Efficiency of use of the solid-state YAG: Nd-Laser for hardening of high-strength cast iron VCH 70-3

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Abstract. The method to increase the durability of high-strength cast iron with spherical graphite YAG:Nd-laser radiation is proposed. The results of studies in laser processing of cylindrical samples of high-strength cast iron grade of the VCH 70-3 are presented by the YAG:Nd-laser, working in pulse-periodic mode. Effect of the treatment with 1 kW YAG:Nd-laser on microhardness of high-strength cast iron has been investigated. More effective laser strengthening is found to be occurred by YAG:Nd-laser processing as compared with continuous CO2-laser one. The results showed that when processing of cast iron in general, the zone of laser influence consists of the reflow zone and the zone of quenching from the solid state. The optimal values of parameters of the hardened layer in the radiation by the solid-state YAG:Nd laser are considered. It is shown that under fluence of laser radiation fluence more than 28 j/mm2 is occured the surface melting of cast iron.

1 Introduction

The processes occurring in the surface layers of cast irons by laser processing, repeatedly theoretically and experimentally investigated [1-10], but attempts to use laser processing for hardening of details from high-strength cast iron with spherical graphite VCH 70-3 were not always successful. Foundry properties of high-strength cast iron grades of the VCH differ from properties of usual gray cast iron grades of the SCH a little. Foundry shrinkage of high-strength cast iron is equal to 1,0-1,25%, but in the presence of a free cementite increases up to 1,75%; fluidity is the same, as in gray cast iron [11-14]. High-strength cast iron rather well gives in to machining. In work [15] it was established that after radiation by the continuous CO2-laser the microhardness of the surface layer of high-strength cast iron increases till 6-10 HPA, however it is known, also, that for surface hardening of steels and aluminum is more effective is use of the YAG:Nd-laser, than CO2-laser of the same capacity [16-17].

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Solid state Nd-lasers work from an active element in the form of a core or plate in intermittent and continuous modes [18-20]. For surface hardening of metal, it is preferable to use solid state Nd-lasers. In this work the possibility of use of the YAG:Nd-laser of average power (1,0 kW) for surface processing of details from high-strength cast iron with spherical graphite VCH 70-3 is investigated.

2 Main part

The laser set is intended for surface hardening of metal, contains in quality of basic elements the laser with power supply unit, an optical system for transportation and focusing of the laser beam, system of positioning of the workpiece, a control system and monitoring of parameters of processing [21-26].

The laser processing of cylindrical samples of high-strength cast iron grade of the VCH 70-3 (3,60 C, 2,7 Si, 0,7 Mn, 0,02 S, 0,1 R, rest is Fe) with a diameter of 24 mm and a length of 15 mm was made by the YAG:Nd-laser working in pulse-periodic mode with a frequency of following of pulses of 150 Hz at the density of power from 1 to 4 kW/cm². The diameter of the laser spot on the sample surface was 4 mm. Processing was subjected to "pure samples", the surface of which is washed with water, and the samples coated at 60° with a coverage of 10-20 % solution of ammonium persulfate, which reduces the reflection coefficient of the laser radiation.

In tables 1 and 2 presents the values of the mechanical properties of cast irons and the recommended chemical composition and heat processing of cast iron.

### Table 1. Mechanical properties of cast irons.

| Grade of cast iron | The limit of the tensile strength (kgf/mm) | Relative lengthening, % | Impact strength, kg·cm/cm² | Hardness, HB |
|--------------------|-------------------------------------------|--------------------------|-----------------------------|--------------|
| VCH 38-17          | 38                                        | 17                       | 6,0                         | 140-170      |
| VCH 42-12          | 42                                        | 12                       | 4,0                         | 140-200      |
| VCH 45-12          | 45                                        | 5                        | 3,0                         | 160-220      |
| VCH 50-2           | 50                                        | 2                        | 2,0                         | 180-260      |
| VCH 60-2           | 60                                        | 2                        | 2,0                         | 200-280      |
| VCH 70-3           | 70                                        | 3                        | 3,0                         | 229-275      |
| VCH 80-3           | 80                                        | 3                        | 2,0                         | 220-300      |
| VCH 100-4          | 100                                       | 4                        | 3,0                         | 302-369      |
| VCH 120-4          | 120                                       | 4                        | 3,0                         | 302-369      |

### Table 2. The recommended chemical composition and heat processing of cast iron

| Grade of cast iron | Mass fraction of elements | Recommended heat processing |
|--------------------|---------------------------|-----------------------------|
|                    | C  | Si  | Mn | P  | S  | Cr | Cu | Ni |
| Wall thickness, mm  |  to 50 | 50-100 | >100 | to 50 | 50-100 | >100 |
| VCH 35             | 3,3 | 3,0 | 1,9 | 0,8 | 0,2 | 0,1 | 0,02 | — |
|                    | 3,8 | 3,5 | 2,7 | 1,3 | 0,2 | 0,1 | 0,02 | — |
| VCH 100-4          | 3,3 | 3,0 | 2,7 | 1,2 | 0,5 | 0,1 | 0,02 | — |
|                    | 3,5 | 2,9 | 0,5 | 0,2 | 0,1 | 0,02 | — | Annealing |
| VCH 120-4          | 3,3 | 3,0 | 2,7 | 1,2 | 0,5 | 0,1 | 0,02 | — |
|                    | 3,5 | 2,9 | 0,5 | 0,2 | 0,1 | 0,02 | — | Annealing |
The structure of samples was studied by methods of optical microscopy on the transverse sections which are cut out from samples in the direction, perpendicular to the movement of the laser beam. The electronic and microscopic analysis has established increase in density of dislocations in a zone of thermal influence.

