

Analysis of Cavitation Erosion Resistance of Grey Cast Iron EN-GJL-200 by the Surface Induction Hardening

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Abstract. By surface hardening of the cast iron having metallic matrix consisting of pearlite and fine lamellar graphite separations, it has been aimed an increase in hardness and wear resistance. Testing of cavitation erosion resistance was done in the laboratory in accordance with the standard ASTM G32 2010. The mass losses curves, depending on the duration of the cavitation attack by induction hardened and tempered at 220 °C samples, were analysed in comparison with those samples obtained after the stress relief annealing at 525 °C. The hardness measurements performed on the longitudinal section of the cavitation samples beside the microstructural investigations of the eroded surfaces allowed the explanation of the wear mechanism both by the action of the graphite stress concentrator and also by the sensitivity of the metallic mass to the notch effect.

1. Introduction

All machineries bodies (pressure valves, distributors, devices and debit regulators), used in the operating hydraulic plants for command, distribution and regulation, are casted from grey cast iron with lamellar or globular graphite [2, 3, 5]. When exploitation conditions impose great working speeds of the liquid environment, in the contraction area from these machineries, the pressure can decrease under a critic value (vaporization pressure) and, consequently, it is initiated the cavitation hydrodynamic process, with all its effects, the most dangerous being the erosion of the flow limits [5, 10, 11].

In Figure 1 it is schematically presented the area exposed to cavitation erosion obtained by the cavitation flow of the liquid from a pressure valve.

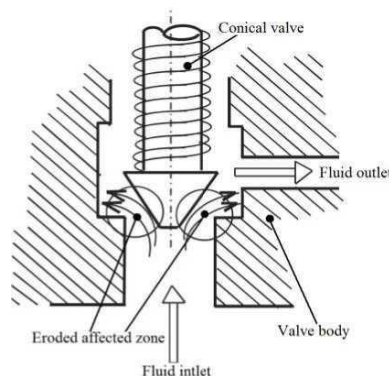


Figure 1. Schematic of cavitation eroded areas for conical valves.

The more the liquid viscosity is lower, close to the water one, the higher is the cavity operating danger [1, 3].

During the maintenance works, on the margins of the devices bodies, in the areas marked in the Figure 1, there have been noticed damages as pitting, specific to the erosion by cavitation. Destructions of these areas is dangerous and unwanted for hydraulic machineries, because it affects the operating of a plant. Moreover, in case of releasable pressure valves [2, 5, 11], as those from the hydraulic presses, pressure forming installations, their blocking cannot be provided and can represent a danger for the operator.

Consequently, specialists started to search for methods in order to increase the resistance of those areas exposed to cavitation erosion. In this direction there are presented the results of this paper, which were obtained from the researches performed on the surface of grey cast iron with pearlite metallic matrix and lamellar graphite separations, hardened by induction currents.

2. Material and experimental procedures

The investigated material (casted bar with diameter $\phi = 25$ mm), is a grey cast iron with metallic matrix composed from pearlite and lamellar graphite separations, subjected to stress relieving annealing, followed by induction hardening and tempering at a temperature of 220 °C for 90min., air cooled (Figure 2).

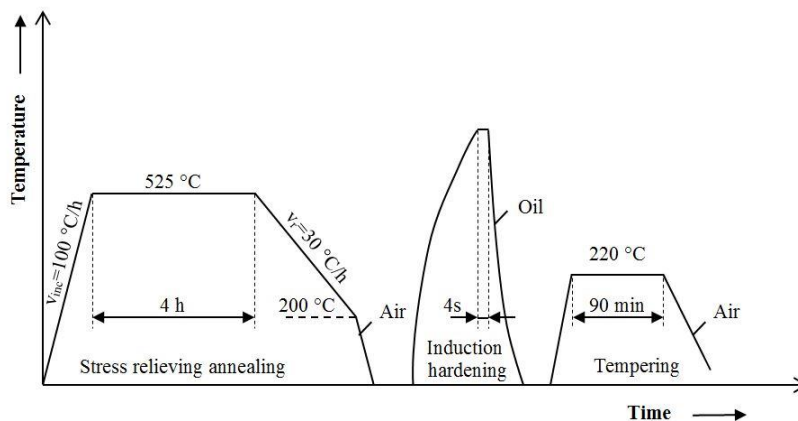


Figure 2. Cyclograms of the applied heat treatments.

