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EVALUATION OF STRAIN DISTRIBUTION FOR THE P91 STEEL UNDER STATIC LOAD USING ESPI SYSTEM

ABSTRACT

The goal of the research was to evaluate the change of displacement/strain phases in the P91 steel under static load conditions. Undertaken tests were aimed at estimation and analysis of the impact of the material state, which was subjected to loading conditions, on the distribution of stress pattern using ESPI system. Specimen made of high temperature creep resistant steel X10CrMoVNb9-1 (P91) used as a construction material for boiler steam feed heaters, vapor tanks, pressure vessels and vapor pipelines, is used in the service conditions of temperature range up of 650°C. Test samples were taken from two P91 steel pipes. One sample came from a segment of a pipeline transporting fresh vapor in time 80 000 h, under the pressure of 8.4 MPa and temperature 540 °C. The second sample was the same material but in the delivery state.

***Key words**: fatigue, electronic speckle pattern interferometry, P91 steel*

INTRODUCTION

The goal of the research was to evaluate the change of displacement/strain phases in the P91 steel under static load conditions. Undertaken tests were aimed at estimation and analysis of the impact of the material state, which was subjected to loading conditions, on the distribution of stress pattern using ESPI system.

Electronic Speckle Interferometry (ESPI- Electronic Speckle Pattern Interferometry) is an optical technique of measurements of surface distortion of tested elements. ESPI is a kind of holographic interferometry based on the analysis of laser light that is distracted on optically coarse surface. Two beams participate in the interferometry process: the first one lightens a tested surface while the reflected light interferes with the other one so-called reference beam (it may be a parallel beam or a beam distracted on coarse surface). The result of the interference is registered with a camera in the form of speckled images. Through the process of reducing the intensity distribution (speckled images) before and after deformation one gets correlational fringes that generate phase maps. Phase maps contain quantitative and directional information concerning deformation that constitute a foundation to assign field distribution of the displacement applied for every particular direction.

Appointing the field distribution of the strain and stress pattern is performed through the execution of mathematical operations with given boundary conditions (given dimensions of a measuring area) and material parameters (Yong's modulus and the Poisson's ratio).

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MATERIAL AND TEST METHODOLOGY

Flat specimens of a geometry designed for observation of field distribution were made of high temperature creep resistant alloy steel X1-CrMoVNb9-1 (Fig. 1), some specimens were cut from a initial material, the rest from an exploited one. One specimen from each stock was used for tensile test in order to measure mechanical properties and determine a yield stress, which was necessary for estimation a load program for field stress characterization [1].

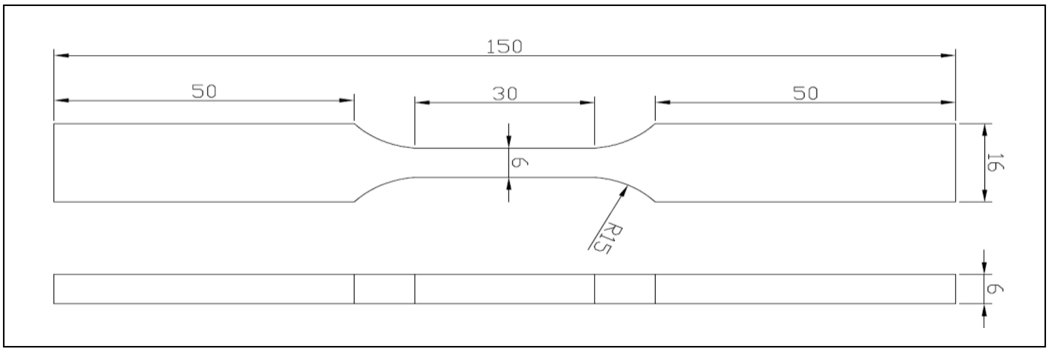


Fig. 1. Geometry of specimen for tensile test and measurement of stress/strain using ESPI method

Two specimens (delivery state material and exploit material) underwent a static tensile test. The initial material was subjected also fatigue test with load of 350 and 370 MPa, the test was stopped on the dynamic growth of average strain increase (measured by extensometer) which intended to introduce considerable degree of damage with a tendency to localization. This effect was created via introducing a crack into the sample. Juxtaposition of all specimens is presented in Table 1.

Table 1. *Juxtaposition of tests specimens for investigation via ESPI method*

No.	Specimen description	State	Pipe	Thickness
1	NP91_1	delivery	delivery state material	3 mm
2	NP91_2	delivery		3 mm
3	NP91_1FC	fatigue, until cracked		6 mm
4	NP91_2FC	fatigue, until cracked		6 mm
5	EP91_1	exploit	exploit for 80 000 h.	3 mm
6	EP91_2	exploit		3 mm

Specimens of different level of mechanical load were prepared. Undertaken tests were aimed for estimation of the influence of the load level on stress distribution at simultaneous static loads during tension test.

