IMPROVEMENT OF CAVITATION EROSION RESISTANCE OF A LOW ALLOYED STEEL 16MnCr5 THROUGH WORK HARDENING

GHERA Cristian [1], MITELEA Ion [2], BORDEAŞU Ilare [3],
CRĂCIUNESCU Corneliu [4]

„Polytechnica“ Universty of Timisoara, Mihai Viteazul No.1, 300222 Timisoara, Romania, EU
[1] cghera@yahoo.com , [2] ion.mitelea@upt.ro, [3] ilarica59@gmail.com, [4] craciunescucm@yahoo.com

Abstract

This paper analyzes the effect of work hardening on the behavior to cavitation erosion for the low alloyed steel 16MnCr5.

Cavitation tests were conducted on a vibrator device with piezoceramic crystals, which fully complies with the requirements imposed by the ASTM G32 – 2010.

The evaluation of behavior at cavitation erosion was made based on curves gradient of hardness on the section of layer hardened by cold plastic deformation, as well as the variation curves of cavitation parameters MDE (depth of penetration of erosion) and MDER (penetration rate of erosion) with the duration of test. The topography of surfaces damaged by cavitation and the structural changes resulting in marginal layer were analyzed with light microscopy and scanning electron microscope, they justified the significant increases of resistance to cavitation erosion.

Keywords: work hardening, low alloyed steel, cavitation erosion

1. INTRODUCTION

The research in the cavitation field have as target to use the modern technologies by hardening of materials surfaces and, default to improve their resistance to the demands generated by impact with the microjets and shock waves, produced during the exploatations, through implosion to cavitations bubbles in the hydrodynamic field [3], [4], [6].

Such a process is the laser shock peening [1], [9]. The process consists of applying an opaque overlay on the surface to be treated, which can be paint or black tape. Over this is inserted a transparent overlay, wich may be water or glass. Under the action of the laser pulse, opaque layer evaporates quickly, ionized gases retained between the sample surface and the transparent layer absorb the energy of the beam and plasma state is created. The phenomenon generates pressure waves that induce compressive stresses of high values in surface layers and adjacent substrates. The microstructural deformations resulted, produce a local work hardening, and the residual stresses in the material leads to a significant increase in hardness and mechanical strength characteristics. By applying such process is estimated a significant reduction in manufacturing costs and in energy consumption needed, compared to other classical method of hardening.

The main purpose is to use beneficially the residual stress, resulting from plastic deformation of the crystalline structure of the material under the action of shock waves generated by the impact of the laser radiation with opaque layer deposited. The materials can be processed in the annealed state, which is an advantage in terms of machining by cutting, following that the pieces will be hardened to surface, and the core them to remain soft and plastic, for to take over dynamic stresses from exploitation.

2. EXPERIMENTAL PROCEDURE

2.1. Material for test

To investigate the effects of work hardening upon the behavior to cavitational erosion, chose a low alloyed steel 16MnCr5 (EN 10084-1998, No.: 1.7131), used in the manufacture of components for control, distribution and regulation devices of hydraulic drive systems [3] [4], whose chemical composition is shown in table 1, with mean values of the mechanical characteristics, in delivery status, according to table 2.

Table 1 Chemical composition of the examined steel 16MnCr5.

Steel mark	Additional and alloying elements, [%]										
	C	Si	Mn	Cr	S	P	Al	Ti	Mo	Cu	Ni
16MnCr5	0,21	0,32	0,97	1,00	0,03	0,09	0,0175	0,035	0,018	0,2	0,1

Table 2 Mechanical characteristics of the examined steel

Steel mark	Rm N/mm^2	$Rp_{0.2}$ N/mm^2	A5 %	Z %	HB daN/mm^2
16MnCr5	1174	1059	12	51	207

2.2. Treatments applied

Test samples, for the experiment, were processed in a cylindrical bar with diameter of 20 mm, subjected prior to a annealing heat treatment, by heating the material at 670 ± 10°C, and mentained at this temperature for one hour, followed by slow cooling in the oven.

After this treatment, the surface that would be subject to cavitational erosion, was rectified and polished to a roughness Rz = 0.2÷0.5 µm. After this, some of the samples were prepared for laser shock peening by applying a film of black paint, over this a quartz glass plate with a thickness of 3 mm.

