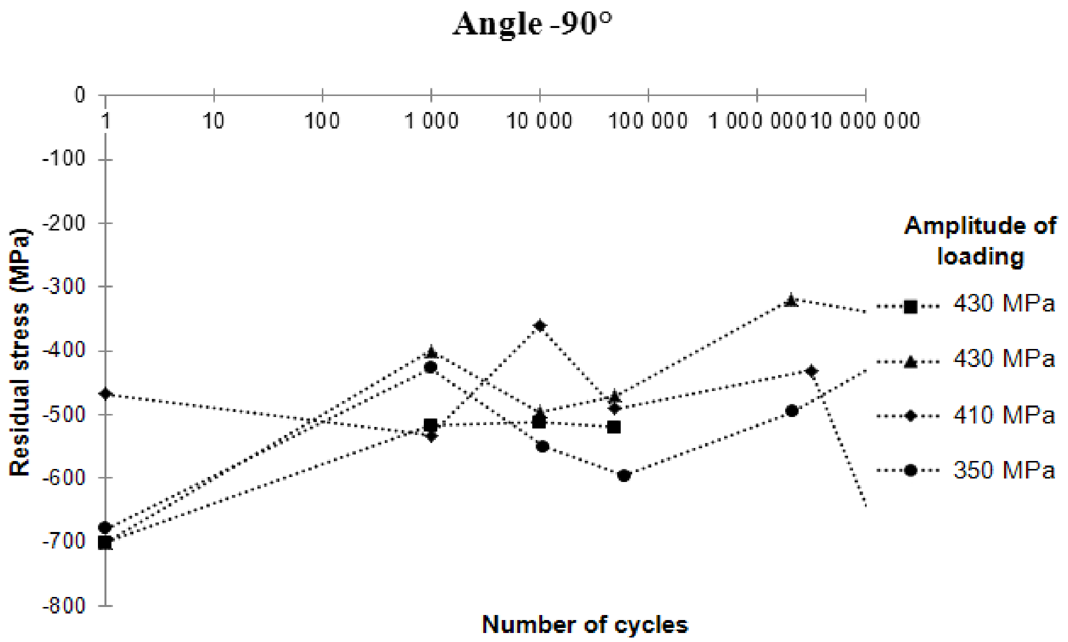

Fig. 7. Behavior of residual stress during fatigue test, steel AISI 316Ti, measured under angle-90°- direction of minimal loading stress

- fatigue limit σ_{oC} related to $N_f = 10^7$ number of cycles was determined for machined and ground specimens σ_{oC} = 320 MPa and for shot peened specimens σ_{oC} = 420 MPa,
- the resistance to fatigue degradation mechanisms is higher after shot peening,
- application of shot peening induced-compressive residual stress into surface

layers what caused hardness increase in these layers (305 HV0.1 on surface vs. 245 HV0.1 at a depth of 0.5 mm under the surface),

- during the rotating bending fatigue test a decrease of residual compression stress in the surface layers of experimental material was observed,
- on specimens tested on higher amplitudes of loading σ_o was observed unstable behavior of residual stress (decrease vs. increase), which what was probably caused by heating of the specimens during the fatigue tests.

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