Static tensile test

Mechanical strength properties of P91 steel before and after exploitation were determined on the basis of static tensile test result. The results are presented in the Table 2 and Fig. 2.

Table 2. *Mechanical strength properties of P91 steel before and after exploitation and according to the standard*

	R_m [MPa]	R_e [MPa]	A [%]
P91 delivery state „0”	903	661	23
P91 state „80 000 h”	662	497	24,5
PN: 10216-2:2004	630-830	>450	17-19

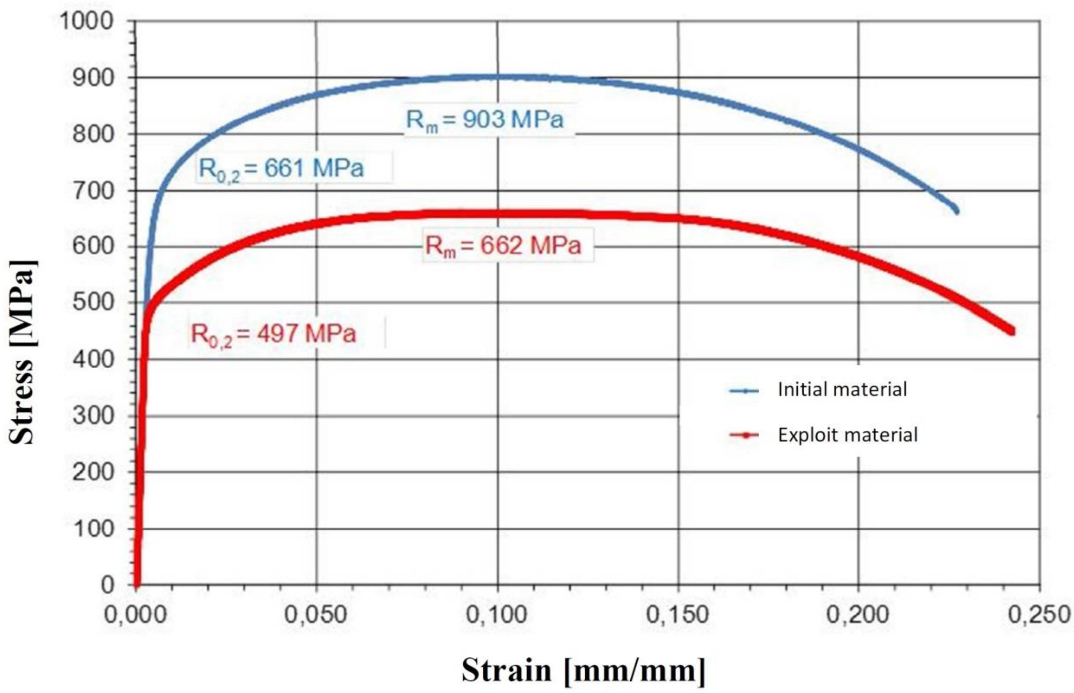


Fig. 2. Stress-strain curve for tested steel specimens in the state of delivery and after exploitation

Stress pattern measurements in the elastic range of introduced stress using ESPI technique

Measurements of stress pattern distributions were done with the use of the Electronic Speckle Pattern Interferometry (ESPI). The program of applying the load to specimens was executed in five steps from 0 to 2.5KN. Load step of 500 N was maximal for preserving the stability of interference fringes which enabled measurement of displacements. Global strain was measured by extensometer produced by the MTS company with gauge length 30 mm (Fig. 3.)

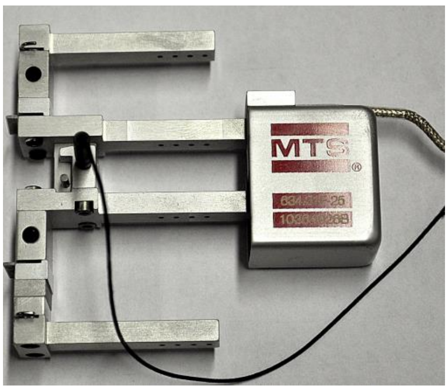


Fig. 3. Extensometer for measuring displacement

Strain measurement with the use of extensometer enabled verification of the results obtained with the use of ESPI technique in axial direction (Y). According to the previous description, the strain measurement with ESPI camera is based on displacement measurements. Displacement according to the local changes of the intensity of speckled images emerged as a result of chaotic dissipation of highly coherent radiation on specially prepared coarse surface of a specimen. Fig. 4 presents the scheme of creating a strain map in the ESPI measurement system [2,3].

