

Investigation of the Effect of Small Hardening Spots Created on the Sample Surface by Laser Complex with Solid-State Laser

O Nozdrina¹, I Zykov¹, A Melnikov¹, V Tsipilev¹, S Turanov¹

¹Tomsk Polytechnic University, Tomsk, Russia

Abstract. This paper describes the results of an investigation of the effect of small hardening spots (about 1 mm) created on the surface of a sample by laser complex with solid-state laser. The melted area of the steel sample is not exceed 5%. Steel microhardness change in the region subjected to laser treatment is studied. Also there is a graph of the deformation of samples dependence on the tension. As a result, the yield plateau and plastic properties changes were detected. The flow line was tracked in the series of speckle photographs. As a result we can see how mm surface inhomogeneity can influence on the deformation and strength properties of steel.

1. Introduction

It is known that the plastic deformation of metallic samples is accompanied by evolving patterns of macroscopic deformation localization in accordance with the stadiality of the loading curve. It is nonuniform at each stage. At the pre-destruction stage localized deformation foci again begin to move with a constant speed for each of them. However, at this stage, the speed of movement depends on the coordinate of the origin of each focus. And the closer this place to the zone of future destruction, the more slowly such a focus moves. The velocities of the foci are automatically synchronized from the beginning of this stage so that their simultaneous "arrival" to the center - "collapse" of the autowave is ensured. The place of destruction and the lifetime of the specimen before destruction prove to be deterministic phenomena occurring at earlier stages of plastic deformation. Slip band (or Chernov-Luders band) is the most notable examples. It arise at the stage of easy slip and the "neck" formed at the stage of pre-destruction of the sample [1, 2].

In this work we conducted experimental attempt to influence the formation of slip band by changing the surface layer of the sample. Laser hardening of large surfaces is not appropriate. In this case sample deformation can lead to the separation of the hardened layer from the base metal [3]. Also, hardened layer can become a stress concentrator with crack forming, which leads to an early destruction of the sample [4, 5]. It was decided to create inhomogeneities system of equidistant hardened surface foci by spot laser hardening on the surface of steel (X45CrSi9-3). Thus, created deformation traps and boundaries of the foci constrain the propagation of cracks in the sample.

The aim of the research is to study the influence of the surface on the deformation processes in the sample volume and to study the collective effects of two-dimensional structure equidistant foci.

2. Materials and methods

Steel samples (grade X45CrSi9-3) with the gage size 60x8x3 mm were prepared for the experiments. The matrix of hardening foci with a pitch of 0.12 mm on both sides of the workpieces was created



with laser system BlackLight. The pulse duration is 12 ms, the power density is $23.4 \text{ kW} / \text{cm}^2$ and the spot diameter is 0.35 mm.

3 types of samples were prepared: whole gage area treated, half-treated and check test specimens. The entire surface treated specimen is shown in figure 1.



Figure 1. Samples after laser treatment.

An universal testing machine LFM-125 kN was used for carrying out the tensile tests. The microhardness was measured with the microhardness tester PMT-3.

The method of double-exposure speckle photography was used to study the inhomogeneity of plastic flow. As a result, a series of double-exposure specklegram of gage area of the specimen were obtained [6].

3. Results and discussion

Figure 2 shows photographs of the laser beam influenced area on the sample surface. In figure 2a it is possible to clearly distinguish two characteristic zones for laser radiation - laser impact zone (LIZ) and heat affected zone (HAZ). The absence of scratch marks in LIZ left by the grinding tool prior to laser treatment shows that the material has melted. There was a quenching from the liquid phase. Areas without etching indicate a very fine-grained structure. Figure 2b shows the cross section of the LIZ. The depth of the non-etching region is about 300 μm .

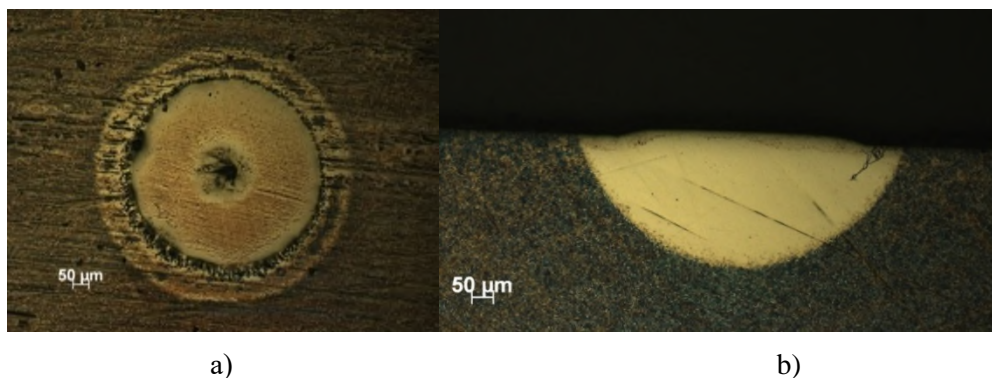


Figure 2. Hardening focus: a) top view; b) sectional view.

