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EFFECT OF LASER HEATING ON CAVITATION BEHAVIOUR OF Fe-Cr-Mn COATING

ABSTRACT

In the paper the investigation of cavitation resistance of Fe-Cr-Mn coating has been shown. This alloy is used in mending of machine elements subjected to cavitation. Chromium nickel stainless steel 0H18N9 was used as the substrate. Clad was tested for three cases: without additional processing, after laser heating of the solid state and after laser melting of the coating. CO_2 laser with a beam power 1000 W was used as a source of radiation. The investigated sample was exposed to cavitation loading at the rotating disk facility. The investigations were performed in the initial period of the clad damage. The plastic deformation on the investigated surfaces was defined using an image analysis. The microstructure, chemical composition and phase identification of the modified layer were examined using scanning electron microscopy (SEM), light microscopy (LM), energy dispersive X-ray spectroscopy (EDX) and X-ray diffractometry (XRD), respectively. The hardness of processed layers was investigated by a Vicker hardness tester. The results indicate, that there is different susceptible to plastic deformation caused by cavitation loading for different kind of laser processing.

Key words: *cavitation erosion, laser processing.*

INTRODUCTION

Among Among many factors contributing in the decrease of lifetime of constructions, devices or tools, wear is probably the one of the highest importance. It is especially important when occurring in areas that cannot be easily inspected using conventional methods. Cavitation erosion is one of the examples this kind of wear. Cavitation i.e. a repeated formation and violent collapse of bubbles in a liquid due to pressure changes can result in deformation and erosion of material in the vicinity of the bubbles. The failure of pipelines, pumps, water turbine blades and other hydraulic sets can often be attributed to cavitation erosion. It was found that laser surface heating of solid body led to substantial increase in its cavitation erosion resistance [1-10]. Laser heating of surface determine the mechanical state features and also creates the new state of residual stresses within processed surface layer. In many cases laser beam machining leads to formation of metastable microstructures of the materials increasing of cavitation erosion resistance of materials [10].

Assessment of cavitation erosion resistance of materials can be done by comparison of erosion curves (volume loss in time and volume loss rate) for different materials [11-13]. However investigations of materials, to determine such relationships, are labour-consuming and very expensive. In recent years many authors try to determine cavitation erosion resistance of materials observing their cavitation behaviors in initial stage of erosion [14-19].

The topic of this paper is the research on the influence of laser surface heating of Fe-Cr-Mn clad, deposited on the chromium nickel stainless steel, on its cavitation resistance. Cavitation properties of laser processed materials have been calculated in the initial stage of erosion, on the surface of about 4 mm^2, on which cavitation intensity was constant.

EXPERIMENTAL PROCEDURES

The sample for investigations in shape of cylinder (30 x 8 mm) was made of 18/8 chromium nickel stainless steel of the grades: max. 0.08% C, max. 2% Mn, 18% Cr, 9% Ni. Next Fe-Cr-Mn alloy was surfacing by welding. Chemical composition of obtained clad is presented in Table 1. The thickness of pad ranged from 1-2.5 mm.

Table 1. *Chemical composition of investigated clad (wt %)*

C	Mn	Si	P	S	Cr
0,35	8,31	0,26	0,069	0,012	10,93

Subsequent prepared sample was superficially processed by laser beam. Continues work CO_2 laser MLT 1.2 was used as a power source. The coating surface was heated in solid state or melted along parallel paths (Fig. 1). The velocity of the sample subjected to laser processing was 0.6 cm/s and diameter of the beam spot on the processed surface was 1.6 mm, in case of laser melting and 3.6 mm in case of laser heating. Argon of purity 99.998% was used as a shielding gas to protect the focusing optics from the fumes and the molten material from oxidation. Laser treated sample was found to be crack free. Before emplacing the sample into the rotating disk, its surface has been polished in order to level roughness remained after the laser processing. After laser beam processing sample was subjected to cavitation loading at the rotating disk facility [20]. The cavitation was generated there by cylinders situated on a disk surface on the circle 300 mm. Tested sample was inlaid in the disk downstream of the cavitator. The rotation speed was 3000 r.p.m. The resulting mean gauge pressure was 155 kPa. The water of temperature 20°C was used as an active medium. The tests were performed in runs 3-5 min. long following one after another, lasting 20.75 minutes in total. The duration of each run was less than the time needed to achieve the steady state cavitation intensity. After each run, the plastic deformation on the processed surfaces (see Figs. 2 and 3), caused by cavitation loading, was defined using an image analysis [18].