The treatment was performed on a laser facility UR HTS 300, at a nominal power P=240 W, applying 39 spots/cm^2 with time of pulse t=8 ms, spot diameter is 2 mm. The energy absorbed by the opaque overlay is approximately E = 1.92 J and is calculated with the relationship:

$$E = P \cdot t \ [J] \quad (1)$$

In this way, under the action of the laser beam, the ionized gas resulted betwen sample surface and the transparent overlay, through vaporized of opaque layer, creates the plasma state. High pressure exerted on the sample surface by plasma, induce high waves by compressive, wich produces deformation of the piece material and thus a working hardening to marginal layer.

The depth of hardened layer resulting was emphasized determined by the hardness gradient curves HV0.3, and the investigations to the optical microscope.

2.3. Method and equipments for research of resistance to cavitation.

The experimental researches were conducted in the Cavitation Laboratory at the Politehnica University of Timişoara, on a vibrator device with piezoceramic crystals. Equipment, procedures of preparing and testing of samples to cavitation, and interpretation of results are fully complies with the requirements imposed by the ASTM G32 rules [5], [7], [8].

Throughout the term of cavitational attack (165 minutes each divided into a period of 5 minutes, 10 minutes and 12 of 15 minutes each), functional parameters of device was maintained at specified values (the power of ultrasonic generator 500W, frequency 20000 ± 2% Hz, amplitude of vibrations 50 µm, sample diameter

15.8 ± 0.05 mm, supply voltage 220V/50Hz, the temperature of the working fluid (drinking water) 22±1ºC. After each interval, samples were washed in acetone, dried in air jet and weighed on analytical balance.

3. EXPERIMENTAL RESULTS

3.1. Microhardness tests

Intensity of microstructural changes produced in the surface layer was evaluated and through microhardness measurements, HV0.3, hardness variation on the hardened layer thickness is shown in Figure 1

Analyzing to optical microscope, in section, the layer resulting from treatment, were observed structural changes characteristic for work hardening phenomenon, on the depth of 0.25 mm. Was observed to the surface of piece a molten layer on a very small depth of up to 5 µm, dark, with oxides resulting from impact between surface and laser beam. Between this and the hardened layer is observed heat affected zone, on a depth of about 10 µm.

In the edge area, there are values of hardness HV0.3 = 560-597 daN/mm^2, the maximum of which is located at a distance of about 0.03 mm from the surface.

The phenomenon is due to the heat affected surface layer, which is characterized by somewhat lower values of hardness.

