# INFLUENCE OF HEAT TREATMENTS WITH CONCENTRATED ENERGY SOURCES ON THE CAST IRONS MECHANICAL PROPERTIES

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ABSTRACT: the cast irons and steels are alloys frequently used in industry, reason for why they favour the application of various technologies to improve the properties. Depending on the applications is searched the suitable technological process. The paper presents the results obtained by applying the heat treatment with concentrated energy sources on gray cast iron and nodular cast iron. In terms of the studied properties, the hardening (quenching) heat treatment with concentrated sources establishes the substantially improving of these, compared with conventional hardening. For the studied gray cast iron the best results are obtained for the laser hardening. In the case of nodular cast iron, throughout the laser hardening offers the best values for the studied properties. For both types of hardening with concentrated sources, the values of the obtained properties by the use cathode beam are close of those obtained with laser. By applying the hardening with the concentrated energy sources either laser or cathode beam is obtained a significant improvement of the studied properties: micro hardness, hardness and wear resistance. As in the steel case the hardening with the concentrated energy sources applied to cast iron causes the improving of the certain properties.
KEYWORDS: cast irons, concentrated energy sources, mechanical properties

## 1. INTRODUCTION

The cast iron is the Fe-C alloy, characterized by a low melting temperature, good fluidity and castability and can be easily processed by cutting. The down side is that cast iron is brittle and can not be deformed neither to cold neither to hot. These disadvantages significantly limit the using in industry of cast iron. Because of the many applications in which cast irons are used, today are melted many types of cast iron, the most common being gray cast iron, malleable iron, iron with lamellar graphite and nodular cast iron. Also, frequently it is used the alloy cast iron and antifriction cast iron. Among the all presented categories of cast iron, frequently used due the mechanical and technological properties are gray and nodular cast iron. As steels, cast iron heat treatments can be applied to improve their mechanical and technological properties. Paper presents the results of the hardening (quenching) treatment application with concentrated sources focused on the cast irons. The concentrated sources of energy used in the thermal treatment were those of laser or cathode beam type. The main application of the concentrated sources (laser or cathode beam) in the heat treatments field consists in the surface hardening of the steels and cast iron parts or tools. In this way, concentrated energy sources began to replace thermo-chemical treatments and surface hardening with flame or induction heating. The figure 1 shows the principle scheme of the superficial hardening with laser radiations [1].

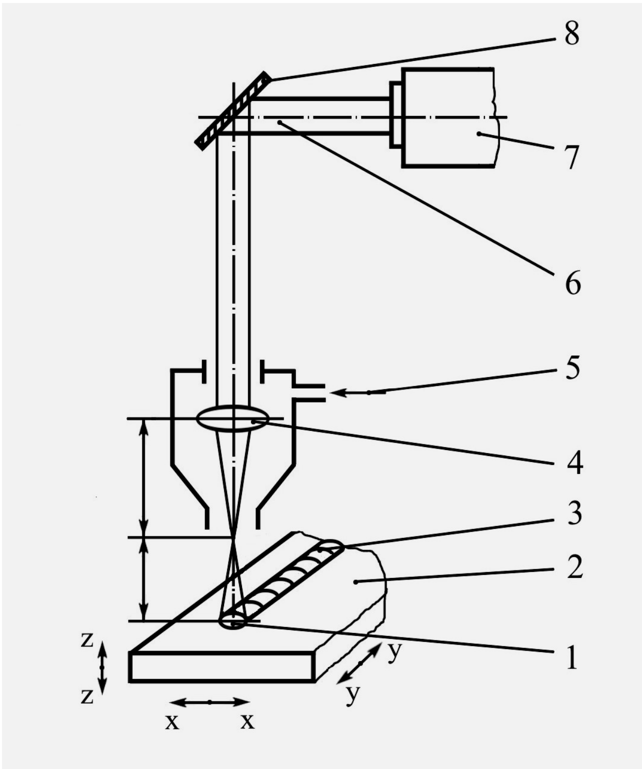


**Figure 1.** Principle scheme of laser heat treatment: 1 – spot laser, 2 – surface, 3 – treated zone, 4 – focusing system, 5 – inert gas, 6 – laser beam, 7 – laser generator, 8 – revolving mirror