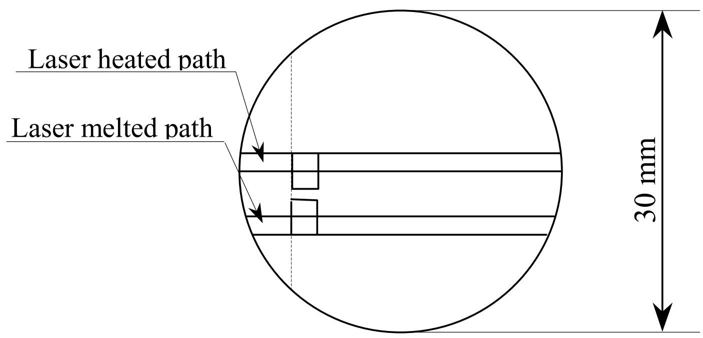

Fig. 1. Shape and dimension of processed sample. Analyzed areas are depicted by rectangles

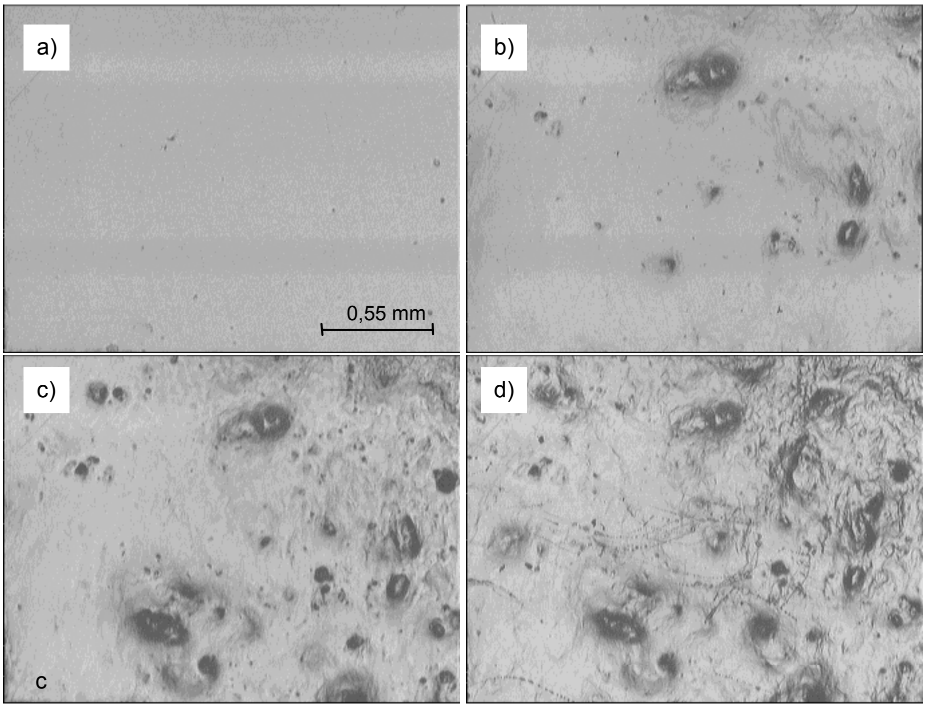

Fig. 2. Sample surface after grinding and polishing – a), and after 2 min, 4 min and 7,5 min of cavitation erosion – b), c), d)

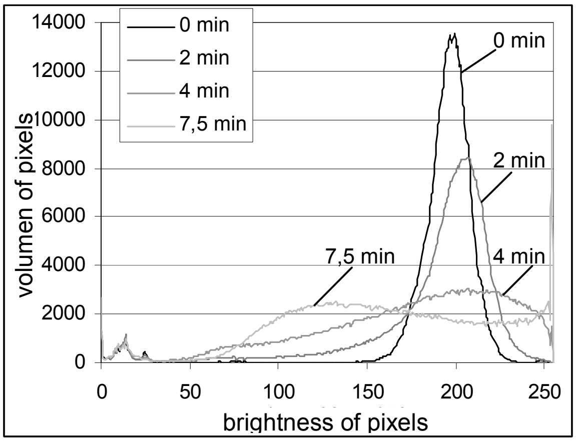

Fig. 3. Histograms of monochromatic pictures presented on the Fig. 2

Relative plastic deformation was defined as a black area fraction in the binary image of eroded surface. Binary image was obtained by binarisation of monochromatic picture with threshold 100 (Fig. 4). It means that every pixel of monochromatic picture was changed on the black if its brightness on monochromatic picture was lower than 100 in the opposite case the pixel was changed on the white (monochromatic picture i.e. eight-bit picture has $2^8 = 256$ levels of gray).

