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The influence of various cooling rates during laser alloying on nodular iron surface layer

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ABSTRACT

The results of research referring to modification of the nodular iron surface layer by laser alloying with cobalt were presented. The aim of this study was to analyze the possibilities of cobalt implementation into the surface layer of nodular iron in various laser heat treatment conditions (by generating different cooling rates of melted surface layer). The modified surface layer of nodular iron was analyzed with OM, SEM, TEM, XRD, EDS and Vickers microhardness tester. The modified surface layer of nodular iron after laser alloying consisted of: the alloyed zone (melted with cobalt), the transition zone and the hardened zone from solid state. The alloyed zone was characterized by higher microstructure homogeneity – in contrast to the transition and the hardened zones. All the alloyed zones contained a dendritic microstructure. Dendrites consisted of martensite needles and retained austenite. Cementite was also detected. It was stated, that due to similar dimension of iron and cobalt atoms, their mutual replacement in the crystal lattice could occur. Thus, formation of phases based on α solution: Co-Fe (44-1433) could not be excluded. Although cobalt should be mostly diluted in solid solutions (because of its content in the alloyed zone), the other newly formed phases as Co (ε-hex.), FeC and cobalt carbides: Co_3C, $CoC_{0.25}$ could be present in the alloyed zones as a result of unique microstructure creation during laser treatment. Pearlite grains were observed in the zone, formed using lower power density of the laser beam and its longer exposition time. Simply, such conditions resulted in the cooling rate which was lower than critical cooling rate. The alloyed zones, produced at a higher cooling rate, were characterized by better microstructure homogeneity. Dendrites were finer in this case. This could result from a greater amount of crystal nuclei appearing at higher cooling rate. Simultaneously, the increased amount of γ-Fe and Fe_3C precipitates was expected in the alloyed zone formed at higher cooling rates. The hardness of nodular iron surface layer, alloyed with cobalt, was up to 4-times higher than the hardness of core material. The hardness of alloyed zones strongly depended on laser treatment conditions. In the case of lower cooling rate, lower hardness was observed due to more coarse-grained microstructure and a presence of pearlite. The hardness of the alloyed zone increased (from 850 to 950HV0.1) together with the increasing cooling rate (from $2 \cdot 10^3$ to nearly $9 \cdot 10^3$ °C/s). Laser treatment enabled a formation of surface layers on nodular iron, alloyed with cobalt. The microstructure of such a surface layer could be controlled by the laser processing parameters. High hardness and fine microstructure of the laser-alloyed nodular iron with cobalt should result in higher resistance to wear, corrosion and even (due to effect of cobalt addition) elevated temperatures during operation conditions of machine parts.

1. Introduction

Plain nodular iron has found a number of applications in the automotive industry and agriculture. This material was commonly used due to its good castability, machinability and relatively low price. Moreover, some mechanical properties of this cast iron were similar to those obtained by cast steel or steel. Nodular iron was applied for engines and machine components such as crankshafts, camshafts, cylinder liners, gears, and break components. Some parts of them were exposed during operation to intense wear, corrosion, elevated temperatures or even thermal shocks. Therefore, appropriate properties of the surface layer were required.

Laser treatment has found wide application in surface engineering in order to modify the properties of the material surface layer. Surface modification by laser heating was a dynamically

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developing technique for improving the surface properties of metal alloys. This treatment was widely used, especially for steels, and to a lesser degree for cast iron. Conditions for microstructure modification during laser treatment differed from the conventional hardening methods. The process was characterized by an extremely fast heating and cooling rate. Cooling rate could achieve 10^6 °C/s reported by Benyounis et al. [3]. The modified surface layer of nodular iron after laser remelting consisted of: the melted zone (very fine-grained region), the transition zone, and the zone hardened from solid state reported by Grum and Šturm [5,6]. The microstructure of remelted zone, formed as a result of high melting rate and ultra-rapid re-solidification velocity during laser treatment, often corresponded to ledeburitic nature, described by Battezati et al. [2] Zhou et al. [13] and Guo et al. [7] reported that cast iron after laser remelting was characterized by higher hardness and better wear resistance than the untreated one. The improved abrasive wear resistance of laser treated coulter flap (in comparison to untreated flap) was proved by Paczkowska et al. [11]. The only single laser track was produced on the tip of the flap. This study showed that such a treatment influenced the surface microstructure and thus, increased its hardness by 1.5–3 times. It resulted in two- to six-fold improvement in wearability of laser treated coulter flaps per hectare of cultivated field in comparison to untreated coulter flaps. Hence, on the base of this research (presented in the article: Paczkowska et al. [11]) it could be stated the usefulness of laser heat treatment also in case of increase of abrasive wear resistance on example of agriculture machine parts.