The depth of laser hardening and the microstructure of the samples were determined by standard metallographic methods after etching in 3% nitric acid solution in ethyl alcohol. To increase wear resistance applied nitriding with subsequent "shot blasting", in which in the surface layers of the products was created the favorable squeezing tension.

Measurements of microhardness was carried on a microthermometry of Lieca VMHT AUTO at a load of 0,98 N, the loading rate of the Vickers pyramid made 40 mkm/s, exposure on loading - 15 s, samplings of two diagonals of a print were made on the computer monitor screen.

Pulse-periodic processing of samples without the absorbing covering at the density of laser radiation up to 3 kW/cm² didn't cause a significant hardening of the surface on which traces of laser processing weren't even noticeable.

The zone of laser influence when processing of cast iron in general, consists of the reflow zone and the zone of quenching from the solid state. Melting of the samples surface at pulse-periodic radiation up to a fluence of 20-22 j/mm² doesn't happen with the absorbing coating , but the increase in fluence up to 28 j/mm² causes microplane surface of cast iron. The microhardness of the regions melted by laser radiation with fluence 30-40 j/mm², increased slightly from H = 2,5 to 3,5 HPA in the initial state until H = 4,5-7,0 HPA.

The zone of melting has melkodendritny structure with graphite inclusions, the presence of which depends on a fluence of radiation and time of influence. When fluence above 40 j/mm² of inclusions of graphite burn out.

The greatest depth of hardening the samples with the absorbing coating is observed at fluence of laser radiation 22-28 j/mm² (figure 1, where q, j/mm² - laser radiation power, h,mm - depth of the hardened layer of high-strength cast iron), while the surface melting doesn't occur. At higher fluences, the laser processing leads to melting on the surface.

| 40  | 3,8 | 3,5 | 3,2 | 2,9 | 2,9 | 1,7 | 1,3 | 1,7 | 0,5-1,5 | 0,3 | 0,02 | 0,1 | — | — | Without processing |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|----------|-----|-----|-----|---|---|---|
| VCH 45 | 3,3 | 3,0 | 2,7-3,2 | 1,9 | 1,3 | 0,5-1,5 | 0,3 | 0,02 | 0,1 | — | — | Without processing |
| VCH 50 | 3,2 | 2,7-3,2 | 1,9 | 2,2 | 0,8-1,5 | 0,3 | 0,02 | 0,15 | — | — | Without processing |
| VCH 60 | 3,2 | 2,4 | 2,4 | 2,6 | 2,8 | 0,3 | 0,2 | 0,15 | 0,4 | 0,3 | Normalization |
| VCH 70 | 3,2 | 2,6 | 2,6 | 0,4 | 0,7 | 0,015 | 0,15 | 0,4 | 0,6 | Normalization |
| VCH 80 | 3,2 | 2,6 | 2,9 | 0,4 | 0,7 | 0,01 | 0,15 | 0,6 | 0,6 | Double normalization |
| VCH 100 | 3,2 | 3,0 | 3,8 | 0,4 | 0,7 | 0,01 | 0,15 | 0,6 | 0,8 | Quenching and tempering |
Figure 1. The dependence of the depth of the hardened layer of high-strength cast iron density of laser radiation power.

Figure 2 (where, h, mm - depth of the hardened layer of high-strength cast iron, Hμ, HPa - microhardness) shows the distribution of microhardness in depth of the sample after processing with a laser radiation power of 1.0 kW. The speed of movement of the laser spot with a diameter of 4 mm on the sample surface made 4 cm/s, the width of hardened zone - 2.5 mm. It is established that the depth of the hardened layer is approximately 1 mm. Up to depth of 0.5 mm hardness changes from 10 to 12 HPA, followed by a vacation area with a minimum hardness of $H = 4.1-9.8$ HPA, and then - the main metal, the hardness of which makes 2.5-3.0 GPA.

From the data [27], it follows that the size of the hardened zones after radiation of high-strength cast iron CO2-laser makes 0.6-0.8 mm slightly lower than that after radiation of a solid-state YAG:Nd-laser. The distinction is probably connected with stronger absorption of more short-wave (1.06 microns) of radiation.

3 Conclusions

It is experimentally shown the efficiency of use of the solid-state YAG:Nd-laser for hardening of high-strength cast iron VCH 70-3. It is shown that under fluence of laser radiation fluence more than 28 j/mm² is occured the surface melting of cast iron. The depth of the hardened layer, the microhardness of which is 3-4 times higher than the microhardness of the starting material exceeds 0.5 mm.
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