Figure 3 shows the results of microhardness measuring in LIZ and near it. The measurement was made from the center of the hardening surface of spot to the edge of the sample. It can be seen from the graph that in the treated area the microhardness increase from 280 MPa to 1050 MPa. The higher microhardness at the periphery of the quenching spot appears due to high cooling rates compared to the center.

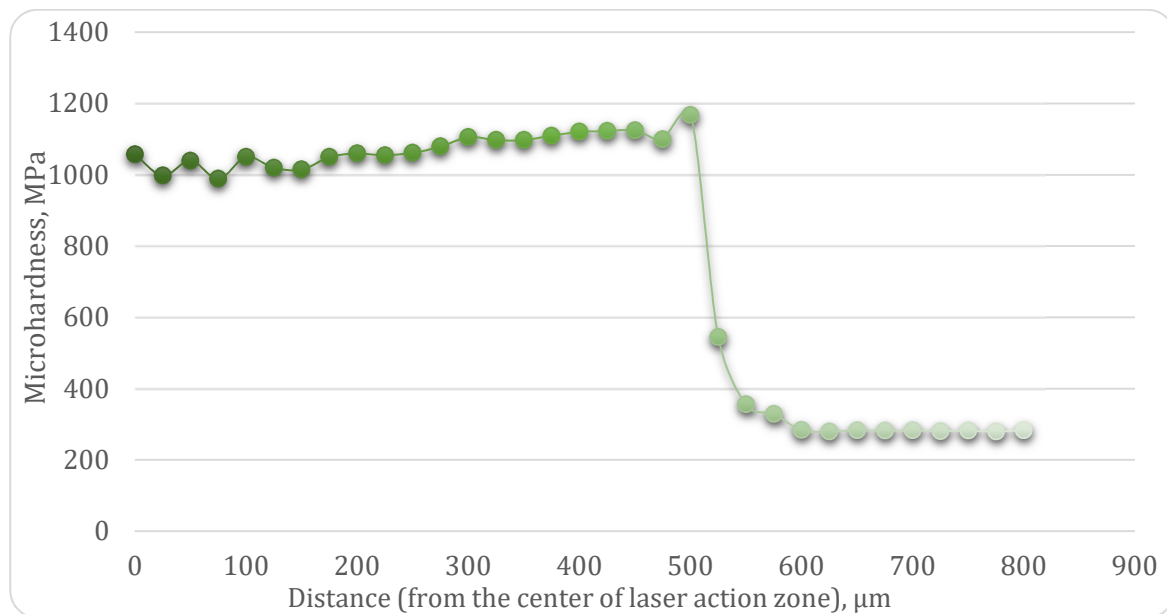


Figure 3. Change in steel microhardness in the area subjected to laser treatment.

Under tension plastic deformation begins with the forming and moving of the slip bands inside the specimen.

Figure 4 shows the characteristic tensile curves for the initial and treated samples. In the tensile diagrams of the initial and half-treated samples yield plateau is visible, while in a fully treated sample it is almost absent. Also on the diagram the dependence of the sample plasticity on the number of consolidation foci is traced, increasing of its number sharply reduces the plasticity. On the diagram of the fully treated sample there is no “necking” stage, which is clearly visible on the diagram of the initial sample.

