Influencing the Mechanical Properties of Engine and Vehicle Constructions Alloy with Laser Surface Heating

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Abstract

The self-hardening aluminum alloys are interesting for producers of casting, because these materials have the required properties without using heat treatment. This casts production result in the following advantages: energy saving, reduction of the costs, no permanent deformation, largest casting dimensions possible, and so on. Nevertheless, it is well known that improvement of mechanical properties and structure of aluminum alloys can often significantly increase the lifetime of casting and reduce costs for fuel and reduction of environmental loading. The basic and energy saving method for improvement of mechanical properties of self-hardened alloys is surface hardening. Surface hardening improves properties such as: corrosion resistance, wear resistance and hardness. In regards this facts great interest in reducing the cost of components makes a great opportunity for use laser surface processing. Therefore this article deals with using laser surface heating and evaluations its influence onto mechanical properties of self-hardening ENAC-71100, i.e. AlZn10Si8Mg cast alloy. This alloy is especially used for engine and vehicle constructions, hydraulic unit and mound so the surface properties are important for application in industries. The results show that laser surface heating have influence on properties, but well defined conditions of heating are very important.

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1 Introduction

Aluminum cast alloys belong to materials which are used for many applications in almost every industry. These materials are profitable for each industry field thanks to the costs, the high mechanical properties, the ductility, the good corrosion resistance etc. and so they can be used as replacements of steels and cast iron for the production of components (Eperješi et al., 2014; Uhríčik et al., 2014; Alfieria et al., 2015; Rosso et al., 2013; Rosso et al., 2014; Castella, 2015). Generally, these alloys contain high percentage of alloying elements that form a structural components. Therefore is necessary to use modification, grain refining, heat treatment, etc. for affecting the morphology of structural components and also for influencing properties such as strength, ductility, fracture toughness, thermal stability, residual stresses, dimensional stability, resistance to corrosion, and stress corrosion cracking in most aluminum cast alloys (Castella, 2015; Rosso et al., 2016; Hurtalová and Tillová, 2015; Hurtalová et al., 2015).

Last few decades is a high tendency to minimize the energy consumption in order to have a minor impact on the environment and therefore is a great effort to use instead of secondary aluminum alloys, self-hardening aluminum alloys for industrial applications (Rosso et al., 2014; 2016; Castella, 2015; Peter et al., 2014; Tillová et al., 2015; Hirsch, 2009; 2011; 2014). Self-hardening aluminum alloys have high mechanical properties without needs of heat treatment, because these materials are subjected to a natural ageing phenomenon at room temperature after casting for a storage period of about 7-10 days (Rosso et al., 2013; 2014; Peter et al., 2014; Tillová et al., 2017) and achieve the desired properties for application in different industrial fields. However, sometimes a request for reduce wear, better mechanical, fatigue properties and corrosion resistance of self-hardening aluminum is, that alloys are exposed to surface treatment (Tillová et al., 2017; Montealegre et al., 2010; Pliszka et al., 2016; Radek, 2008; Bergant et al., 2016; Spadaro et al., 2007). One of the surface treatment possibility is laser surface heating = laser hardening (Fig. 1) which is used to reduce wear and improve fatigue resistance of products especially where hard surface layers are required on tough and possibly cheap base materials and where no measurable thermal

distortion is allowed. At nowadays, there are three major types of laser sources: CO_2 lasers; Nd: YAG lasers; and excimer lasers (Tillová et al., 2017; Montealegre et al., 2010; Parker, 2010; Bauernhuber et al., 2016; Markovits et al., 2013). The fundamental problem in surface heating substances by laser radiation is well defined conditions of heating. Therefore, it is necessary to specify the wavelength of laser type to be used, the shape of the laser beam, for the interaction of laser radiation and matter, and we cannot forget the side effects accompanied with given technological operation (Tillová et al., 2017; Wang et al., 2000).
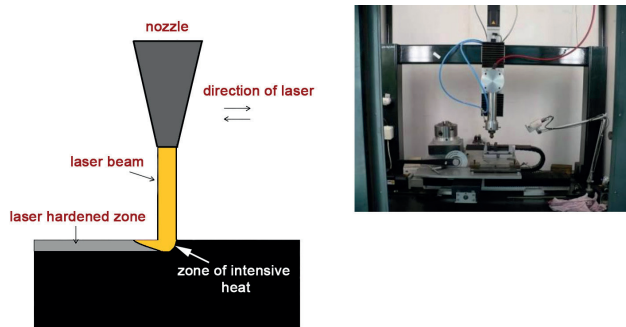

Fig. 1 Laser surface hardening with Nd:YAG laser

The present study is focused on self-hardening Al-Zn-Si aluminum alloy which can be used for casting new products for mechanical engineering, hydraulic castings, textile machinery parts, car components, and so on (Peter et al., 2014; Tillová et al., 2017). Therefore is necessary to study possibilities of increasing properties of these alloys and one way is laser surface hardening.

