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Cavitation erosion behaviour of laser processed Fe-Cr-Mn and Fe-Cr-Co alloys

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Properties

ABSTRACT

Purpose: Purpose of this paper is investigation of influence of the surface processing by laser method on the cavitation performance of the Fe-Cr-Mn and Fe-Cr-Co alloys. This kind of alloys are frequently used in Polish power plants to routine repairs of damaged blades working under cavitation loading.

Design/methodology/approach: Padding welds were tested for three cases: without additional processing, after laser heating of the solid state and after laser melting of the coating. Cw. CO_2 laser with a beam power 1000 W was used as a source of radiation. The investigated samples were subjected to cavitation loading at the rotating disk facility. The microstructure, chemical composition and phase identification of the modified and subjected to cavitation loading layers were examined using scanning electron microscopy, light microscopy, and X-ray diffractometry, respectively.

Findings: Results revealed that structure refinement due to laser processing contributes to delaying of austenite → martensite phase transformation. Kinetic of austenite → martensite transformation is different for investigated alloys and depends on the chemical composition and applied laser processing.

Research limitations/implications: Reported research ought to be completed and full cavitation curves (volume loss in time) for processed padding welds must be done.

Practical implications: Obtained results indicate that for low intensity of cavitation loading, like in field conditions, laser beam machining can increase of cavitation erosion resistance of investigated alloys due to increase of hardness and structure fine degree.

Originality/value: Confirmation that creation of the transformed and hardfacing structures by laser techniques leads in many cases to considerable changes in cavitation erosion properties of the processed materials.

Keywords: Erosion; Cavitation; Laser processing; Fe-Cr-Mn and Fe-Cr-Co alloys

1. Introduction

The cavitation phenomenon consist of the formation, evaluation and collapse of gas or vapor bubbles and may occurs in liquid phases under pressure gradients in static as well as in dynamic conditions. As a results of cavitation phenomena such a luck of efficiency of the equipment, vibration, noise and erosion of solid surfaces in contact with the liquid can occur. This loss of material is known in the literature as cavitation erosion. Cavitation wear of the metallic surfaces occurs in hydraulic turbines, ship propellers, pumps, mechanical heart valves, echo sounder membranes and other hydraulic sets.

Creation of the transformed and hardfacing structures by laser techniques leads in many cases to considerable changes in cavitation erosion properties of the processed materials [1-10]. Laser beam heating and subsequent rapid cooling leads as a rule to grain refining with sharp boundaries due to diffusion retarding and creates the state of residual stresses within the processed surface layer [11-12]. Another result of an application of laser beam to metal processing is the most cases the formation of metastable structures of the materials [13, 14].

Assessment of cavitation erosion resistance of materials can be done by comparison of their cumulative volume loss in time [15]. However investigations of materials, to determine such relationships, are labour-consuming. In recent years many authors try to determine cavitation erosion resistance of materials observing their cavitation behaviors in the initial stage of erosion [16-19].

Despite substantial progress in understanding cavitation erosion mechanism to be observed in the last years, assessment of cavitation erosion resistance of materials is not still synonymous. For example results of the International Cavitation Erosion Test (ICET) proved substantial differences in ordering of materials tested at different erosion rigs even if the same criterions of resistance assessment were applied [20-21].

In this paper influence of the laser surface processing of the Fe-Cr-Mn and Fe-Cr-Co alloys on their cavitation performance is discussed. The special attention was paid to the behaviour of these materials in the incubation period of the erosion. As a criterion of cavitation performance of investigated materials depth of hardened surface layer and hardening work degree were considered.

2. Experimental procedures

The samples for investigations in shape of cylinder (30 x 8 mm) were made of X5CrNi18-10 stainless steel of the grades: max 0.08% C, max 2% Mn, 18% Cr, 9% Ni. Tested samples were covered with Fe-Cr-Mn and Fe-Cr-Co electrodes. Chemical compositions electrodes used to obtain padding welds are presented in Table 1.