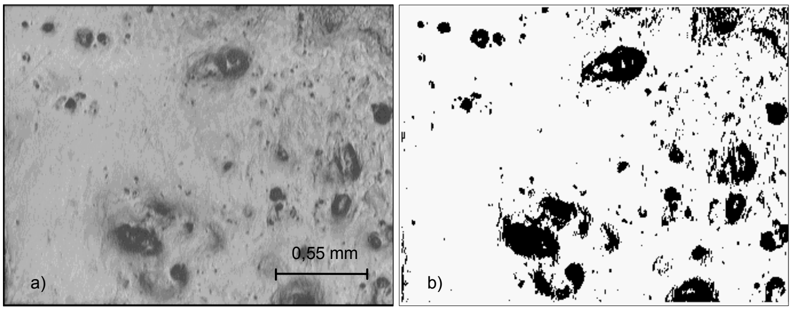

Fig. 4. Monochromatic picture of deformed surface – a) and the same picture after binarisation with threshold 150 – b)

RESULTS AND DISCUSSION

Microstructure of investigated clad contained martensite, austenite and $Cr_{23}C_6$ carbides (Figs 5 and 6). Microscopic and X-ray diffractometry investigations reveled in microstructure lower content of $Cr_{23}C_6$ after laser beam processing. Laser melting and heating in solid state caused dissolution of chromium carbides (Fig. 7 and 8). Average microhardness of not processed clad achieved 579 HV. Laser heating in solid state caused increase microhardness to 619 HV (6.8 %) and laser melting to 628 HV (8.5%). Depth of processed surface layer equaled 0.4 mm in case of laser melting and 0.2 mm in case of laser heating in solid state.

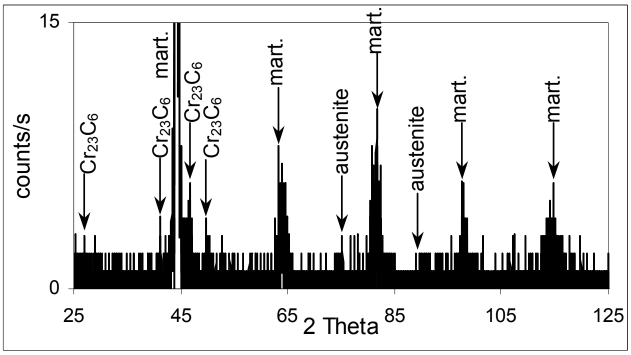

Fig. 5. Result of XRD analysis on the surface of not processed clad

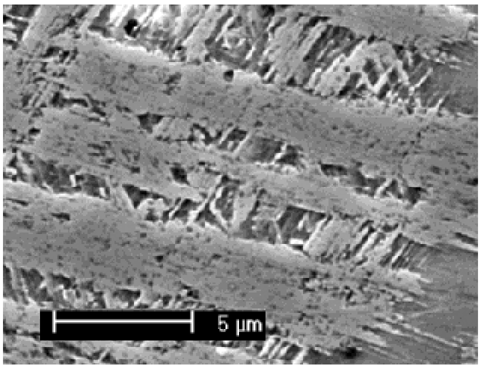

Fig. 6. Microstructure in surface layer of not processed clad reveled on the cross section (SEM)

