Methods of estimating local microdeformation in the sample with defect

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Abstract. Currently, much attention is paid to the choice of approaches in describing the limit States of load-bearing structures of complex technical systems with high requirements for their strength, resource, survivability and safety. Application of complex macro-approach is considered as a new scientific basis of complex diagnostics for predictive assessment of resource, survivability and risks of emergency and catastrophic situations. Characteristics of local true deformations and damages have possibility of the analysis of difficult local processes of transition to limiting stages of deformation. In this paper, methods for determining local microdeformations by applying diamond pyramid prints are proposed. The stress–strain state of bodies with a crack was evaluated on rectangular samples with a weld in the middle of the working part of the sample and simulation of a crack in the middle of the working part of the sample. The effect of microdeformations on the local hardness of the sample surface along and perpendicular to the loading line is investigated. The obtained results confirmed the possibility of estimating local deformations by the proposed methods.

1. Introduction
At present, much attention is paid to selection of approaches and their calculation and experimental validation in describing limit states of load-carrying structures of nuclear reactors, rocket-and-space systems, aviation engineering, etc. with strict requirements for their strength, resource, viability and safety [1,2].

Using the comprehensive macro-approach on laboratory samples, models and full-scale structures in experiments can be considered as a new scientific basis for comprehensive diagnostics in predictive assessment of resource, viability and risk of emergency and disastrous situations.

Force approach in stresses may cause misconception of fault rate reduction after the conditional strength limit is reached and can have little sensitivity to strain in conditions of developed elastic-plastic strain.

Characteristics of local true strain and damage have a new possibility of analysis of complex local processes of transition to the limit stages of strain both on mean normal strain, and their variation coefficients.

If, in the process of loading, you carry out local measurements of strains, for example, by the hardness tester pyramid pinning method, then you can find kinetic static characteristics of local strain values on corresponding micro-, meso-, macro-bases and functions of their distribution, and thereby accumulated damage.
The purpose of this work was to work out a way of local strain assessment using the durometric measurement method.

The main focus in the work was put on acquisition of direct experimental information of state of the materials at the set stage of loading (strain) mostly by the current values of the strain parameters.

2. Procedure and samples
Assessment of the stress and strain state of objects with a crack was made on rectangular section samples, with the working part having the length of 90 mm, made of 2.5 mm thick (mark - steel 3) grade steel with a weld in the middle of the 17 mm wide working part of the sample. A hole with a diameter of 3 mm was drilled 13 mm away from the middle of the working part along the axis to simulate cracks and creation of inconsistent stress and strain state (figure 1).

The samples were tested for tension at consistent rate of loading up to destruction [3]. Destruction occurred in the middle of the working part of the sample along the weld. For the durometric tests, a Shimadzu microhardness tester was used, which can measure Vickers microhardness [4]. In order to get the sample surface hardness values, a hardness measurement chart was made along and across the working part of the sample with different remoteness from the hole. The prints were applied at the exact step: it was 1.3 mm for the line along the sample, and 0.95 mm - for the line across the sample, where the diagonals of the print were oriented in parallel to the axial line of the load application to the sample. Initial hardness was measured before the test along each line (figure 2) that according to 20 prints was 190HV on the average, which meets the reference data for hardness of steel 3. After destruction of the sample, the hardness measurement was repeated with the previous prints, where variation of the diagonal size of the initial prints and distance between the prints themselves was recorded.

3. Test results
The hardness measurement results have shown that it increased both along, and across the sample. Besides, this variation was ≈12% along the sample and ≈4% across it (figure 3). The increase of the hardness can be explained by strain of the grainy structure of the sample followed by increase of the steel 3 micro-strain value, and the difference - by different degree and type of strain, as it increases along the sample and decreases across it. In figure 3a, you can see abrupt drop of hardness on the 6th print, which is connected with close location of the hole in the sample to the print line. In figure 3b, you can see abrupt drop of hardness on the 19th print, which is connected with close location of the edge of the sample to the last prints. The impact of the thermal mechanical processing (holes and edges of the sample) on hardness of the sample surface can be explained by redistribution of surface residual stress introduced by rolling during manufacturing of the steel billet of the sample.
Measurement results of diagonal lengths of initial prints after destruction of the samples showed change of their size, as they are equal in the initial state. At the known original size of the print, the strain of the print was calculated both along the sample line, and across it (figure 4).

In figure 4a, line 1 shows strain of print diagonals applied along the working part of the sample and located in parallel to the load action line, we can see two strain growth peaks; the first on the 6th print responds to hole strain, the second on the 12th print shows local residual strain next to the sample destruction place. In figure 4a, line 2, which shows strain of print diagonals, applied along the working part of the sample and located perpendicular to the load action line; also, we can see two peaks in the sample places, but they are smaller in size, although they are connected with the same.

**Figure 2.** Hardness measurement chart in the working sample: 1 – print line along the working part of the sample, 2 – print line along the working part of the sample

**Figure 3.** Hardness measured a - along the working part of the sample (line 1 (figure 2) and b – across the working part of the sample (line 2 (figure 2): 1 - before the test, 2 – after destruction
In Figure 4b, line 1 shows strain of print diagonals applied along the working part of the sample and located in parallel to the load action line; we can see two strain growth peaks; the first shows growth on the 3rd print and responds to hole strain, the second on the 13th print shows local negative strain connected to the local compression in this point. In Figure 4b, line 2, which shows strain of the print diagonals applied across the working part of the sample and located perpendicular to the load action line; we can also see the growth peak on the 3rd print connected with strain of the hole.

Measurement results of print step showed its change after destruction of the sample, both along, and across the working area. At the known original distance between the prints, its strain was calculated both along the sample line, and across it (Figure 5).

**Figure 4.** Print strain measured a - across the working part of the sample (line 1 (Fig. 2) and b – along the working part of the sample (line 2 (Fig. 2): 1 – location of the diagonal in parallel to the load action line, 2 – location of diagonal perpendicular to the load action line.

**Figure 5.** Strain of the distance between the prints measured a - along the working part of the sample (line 1 (figure 2) and b - across the working part of the sample (line 2 (figure 2))

Figure 5a shows relative change of distance between the prints applied along the working part of the sample; we can see two strain peaks - the first shows the growth on the 4th step connected with strain of the hole, the second shows drop on the 10th step connected with the destruction zone of the sample.

Figure 5b shows relative change of distance between the prints applied along the working part of the sample; we can see two strain peaks - the first shows the growth and then fall on the 3rd, 4th step
connected with strain of the hole, the second shows a small growth and fall on the 18th, 19th step connected with the strain of the sample end.

4. Conclusions
Hardness measurement allows finding places of local strain of the sample surface, which is connected with redistribution of the residual stress in the surface of the sample, but only before it is loaded, and after destruction of the steel sample the hardness is supposedly impacted mostly by the strain value of the grainy structure acquired in the loading process.

Strain measurement of print diagonals after the destruction of the sample showed that this procedure is applicable for assessment of local strains, it shows a clear response to presence of stress and strain concentrator located near.

Measurement of relative change of distance between the prints showed that this procedure is applicable for assessment of local strain, it shows clear response to presence of stress and strain concentrators located near, where the accuracy of this method can be both increased, and decreased by changing the distance between the prints.

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