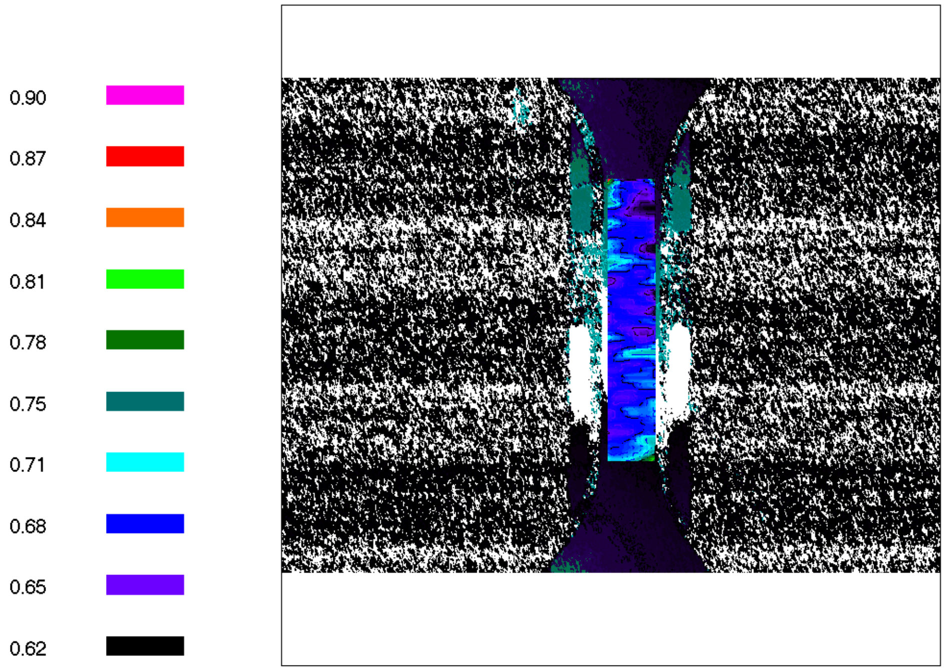
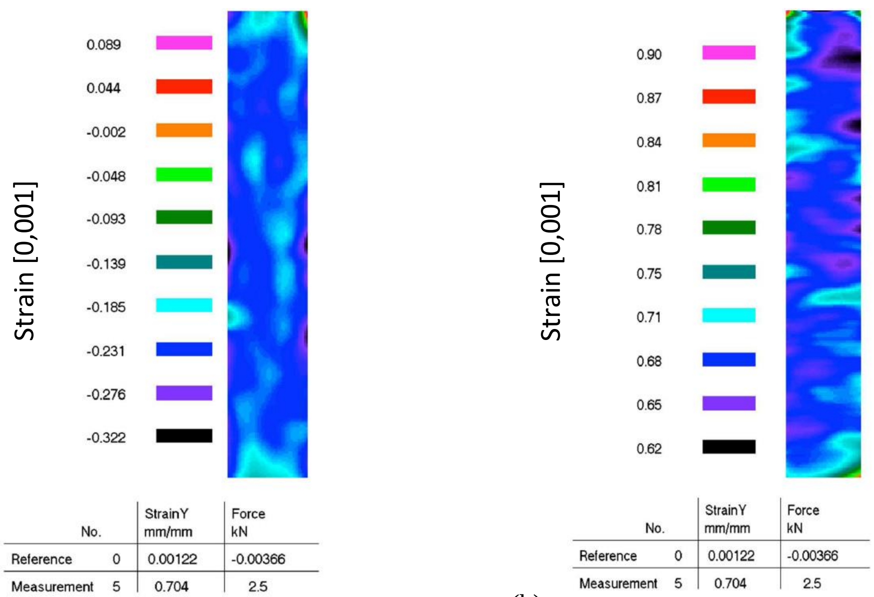


Fig. 4. Phase map with a layer of strain map in the measured section of the specimen generated by the ESPI system



(a) (b)

Fig. 5. Strain pattern distribution towards the X direction transversal to the direction of stress loading (a) and towards the Y direction consistent with the stress direction (b) for the NP91_1 specimen