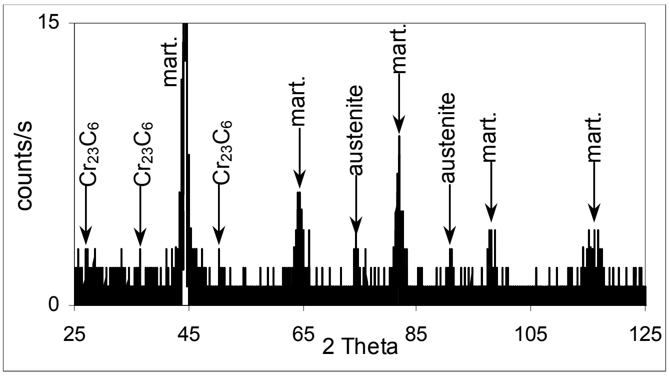

Fig. 7. Result of XRD analysis on the surface of laser melted clad

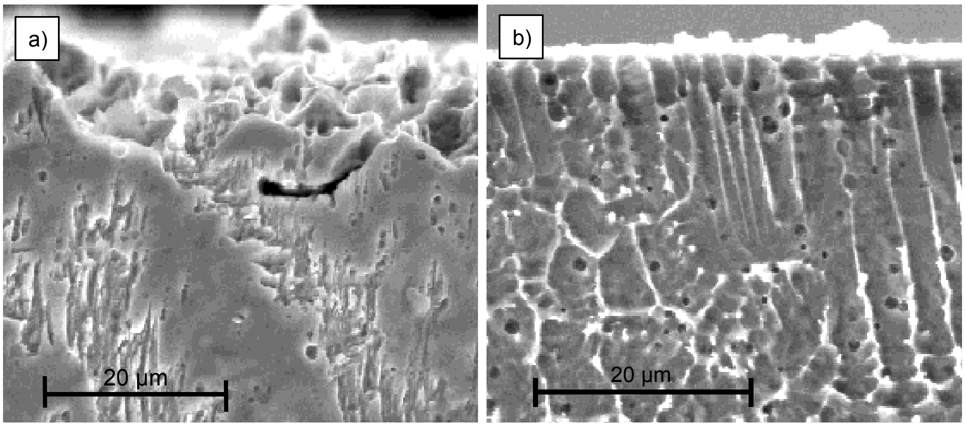

Fig. 8. Microstructure in surface layer of laser heated (Fig. a) and laser melted (Fig. b) clad reveled on the cross section (SEM). Plastic deformation and microcrack caused by cavitation loading (Fig. a) and micropores due to melting (Fig. b) are visible

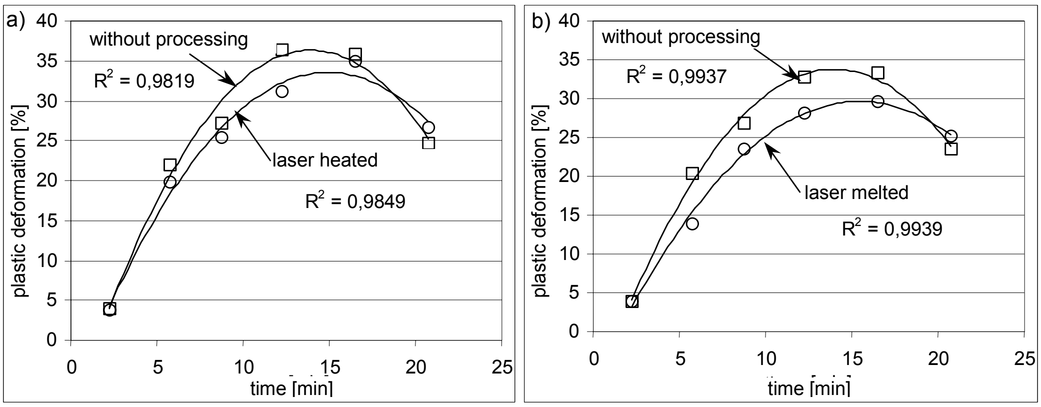

Fig. 9. Variations of the relative plastic deformation of surface as a function of cavitation time for laser heated area (Fig. a) and laser melted area (Fig. b)

The series of cavitation erosion curves i.e. time variations of relative plastic deformation are presented in Fig. 9. In all investigated cases, the cavitation damage of the laser processed surface was less than damage not processed surface. Energy of cavitation cloud is changed on the work of plastic deformation of surface W_{pl}. W_{pl} can be defined as:

$$W_{pl} = \int_0^T z(t)\,dt \tag{1}$$

where z(t) – function of plastic deformation of surface, T – time of reaction of cavitation loading.

Mathematical model describing cavitation erosion of materials was proposed in [23]. The model describes influence of material properties i.e. resistance to plastic deformation under cavitation loading, relative stress intensity factor of eroded surface layer under cavitation loading, and depth of cavitation stresses act in material, on the progress of cavitation erosion. In this model the runs of cavitation erosion curves depend not only on the intensity of cavitation loading and materials performance, but also on the eroded volume of material.