2 Experimental material

As an experimental material was used secondary self-hardening AlZn10Si8Mg cast alloy which is characterized by very good casting properties, good wear resistance, low thermal expansion and very good machining, polishability, and weldability (Rosso et al., 2013; 2014; Peter et al., 2014; Tillová et al., 2017). The experimental material, with chemical composition (in wt. %) 9.6 % Zn, 8.64 % Si, 0.1143 % Fe, 0.181 % Mn, 0.452 % Mg, 0.0622 % Ti, 0.0022 % Ni, 0.005 % Cu, 0.0014 % Cr, balance % of Al, has been produced by gravity casting into the sand molds without modifying or grain refining in foundry Zátor, Ltd. Czech Republic. Experimental material was received in the form of bars (with dimensions: ø 20 mm, length 300 mm) which were after a natural ageing phenomenon at room temperature after casting for a storage period of about 10 days.

3 Experimental procedure

Samples for metallographic observation and laser treated layer quantification were sectioned from the mechanical test specimens and prepared via standard procedures (wet ground on SiC papers, DP polished with 3 µm diamond pastes followed by Struers Op-S) and etched first by standard reagents (Keller, HF-hydrogen fluoride) and next by color reagent (Weck-Al,

MA- Ammonium molybdate) for better highlighting the laser treated layer. The microstructures and laser treated layer were studied using an optical microscope (Neophot 32) under 50x, 100x, 500x and 1 000x magnification. The quantitative analysis of laser treated layer was made using optical microscope and Image analysis software NIS Elements 4.2. The results of quantitative analysis represent the measured values on about twenty-five field of each sample.

Specimens for mechanical properties testing were made from bars (ø 20 mm x 300 mm) with turning and milling operation (Fig. 2a). Mechanical characteristics were measured according to standards: STN EN 10002-1, STN EN ISO 100045-1, STN EN ISO 6506-1 and STN EN ISO 6507-1. Tensile strength (UTS) was measured on testing machine WDW 20 with the evaluation software Win WDW and the shift operation was 2 mm. Bending impact test was performed on Charpy pendulum hammer (with max. energy 30 J). Hardness measurement for experimental alloy was performed by a Brinell hardness tester with a load of 62.5 kp (1 kp = 9.81 N), 2.5 mm diameter ball and a dwell time of 15s (HBW 2.5/62.5/15) and Vickers hardness tester with a load of 98.7 kp (1 kp = 9.81 N) and a dwell time of 10 s (HV 10). The evaluated UTS, HBW and HV reflect average values of at least six separately experimental specimens.

The microhardness of laser treated layer and structural parameters (eutectic and α-phase = matrix) was measured with using Vickers microhardness testing machine ZWICK/Roel ZHµ with the evaluation software ZWICK/Roel ZHµ/HD under a 5 g load for 10 s (HV 0.05) on metallographic samples.
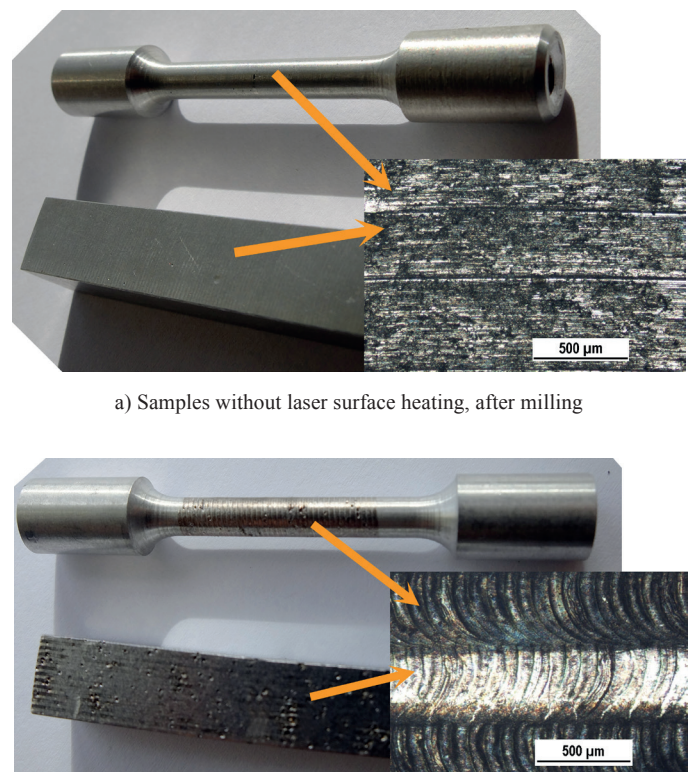
a) Samples without laser surface heating, after milling