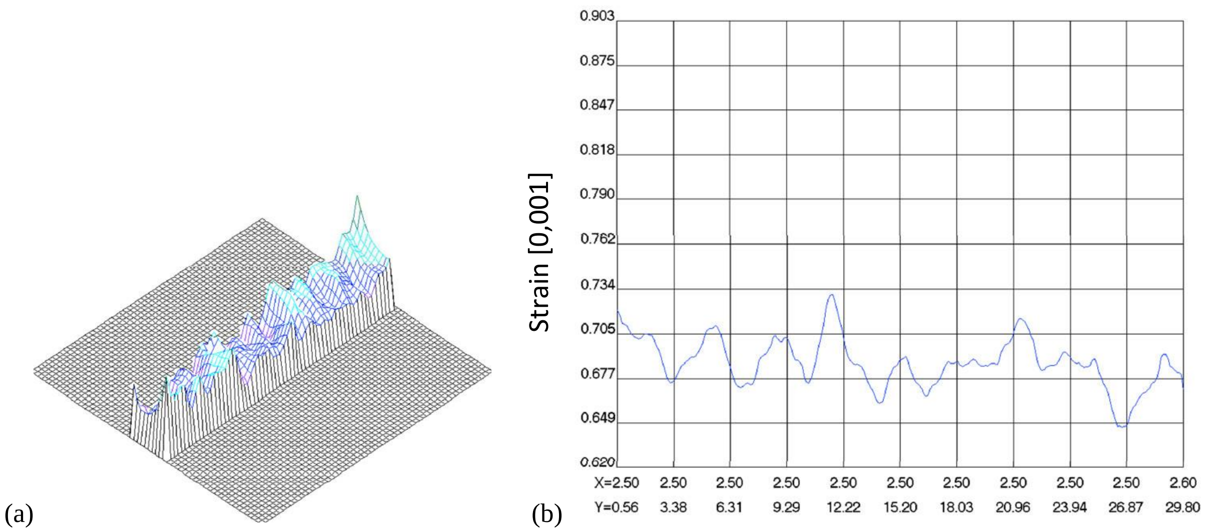


Fig. 6. 3D strain profile in the direction of tensile (a) and line graph in the axis of the main NP91_1 specimen (b)

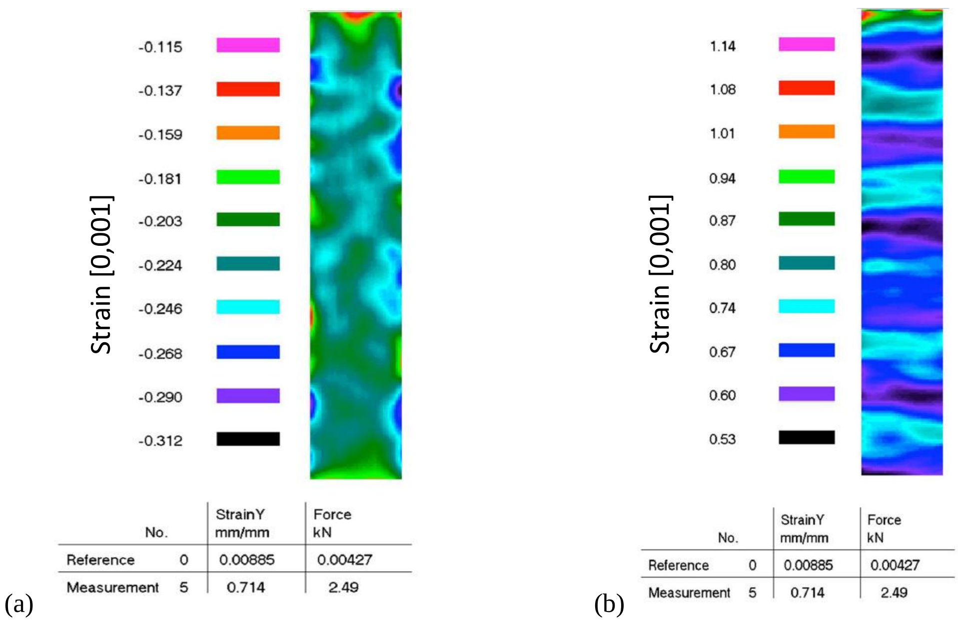


Fig. 7. Field strain distribution towards the X direction transversal to the direction of stress (a) and towards the Y direction consistent with the direction of stress (b) for the NP91_2 specimen

