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SEARCH FOR LASER PROCESSING PARAMETERS WARRANTING AN INCREASE IN THE CAVITATION EROSION RESISTANCE OF 2H13 AND 1H18N9T STEELS

ABSTRACT

In the paper the investigations of cavitation erosion of 2H13 and 1H18N9T steels superficially remelted by laser beam arepresented. The experiments were carried out at the incubation period of the erosion. Rotating disk facility was used for generation of the cavitation loading. Influence of the parameters and processing conditions on the increase of cavitation erosion resistance was assessed. It was established that martensitic structure in 2H13 steel, created due to rapid cooling within the narrow path of the remelting did not lead to durable improvement of the metal resistance to cavitation attack. It was also stated, that strain-hardening of the remelted layer manufactured in 1H18N9T steel as well as the residual stresses relaxation in course of the pulse radiation processing are most profitable for increasing of the caviation resistance of the latter material.

INTRODUCTION

Cavitation erosion resistance of the materials is related to the specific intensity and the structure of the erosion impingements and depends on the structural and mechanical features of the solid body. In order to achieve the desirable level of the resistance the proper way of the material processing should be applied. Especially, the choice of the method and parameters of the processing by laser beam radiation is of great significance in case of the material protecting by manufacturing of the appropriate surface layers.

The results of numerous works prove that laser remelting, transformation hardening, alloying or cladding lead to the substantial increase in the cavitation erosion resistance of the materials (e.g. [1-8]). However, effectiveness of the processing depends decisively on choice of the laser beam and processing parameters. Any variations of the time and space characteristics of the laser radiation cause variations in temperature fields as well as the rates of material heating, cooling or phase transformations. As a consequence, various microstructures and internal stresses fields within the processed steels are formed.

An interest in developing of laser methods for the protection of solids against cavitation erosion links to the conviction that manufacturing of the hardfacing surface layers could eliminate the threat of erosion in case of low intensity cavitation. Results of the laboratory observations indicate that even slight increase of cavitation resistance defined in the incubation period of the erosion at high intensity cavitation loading is tantamount to the achievement of high resistance (high durability of the manufactured surface layers) at the field conditions, which are usually characterised by the low intensity loading.

In this paper the results of the investigations of cavitation erosion of steels 2H13 and 1H18N9T remelted superficially by CO_2 laser beam (of approximately 6000W for both pulse and continuous wave modes) with various distributions and densities of the power are presented. Moreover, the cavitation performance of the samples processed by 1000W cw CO_2 laser along multiple parallel paths are shown.

SETUPS AND PERFORMANCE OF EXPERIMENTS

The investigated samples were prepared of 2H13* chromium steel (of chemical composition [%]: 0.16-0.25 C, max 0.8 Mn, 0.8 Si, 0.04 P, 0.03 S, 0.6 Ni, min 13.0 Cr) hardened and low tempered before the laser processing and of 1H18N9T[*]* acid resistant steel (of chemical composition [%]: 8-10 Ni, 17-19 Cr, max 0.1 C, 2.0 Mn, 0.8 Si, 0.045 P, 0.03 S) subjected to quenching at 1050°C. These steels are commonly used in hydro-machines building as well as for constructions exposed to corrosion/erosion processes. Thermal processing of steel 2H13 – hardening and low tempering – was accomplished for twofold reasons: (1) in order to preserve the residual stresses field petrified within the laser remelted regions of the samples and (2) not to lower the hardness of the material, which is the case of high tempering. Low tempering is accepted thermal processing in case of steel 3H13 for the above mentioned reasons.

The basic parameters of laser interaction conditions are presented in Tab. 1. The steels processed with 6 kW power beam (laser installed in Technical University of Kielce, designated here as LK) were heated uniformly along the 20 mm and 10 mm width paths and nonuniformly – along the 3 mm width paths with power distribution related to TEM 01 mode. The areas of the steels processed with 1 kW beam (laser installed in Institute of Fluid-Flow Machinery in Gdańsk, designated here as MLT1,2) were covered by attached or separated parallel traces. As a result of the heating, the surface layers were remelted up to 0.3 mm in depth. The method of the laser processing was described in details in [9]. In order to shape the laser radiation spot as a rectangle, the outer mirror optics was applied.
Further preparation of the samples consisted in polishing of their surfaces in order to smooth out the roughness remained after laser treatment.