Wear resistance, as well as corrosive and thermal properties could be additionally enhanced by introducing the alloying element into the surface layer during laser treatment. Hardness and wear resistance of nodular iron were efficiently improved using laser alloying with boron by Paczkowska [9]. Cobalt was an element that could also change the properties of the surface layer. Addition of this element to steels caused enhancement of their durability and abrasion resistance. Cobalt increased also the corrosion resistance and reduced the hardness decrease at elevated temperatures. An advantageous influence of cobalt on the hardness at elevated temperature was noticed by Ding et al. [4] in case of laser alloying of low alloy steel with this element. Presented research showed that 3–6 wt% of cobalt in the alloyed zone was sufficient to increase the creep resistance of the surface layer. It could be expected that laser alloying of nodular iron with cobalt should also improve the properties of its surface layer. Cobalt has been previously used during the laser alloying of cast iron together with other elements, e.g. with tungsten, vanadium and chromium by Jianglong et al. [8] or with silicon and boron by Riahi [12]. It should be emphasized that cobalt increased the critical cooling rate. As a consequence, addition of cobalt into the surface layer by laser treatment (without other alloying elements which reduced the critical cooling rate) could cause appearing the metastable phases, like pearlite. Thus, the selection of appropriate laser processing parameters was very important, especially, taking into account the influence of cobalt on the hardenability, mentioned above.

The aim of the presented research was to evaluate the possibilities of laser alloying of nodular iron with cobalt. Such a treatment could provide the surface layer with advantageous properties. The influence of different cooling rates (generating by different combination of laser treatment parameters) on the microstructure and hardness was studied.

2. Experimental method

Nodular iron type 500-7 which has pearlite–ferrite matrix containing graphite nodules was chosen as the research material. The properties of the 500-7 material are as follows: Rmr = 560 MPa, R p0.2 = 369 MPa, A5 11.0%, HBr = 190 MPa, HV0.1 matrix = 223 MPa. The chemical composition of this material was as follows: C = 3.52 wt%, Si = 2.92 wt%, Mg = 0.045 wt%, Mn = 0.30 wt%, Cr = 0.03 wt%, P = 0.03 wt%, S = 0.013 wt%, Cu = 0.265 wt%, Al = 0.013 wt%.

Laser surface modification was carried out using the molecular CO_2 continuous Trumph laser type TLF 2600 t at 2.6 kW output power. TEM_{01} mode of laser beam was applied. The covering paste consisted of an alloying material (cobalt: 2 μm, 99.8%, Sigma-Aldrich) and water glass. Cobalt powder was presented in Fig. 1. The covering paste has been put on the surface of the nodular iron before laser heating. The average mass of the covering paste per the surface unit of the samples was equal to 12 mg/mm^2. Laser treatment parameters were selected to attain various conditions during microstructure creation of the alloyed zone (Table 1). Laser beam interaction time was in range of 0.19–2.15 s, and laser beam power density ranged from 19 to 207 W/mm^2. Constant laser beam fluence (F = 40 J/mm^2) and the dimension of laser spot size (4 mm) were applied to each variant of laser treatment. Single laser tracks were performed. Selected combinations of laser processing parameters enabled to obtain different temperature and the changeable cooling rate distribution from the surface to the material core during the treatment. The temperature and the cooling rate distributions as functions of laser treatment parameters (laser beam:

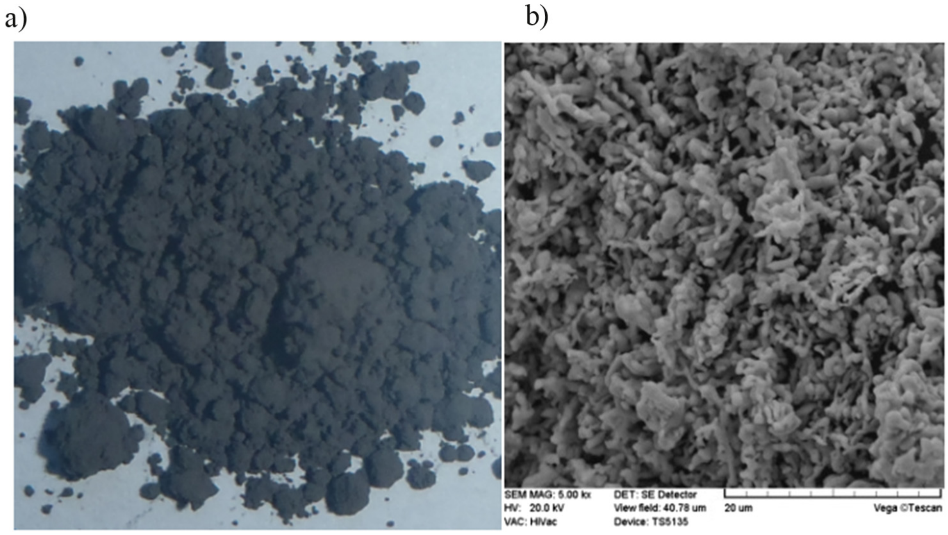

Fig. 1. Cobalt powder used for laser alloying of nodular iron type 500-7: macroscopic image (a); microscopic image (b).