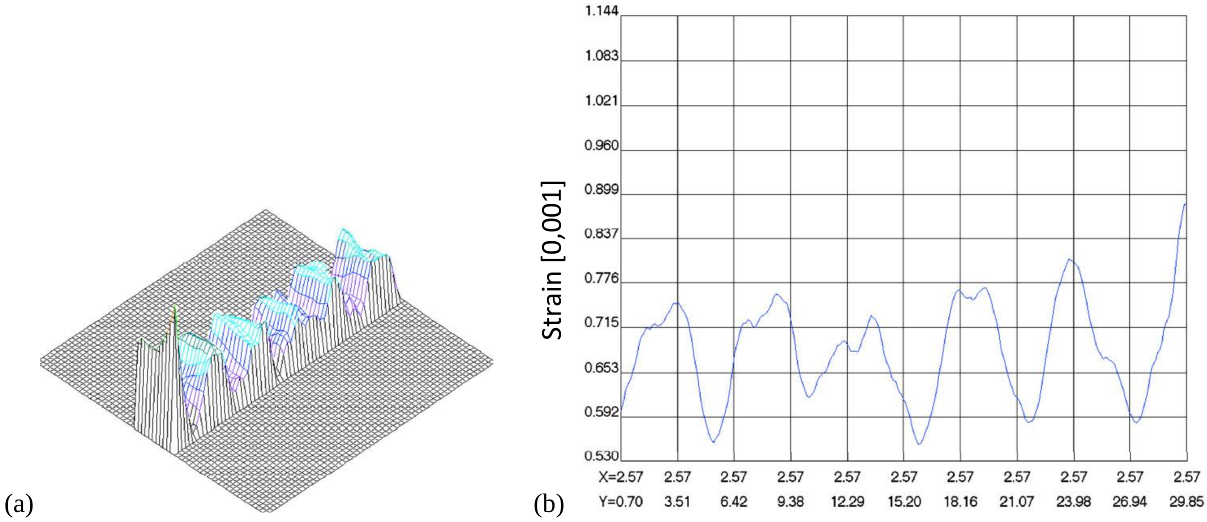


Fig. 8. The 3D strain profile towards the tensile direction (a) and the linear profile in the axis of the main NP91_2 specimen (b)

NP91_1 and NP1_2 specimens have represented steel in the delivery condition without the preliminary load. In both cases deformation is homogeneous, with no clear localisations.

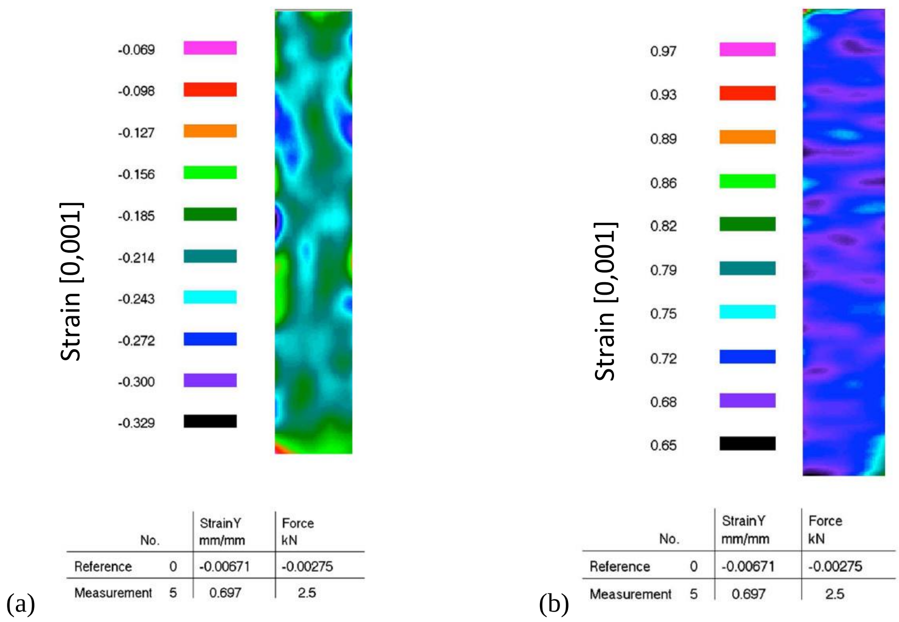
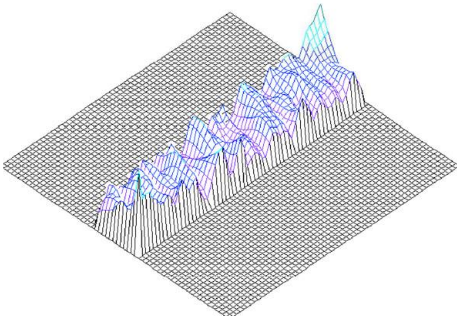


Fig. 9. The field strain distribution towards the X direction transverse to the stress direction (a) and towards the Y direction compatible with the stress direction (b) for the EP91_1 specimen

(a)



(b)