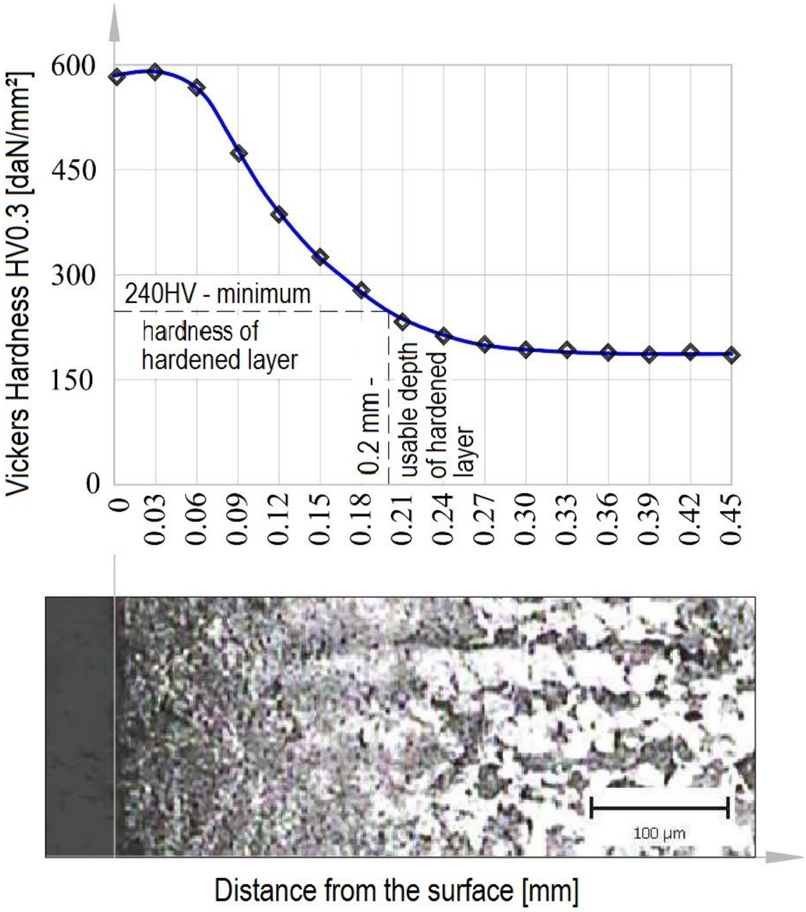


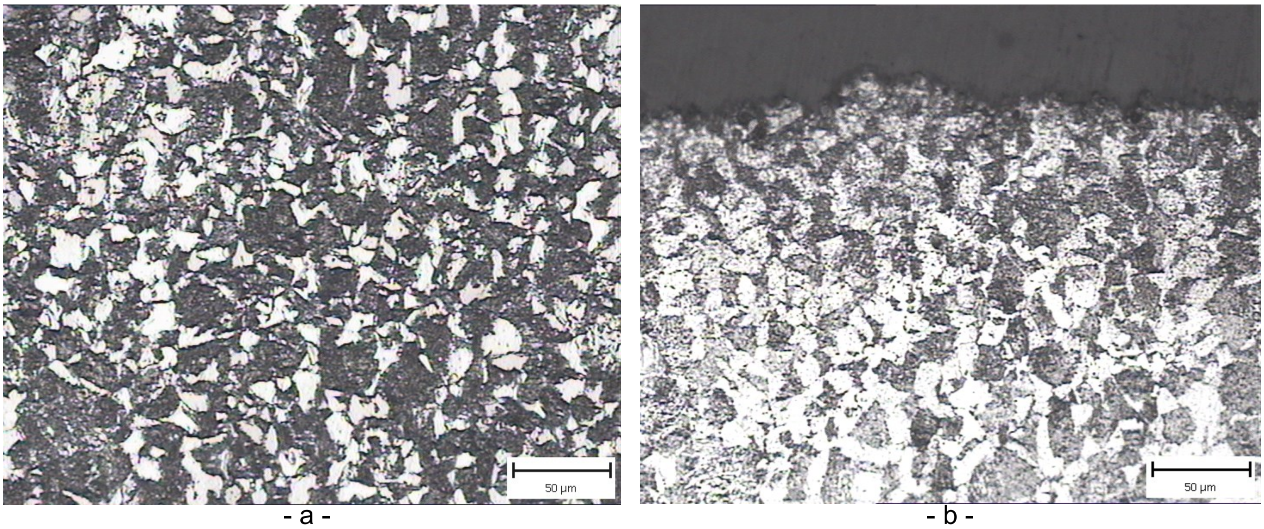
Fig.1 Hardness gradient curve from the surface toward the centre

After this maximum, the hardness values to measured points begin to decrease with increasing the depth, reaching after about 0.3 mm to the base material hardness value in annealed state, HV0.3 = 190 daN/mm^2.

Usable depth which is consider is about 0.2 mm from the surface , corresponding to hardness value HV0.3 = 230-250 daN/mm^2.

3.2. Micrographic analysis

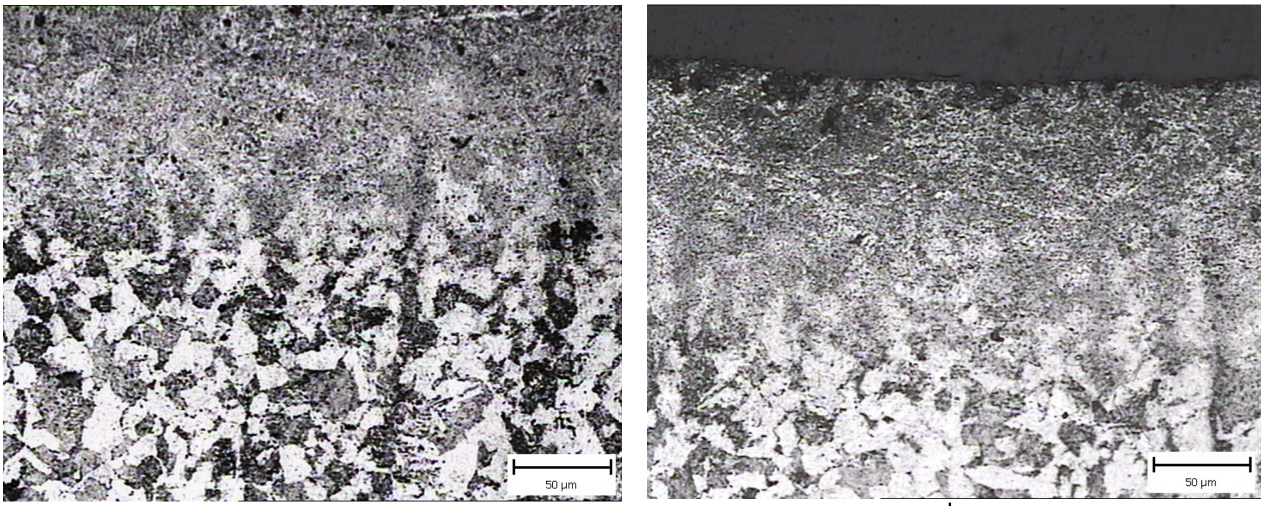
Investigations carried out to the optical microscope at different magnification orders, before and at the end of vibratory cavitation, have highlighted the nature of the structural constituents, for each phase of treatment, as on see in the pictures below (fig. 2 and 3):



