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FEMTOSECOND LASER SURFACE TEXTURING OF AISI 1045 STEEL

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Abstract

Morphological changes**,** including texturing and production of highly oriented periodical surface structures (LIPSS)**,** on AISI 1045 steel were carried out by femtosecond laser pulses. The surface changes, induced by laser, are highly localized with minimal hydrodynamic effects and without the presence of a debris. The produced LIPSS have the periodicity of 700 nm, and were more prominent in case of triple scanning. Elemental analysis of the surface showed chemical changes, due to formation of oxides and diffusion of carbon from the bulk. These changes are also more obvious in case of triple scanning.

Introduction

The laser surface modification, including laser beam texturing**,** is of great fundamental and technological interest. Interaction of pulsed femtosecond laser beam with high quality steels, especially AISI 1045 steel, is not extensively reported in literature. AISI 1045 steel is within the class of medium carbon content steels. Presence of carbon increases steel hardness and strength and improves hardenability. Due to these, as well as other physical and chemical properties, the AISI 1045 steel can be used for component parts in machinery, automotive and allied industries. Carbon steels also have considerable applications in nuclear technology, e.g. piping systems, low and high pressure turbine sections, reactor vessels, etc. Our emphasis in the present paper is on the study of texturing with the production of specific periodic structures, using femtosecond laser emitting at 775 nm on AISI 1045 steel surface.

Experimental

The laser used in this work was Clark-MXR CPA2010 femtosecond laser system. The laser has a central wavelength of 775 nm at a fixed repetition rate of 1 kHz, with a pulse energy of 3 μJ and pulse duration of 160 fs (FWHM), confirmed with an autocorrelator. The output beam was linearly polarized, and directed to scanning galvanometer with 100 mm f-theta focal lenses. Specimen of AISI 1045 steel was mounted on axis precision motion control system, with a repeatability of 0.5 μm. The laser beam was focused perpendicularly on the top surface of the specimen. Irradiation was conducted in air. The sample was a round plate of 15 mm radius and 2 mm thickness. The surface was mechanically polished down to an average roughness of about 200 nm. Square areas (1 mm side) were modified using scanning rate of 10 mm/second, with one and three overscans.

Results and Discussion

Laser induced periodic surface structures are known since the 1970s. Much work has been carried out on the mechanisms of their origin [1], but it is still an area of extensive research. Investigation of the morphological changes induced by laser on AISI 1045 steel surface has shown their dependence on laser beam characteristics [2], particularly here on the number of pulses (N) and overscans. Generally, interaction of femtosecond laser with AISI 1045 steel, at the fluence of 0.77 J/cm^2 during experiment, resulted in the production of modified area without the presence of debris and hydrodynamic features.

Surface texturing of the steel, at the constant energy, was initially done by a different number of pulses, on the same location of the sample (Fig. 1). Appearance of the primary periodic structures occurred after five successive laser pulses, and the texturing was homogeneous over the modified area. In case of N> 100**,** the LIPSS are distorted and the central part of the area is ablated.

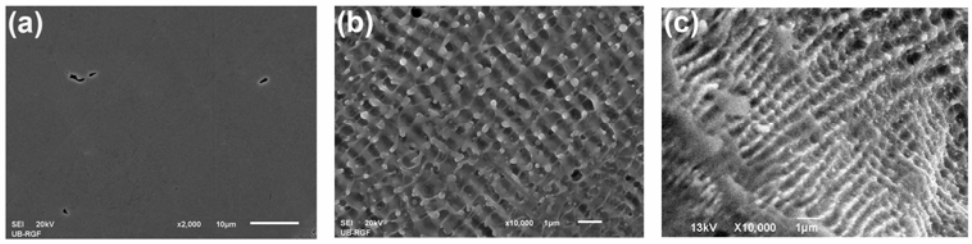

Fig.1. The surface of AISI 1045 steel prior to laser radiation (a), and after N=10 (b) and N=500 pulses (c).

The LIPSS obtained on the steel surface are, in both cases (deposition of pulses and laser scanning), oriented in the same way, perpendicular to the vector of the incident electric field (Fig. 2).

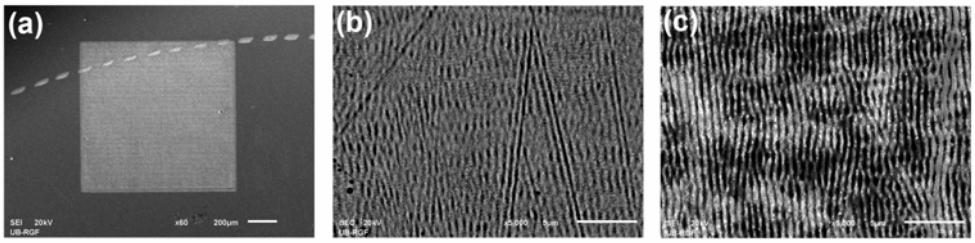

Fig.2. Textured AISI 1045 steel area produced by triple laser scanning (a) and LIPSS occurring after one (b) and three scans (c).

In case of overscan repeated three times, the features self align with features produced by preceding scan lines and are more prominent [3]. The periodicity of the LIPSS is ~700 nm in all cases, which is approximate to the laser wavelength. The origin of these ripples can be attributed to existing interference of the incident

laser beam with the so-called surface waves scattered off imperfections on the target surface and running along the surface [4].

Elemental EDX analysis showed the changes in the surface chemistry after laser scanning. It can be seen from the Table 1 that the concentration of iron is higher on the irradiated area, and the oxygen content decreases. This can be explained by the formation of iron oxides on the irradiated surface. Concentration of carbon is increased on the textured area, which can be due to diffusion of carbon from the bulk of the sample. These changes are also more prominent in case of triple scanning.

Table 1. EDX analysis of the steel surface prior to irradiation, and after single and triple laser scanning. Other alloying elements (Mn, Cr, Ni, Si) are balanced to a 100 percent and their concentration is not changed significantly with irradiation.

Spectrum	**C [wt. %]**	**O [wt. %]**	**Fe [wt. %]**
Non-irradiated	3.405	0.24	95.815
Single scan	5.44	0.84	93.08
Triple scan	9.31	2.85	87.27

Conclusion

Femtosecond laser pulses were used for the surface texturing and the production of highly oriented periodical surface structures on AISI 1045 steel. It has been shown that the morphological changes induced by femtosecond laser pulses are highly localized, with minimal hydrodynamic effects and without the presence of a debris. Obtained textured surface of the steel, as well as other metallic materials, has numerous potential applications.

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