b) Samples with laser surface heating
Fig. 2 Samples for mechanical tests

The evaluated HV 0.05 reflect average values of at least ten measurements on each structural parameter.

The laser surface heating was carried out on samples for mechanical testing (Fig. 2b) in collaboration with the Centre for Laser Technologies of Metals, Kielce, Poland. The subsequent laser heating was performed with the aid of a BLS 720 laser system employing the Nd: YAG type laser operating in the pulse mode. The parameters for the laser surface heating were: laser spot diameter 0.7 mm, beam shift rate 250 mm/min, nozzle-sample distance 6 mm, pulse duration 0.4 ms, frequency 50 Hz, protective gas-nitrogen 25 l/min, shift of beam 0.4 mm, laser average power 50 W and 80 W. After the laser surfaces heating the mechanical properties were measured, next the samples were sectioned and structuraly analyzed.

a) α- matrix, porosity, etch. Keller

4 Experimental results and discussion

The mechanical properties are influencing with porosity and morphology of structural particles to a large extent in all aluminum alloys, therefore was assessment of experimental samples microstructure made.
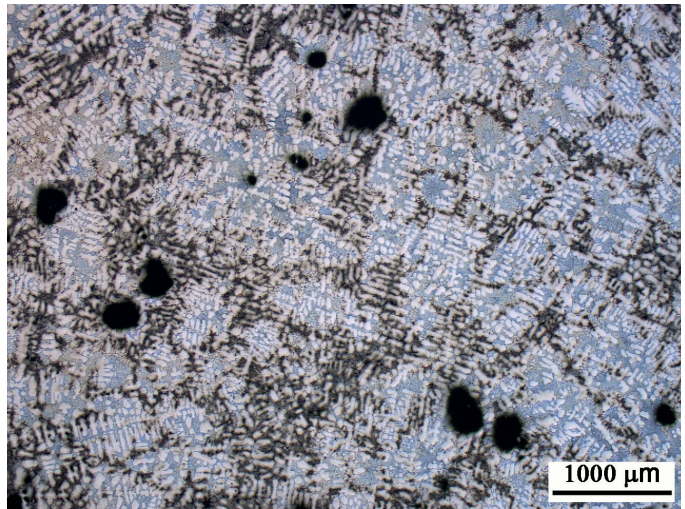
The microstructure of experimental material AlZn10Si8Mg cast alloy consists of a α-solid solution (matrix), a eutectic mixture of α-matrix and spherical phases (silicon particles) and variously type's intermetallic phases.

The α- matrix precipitates from the liquid as the primary phase in the form of dendrites and is nominally comprised of Al and Zn (Fig. 3a). As was mentioned the experimental material was cast into the sand molds, therefore the large pores were observed in microstructure too (Fig. 3a). The silicon particles were observed in a typical fine and rosette-like morphology (Fig. 3b), because this material was not modified or grain refined. This result about Si morphology is in accordance with previous reports for unmodified Al-Si alloys (Pedersen and Arnberg 2001; Romankiewicz and Romankiewicz, 2014).

The presence of additional elements in the Al-Zn (group 7xxxx) alloys allows many complex intermetallic phases to form, such as (Seifeddine, 2007; Cao and Campbell, 2004; Shabestari, 2004):

- binary phases, e.g. Mg_2Si, Al_2Cu;
- ternary phases, e.g. Al_2CuMg, Al_5FeSi, AlFeMn, $A_{17}Cu_4Ni$ and AlFeNi;
- quaternary phases, e.g. cubic α-$Al_{15}(FeMn)_3Si_2$ and $Al_5Cu_2Mg_8Si_6$.