In the manufacturing process with concentrated sources of energy, as a result of rapid heating and cooling, appear the phase transformation in the cast iron structure. In the heating time the pearlite is transformed into austenite and in to martensite in the cooling time (with 670 HV hardness). The thermic cycle of the superficial hardening with concentrated sources is sharp (the surface layer temperature varies very quickly, both in the heating and cooling) and processing is done without maintaining the maximum temperature reached in the cycle. The gray cast iron is interesting for the concentrated sources hardening because it contains graphite, which can be used as carburizing internal sources of matrix that it contains. By the laser hardening, the wear resistance of cast irons may be increased of 5-15 times (depending on the type of cast iron, the graphite shape, the base mass character) due to the decrease of friction coefficient and other tribological factors. The laser or cathode beam hardening has the same selectivity, the same specific power and heating rate and both use the natural cooling. In term of efficiency the cathode beam ($\eta \cong 75\%$) is superior to laser ($\eta \cong 7$-$10\%$). The laser hardening can be applied to small surfaces (less 600 $mm^2$ for the most used powers of 3-4 kW). The hardening by cathode beam can benefit of power up to 500 kW, the good results are obtained when the beam is directed normal to the surface.

The non conventional treatment demonstrated more improvement in the wear resistance and hardness compared with conventional heat treatment [2]. An example is as the transition zone between the substrate and the coating should possess enough ductility and toughness [3]. The quenching and partitioning novel treatment can be used to generate microstructure with martensite/austenite combination for giving attractive properties [4]. An advantage of induction-plasma hardening is the possibility of regulating over a wide range, the depth of the total hardened layer, as a result of high frequency quenching [5]. In the worldwide there are many attempts to improve the tools performance, using the unconventional processes. In the case of HSS, through cryogenic treatment the tool performances can be increased with 44%, in certain cutting conditions [6].

## 2. THEORETICAL CONSIDERATIONS

Considering the unidirectional heating case of a semi bounded body (most current applications) with a superficial source of constant intensity can be determined the technological parameters necessary to the heating for hardening. The hardening heating time is [7]:

$$t_k = 0.785\left(z_k^2 / a\right)\left[T_{top} / \left(T_{top} - T_k\right)\right] \text{ [s]}, \qquad (1)$$

where:
- $z_k$ – hardening depth [mm];
- a – diffusivity [$m^2$/s];
- $T_k$ – hardening heating temperature [K].

The hardening depth is determined by the relation:

$$v_{inc} \cong 2.546 \cdot a \cdot \sqrt{\left(T_{top} - T_k\right)^3} / \sqrt{T_{top}} \cdot z_k^2 \text{ [grd/s]}. \qquad (2)$$

The hardening depth is determined by the relation:

$$z_k = 1{,}59 \cdot \sqrt{a \cdot r / v} \cdot \left[\left(T_{top} - T_k\right) / T_{top}\right] \text{ [m]}, \qquad (3)$$

where:
- r – laser spot radius [m];
- v – movement speed of the concentrated sources [m/s].

The efficiency of relations (1, 2, 3) were verified in practice and had good results. For the GJL 250 cast iron, the figure 2 shows the dependence between the heating depth and movement speed when is used different laser power.

