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RESIDUAL STRESS STATE AMD MICROHARDNESS OF LASER HARDENED CARBON STEEL

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The contribution deals with studies on residual stresses and microhardness of laser hardened carbon steel surfaces. Laser hardening can greatly improve the wear and fatigue properties by inducing a hardened and compressed surface layer. Residual stress distribution across the hardened tracks were measured by means of X-ray diffraction. It has been found that compressive stresses exist in the hardened zone of all the specimens studied. The microhardness increased by as much as 350%.

1. Lasers in surface engineering of materials

Light Amplification by Simulated Emission Radiation, shortly LASER, is a highly directional and collimated beam of coherent light. Since its first appearance in Huges research laboratory in Chicago in 1960, the laser found numerous applications in diverse areas including medicine, data storage, military, entertainment, material processing, etc.

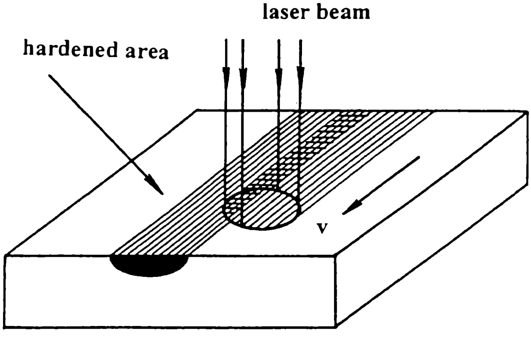

Fig.1 Schematic demonstration of laser hardening process. Multipasses have been produced to cover a larger area

In the field of material processing laser were used mostly as a tool for cutting and drilling in the early times. With the development of high power laser in the late 70's, the application of lasers to welding and heat treatment of metals, has become feasible and thus has attracted a lot of

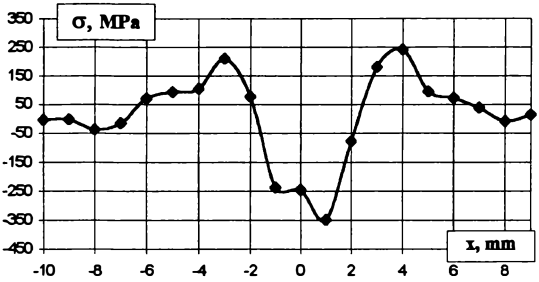

Fig.2 Plot of residual stress $\sigma(x)$ vs distances x from the middle of the laser beam track.

attention.

By using lasers as heat sources, the surface properties of metals can be modified in different ways, including laser shock hardening, transformation hardening, glazing, alloying, cladding, etc. For laser shock hardening it is carried out by user pulsed lasers with extremely high energy densities and short dwell times to work-harden the surface with shock waves created by the vaporization of a sacrifical overlay. Laser glazing can improve wear and corrosion resistance of a material by rapidly melting and re-casting the surface layer for a fine-grained structure. If alloying elements are added to a laser melted surface, the process is then called laser alloying. Desired surface chemical composition can be obtained in this way to modify the surface mechanical and chemical properties. An alloy can also be fused onto the surface of a metal with minimum of dilution with the substrate so to obtain a composite. This process is similar to the conventional hard facing and is called laser cladding. Finally, laser transformation hardening, employing relatively low power density and longer dwell time, is carried out simply by heating and then quenching the surface layer of an iron-based alloy to obtain a hard martensitic structure. It can be used to increase wear and fatigue resistance.

2. Laser hardening

Laser is in principle used as a heat source in laser hardening. Figure 1 shows how the hardening is performed on a flat specimen by a series of side-by-side passes, or multi-passes. As laser beam is passed over the specimen at a given speed v.

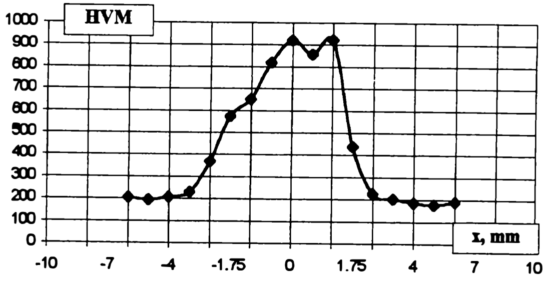

Fig.3 Plot of microhardness $HVM(x)$ vs distances x after grinding off the 40μm thick surface layer

Due to the interaction between the laser beam and the specimen surface the temperature of the surface layer under the laser beam will raise to a critical point which cases austenitic transformation in the layer. When the laser beam is removed from the area the austenite is quenched by heat conduction into the surrounding bulk material and hard layer of martensite is thus obtained. The process is often characterized by an extremely rapid heating and cooling rate, which is typically on the order of $(10^2\text{-}10^5)Ks^{-1}$ [1].