These intermetallic particles had different morphologies, such as platelet or needles, skeleton- or script-like or "Chinese script" too and oval. The intermetallic phases on base iron, manganese and copper were identified in experimental material. Fe-rich intermetallics, such as AlFeMnSi phases, are formed between the α-dendrites. The morphology of this Fe-rich phase is plate-like (thin and long brown needles in Fig. 3c) with a thickness of a few tenths of micrometers.
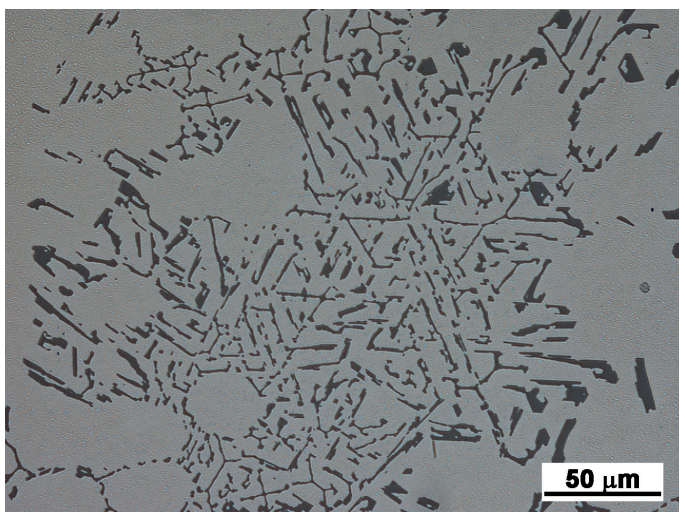
b) eutectic Si particles, etch. 0,5 % HF
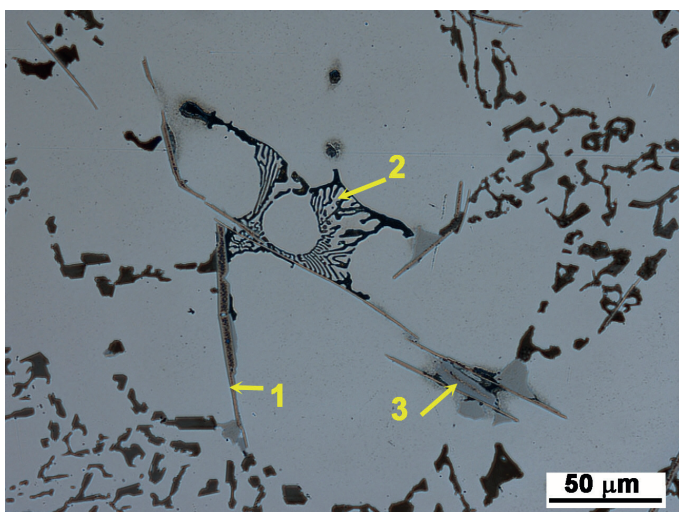
c) intermetallic phases, etch. MA;
1-AlFeMnSi, 2 - Mg_2Si, 3 - Al_2CuMg
Fig. 3 Microstructure of experimental material

Addition of Mg to experimental material leads to formation Mg-intermetallic compounds. Mg-phases can in Al-Zn-Si alloy solidify in two different forms: Mg_2Si and Al_2CuMg. The Mg_2Si phase was identified in microstructure of experimental material as individual skeleton-like or script-like so called "Chinese script" morphology (black phase - Fig. 3c). The oval round-like particles was detected as S-phase (Al_2CuMg - light grey phase – Fig. 3c). Metallographic assessment of laser treated layer shows that with an increasing of the laser power, the thickness of laser treated layer – remelting zone was increased (Fig. 4a, Fig. 4b).

The thickness of laser treated layer after 50 W laser average power was about 57.95 ± 0.5 µm and after 80 W laser average power about 94.39 ± 0.5 µm. The quantitative assessment shows that laser treated layer after 50 W laser average power was compact and in the layer were no-cracks, while on samples after 80 W laser average power were observed areas with cracks in layer (Fig. 5). These cracks may act as concentrator which led to failure of material. Also these defects probably cause decreasing of mechanical and fatigue properties which was shown in the work Bokůvka et al. (2011). This assessment shows that is very important to have well defined conditions of heating.