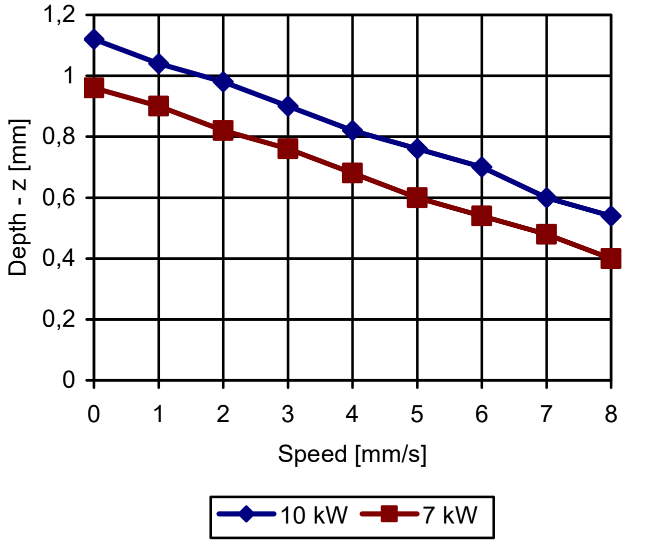


**Figure 2.** Dependence between heating depth and movement speed for GJL 250

In the case of nodular cast iron GJS 400-12 the dependence between the heating depth and movement speed is presented in figure 3.

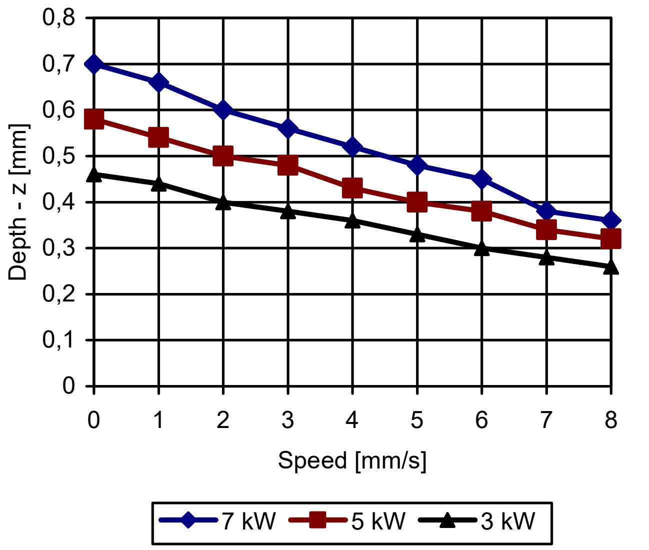


**Figure 3.** Dependence between heating depth and movement speed for GJS 400-12

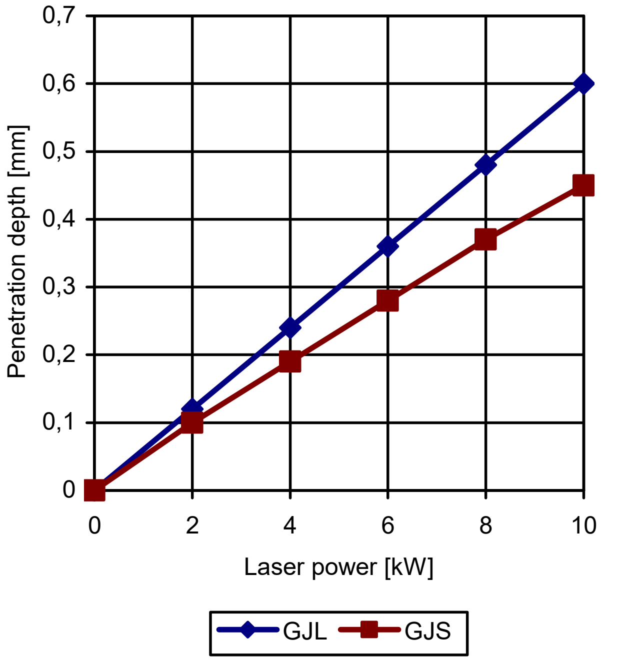


**Figure 4.** Dependence between heatind depth and laser power (movement speed 7 mm/s)

For the studied cast irons, the higher depths are obtained at low movement speed and high power. Between the two parameters the major influence has the movement speed.

For the same movement speed (v = 7 mm/s) the influence of laser power on heating depth is shown in figure 4. For the gray cast iron the heating depth is higher than nodular cast iron when the laser power is same.

At the beginning cathode beam was used in melting, welding and drilling operations, the process being applied later to the heat treatments. Knowing that the price of cast iron is lower than of the steel and that cast iron properties depend of the graphite shape, size and distribution, the hardening with concentrated sources was applied to the next types of cast irons: GJL 250 (Fc 250) and GJS 400-12 (Fgn 400-12). Their choice depended of the frequency of use in the industry.