- a - - b -

Fig. 2 OM image of the 16MnCr5 in annealed state: a) x200 base material, b) x200 section through the eroded zones.

In Fig. 2a results that in annealed state, the resulted microstructure is consists of ferrite, separated between the critical temperatures Ar 1 ... Ar 3 and pearlite, formed when is reached the temperature Ar1. Usually, for carbon contents of about 0.16%, the proportion of proeutectoid ferrite is higher than the pearlite [1], [5]. But, the presence of the alloying elements (Cr and Mn) in the steel chemical composition, reduced the carbon concentration for the eutectoid point, and increases stability to transformation austenite [1], [5]. Therefore, the microstructure will be composed of 65-70% pearlite (dark) and 30-35% ferrite (white). The image in Figure 2b show the extent of damage by cavitational erosion for annealed sample surfaces.



- a - - b -

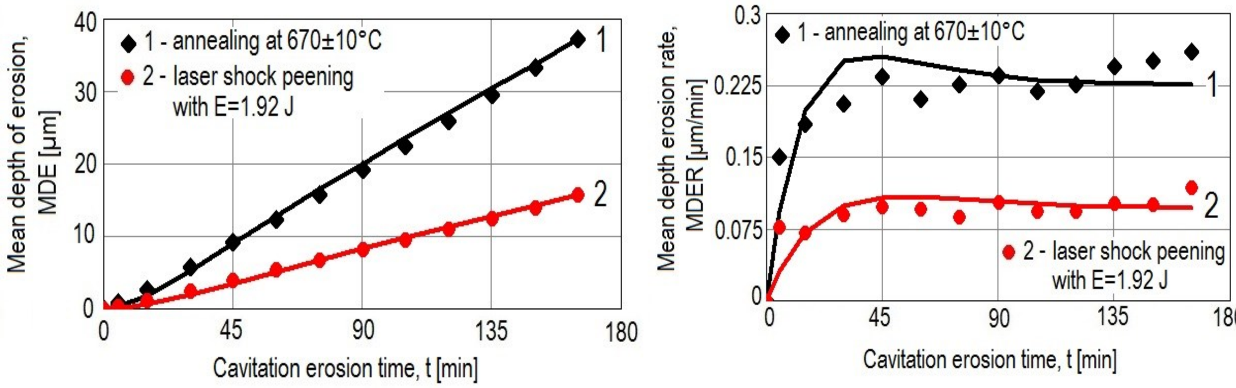
Fig.3 OM image of the 16MnCr5 in work hardened state: a) x200 the zone between the work hardened layer and the base material, b) x200 section through the eroded layer.

In Figure 3 is shown the microstructure of the work hardened layer by laser shock peening, before the cavitational attack (3a), and after its completion (Fig. 3b). It see that work hardening phenomenon causes the fragmentation and finishing of the structure of ferrite and pearlite, wich become heavily saturated with dislocations, which causes a low level of penetration of cavitation erosion in marginal layer.

Analyzing comparatively images in Fig. 2b and 3b, it is obvious that work hardened surface have a greater resistance to damage caused by impact with microjeturile and shock waves generated by the implosion of cavitation bubbles. These images show the beneficial effect that can have the laser shock peening treatment for increase the surfaces resistance, wich running in cavitational hydrodynamic fields.

3.3. Cavitation curves

Based on the mass losses, recorded at the end of each test period (5, 10 and 15 minutes) using specific relationships [3], [4] we determined the mean depth of erosion MDE, respectivly mean depth erosion rate MDER for each interval, and after that were raised the mediation curves MDE(t) and MDER(t) shown in fig. 4a and 4b.



- a - - b -

Fig. 4 The variation of cavitation parameter with time of the attack: a) mean depth of erosion; b) mean depth erosion rate

The samples 1 in annealed state, after the initial period, suffers great losses due to massive expulsions of crystalline grains and parts of those. According to investigations from the previous paragraphs, it was observed that the material in this state, is characterized by a structure composed of ferrite and pearlite, constituents with relatively low mechanical characteristics and resistance to cavitational erosion. After this phases, the mean depth erosion rate tends to stabilize at values close or slightly lower than the maximum, due to cold hardening of material and the air that entering the resulted caverns, characteristic behavior of materials with high plasticity.