The previous studies show that sand casting alloy AlZn10Si8Mg achieve high values for tensile strength (190 ÷ 250 MPa), offset 0.2 % yield stress (170 ÷ 230 MPa), however the low ductility limits (1 ÷ 2 %), hardness HB 90 ÷ 100 and fatigue resistance (80 ÷ 100 MPa) (Tillová et al., 2015; 2017). The assessments of basic mechanical properties of experimental material shows that laser surface heating have effect on these properties (Fig. 6).

Ultimate tensile strength increases from 167 MPa (on samples without laser heating) to 195 MPa after laser surface heating at 50 W laser average power, but at laser average power 80 W decreases to 162 MPa. The decreasing is probably due to the presence of cracks in laser treated layer and porosity in material (Fig. 5), because the structure was comparable for each condition of experimental material. The iron creates still the same intermetallic phases and silicon particles morphology was the same, too. The hardness measurements (Brinell and Vickers) show that highest hardness was on samples laser surface heating at 80 W laser average power (117 HBW, 116 HV) and lower at samples without laser heating (96 HBW, 106 HV) (the increasing was about 8 %). The result is, with the increase of the laser average power the hardness increase too, because increase of the thickness and the width of remelting zone.

Microhardness of the structural parameters (Fig. 7a, Fig. 7b) are: α-phase 73 HV 0.05 and eutectic 89 HV 0.05. These values were measured for all samples from experimental material with and without heat treatment. The microhardness of laser treated surface layer after 50W laser average power was 109 HV 0.05 and for laser treated layer after 80W laser average power was 110 HV 0.05 (Fig. 7c).

The results show that experimental samples have comparable microhardness of surface laser treated layer after heating.
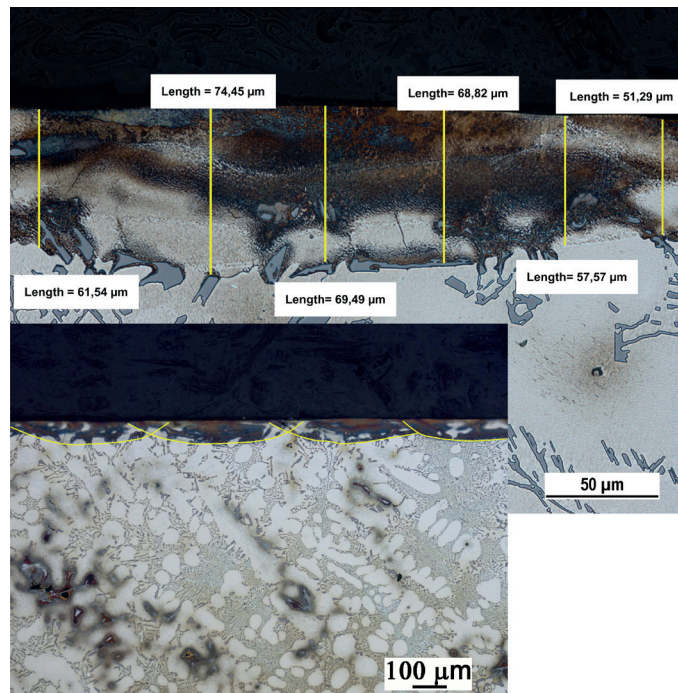
a) 50 W laser average power, etch. Weck-Al
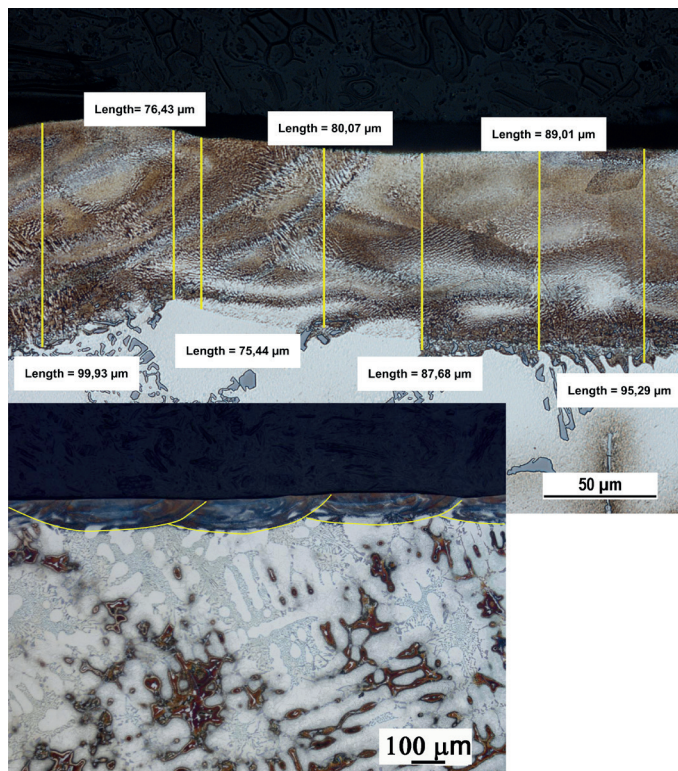
b) 80 W laser average power, etch. Weck-Al
Fig. 4 Quantitative assessment of laser treated layer after laser surface heating