Table 1.
Chemical composition of used electrodes

	C	Mn	Si	P	S	Cr	Co
Fe-Cr-Mn	0.35	8.31	0.26	0.069	0.012	10.93	-
Fe-Cr-Co	0.31	0.55	0.30	0.016	0.010	16.5	6.07

The thickness of obtained padding welds ranged from 1-2.5 mm. Subsequent prepared samples were superficially processed by laser beam. Continuous work CO_2 laser MLT 1.2 was used as a power source. The padding welds surface were heated in solid state or melted along parallel paths. 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 samples were found to be crack free. Before emplacing the samples into the rotating disk, their surfaces have been polished in order to level roughness remained after the laser processing. The processed samples were subjected to cavitation loading at the rotating disk facility [22]. The cavitation was generated there by cylinders situated on a disk surface on the circle 300 mm. Tested samples were 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 duration of cavitation test was 70 minutes. A scanning electron microscope Philips 30/ESEM and light microscope Neophot 32 were used for visualization of microstructures in the plane normal to the processing path. Chemical composition analysis was carried out by means energy dispersive spectroscopy EDAX. The analysis of the chemical composition at the surface of the tested samples was done at the accelerating voltage of 25 kV. Phase identification of the modified layers was examined using X-ray diffractometry (XRD).The measurements of the hardness were done by means of a Vickers tester. The microhardness within the processed zone was detected at the load of 2 N.

3. Results and discussion

Microscopic investigations revealed that microstructure of both not processed padding welds consisted in austenite, martensite and $Cr_{23}C_6$ carbides. This kind of microstructure, for chemical compositions presented in Table 1, stay in accordance with the Schaffler diagram. The laser beam machining caused microstructure changes within the investigated alloys. The content of the martensite within processed regions is increased due to laser heating and rapid cooling particularly for laser melted zones. Laser melting and laser heating in solid state resulted also quench annealing of some amount of $Cr_{23}C_6$ carbides because of high degree of underheating. Besides micropores due to the laser surface processing in microstructure of melted padding welds were observed (Fig. 1). Present of micropores can decrease of cavitation erosion resistance of processed materials due to decrease in fatigue strength. In other hand laser beam machining creates the state of residual stresses within the processed surface layer. Compressive stresses can increase of cavitation erosion resistance of processed materials while tensile stresses can decrease this resistance. In addition to laser processing resulted grain refining. Due to reasons mentioned above laser processing of the padding welds led to an increase of the surface hardness.

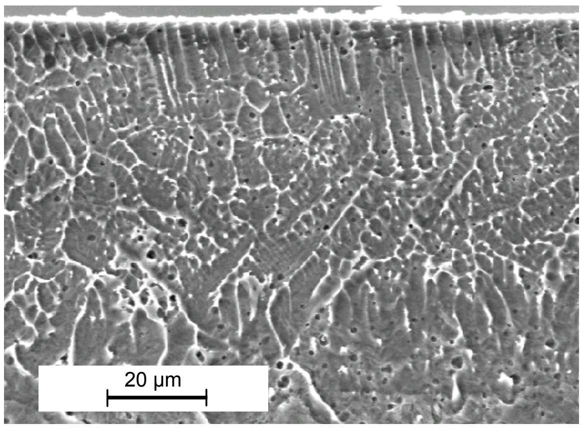

Fig. 1. Refining dendritic structure in surface layer of melted Fe-Cr-Mn padding weld reveled on the cross section (SEM). Amount of micropores is visible

Increase hardness due to laser processing is not obliged to lead to increase of brittleness of processed material because of decrease amount of carbides. On the contrary increase of hardness due to work hardening causes increase of dislocation density and lead to toughness decrease especially in presence of micropores. In other hand stress relaxation proceeds by plastic deformation or/and by crack formation. Therefore susceptibility to work hardening guarantees high cavitation erosion resistance. Kinetic of work hardening will influence on the cavitation erosion progress. Depth of work hardening is a second parameter deciding on the cavitation erosion progress. If padding weld surface layer is hardened deeper due to cavitation loading eroded material is split off on the bigger particles and volume loss rate of eroded material is higher. For those reasons depth of work hardening and work hardening degree will be considered as a parameters describing cavitation erosion resistance of the laser processed padding welds and they will be compared with those parameters for not processed padding welds.

As results from hardness investigations increase of hardness is much more due to work hardening, as a rule, than caused by laser processing. Particularly high increase of hardness for not laser processed Fe-Cr-Mn padding weld subjected on the cavitation loading is observed. It could be caused by phase transformation. High susceptibility of manganese austenite to transformation in martensite was reported in [13, 23-24]. Many cavitation erosion resistance alloys do undergo phase transformation [25-26]. The martensitic transformation depends on the composition of alloys, temperature, strain rate and stress state [27]. For reasons mentioned above, no simple quantitative correlation could be established between mechanical properties of eroded materials and their cavitation erosion resistance. Mutability of mechanical properties due to phase transformation depends also on the cavitation loading intensity. It should be noted that bubble or vortex collapse impingement is different from shock loading cases and acts only on a localizes surface of eroded material.