Induction hardening process parameters are: specific capacity $AP = 0.9\text{ kW/cm}^2$, heating period $t = 4\text{ s}$; frequency, $f = 32\text{ kHz}$; cooling was made in the oil. The structure of the heat treated samples was investigated by optical microscopy and scanning electron microscopy. The intensity of microstructural changes produced in the substrate coating system was evaluated by Vickers hardness measurements.

The chemical composition of the grey cast iron has been: 3.26 %C; 1.94 %Si; 0.90 %Mn; 0.12 %P; 0.11 %S. After the stress relieving annealing the tensile strength of the material was $R_m = 247\text{ N/mm}^2$ and the hardness of 192 HV.

Cavitation resistance investigations of the samples surface after the annealing and induction hardening treatment, have been performed by sets of three samples, using the standard vibrating machinery with piezoceramic crystals, presented in Figure 3, from the Cavitation Laboratory of the Polytechnics University from Timisoara.

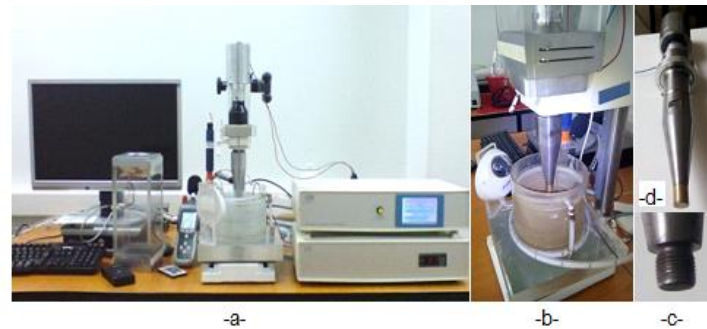


Figure 3. Standard vibrating equipment with piezoceramic crystals.

a-overall image; b- image during the cavitation attack period; c - sonotrode head where it is fixed the cavitation sample; d - mechanical vibrating system with the sample fixed in the sonotrode

Laboratory regulation, regarding the investigation procedure (total period and the intermediary periods of the cavitation attack, cleaning and washing the cavitation sample, Fig. 2d, evaluation of the mass loss, samples preserving) is in conformity with the standard ASTM G32-2010 [3], [4], [5], [9], [12].

During the entire period of the cavitation test, functional parameters of the equipment (vibrations amplitude and frequency, electric capacity of the ultrasounds electronic generator) and the distilled water temperature ($22 \pm 1^\circ\text{C}$) [3], [4], [5] have been maintained under the values recommended by the ASTM G32-2010 standard.

3. Cavitation test results. Discussions

In Figure 4 and 5 are indicated the experimental values and the approximation analytical curves of the mass loss and of the related erosion speeds, obtained in conformity to the cavitation test for the hardened grey cast iron and for the stress relieving annealed, at 525°C used in order to highlight the resistance increase, obtained by induction surface hardening.

These diagrams are drawn up based on the mass loss, m and of the erosion rate registered at the end of each period of the cavitation attack, $t = 5, 10$ and 15 minutes, which have been summed while the cavitation attack period increased until the final value of 165 minutes. The calculation relations which have been used are [4, 5, 6, 7, 8]:

- for the cumulated mass, lost by erosion during the cavitation attack

$$M_i = \frac{1}{3} \sum_{i=1}^{12} \Delta m_i \quad (1)$$

- for the erosion rate, related to each exposing period to the vibrating cavitation

$$v_i = \frac{1}{3} \sum_{i=1}^{12} \frac{\Delta m_i}{\Delta t_i} \quad (2)$$

The mediation/approximation curves of the experimental values are drawn using the following analytical relations [5.9]:

- for the mass lost by erosion:

$$M(t) = A \cdot (1 - e^{-B \cdot t}) \quad (3)$$

- for the erosion rate:

$$v(t) = A \cdot (1 - e^{-B \cdot t}) + A \cdot B \cdot t \cdot e^{-B \cdot t} \quad (4)$$

where: parameters A and B are statistically established according to the method used within the cavitation laboratory of UP Timișoara [5].

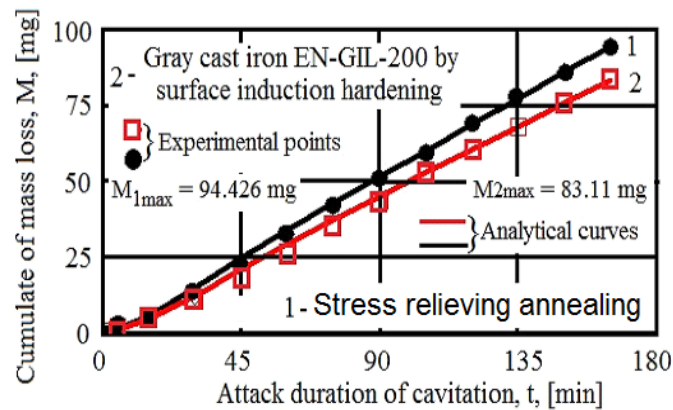


Figure 4. Mass loss variation with the vibrating cavitation attack period.

