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The evaluation of the influence of laser treatment parameters on the type of thermal effects in the surface layer microstructure of gray irons

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A B S T R A C T

The aim of the presented research was to create a laser heat treatment (LHT) diagram presenting singular modifications such as remelting, alloying, hardening from the solid state, tempering the surface layer of gray iron in individual ranges of laser beam parameters (power density and its interaction time). A synthesis of such different thermal phenomena taking place in gray irons surface layer resulting from LHT was the aim of this analysis.

The performed research allowed specifying similar, previously created diagrams concerning different engineering materials in general. The created LHT diagram presents singular modifications in the surface layer of gray iron in individual ranges of laser beam parameters.

This diagram allows distinguishing ranges of laser beam parameters that could be useful in selecting the LHT parameters or forecasting their effects in the gray iron surface layer.

It has been observed that it is possible to achieve the modification of the surface layer of gray iron by applying values of laser beam power density lower than the values of density presented in previously created diagrams related to the influence of LHT parameters on their effects in the surface layer referring to different groups of engineering materials. The limit of the laser beam density was defined resulting in the modification of the surface layer for interaction time $t < 0.2$ s (remelting or alloying) and $t > 0.2$ s (hardening from the solid state). It is not possible to achieve melting or hardening of the surface layer in gray irons using a laser beam density of less than 10 W mm^{-2}. Hardening is possible only with the interaction time longer than 0.2 s and the power beam density between 10 and 40 W mm^{-2}. Tempering of the surface layer is possible with the density of nearly 10 W mm^{-2} but only with a relatively long interaction time (i.e. 4 s).

1. Introduction

Lasers are widely used in many fields, for example in medicine (for example dentistry, or cancer recognition and treatment) analytical chemistry, bioanalysis, agricultural and environmental applications, for monitoring of air and water quality, vegetation, in atomic and molecular spectroscopy, interferometry, in development of frequency standards, metrology, holography, cryptography, telecommunication, in atomic optics, space and defense applications [1–5].

Another widely application of lasers is material processing, including laser heat treatment (LHT). LHT such as remelting or alloying in particular, is a still a developing method for improving material surface layer properties of machine parts. Surface layer modifications of relatively low-cost popular materials are a special trend in scientific investigations.

Cast irons, especially gray irons are popular materials in automotive, agricultural and many other industries. Gray irons are widely used in practice because of their good castability, machinability with lower (about 10%) density (compared to the density of steel) and relatively low price. It is noteworthy to underline that sometimes the mechanical properties of cast irons (nodular irons) approximate those of cast steel or even steel [6]. Gray irons are used for parts of engines (crankshafts, camshafts, cylinder liners, gears etc.), break parts (discs and drums) or parts of agricultural machines (shafts of harvest machines, teeth harrows, disc harrows, seeders). Some fragments of those parts are exposed to intense wear and corrosion during operation.

Therefore, suitable properties of the surface layer are necessary. LHT such as laser remelting, alloying or hardening from the solid state provides the possibility of modifying the microstructure and properties of local surface layers [7–38,40]. LHT can improve the hardness, wear and corrosive resistance of the surface layer.

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Laser heat treatment is mainly used in ferrous and nonferrous metal alloys. This treatment is widely used particularly in steel. There is a lot of information on the influence of laser treatment conditions on the surface layer effects in steel parts (less in cast iron).

Thermal and thermophysical properties of cast iron are significantly different than steel. It is of paramount importance when LHT is considered. The values of density of cast iron, its melting temperatures, specific heat capacity or thermal conductivity are extremely varied within metal alloys and even within ferrous alloys. Therefore, if the same laser treatment conditions (and even the same laser beam parameters) are applied, changes achieved in the surface layer past LHT could be different in steel and cast iron.

It is worth emphasizing, that CO_2 lasers are most often used lasers since offer high powers of the laser beam for surface treatment of metal alloys e.g. steels [23–28] and gray irons [29–34]. Nevertheless, other lasers like fiber [35] or Nd: YAG [36, 37] can be applied to modify gray iron surface.

The interaction time and laser beam density has a crucial importance in generating of the temperature in the surface layer of treated material. In gray irons, by appropriate selection of laser beam density and its interaction time different temperature in the surface layer can be achieved. Consequently, different thermal effects in the surface layer can be reached, like: remelted zone (if the temperature caused melting), hardened zone from the solid state (if the temperature caused only phase transformation and austenite appeared during laser heating), annealed or tempered zone (if the temperature did not exceed transformation temperature). Certainly, evaporation could also occur if the temperature exceeds the boiling point. It is worth emphasizing, that the temperature could be monitored using many thermometric techniques [39–42]. Pyrometry seems to be quite useful and simple method for surface temperature assessment during laser treatment [40–42].