The volume loss of eroded material in this model is described by formula:

$$V(t) = V \cdot \exp\left\{ \frac{H}{h} \ln\left[1 - \exp\left(-J \cdot A \cdot h \cdot \left(\frac{t}{K_{c_d}} \right)^{\frac{1}{W_{pl}}} \right) \right] \right\} \tag{2}$$

where:

- V – volume of eroded material,
- H – height of eroded sample,
- A – eroded area,
- J – relative intensity of cavitation,
- h – reaction depth of cavitation stresses in material (depth of strain hardening)
- W_{pl} – relative work of plastic deformation on the eroded surface,
- K_{cd} – relative stress intensity factor of eroded surface layer under cavitation loading.

Equation for velocity of erosion is got after differentiation and reduction (1):

$$\frac{dV}{dt} = V(t) \cdot \frac{V \cdot I \cdot t^{(1-W_{pl})/W_{pl}}}{W_{pl} \cdot \left(K_{c_d}\right)^{1/W_{pl}}} \cdot \frac{\exp\left[-I \cdot A \cdot h \cdot \left(\frac{t}{K_{c_d}} \right)^{1/W_{pl}} \right]}{\left\{ 1 - \exp\left[-I \cdot A \cdot h \cdot \left(\frac{t}{K_{c_d}} \right)^{1/W_{pl}} \right] \right\}} \tag{3}$$

How result from formulas (1) and (2) cavitation erosion progress depends on the resistance to plastic deformation of materials under cavitation loading ($1/W_{pl}$).

On Figs 10 and 11 influence of resistance to plastic deformation of eroded material surface ($1/W_{pl}$) on the run of cavitation erosion curve is presented. How result from these figures increase of resistance to plastic deformation causes prolongation of incubation period and also it strongly influences on the volume loss rate. Both low resistance to plastic deformation and high resistance causes high erosion velocity. Such relationship can explain reports of other authors that neither high nor low hardness of material does not guarantee high cavitation erosion resistance [6, 21, 22].

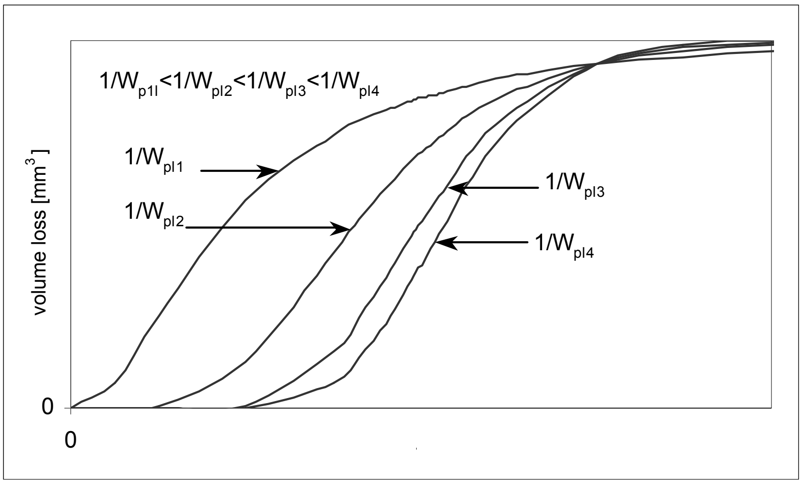

Fig. 10. Influence of resistance for plastic deformation under cavitation loading on the volume loss of eroded material in time

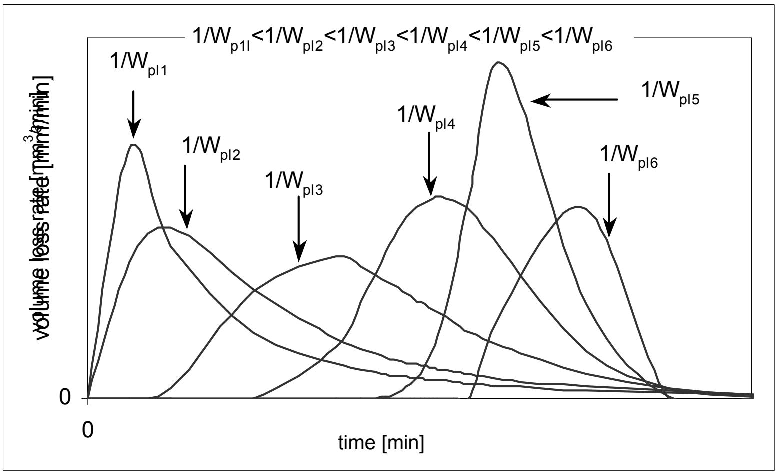

Fig. 11. Influence of resistance for plastic deformation under cavitation loading on the velocity of cavitation erosion

For investigated sample areas processed by laser beam have lower W_{pl}. W_{pl} for laser heated area achieved 7% and for laser melted area 13.5% lower value than for not processed areas (Fig. 12).