Decrease of work hardening degree for laser processed Fe-Cr-Mn padding weld is also observed. Refinement of structure due to laser processing resulted delaying phase transformation. This is confirmed by XRD diffraction measurements. Laser melting of surface resulted higher degree of fineness than laser heating in solid state and austenite transformation rate was lower. Slower phase transformation for the remelted stainless steel, by TIG welding method in comparison with grinded surface was also reported in [14]. Because work hardening degree for both laser processed surfaces was almost the same it could be inferred that work hardening for laser melted regions depends much more from increase of dislocation density than in laser heated case. Austenite - martensite transformation for unprocessed Fe-Cr-Mn alloy was also observed. The relaxation mechanism is identifiable by atriangular structures, resulting from sliding, as shown on the Fig. 2. This phase transformation is equivalent to a stacking fault created as every two adjoining $(111)_{fcc}$ atomic planes are successively displayed towards the $[112]_{fcc}$ direction. As a consequence of this relaxation mechanism, a triangular geometry is built up from three cross {111} planes [14]. Case of Fe-Cr-Co padding weld is opposite. For not laser processed padding weld work hardening degree of surface layer subjected to cavitation loading is the lowest and the depth of work hardening is similar like for Fe-Cr-Mn alloy. XRD investigation let identify that phase transformation is also responsible for work hardening (see Fig. 3).

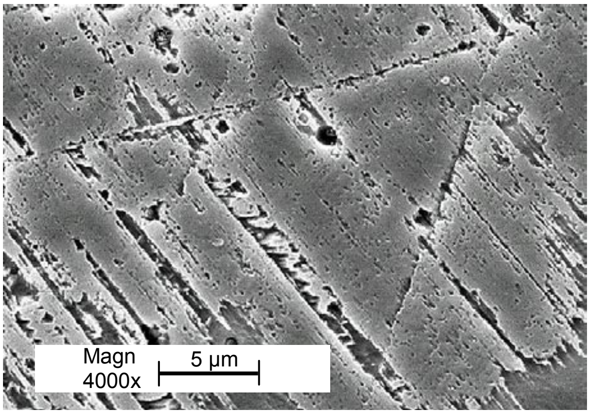

Fig. 2. Appearance of surface layer microstructure after 70 min of cavitation loading raveled for Fe-Cr-Mn padding weld

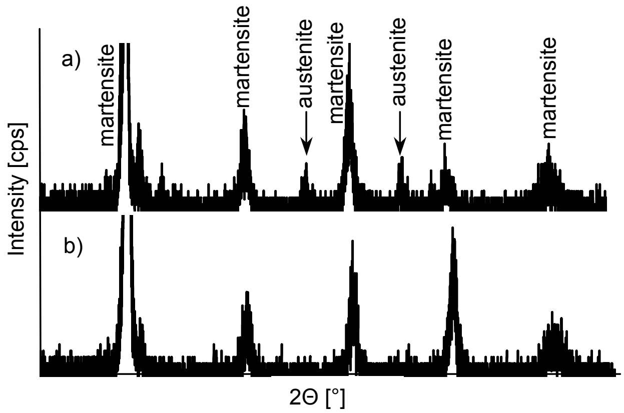

Fig. 3. Results of XRD diffraction measurements for Fe-Cr-Co not processed padding weld (a) before cavitation erosion test and (b) after 70 min of cavitation loading

But kinetic of austenite → martensite transformation is different. It is probably due to stabilizing role of cobalt, which presence contribute to reduction of stresses caused by cavitation loading. As earlier investigations identified [28] time incubation for both not processed alloys was the same. Nevertheless progress of cavitation damage in second stage of erosion for Fe-Cr-Mn alloy was faster. It seems that the faster cavitation erosion was also induced by higher content of phosphor (0.069% for Fe-Cr-Mn alloy and 0.016% for Fe-Cr-Co padding weld) witch resulted increase of Fe-Cr-Mn brittleness.

4. Conclusions

Made investigations allow to draw some general conclusions concerning influence of chemical composition and laser beam processing on the cavitation erosion behaviour of Fe-Cr-Mn and Fe-Cr-Co alloys:

1. laser melting of Fe-Cr-Co padding weld results the highest increase of hardness in processed surface layer and decrease

of susceptibility to work hardening in comparison with laser heating in solid state. Nevertheless in both cases of laser beam processing, susceptibility to work hardening was higher and depth of hardened surface layer was lower than for not processed alloy.
2. Laser beam processing decrease of susceptibility to work hardening in comparison with not processed Fe-Cr-Mn alloy.
3. Results revealed that structure refinement due to laser processing contributes to delaying of austenite → martensite phase transformation. Kinetic of austenite → martensite transformation is different for investigated alloys and depends on the chemical composition and applied laser processing

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