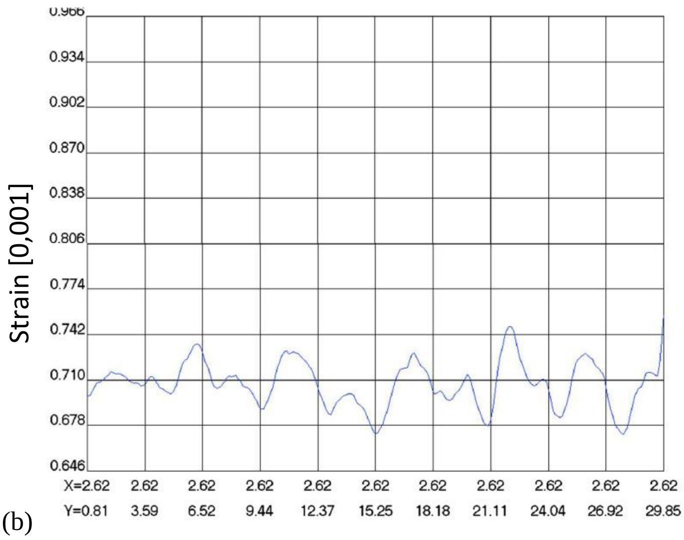
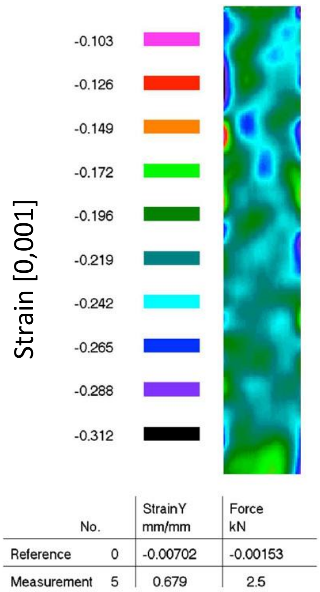


Fig. 10. The 3D strain profile towards tensile direction (a) and a linear profile in the axis of the main EP91_1 specimen (b)

(a)



(b)

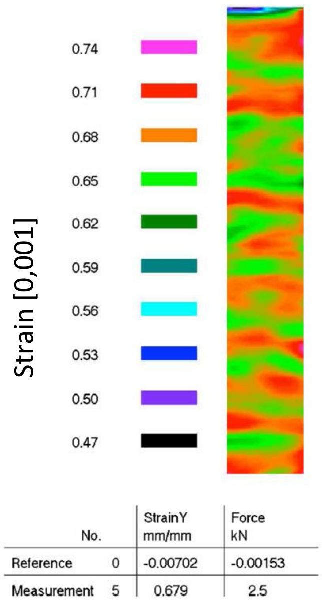
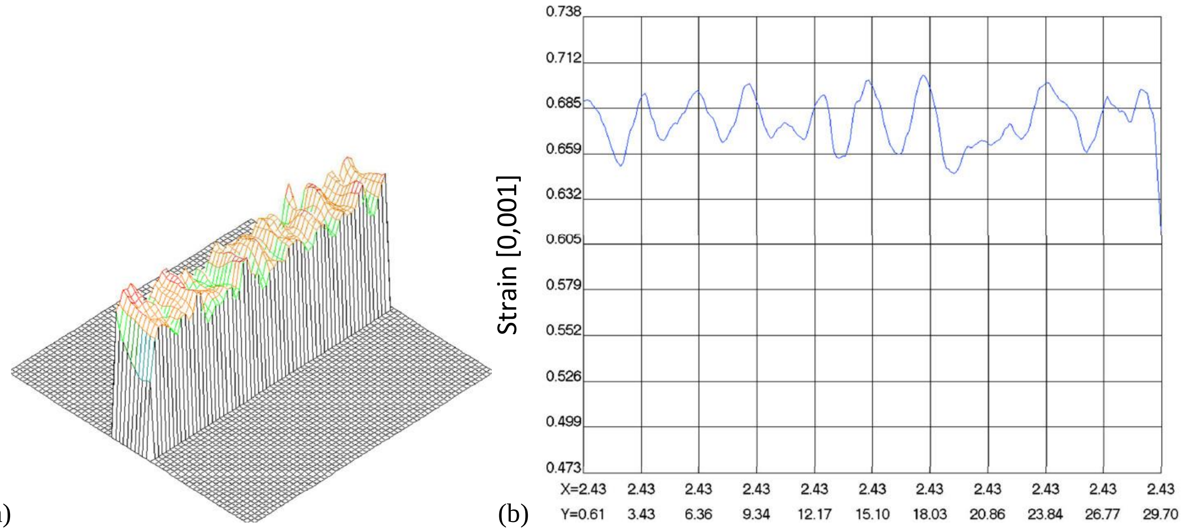