In spite of extensive research concerning LHT of gray iron [12–20,29–38], it is still hard to determine the range of laser treatment surface modifications such as remelting, alloying, hardening from the solid state, tempering the surface layer in individual ranges of laser beam parameters (power density and its interaction time).

The general dependence (in metal alloys) of absorbed laser beam power density and its interaction time on the thermal phenomena effects occurring during the CO_2 laser heating has been presented in literature [21,22]. Literature also shows the approximated values of laser beam parameter spreads of different technology groups (Fig. 1). The specification of such data for gray irons, especially for their hardening from the solid state, remelting, alloying or tempering could be useful in the selection of the laser beam parameters. Such refinement could be particularly helpful if LHT for machine parts made of popular irons is applied (automotive industry – flake irons with pearlite matrix or nodular irons with ferrite, ferrite–pearlite, pearlite or ausferrite matrix). Therefore, it is reasonable to assess the influence of LHT on the surface layer microstructure of selected gray irons using different combinations of laser beam parameters (different laser beam power densities and interaction times i.e. different heating and cooling rates of the surface layer).

Because of wide application of gray irons (and need of their surface treatment) the diagram presenting particular thermal effects of the their surface layer, such as remelting, alloying, hardening from the solid state, tempering in individual ranges of laser beam parameters (power density and its interaction time) exactly for gray irons was found as crucial purpose to achieve.

The aim of the following research was to create an LHT diagram presenting singular modifications such as remelting, alloying, hardening from the solid state, tempering the surface layer of gray iron in individual ranges of laser beam parameters (power density and its interaction time). A synthesis of such different thermal phenomena occurring in gray irons surface layer resulting from LHT was the aim of this analysis.

2. Experimental procedure

The following gray irons were investigated: EN-GJL-200, EN-GJL-250 flake iron, EN-GJS-400-15, EN-GJS-500-7, EN-GJS-600-3, EN-GJS-800-8 nodular iron and EN-GJMB-450-6 malleable iron. The chemical composition of the investigated gray irons has been presented in Table 1.

The laser heat treatment was performed with a molecular CO_2 continuous wave Trumph laser (TLF 2600t at 2.6-kW output power

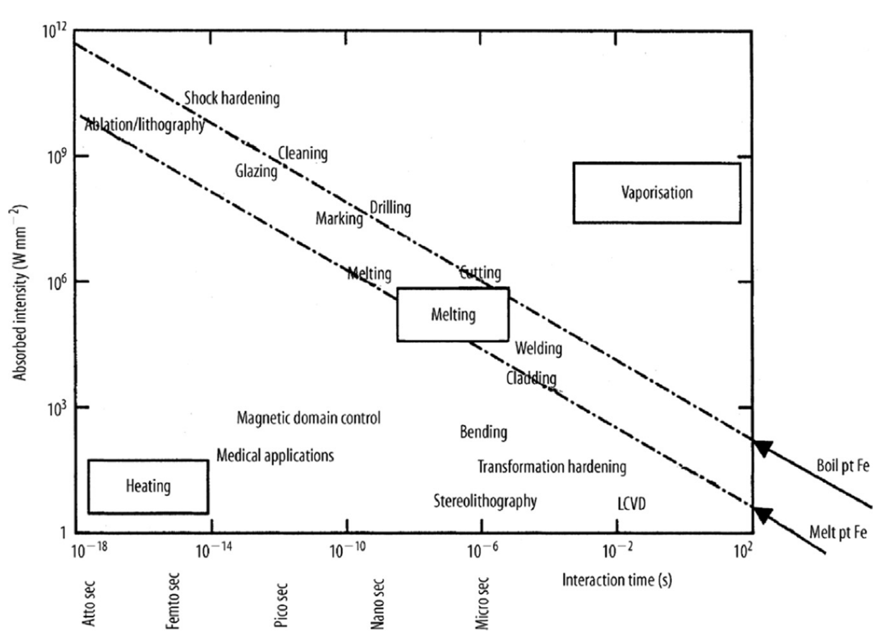

Fig. 1. The range of laser processes mapped against power density and interaction time. The diagonal lines represent the lines of constant temperature for the boiling and melting point of iron [21].