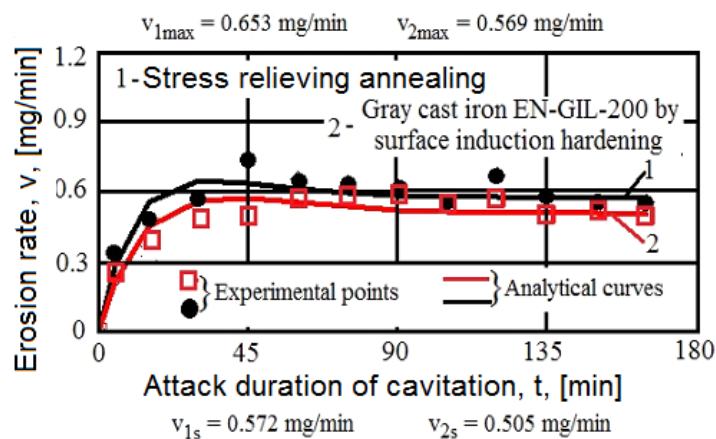


Figure 5. Erosion rate variation with the cavitation attack period.

The experimental points dispersions, of the mass losses related to the approximation curves, Figure 4, are very reduced, which indicates the fact that the structure of hardened surface layer is fine and homogeneous. The comparison with the annealed cast iron indicates that by performing the surface hardening, the mass loss, within 165 minutes of erosion by vibrating cavitation, is diminished by approximately 13.6 %.

The experimental points distribution, of erosion speeds, Figure 5, indicates that, during the cavitation attack, at certain moments (90, 105, 150 and 165 minutes), the behaviours are identical. From the mechanical damage point of view of the cavitated layer, the explanation is offered by identical values of the expelled metal mass, composed by equal dimensions, respectively summed, of graphite particles.

But, as seen in the experimental values distribution, after 30 minutes of cavitation attack, when the process is effectively running in the metallic structure, generally, it is brought a resistance increase, the approximation curve of the hardened cast iron being under the one of the annealed one for tempering. This growth is due, mainly, to the strength increase obtained by the surface hardening. Consequently, according to the maximum value of the erosion rate, the increase is of 14.7 %, and after the value tends to stabilize at 13.2 %.

It is interesting that in both cases, the approximation curves reach to the maximum value after nearly equal times of the cavitation attack (30-35 minutes). Similar evolutions of approximation curves $v(t)$ suggest that, from point of view of the cast iron behavior to the vibrating cavitation, by this surface hardening method, no substantial modification was obtained, but, by hardness, as indicated the correlation between the specific parameters, the surface resistance to the cavitation microjets impact increased.

4. Sclerometer examinations and microstructural analysis

The intensity of the microstructural modifications produced in the layer-substrate system has been evaluated by the Vickers hardness measurements. In Figure 6 it is shown the hardness variation curve recorded on the cross section of the induction surface hardened samples followed by tempering at low temperature. As it was expected, the hardness gradient curve corresponds to the distribution of the structural constituents present in the parts subjected to this composed heat treatment.

The layer hardened to martensite, having the highest carbon concentration interstitially dissolved in the lattice of the solid solution α , respectively a high density of lattices defects, will have the highest hardness values.

The recorded hardness values were HV = 480 - 490 daN/mm² in the marginal zone and 190 - 195 HV in the core of the sample. The working depth, defined by the depth where after the heat treatment of hardening and tempering at low temperature, it is obtained a hardness of over 480 HV, is 1.7 – 1.8 mm (Figure 6).