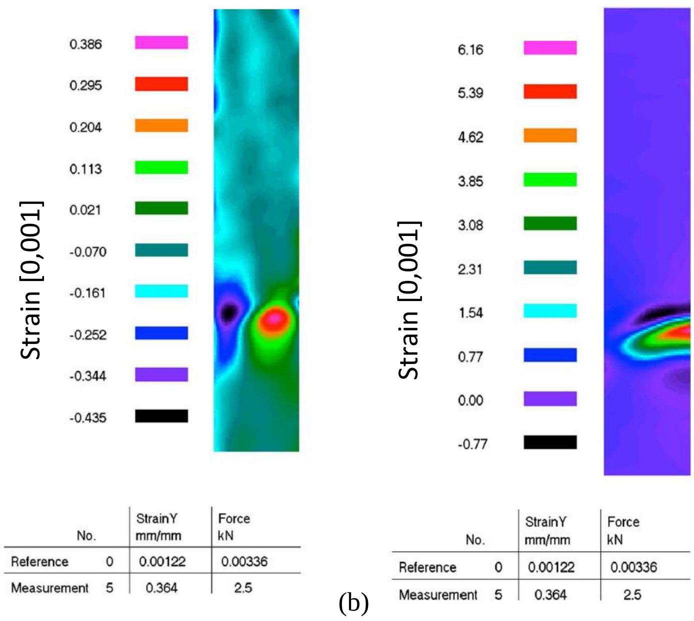
Fig. 11. The field strain distribution towards X direction transverse to the stress direction (a) and towards Y direction compatible with the stress direction (b) for the EP91_2 specimen



(a) (b)

Fig. 12. The 3D strain profile towards tensile direction (a) and the linear profile in the axis of the main EP91_2 specimen (b)

Exploited specimens and new specimens reveal a similar character of deformation evolution in the same scope of loading. Results indicate that the strain distribution is homogeneous on the whole surface of the measured part of the specimen, and the statistical dispersion does not go beyond 0.035%.



(a) (b)

Fig. 13. The field strain distribution towards X direction transverse to the stress direction (a) and Y direction compatible with the stress direction (b) for the NP91_1FC specimen

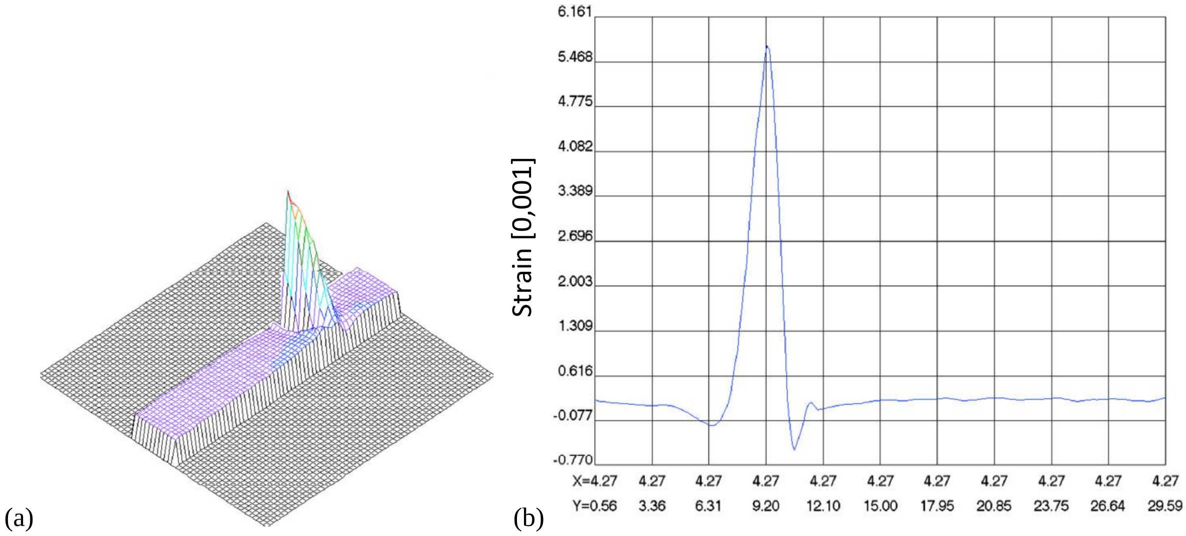


Fig. 14. The 3D strain profile towards the tensile direction (a) and the linear profile in the axis of the main NP91_1FC specimen (b)