The prepared workpieces were subsequently subjected to cavitation impingement at the rotating disk facility [10]. The cavitation was generated there by bolts situated on the disk surface along circumference of 300 mm in diameter. Cavitation bubbles collapsed in core of vortexes appeared behind the bolts. The specimens were inlaid in the disk, downstream of the bolt. Their rotation speed stand for 3000 r.p.m. Resulting mean gauge pressure was 1550 hPa. Total duration of the samples exposition to the cavitation attack was 30 minutes and the tests were performed in 3 or 4 minutes long runs.
After each run the microscopic observations of the sample surfaces were done and the level of their blackening due to increase of cavitation pits and indentations was registered.

The relative resistance of the processed part of the material to its unremelted part was defined by the following index: η = (Nref-N)Nref, where N stands for the blackening of the laser processed part and Nref refers to the blackening of the analogous area on the reference surface. This method of defining of the cavitation resistance gives approximate results to the method based on pits counting. The latter is accepted way of quantifying the cavitation damage of the materials (e.g. [11]). In our work, the pits of various dimensions exerted by cavitation impact were counted both for processed and so-called reference specimens. In order to trace the time changes of

[*]designation according to Polish Standards PN-71/H86020

cavitation resistance of the samples, the quantity η = (Nref-N)Nref was calculated and potted as a function of time. N means the area under the size distribution of the pits registered on the alloyed surface, and Nref – the area under the size distribution of the pits on the reference (not alloyed) material.

Table 1. *Conditions of the surface processing*

	Laser LK	**Laser MLT1,2**
Beam power [W]	6000	1000
Beam mode	TEM 01	TEM 01 + TEM 00
Beam diameter [mm]	16	12
Beam divergency [mrad]	2	1.5 - 1.7
Focussing element	Set of the mirrors (Kugler)	ZnSe lens
Focus length		3.5”
Diameter of the beam spot on the metal [mm]		1.6
Sample velocity [cm/s]	*	0.6
Schielding gas	Argon	Argon

Samples processed with LK laser			
Sample designations	**Dimensions of the spot**	**Sample velocity**	**Working mode**
2H13-1	dia 3 mm	1.8 cm/s	cw
2H13-2	rectangle 10mm x 1mm	1.8 cm/s	cw
2H13-3	rectangle 20mm x 1mm	1.2 cm/s	cw
2H13-4	dia 3 mm	3.6 cm/s	cw, beam power: 5300 W
2H13-5	dia 3 mm	1.8 cm/s	cw, beam power: 5300 W
1H18N9T-1	dia 3 mm	1.8 cm/s	cw
1H18N9T-2	rectangle 10mm x 1mm	1.8 cm/s	cw
1H18N9T-3	rectangle 20mm x 1mm	1.2 cm/s	cw
1H18N9T-5	dia 3 mm	1.8 cm/s	100 Hz

Samples processed with cw CO_2 MLT1.2 laser			
Sample designations	**Dimensions of the spot**	**Sample velocity**	**Mutual situation of the remelted traces**
2H13(51)	1.6 mm	0.6 cm/s	Attached
2H13(52)	1.6 mm	0.6 cm/s	Separated

RESULTS AND DISCUSSION

Values of η at various times of cavitation erosion of 2H13 steel (samples 1, 2, 3) remelted superficially at various geometry of interaction with laser beam are presented in Fig. 1. The results presented in Fig. 1 indicate, that until the 3 min of cavitation the surface deformation of the processed sample was imperceptible, as regard to the deformation of the unprocessed sample.

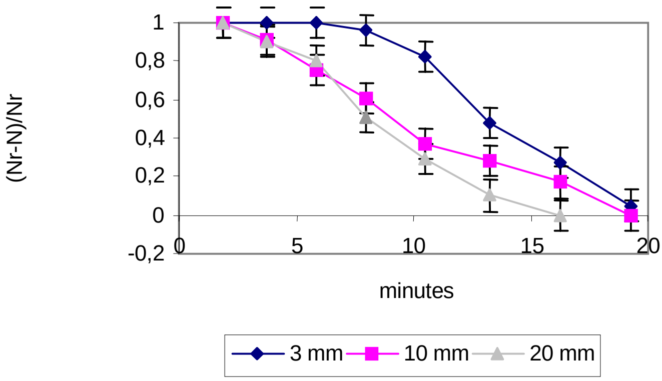

Fig. 1. Variations of the value of η coefficient detected on the 2H13 steel surface with respect to the time of the exposition to cavitation loading. The samples were remelted along the paths of 3, 10 and 20 mm width

Moreover, the differences between the shapes of the curves plotted for various widths of the remelted paths are not observed. The more substantial decrease of the resistance (the increase of the relative pits multiplication rate defined by η) at shallow and wide remelted paths was caused by perpendicular dendritic structure formed within this layer (Fig. 2) and due to high hardness of the core material which deters the developing of the cracks. The edge of the sample processed by 6000 W beam of 20 mm width and at the relative velocity of 12 mm/s is presented in Fig. 3. The sample visualised was subjected to the cavitation loading of very high intensity for 20 mins. Significant differentiation of the microhardness within the whole section of the sample was detected (Fig. 4). The highest value of 488 HV0.5 was found within the transient zone between the heat affected zone and the remelted region. Microhardness of the dendritic structure of the surface-remelted layer (339 HV0.5) happened to be less than microhardness of the martensite at heat affected zone (398 HV0.5).