The chemical composition of the two materials is shown in the table 1. The fracture strength is of 160-270 MPa for GJL cast iron and of 400 MPa for GJS cast iron.

**Table 1.** Chemical composition of the studied cast irons

| Cast iron type | Chemical composition [%] | | | | | |
|---|---|---|---|---|---|---|
| | C | Si | Mn | Ni | Cr | P |
| GJL 250 | 3.21 | 2 | 0.7 | 1.5 | 0.7 | 0.6 |
| GJS 400-12 | 3.39 | 2.27 | 0.40 | - | 0.20 | - |

## 3. EXPERIMENTAL RESULTS

The cooling for the laser or electron beam surface (superficial) heating is done spontaneously by conduction in all piece volume that is large and cold. The piece volume is much higher in relation with the volume of the superficial layer. This favourable ratio ensures the cooling with high speeds ($10^{-2}$-$10^{-4}$ degree/s) that exceeding the cooling critical speeds of cast irons. The spot dimensions of the concentrated sources are insufficient to heat large areas that must be hardened, reason that requires progressive warming. The processes that have place in the superficial layers of the ferrous alloys when are treated with laser or electron beam sources depend of the heating technology parameters, applied for the each process. The main parameters are: the sources power and the time of its action. Technological parameters used during laser heating samples were:

- power density – q=50 W/cm$^2$;
- time – 6.5 · $10^{-3}$ s;
- defocus value – Δf=4 mm;
- sample movement speed (rate) – v =7 mm/s;
- power – 10 kW;
- wave length - λ=60 µm.

Technological parameters used during cathode beam heating samples were:

- accelerating voltage – $U_{acc}$=10kV;
- intensity – I=0.2 A;
- superficial flow – q=40 W/cm$^2$;
- movement speed – v= 7mm/s;
- time – 0.01 s;
- power – 7 kW.

The heat treatment alternatives for the two types of cast irons were:

- alternative 1 – classic treatment: heating at 850$^o$C, maintaining 4 hours, followed by air cooling;
- alternative 2 – rapidly heating with laser, fallowed by air cooling;
- alternative 3 – rapidly heating with cathode beam, fallowed by air cooling.

The tests showed that the hardening depth was 0.6 mm for the laser method and 0.4 mm in the cathode beam case. The tested samples have cylindrical shape with the dimensions of 100 x 100 x 8 mm, the width of the treated layer being of 4 mm. Also, it has been used a cooling layer of carbon black (as paste with a thickness of 1 mm). The figure 5 presents micro hardness dependence in according with the depth for the GJL 250 cast iron, when it is used concentrated sources of energy (laser and cathode beam).