It is probably related with the presence of thermal cracks in the laser surface (Fig. 5). Also the laser treated layer is harder than the microstructure of experimental material. Therefore it is the assumption that the laser treated layer ensure the wear reducing, increasing fatigue properties and corrosion resistance of experimental material.
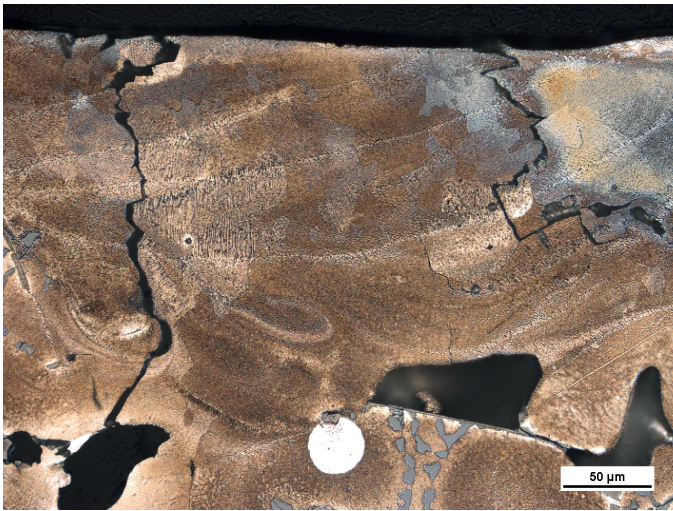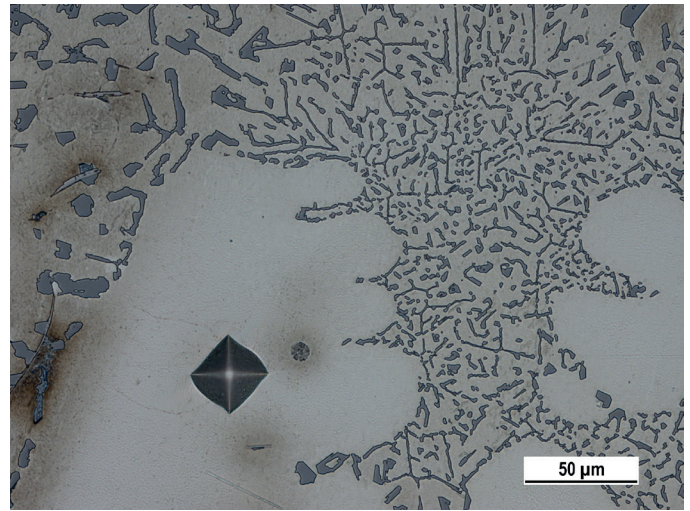
Fig. 5 Cracks in laser treated layer after 80 W average power, etch. Weck-Al
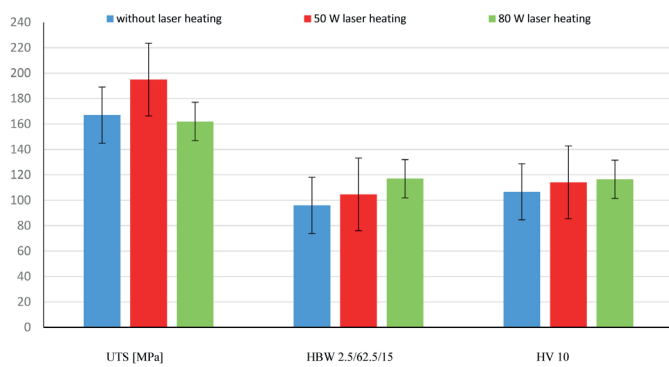

a) α-phase

Fig. 6 An overview of basic mechanical properties of experimental material


b) eutectic

5 Conclusion

The results presented a few facts about influence of laser surface heating on basic mechanical properties in the self-hardening AlZn10Si8Mg cast alloy. Therefore, the complexes conclusion about influence of laser surface heating on properties of experimental material cannot be summarized. There have been observed these results:

- The microstructure of experimental material AlZn-10Si8Mg cast alloy, consist of primary phase (α-matrix), eutectic (mixture of α-matrix and fine spherical Si-particles) and intermetallic phases on base Fe, Cu and Mg.

- The quantitative assessment of laser treated layer shows that after 50 W laser average power the laser treated layer is smaller than samples after 80 W laser average power, but layers after 80 W laser average power have areas with cracks, which is not acceptable.

- Ultimate tensile strength was the highest on samples after laser surface heating at 50 W laser average power, but at laser average power 80 W it was decreased. The decreasing is probably due to the presence of cracks in laser treated layer and porosity in material. The hardness measurements (Brinell and Vickers) show that highest hardness was on samples laser surface heating at 80 W
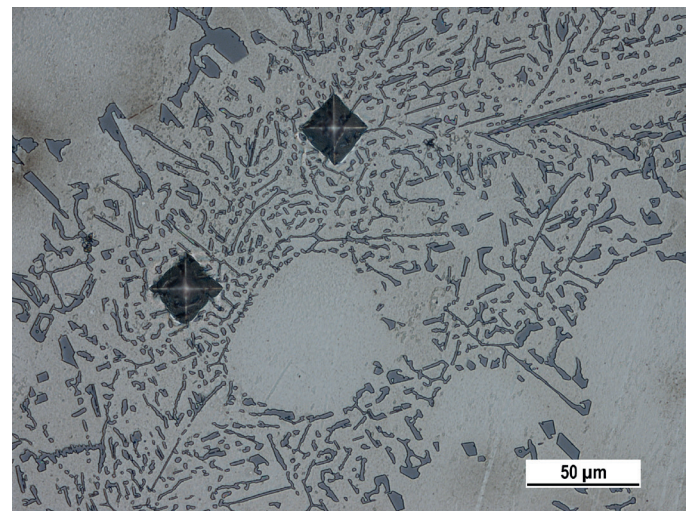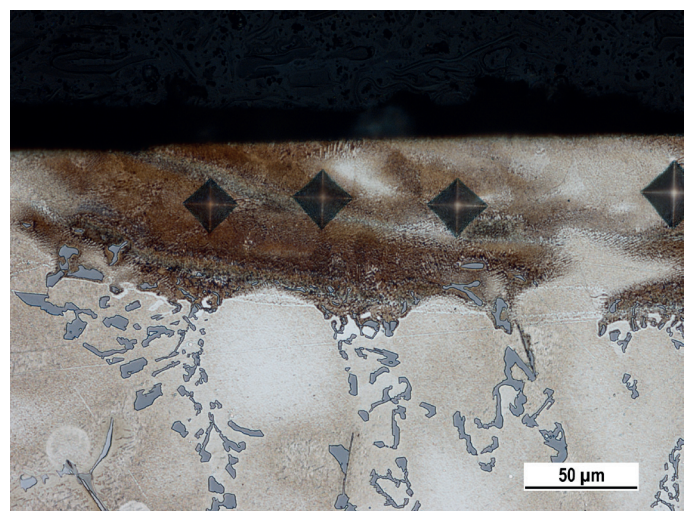
c) laser treated layer

Fig. 7 Microhardness of structural parameters and laser treated layer

laser average power and lower at samples without laser heating (the increasing was about 8 %).

- Microhardness tests show that laser treated layer have higher microhardness in comparison with hardness other structural parameters in microstructure of experimental material, which probably increase wear and fatigue resistance of casts form this experimental material.

Considering the partial results about influence of surface heating with laser on properties of self-hardening aluminum alloys casts, with accent to minimize the energy consumption to have a minor impact on the environment, is lower laser average power using more effective to achieve the desired properties.

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