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The utmost thickness of the cut sheet for the qualitative oxygen-assisted laser cutting of low-carbon steel

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Abstract

The peculiarity of the laser cutting is its high speed combined with the high quality of the cut surface. The issues, how the cutting speed and cut roughness change with the sheet thickness, and what is the utmost thickness at which the quality is acceptable, are of practical importance. Theoretical models of the laser cutting developed today do not permit answering these questions. In the present work, the task is solved experimentally for the oxygen-assisted laser cutting of low-carbon steel. Under study was the dependence of the cut surface roughness on the cutting speed within the wide range of cut sheet thicknesses. The experiments were carried out with the CO_2 laser. The empirical dependencies of the optimal cutting speed (at which the cut surface roughness is minimal) on the sheet thickness are found. It is demonstrated that there is the utmost thickness of 40...50 mm, and above it the qualitative cutting is impossible. The obtained results are compared to the similar ones obtained for the fiber laser.

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Keywords: laser cutting; CO_2 laser; fiber laser; uncontrolled burning; utmost thickness

Nomenclature

V	cutting speed
t	sheet thickness
W	laser power
b	kerf width
γ	thermal diffusivity

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1. Introduction

In the recent decade, metal cutting is dominating in the world. Laser technologies in material processing provide high production rate and accuracy, save energy and materials, permits implementing new technological solutions and using hard-to-machine materials, plus guarantee environmental compliance. Today, the most common lasers used for the cutting are the gas-discharge CO_2 laser with the wavelength of 10.6 μm and fiber or disc lasers with the wavelength of about 1 micrometer (Steen 1991, Powell et al. 2012, Scintilla et al. 2013).

The quality of the processed part is one of the critical parameters of the laser cutting. For many applications, cut surface roughness and dross absence are the main quality indices (Orishich et al. 2014). At the minimal roughness, the other indices of the cut quality are also within tolerance. Thus, the laser cut of minimal roughness and no dross is of practical interest. It must be emphasized that the maximal cutting speed is not always optimal from the viewpoint of the cut quality (Mahrle et al. 2009, Orishich et al. 2015).

The present work deals with the investigations of the high-quality oxygen-assisted laser cutting of low-carbon steel by the fiber and CO_2 lasers in order to determine the utmost thickness of the cut sheet. The obtained results permit better understanding the scope for laser cutting.

Laser-oxygen cutting presents the forced burning of iron in oxygen. In this case, the laser power and exothermic reaction of oxidation make approximately equal contribution in the energy balance [Steen W. M., 1991]. During the laser-oxygen cutting, pure energy of the iron oxidation reaction is not enough to melt the material and propagate the cut front. Thus, the cut is “bound” to the laser beam, the cut channel width cannot essentially increase the diameter of the focused beam. The cut surface roughness is not too much in the steady mode, the maximal cut quality is reached at the velocity of V_{opt}.

The steady mode of the forced burning with the low roughness is reachable within a limited range of cutting speeds. The lower boundary of this range V_{bur} depends on the transition to the uncontrolled self-sustained burning. As the cutting speed decreases, the material temperature rises near the cut front, and, as the speed is below V_{bur}, iron burning and melting front propagation are possible without laser radiation support, just owning to the oxidation reaction energy. The cut channel width in this case may extend sideward within the limits of the oxygen jet which may have the diameter of 2 mm and more in the case of thick sheets. The oxygen jet at the laser-oxygen cutting is not optimized for the cut channel formation, the front of material rupture propagates irregularly, and the process becomes uncontrolled. Consequently, the cut channel has an uneven side surface and high roughness.

Having the speed V_{opt} of the high-quality cutting and its dependence on the sheet thickness, plus the critical speed V_{bur} of the transition into the uncontrolled mode, it is possible to find the utmost thickness from the condition $V_{opt}=V_{bur}$, above which the cut width and roughness rise dramatically, and the high-quality cutting is impossible.

2. Experimental technique

In the present experiments, cutting was performed by an IPG/IRE-Polus ytterbium fiber laser with a power W = 2kW, a beam parameter product (BPP), which is the product of the beam radius in the near field and the angular radius of the beam in the far field, BPP = 3.8mm·mrad, and an IPG collimator (D5-WC/AC model). The beam diameter on the focusing lens behind the collimator was 17 mm, and the focal length of the lens was 200mm. Fiber laser cutting was performed by laser beams with chaotic polarization. A CO_2 laser with BPP=4.7mm·mrad and a self-filtering cavity with a power up to 8 kW was also used. The beam diameter on the focusing lens was 25 mm at focal lengths of the ZnSe lens of 190 and 256 mm. CO_2 laser cutting was performed by laser beams with circular polarization. The distribution of radiation intensity in the focal spot was close to the Gaussian distribution. The focal spot diameter was estimated as the sum of the diffraction diameter of the beam and the diameter of the scattering region due to spherical aberration. The calculated total diameter was 180 μm for the fiber laser and 160 μm forthe CO_2 laser.

Low-carbon St. 3 steel sheets 3-25 mm thick were cut by using laser beams with a power W = 0.5–4.0 kW. The measure of roughness was taken to be the characteristic height of the roughness element R_z and the mean arithmetic deviation of the profile shape R_a. These parameters were measured by an Olympus LEXT laser confocal scanning microscope and a Rank Taylor Hobson profilometer of the FormTalysurf series.