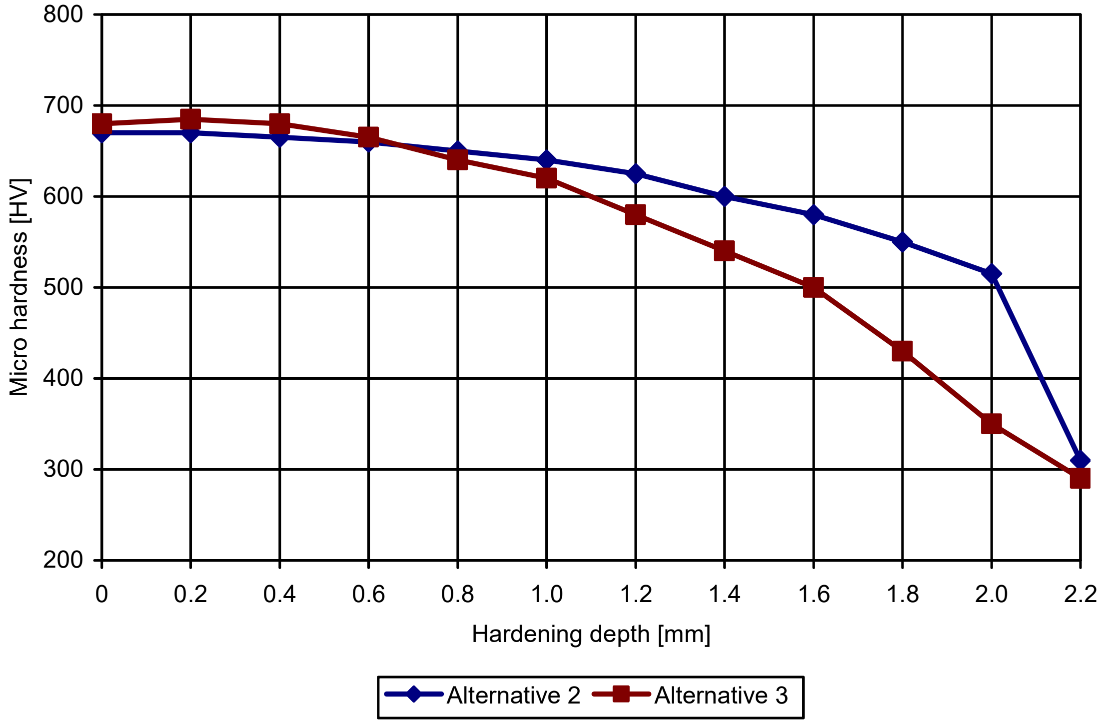


**Figure 5.** Hardening method influence on the gray cast iron micro hardness

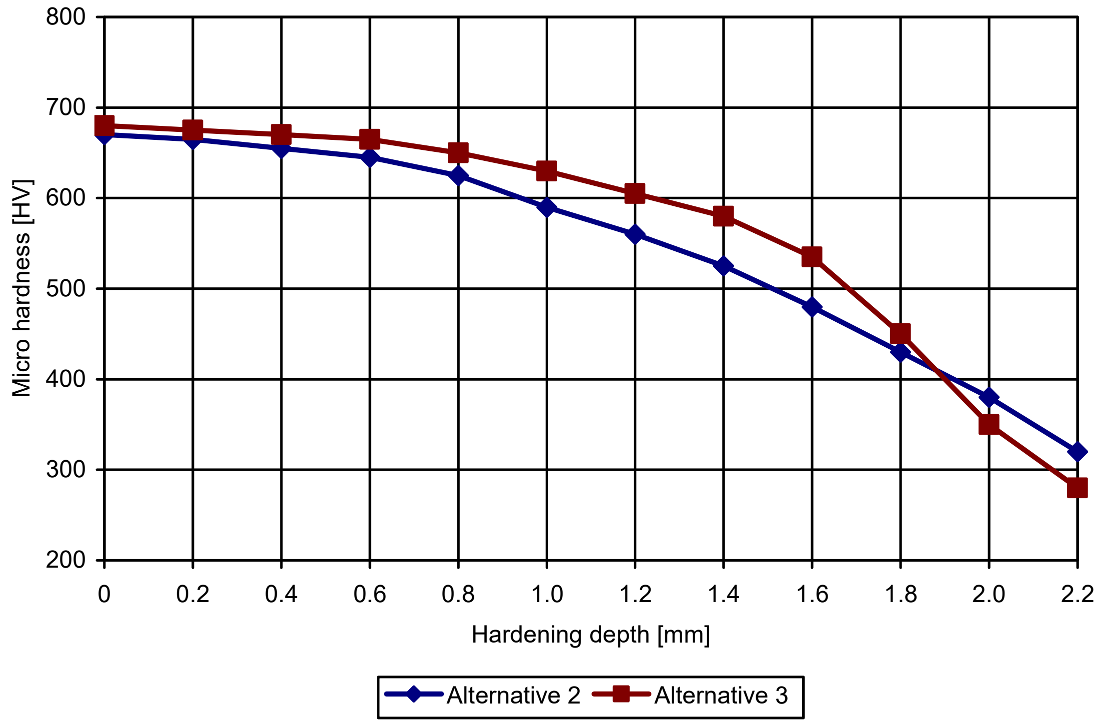


**Figure 6.** Hardening method influence on the nodular cast iron micro hardness

The GJS 400-12 cast iron was heated for hardening with laser and cathode beam sources. The results of these tests are shown in figure 6.