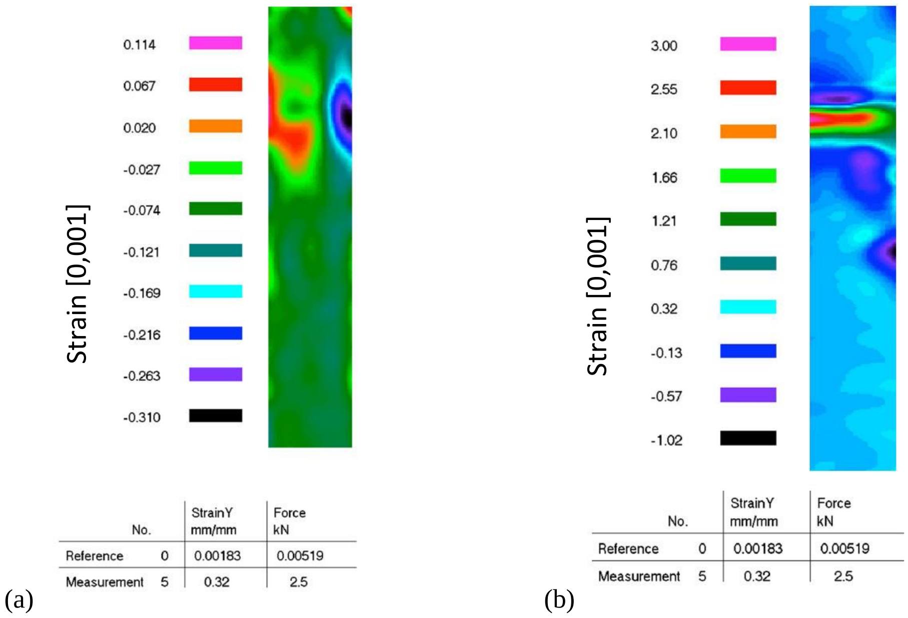


Fig. 15. The field strain distribution towards X direction transverse to the stress direction (a) and towards Y direction compatible with the stress direction (b) for the NP91_2FC specimen

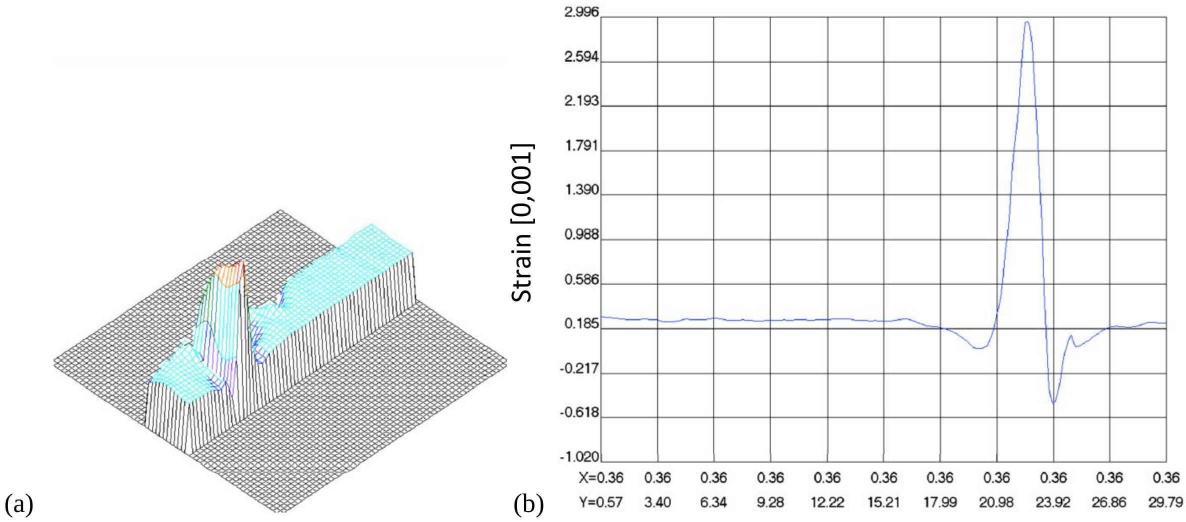


Fig. 16. The 3D strain profile towards the tensile direction (a) and the linear profile in the axis of the main NP91_2FC specimen (b)

NP91_1FC and NP91_2FC specimens have undergone fatigue tests in the scope of cycle tensile stress with amplitude of 370 and 350 MPa, until the occurrence of a crack, but before losing the integrity of the specimen [4]. With the same values of applied force, but with twice less stress than in the case of the earlier specimens the increase of the deformation localised directly around a crack is almost tenfold.

CONCLUSIONS

Specimens before exploitation as well as those after 80000 hour exploitation do not show clear strain concentration zones in the scope of inflicted loads (elastic range). The measured values of the Young's modulus as well as Poisson's ratio are close to the norm values for the tested steel.

Specimens exposed to cycle loads, which result in a fatigue failure in a form of the dominant crack, show a significant decrease of rigidity.

According to the field measurement of surface deformation methods both quantitative and qualitative evaluation of a tensile failure are possible. Clear concentration of strain around the crack is observed in the form of a strain concentration zone, and the filed profiles allow to evaluate the dimension of the failure and its localisation.

The possibility of early detection and monitoring of the evolving tensile failure is a huge advantage of optical methods of surface deformation measurement. It gives perspectives that diagnostic capabilities in presently exploited, responsible structural elements can be improved.

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