The are a variety of lasers for material processing. They can operate at wavelengths ranging from the ultra-violet to the infra-red. For applications in heat treatment, continuous wave CO_2 gas lasers of wavelength 10,6μm developed to operate at high power are especially suitable. Since at this wave-length a machined metallic surface will reflect most of the laser energy, a coating has to be applied onto the surface to increase the absorption of the energy. Most commonly used absorbent coatings include colloidal graphite, manganese phosphate, zinc-phosphate, black paint, etc. The absorption coefficients depends on the thickness, coarseness, adherence to substrate, and the temperature of the coating.

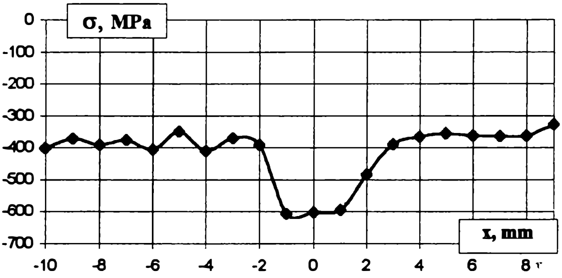

Fig.4 Plot of residual stress *σ(x)* vs *x* after grinding off the 40μm thick surface layer.

As an alternative to other surface heat-treatment methods, laser transformation hardening can be used to improve wear resistance, corrosion resistance and fatigue properties of steels. The process has also some limitations. For example it is difficult to obtain a uniformly hardened large area. Besides the maximum depth of gardening is limited to within 2,5mm, usually less than half of this value. Therefore the best application of the technique will be where local or small area hardening is required.

3.Residual stress and microhardness analysis of combined effect due to laser hardening and subsequent grinding

Material investigated and its treatment

The surface of carbon steel of Czech grade ČSN 12 060 being thermally stress relieved was heat hardened by means of CO_2 laser with 2kW output and 11mm beam diameter. The 600mm.min^{-1} rate of sample shift with respect to the laser beam was applied.

Diffraction techniques used

X-ray one-tilt method without reference substance and CrKα radiation was applied to measure residual stresses in the direction which was perpendicular to the track axis [2]. The irradiated area amounting to approximately 12.5mm^2. The sample oscilated during the measurement along the track axis direction (±5mm).

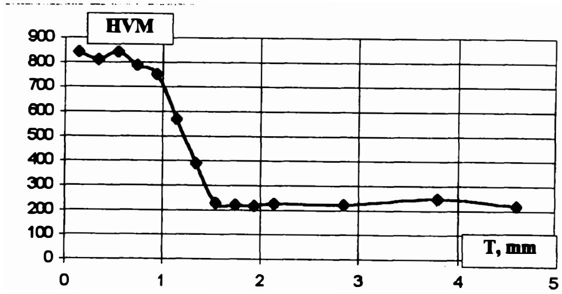

Fig.5 Plot of microhardness *HVM(T)* vs distance *T* from the hardened surface

Microhardness measurement technique used

Microhardness tests were carried out with a microhardness tester, with an applied load of 500grams.

Results of experiments

☞ In the middle of the track the compressive stresses -350MPa have been found. Tensile stresses arise at the interface of the track and initial surface. (Fig.2).

☞ The stress $\sigma(x)$ and microhardness $HVM(x)$ distributions correspond very well. On the hardened surface the microhardness increased by as much as 350% (Fig.3).

☞ The compressive stresses arose on the hardened surface after thin layer grinding off are added to stresses due to the laser heat treatment. The grinding off the 40μm thick layer simulates the final treatment of the heat hardened functional surfaces of machine components and tools. The grinding caused compressive stresses ≈-350MPa (Fig.4).

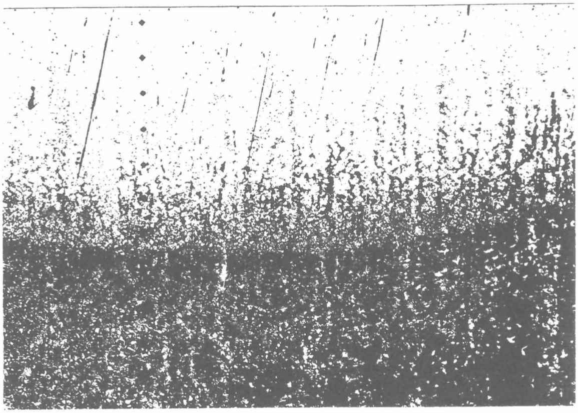

Fig.6 Microstructure and hardness difference near the surface in the region of the laser hardened track, 50x

☞ The microhardness profile of track (the variation of microhardness *HVM* versus depth *T*) can be seen in Figures 5 and 6.

References

[1] Ru Lin: Lindköping Studies in Science and Technolgy, N°286, Linköping University, 1992

[2] Kraus I. and Ganev N.: Difrakční analýza mechanických napětí. Vydavatelství ČVUT, Praha 1995.

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