The conclusion is that for this cast iron type the better results of micro-hardness are obtained for the cathode beam heating. To study the wear behaviour of cast iron heated with concentrated sources of energy were used disc samples with dimensions 18 x 11mm. The wear resistance calculus was made by gravimetric method, using for determination an analytical balance (Sartorius type). After each test, for a better accuracy of the results, all the samples were cleaned in an ultrasonic bath of alcohol before weighing [8]. The wear was determined by the weight loss, the attempts being made in the same lubricant medium (oil). The test rotation was of 1700 rpm. and the pressure force of 100 daN. After tests perform and the results processing, is made their interpretation. For the gray cast iron in the case of laser hardening the hardened layer depth was 0.6 mm. Due to the high temperature and high speed cooling it is made the granulate of graphite, pearlite and ferrite content in the structure. From the point of view of the treated area hardness by laser or cathode beam hardening is obtained the nearby hardness and more superior to the classical alternative. The close harnesses determine the similar wear resistances (see figure 7).

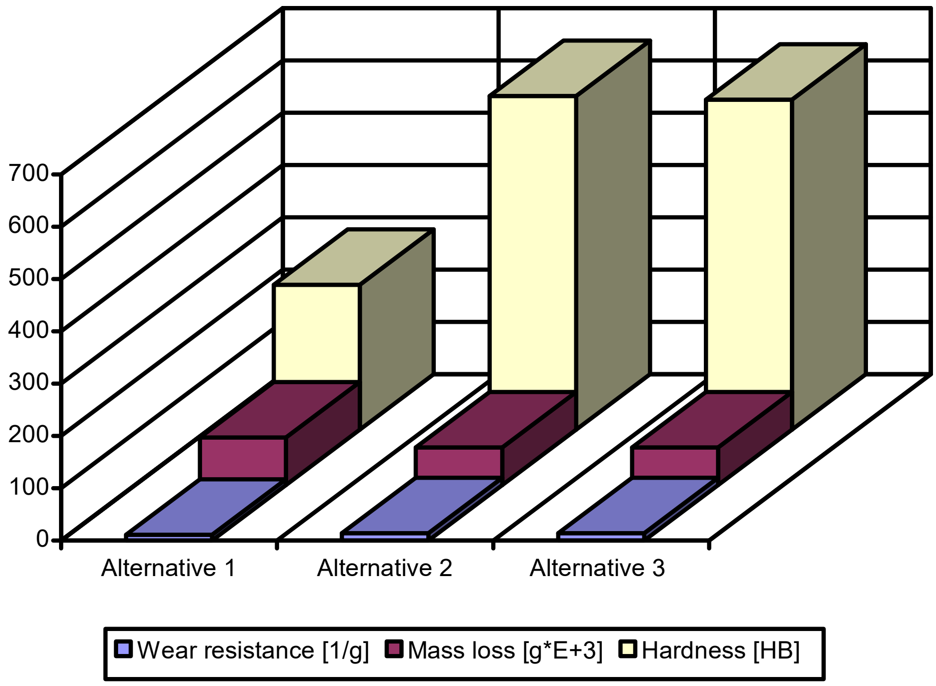


**Figure 7.** Heat treatment influence on GJL 250 cast iron mechanical properties

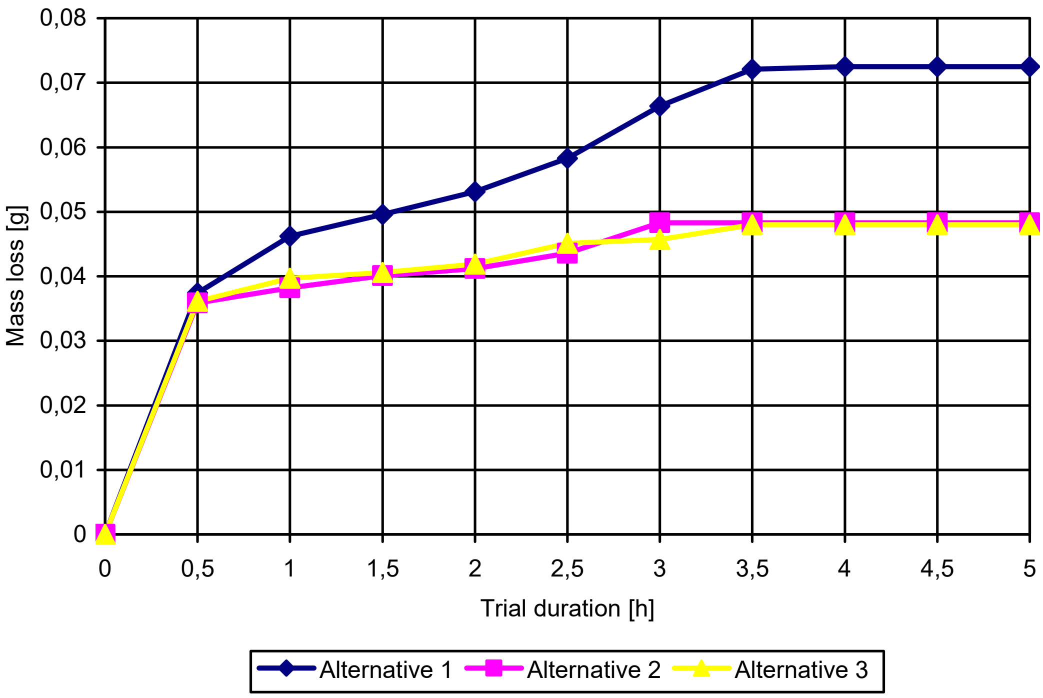


**Figure 8.** Gray cast iron mass losing in function of test duration

Studying the mass losing depending of the test duration it is established that after the running in (lapping) period, the mass losing is almost double for conventional treated samples (see figure 8). The cathode beam hardening determines a layer depth of 0.4-0.6 mm. Due to the high speed cooling the structure has same aspect as in the laser hardening case.

In the nodular cast iron case for the cathode beam the treated layer depth is of 0.5-0.7 mm (greater than laser hardening). The hardness and wear resistance evolution for all treatment alternatives is shown in figure 9.