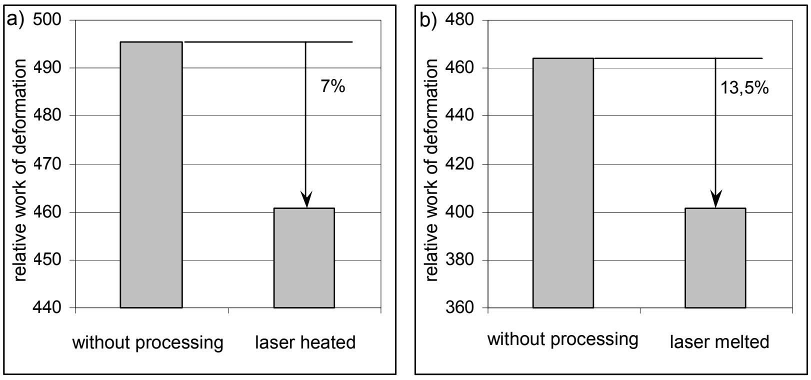

Fig. 12. Relative work of plastic deformation W_{pl} for laser processed and not processed clad for T = 20 min

Figs. 13-14 present influence of depth of processed surface layer (H) on the cavitation erosion. These figures are showing that, when depth of processed surface layer is increasing, incubation period is increasing too and velocity of erosion is decreasing. Laser surface processing causes obtainment thin surface layers (in this case 0.2-0.4 mm), that is why the main aim of surface processing ought to be obtained surface layer with long incubation period.

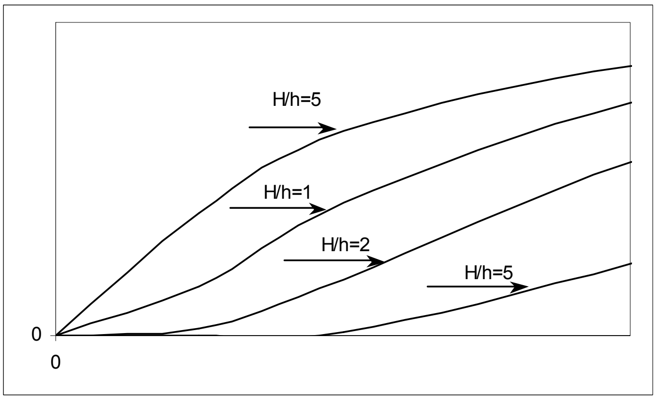

Fig. 13. Influence of depth of processed surface layer (H) on the volume loss in time (h = const)

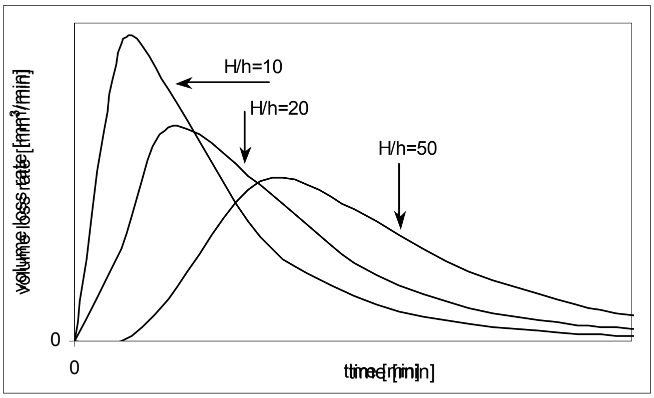

Fig. 14. Influence of depth of processed surface layer (H) on the velocity of erosion in time (h = const)

CONCLUSIONS

1. The laser surface melting lets obtain deeper processed surface layer than the laser heating in solid state. Increase volume of processed material prolongs incubation period and decrease maximum volume loss rate [23].
2. The laser surface processing causes increase of resistance to plastic deformation of processed surface layer about 15.6% in case of laser melting and 7.5% in case laser heating in solid state. Increase resistance to plastic deformation prolongs incubation period too [23].
3. The laser surface melting causes obtainment of microstructure with micropores what can decrease of cavitation erosion resistance of processed surface layer.

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