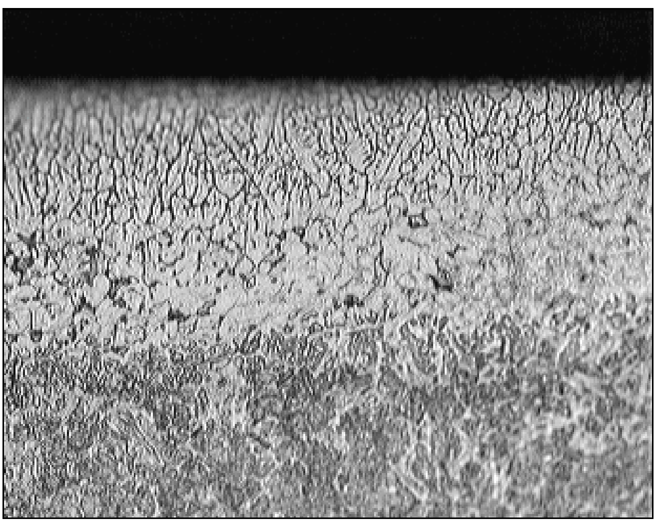

Fig. 2. Microstructure of the surface layer of steel 2H13 remelted along the path of 20 mm width. Etched with $C_6H_2(NO_2)_3OH$-HCl. Surface hardness equalled 644 HV5. Magnification 250x

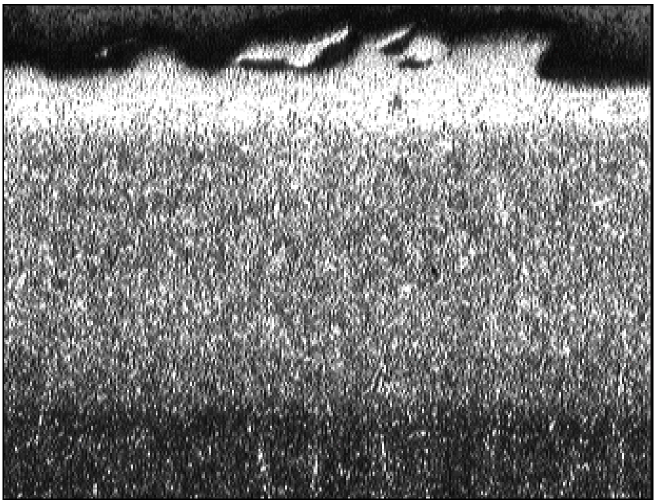

Fig. 3. Deformations of the 2H13 steel surface after 20 mins of cavitation, visible in the cross section of the sample remelted by laser beam of 20 mm width. Etched with $C_6H_2(NO_2)_3OH$-HCl. Magnification 63x

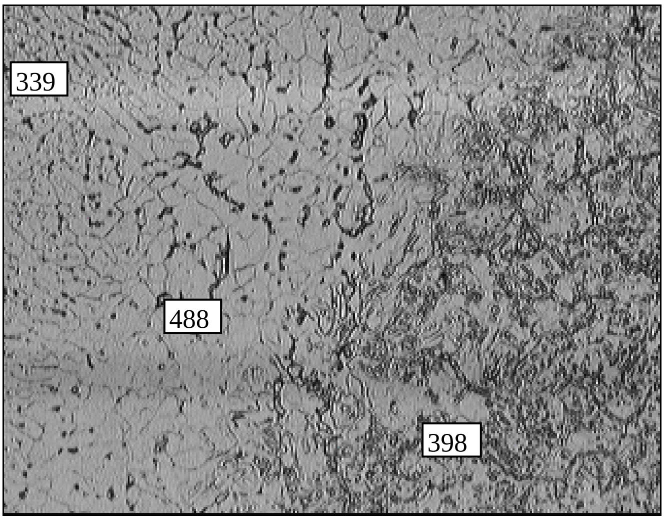

Fig. 4. Variations of microhardness (µHV0,1) along the line: remelted zone – heat affected zone. Steel 2H13. Etched with $C_6H_2(NO_2)_3OH$-HCl. Magnification 250x