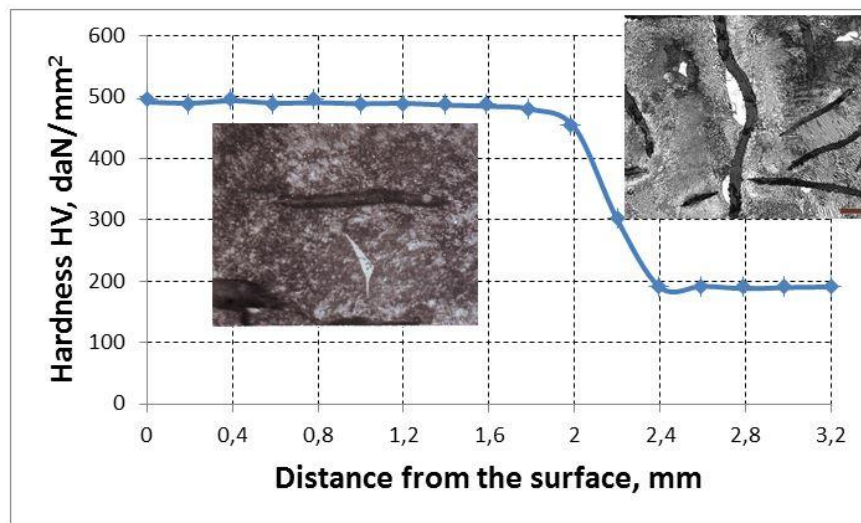


Figure 6. Hardness gradient curve on the cross section of the induction hardened sample.

By surface hardening of grey cast iron parts with pearlitic matrix it is desired to obtain a significant increase of the wear resistance. The existence of lamellar graphite separations in the metallic mass structure lowers the transformation stability of the subcooled austenite and initiates its decomposition in ferrite or pearlite. For this reason, the austenite contained by the cast iron is more inhomogeneous regarding the carbon content. These elements justify the lower hardness values obtained in the surface layer and a limited increase of the cavitation erosion resistance. Moreover, the presence of graphite reduces the metallic matrix which takes the mechanical requests during cavitation and concentrates the mechanical loads in the separations peak, due to their notch effect. The sharper the graphite separations peaks, the more powerful the notch effect and cavitation resistance.

Typical topographies of the cavitated zones of the different heat treated samples (Figure 7), highlights a more pronounced surface degradation in case of stress relieving annealed samples compared with the induction hardened one.

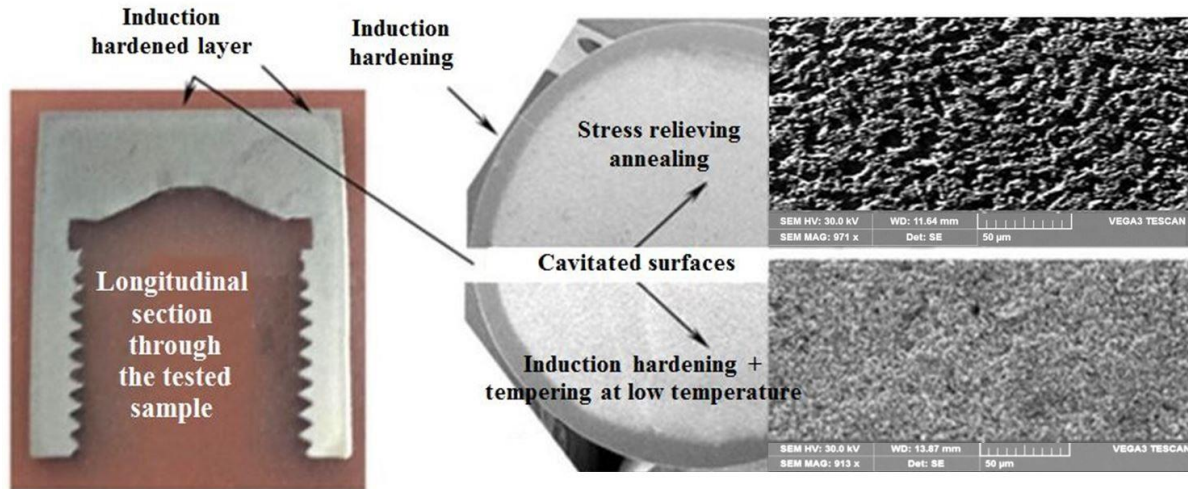


Figure 7. Macroscopic aspect of the hardened layer and of surface tested to cavitation.

5. Conclusions

Induction surface hardening of grey cast iron parts with pearlitic matrix and lamellar graphite, subjected first to the stress relieving annealing, leads to increasing of cavitation erosion resistance, expressed by the mass loss determined in 165 minutes of cavitation exposure, respectively by the final value of the erosion rate of about 13 %.

Limited increase of the cavitation resistance is justified by:

- the graphite effect, non-metallic structural constituent, which reduces the transformation stability of subcooled austenite, favouring its partial decomposition into ferrite or pearlite;
- the role of stress concentrator given by the graphite;
- matrix sensibility to the stresses concentration.

Typical topographies of the cavitated areas show a lower degradation of the induction surface hardened samples.

6. References

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