At samples 2, in work hardened state, due to fragmentation and finishing of the crystalline structure of the material which result indenting hardness and mechanical strength characteristics, the mass loss are greatly diminished.

In Figure 4a are given variation experimental values at the mean depth of erosion MDE with the attack duration t. These values are proportional to the mass loss being, negligible in the first 15 minutes, period characterized by the production of cracks and elastic-plastic deformations [4].

Comparing the cumulative values of mean depth of erosion, after 165 minutes, of the two types of specimen, result that the resistance for work hardened state is of about 2.4 times higher than in the annealed condition.

In fig.4b are given the variations of the mean depth erosion rate MDER with duration of attack t. After the evolution of mediation curves MDER(t), with a tendency to stabilize at maximum, is specific for the materials with high resistance to cavitational erosion [4]. The dispersion of experimental points on the mediation curve, much lower after 15 minute, shows a microstructure homogeneity and uniformity of hardened layer, respectively to mechanical characteristics that influence resistance to cavitation. Comparing the values towards which tend to stabilize mean depth erosion rates, is observed that the work hardened layer has a resistance of about 2.5 times higher.

4. CONCLUSIONS

The analysis of results based on cavitation parameter variation curves MDE(t) and MDER(t), hardness gradient curve on the hardened layer thickness, correlated with metallographic investigations, concerning morphology the eroded structures, result that for laser shoc peening is substantially improves the behavior and the resistance to cavitation for low alloy steel 16MnCr5 compared with annealed state, thereby increasing the life of the equipment in highly developed cavitation conditions.

The typical topography at the cavitated surface, for the samples heat treated differently, shows a preferential degradation to areas of ferrite, a microstructural constituent with with a low resistance to crack initiation, an important role having the crystalline grain dimension.

Thus, the annealed material is characterized by a ferritic-pearlitic coarse crystalline structure with high content of ferrite, which favors the initiation and crack propagation, resulting in massive expulsions or parts of this. The mean depth of erosion resulted from cavitation erosion, after the test period of 165 minutes for the material in annealed state is about. 2.4 times higher compared with work hardened material.

Crystal structure strongly deformed and saturated with dislocations, resulting from laser shoc peening treatment, is characterized by a increased degree of fragmentation and finishing,that stimulates growth of hardness, mechanical characteristics and a reduction of mean depth erosion rate of about 2.5 times as compared with the annealed state.

ACKNOWLEDGEMENTS

The support by a grant of the Romanian National Authority for Scientific Research, CNCS – UEFISCDI, project number PN-II-ID-PCE-2011-3-0837 is acknowledged.

REFERENCES

[1] MITELEA I., TILLMANN W. Ştiinţa materialelor vol. I, ed. Politehnica, Timişoara, 2007

[2] MITELEA I., TILLMANN W. Ştiinţa materialelor vol. II, ed. Politehnica, Timişoara, 2007

[3] BORDEAŞU I., POPOVICIU M. Comportarea la cavitaţie a unor materiale utilizate în construcţia aparatelor hidraulice de comandă şi reglare, Conferinţa Internaţională de Sisteme Hidropneumatice de Acţionare, Vol III, Timişoara, 1995

[4] BORDEAŞU I., (2006) Eroziunea cavitaţională a materialelor, Editura Politehnica, Timişoara

[5] MITELEA I., GHERA C., BORDEAŞU I., CRĂCIUNESCU C., Ultrasonic cavitation erosion of a duplex treated 16MnCr5 steel, International Journal of Materials Research, Vol. 106, No 4, April 2015, pp: 391–397

[6] BORDEAŞU, I., MITELEA, I., KATONA, S.E. Considerations regarding the behavior of some austenitic stainless steels to cavitation erosion. METAL 2012, 21th International Conference on Metallurgy and Materials, May 23-25, 2012, Brno, Czech Republic, pp.730-735.

[7] OANCĂ O., Tehnici de optimizare a rezistenţei la eroziunea prin cavitaţie a unor aliaje CuAlNiFeMn destinate execuţiei elicelor navale, Teza de doctorat, 2014, Timișoara

[8] *** Standard test method for cavitation erosion using vibratory apparatus ASTM G32-2010.

[9] *** http://en.wikipedia.org/wiki/Laser_peening