In case of the materials undergoing the phase transformations during the laser processing, the influence of the residual stresses on the cavitation resistance in the initial stage of the erosion is noticeable [12, 13]. It is reflected by the values of η coefficient in Fig. 5 calculated for attached or separated paths. Within the separated paths there exists fully untempered martensite [14]. The decrease in its cavitation erosion resistance is to some extend linked to relaxation of the residual stresses. The decrease in the cavitation erosion resistance of the separated paths after 25 min. of cavitation was probably caused by lose of its stability due to the brittleness and the fatigue mode of the erosion (as in [15]). The unstability of the fully martensitic structures was pointed in [14, 16]. However, it is to be underlined, that the rate of the mass loss of the martensite during the stage of advanced erosion was relatively low due to high hardness, refined structure and destruction of the material only within thin surface layer of the steel.

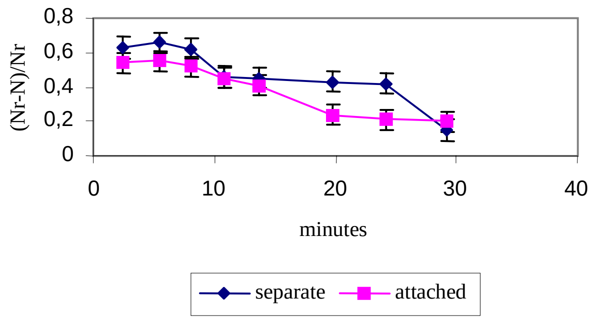

Fig. 5. Variations of the value of η coefficient detected on the 2H13 steel surface with respect to the time of the exposition to cavitation loading. The samples 2H13(51) and 2H13(52) were remelted superficially along the attached and separated paths respectively

There was revealed the dependence of the cavitation resistance of steel 2H13 achieved due to laser processing on the velocity of the investigated samples; e.g. at the velocity of 3.6 cm/s (for samples processed with the beam of the power equalled 5300 W) the high values of microhardness – 572 HV at the surface – were achieved and the increase of cavitation resistance was observed (curve 1 in Fig. 6). The twofold decrease in the processing velocity led to noticeable decrease in the cavitation resistance (curve 2 in Fig. 6).

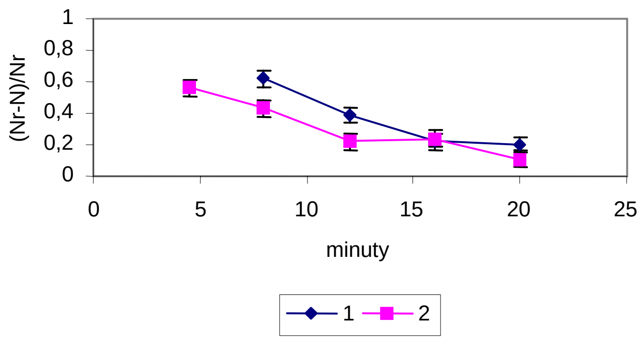

Fig. 6. Variations of the value of η coefficient detected on the 2H13 steel surface with respect to the time of the exposition to cavitation loading. The samples 2H13-4 and 2H13-5 were remelted at the velocities of 3,6 cm/s i 1,8 cm/s

An increase in the cavitation erosion resistance of chromium-nickel steel (1H18N9T) caused by the laser remelting was insignificant (Fig. 7) due to lack of the martensite transformation. The rapid decrease of η at the initial stage of cavitation for samples processed by the beam of 3 mm width should be attributed to the high brittleness and reduced strain hardening capability [16]. The slight increase in hardness and tensile strength of the melted structure is accompanied by the increase in brittleness and the decrease in the hardening capability due to deformations. The visible increase in η values observed since 8 min. of cavitation (case of 3 mm width path) or since 12 min. of cavitation (case of the pulse mode of the processing) was probably linked to the more effective strain hardening of the more refined structure (the increase in the surface hardness equalled 25%). The effect of grain size on the elastic limit of fcc structure metals is considered among others in the works [17, 18, 19]. The role of local transformations of austenitic structures of iron alloys under the cavitation loading was considered in [20, 21]. It was corroborated that erosion rate of the remelted zone with fine austenitic structure is lower than erosion rate of the reference (core) material (Fig. 8) for the fatigue mode of the erosion [22]. At the surface of the unremelted samples the numerous intergrain cracks and slip deformation bands are visible (Fig. 9). The cast structure within the remelted zone is very fine and the erosion rate is in this case specified by extraction of the entire grains, whereas the deep cracks and their easy propagation is specific for the erosion of large grains of untransformed steel. Apart from refining of the grains, dissolving of impurities and the second phase particles also contribute to the increase in cavitation erosion resistance of the remelted layers.

