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ScienceDirect

Physics Procedia 56 (2014) 477 – 486

Physics Procedia

8th International Conference on Photonic Technologies LANE 2014

Impact of process parameters on the laser-induced nanoparticle formation during keyhole welding under remote conditions

Tobias Scholz[a,]*, Klaus Dickmann[a], Andreas Ostendorf[b]

[a]Laser Center (LFM), Muenster University of Applied Sciences, 48565 Steinfurt, Germany
[b]Chair of Applied Laser Technology, Ruhr-Universität Bochum,44780 Bochum, Germany

Abstract

The interaction between the vapor plume and the incident laser radiation affects remote laser welding. Relating to laser systems with an emitted wavelength around 1 µm, a significant loss mechanism can be traced back to the extinction by laser-induced particle formation. Due to the tight coupling between the particle formation and the evaporation rate inside the keyhole, the particle formation shows a strong dependence on the keyhole geometry and thus on process parameters (e.g. feed rate and laser beam power). In order to verify the relationship between particle formation and process parameters, the beam of a broadband LED was guided through the vapor plume during the welding processes with a fiber laser. The attenuated probe beam was analyzed in dependence on the wavelength. In addition, the propagation of the vapor plume was investigated by using high speed imaging.

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH

Keywords: Nanoparticles; remote processing; attenuation; welding; particle formation

1. Introduction

During laser material processing with high intensities on the work piece surface, a strong vapor formation can occur. Referring to the laser keyhole welding, the vapor acts on the melt. If the vapor pressure exceeds the surface tension of the melt, a keyhole is formed. After leaving the keyhole, the evaporated material expands in the ambient atmosphere. High evaporation rates and the propagation of the vapor plume in the ambient atmosphere result in a

* Corresponding author. Tel.: +49-2551-962328 ; fax: +49-2551-962490 .
E-mail address: scholzt@fh-muenster.de

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH
doi:10.1016/j.phpro.2014.08.151

heat exchange with the ambient atmosphere and a supersaturation of the vapor plume. A condensation process is initiated and nanoparticles are formed in the vapor plume. The incident laser radiation interacts with the vapor plume. Among other things, the interaction effects can cause changes in the intensity in the keyhole and thus can influence the keyhole stability. Investigations have shown that even small fluctuations of the laser beam power can lead to a collapse of the keyhole, see Klein et al. (1994). The interaction effects include refractive index fluctuations, inverse Bremsstrahlung and extinction by particles.

Relating to a laser system with an emitted wavelength around 1 µm, it dominates the extinction of the incident laser radiation by particles, see Hansen and Duley (1994). If the particles are very small in relation to the wavelength of the incident laser radiation, the extinction process can be described by the Rayleigh approximation, see Bohren and Huffman (1998). Following the formulation of Bohren and Huffman, the extinction depends on two parts: the scattering and the absorption. The related cross sections are measures of the strength of the interaction mechanism between the incident laser radiation and nanoparticles. Fig. 1 shows the respective cross sections of iron nanoparticles up to a particle radius of 50 nm. Within the entire range of the presented particle radii, it becomes obvious that the dominant part can be traced back to the absorption of the incident laser radiation by particles.

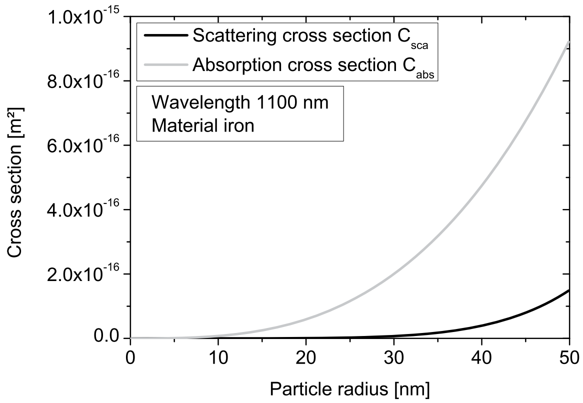

Fig. 1. The scattering and absorption cross section of iron particles in relation to the particle radius. The theoretical results refer to a wavelength of 1100 nm.

Matsunawa et al. (1984) establish a relationship between the particle formation and laser material processing. They assume that the interaction between the incident laser radiation and ultra-fine particles can influence laser material processing. Scholz et al. (2012) relate to the effect of the particle formation on the ablation process of stainless steel with a single mode fiber laser. The results offer a reduction of the ablation speed due to the interaction between nanoparticles and laser radiation. Greses et al. (2004) show experimental results of the particle formation during the laser welding of mild steel with a 8 kW Nd:YAG laser and compare them with results from Tu et al. (2002). Tu et al. are concentrated on the particle formation during the laser welding with a 20 kW CO_2 laser. The comparison between these two particle formation processes points out that the particle formation during the laser welding with the Nd:YAG laser offers higher average particle sizes. In addition, Greses et al. (2004) summarize that the particle formation in the vapor plume leads to a significant attenuation of the incident laser radiation. Michalowski et al. (2007) also confirm that the interaction between the laser radiation and formed particles can influence the laser welding process. As part of the presented experimental work, three probe laser beams with different wavelengths were guided through the vapor plume. Based on the relation between the transmitted parts of the probe laser beams, the particle sizes were determined. The results show that the particle diameters are between 115 nm and 192 nm during the laser welding of stainless steel with a 3 kW thin disk laser. They conclude that especially for laser remote processing the interaction between the laser radiation and the vapor plume can decrease the laser beam power in the interaction zone. Shcheglov et al. (2011) relate to the plume attenuation during high power laser welding of mild steel plates with a feed rate of 2 m/min. A probe laser beam was directed through the