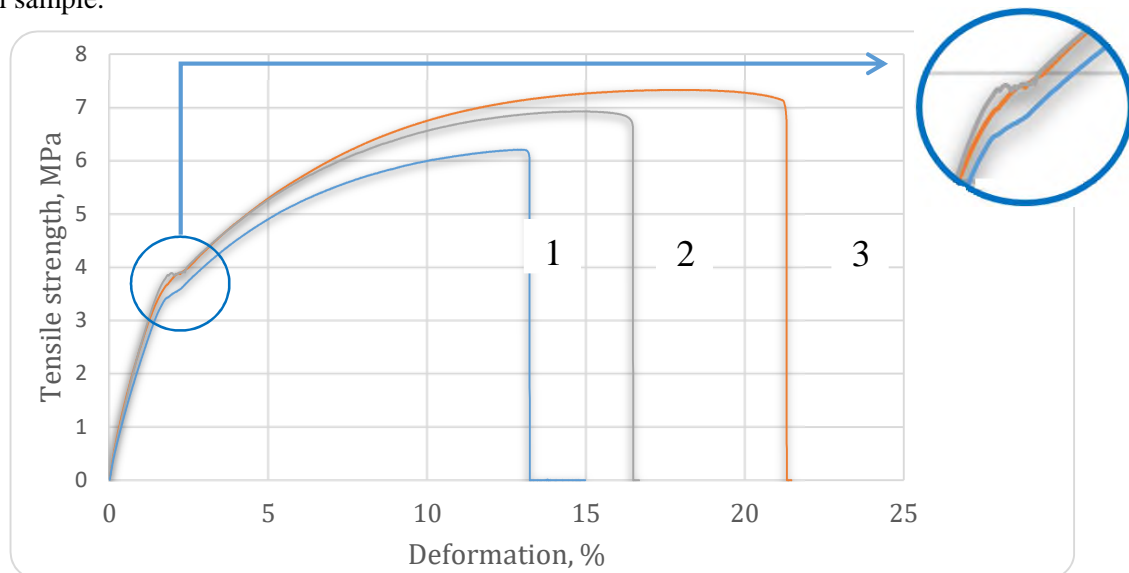


Figure 4. Tensile diagrams of samples with different areas of treatment: 1 - fully treated; 2 - half-treated; 3 - initial, without treatment.

Tensile diagrams of the initial and half-treated samples are almost identical up to that time (deformation is about 6%), when the motion of the slip band does not reach the processed part of half-treated sample. Then the stresses in the samples reach such values when cracks form in the treatment spots. Stresses begin to decrease and the sample breaks down in the focus area.

In a fully treated sample an easy glide stage is observed slightly. The slip band originates on the unprocessed part of the sample near mobile grip and disappears to the processed part. The increasing stresses in the foci lead to cracking, as a result the module decreases.

The bands appear in all samples at the hundredth second after the beginning of stretching. In the initial sample three slip bands (figure 5a) are formed at once and freely moving along the entire length of the sample. After that specklegram of initial sample doesn't change. The sample was ruptured through the forming of "neck" in the middle of gage.

In a half treated specimen the band starts from grip with the unprocessed sample part and moves toward the center of the sample (figure 5b). 12 seconds after the beginning of the movement one more slip band has formed on the border with treated area and start moving towards the first. After the collapse of these bands in the tension diagrams of samples 2 and 3 (up to now almost identical) distinction begins to occur. In a half treated specimen on the edges of the gage in untreated areas two more bands appear. It moves to the grips, after which a rupture occurs.

At the same time, in a fully treated sample only one localization band forms in a narrow transition zone between the fixed grip and the treated area.

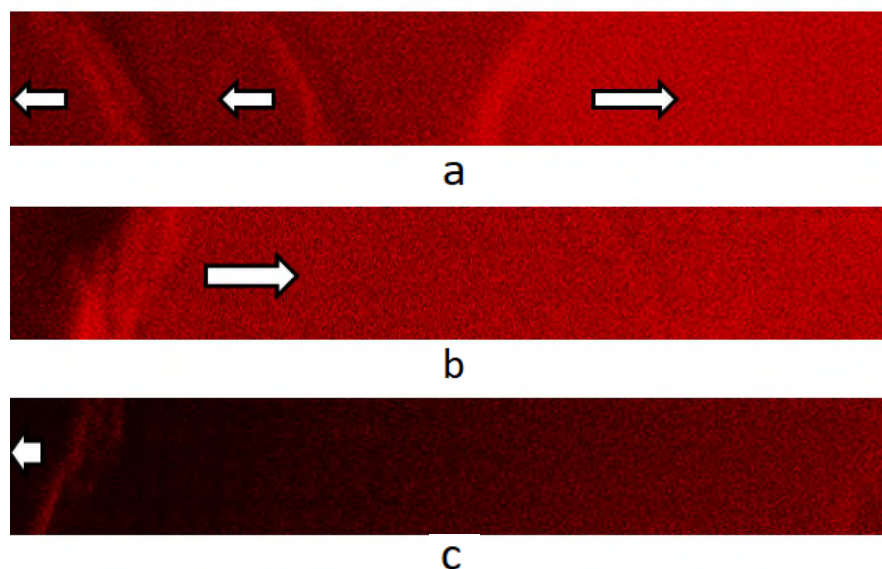


Figure 5. The origin and motion directions of slip bands in the samples:
a - initial; b - half-treated; c - fully treated.

With further increase in the load in the treated samples the foci were not deformed due to their high hardness and low plasticity. Cracks appeared in foci and moved forward, but stopped at the boundary of treated and untreated areas. This subsequently led to the rupture. Untreated sample was destroyed with the formation of a pronounced "neck".

4. Conclusion

This is the surface type of steel treatment, total volume of hardening foci is much smaller than the sample volume. The foci sectional area is not more than 5% of the sectional area of the sample. When the samples are stretched, the slip band cannot pass through the region of the hardening points, which leads to its suppression (see the tensile diagram of samples 2 and 3). Due to the suppression of localization the loading diagram has changed quite significantly. In the fully treated sample easy glide stage was almost completely possible to get rid. This indirectly indicates that the staginess of the loading curve can be a consequence of the localization of the deformation. At the same time, the hardening foci are stress concentrators and areas of formation of brittle cracks that reduce the strength and plasticity of the samples. This indicates necessity of optimization the structure and, as a consequence, the processing mode of the material.

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