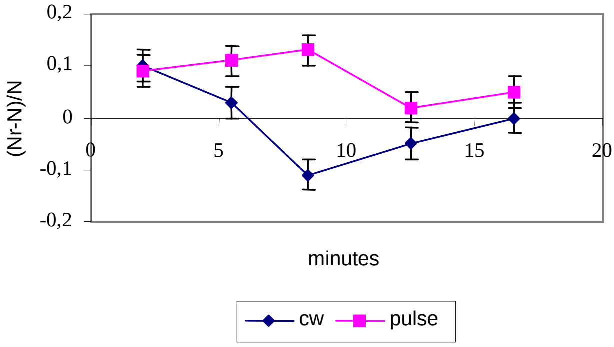

Fig. 7. Variations of the value of η coefficient detected on the 1H18N9T steel surface with respect to the time of the exposition to cavitation loading. The samples were remelted with the continuous and pulse (at the frequency of 100 Hz) laser beam along the path of 3 mm width

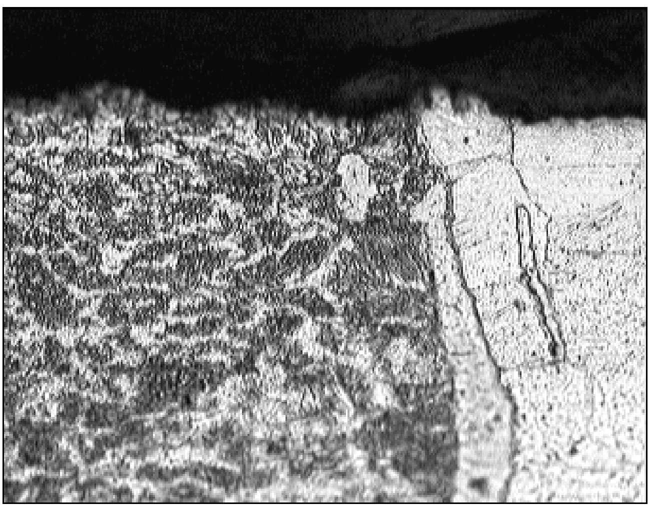

Fig. 8. Steel 1H18N9T. The edge of the sample at the boundary between the remelted and unremelted zones – after 30 mins of cavitation. Etched with HNO_3–HF.
Magnification 250x

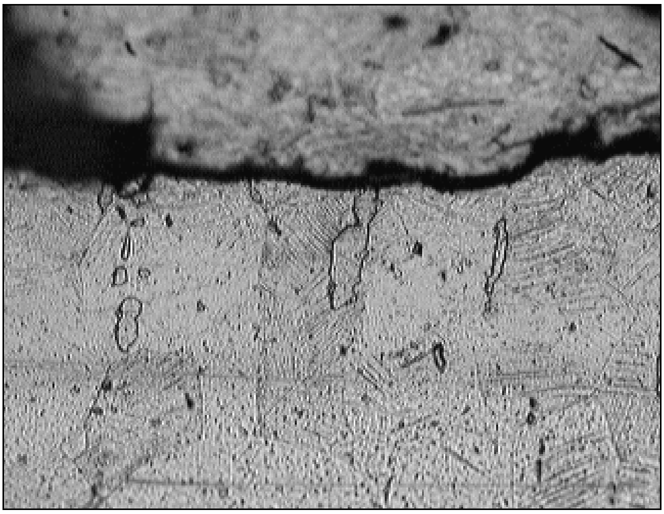

Fig. 9. Steel 1H18N9T. The edge of the unprocessed after 30 mins of cavitation. Etched with HNO_3–HF. Magnification 250x

CONCLUSIONS

1. Processing of the steel 2H13 by the radiation of high intensity let to achieve better cavitation erosion resistance than processing by uniform and broad laser beam of relatively reduced intensity.
2. The effectiveness of the improvement of cavitation erosion resistance of steel 2H13 depends on the intensity of the laser radiation. However for all modes of the processing, the erosion resistance achieved is observed to diminish in time, finally approaching the value specific for the untreated material.
3. The laser remelting of the chromium-nickel austenitic steels seems to be advantageous from the point of view of their performance under the cavitation loading, because of the refining and uniforming of the structure as well as due to facilitating the strain hardening process.

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