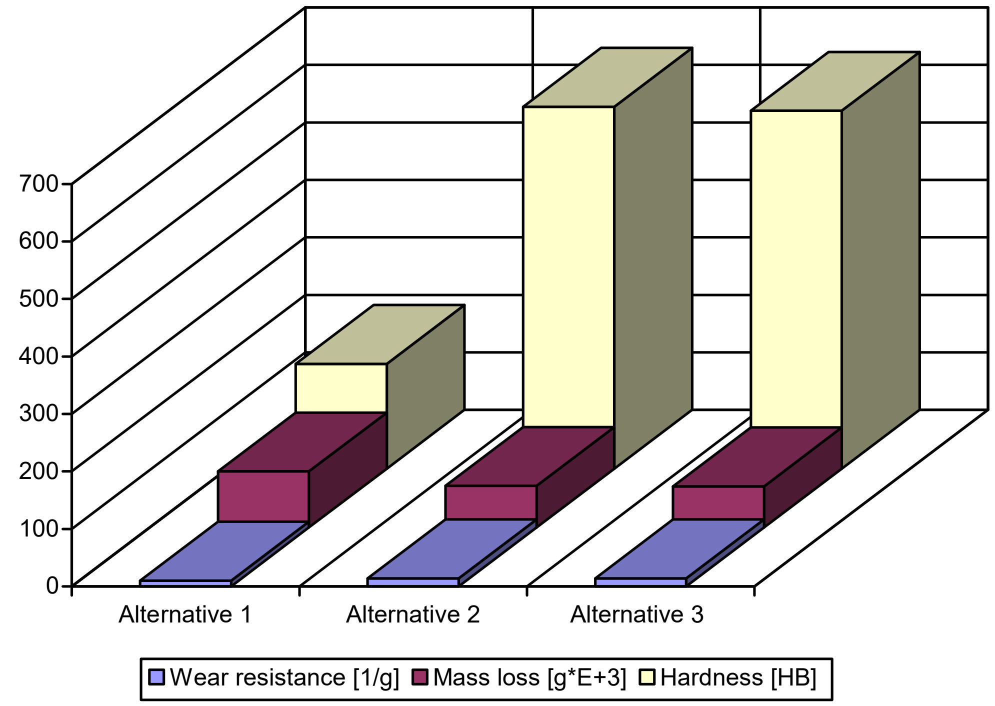


**Figure 9.** Heat treatment influence on GJS 400-12 cast iron mechanical properties

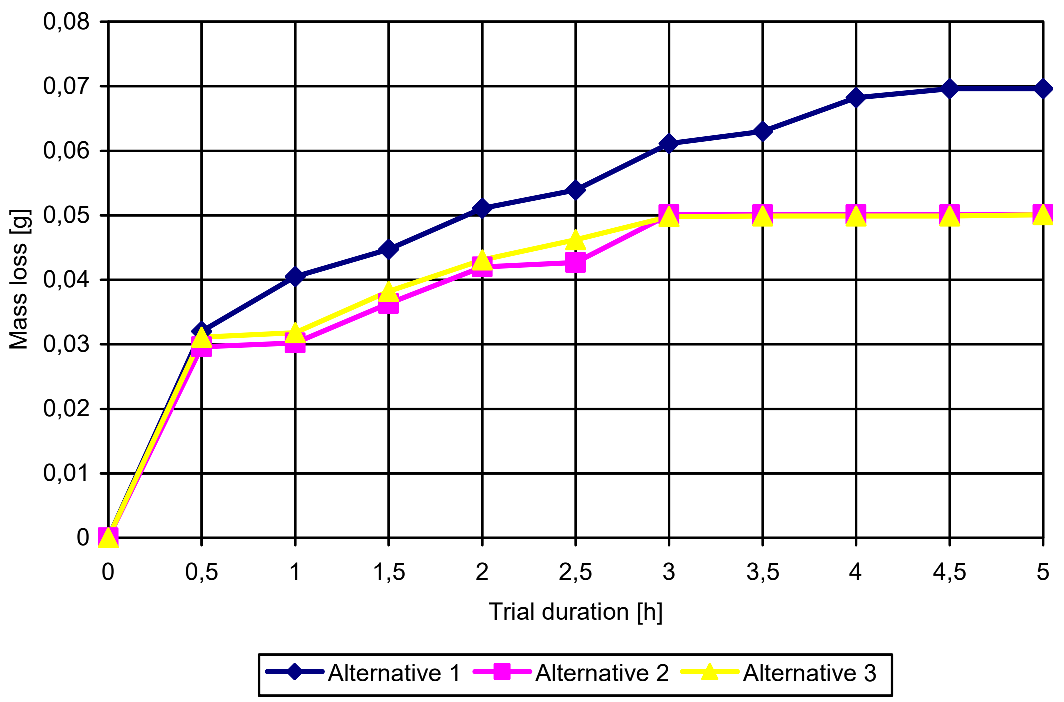


**Figure 10.** Nodular cast iron mass losing in function of test duration

The highest hardness was obtained for laser heat treatment, cathode beam providing a close hardness. The same trend was registered for the wear resistance. Regarding the mass losing over time, in the figure 10 is observed that in the classical hardness treatment, this is with 75% greater than the heat treatment alternative with concentrated sources.

## 4. CONCLUSIONS

The cast irons are alloys still commonly used on the industry, reason for thus this research was initiated.

The heat treatment with concentrated sources of energy successfully replaced those classical. Compared with the conventional heat treatments applied to the studies cast iron these types of treatments permit the obtaining of improvement properties for the alloys which are implemented. For the two types of cast and for both hardening processes with concentrated sources, the hardnesses are superior to those obtained by conventional hardening.

The wear resistance is improved when are applied the heat treatment with concentrated sources, depending of the cast irons type, better values are obtained either for the laser heat treatment or for cathode beam.

The favourable mass losing (smaller) in time it was for the samples processed with concentrated sources of energy. These values can be diminished to a half. As in the other Fe-C alloys (steel category) the hardening with concentrated sources of energy allows the obtaining of better values for the studied properties.

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