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Relationship between microstructure of laser alloyed of C45 steel and its cavitation resistance

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Abstract: In this work laser surface alloying of Mn, Ni, Cr, Nb, Mo, and Co on carbon steel (0.45 % wt. C) was carried out using a 6 kW cw CO_2 laser. The microstructure, chemical composition and phase identification of the modified layer were examined using scanning electron microscopy, light microscopy, energy dispersive X-ray spectroscopy and X-ray diffractometry, respectively. Cavitation behaviour of produced layers was investigated in a rotating disc facility. Cavitation properties of laser processed steel have been calculated in the initial stage of erosion, on the surface of about 4 mm^2, on which cavitation intensity was constant. Among properties characterising the cavitation erosion resistance of materials have been proposed such as intensity factor of strengthened surface layer under cavitation loading and resistance of surface to plastic deformation under cavitation loading. It was found, that better resistance to cavitation erosion was achieved if steel microstructure was susceptible to strain hardening due to content of some amount of austenite.

Keywords: Cavitation erosion resistance, Laser processing

1. INTRODUCTION

Cavitation, a repeated formation and violent collapse of bubbles in a liquid created by pressure changes, can result in deformation and erosion of material in the vicinity of the bubbles. Cavitation erosion of the materials occurs the most frequently in the fluid-flow machines operating in cavitation conditions. It is especially met in turbines, ship propellers, pumps or motor engines. The results of numerous works prove that laser surface modification leads to the substantial increase in the cavitation erosion resistance of the materials [5]. In recent years some researches attempted to improve the anti-cavitation properties of steels by enriching their surface layers with various kinds of metal or ceramic particles. However, the problem of determining the microstructures and chemical composition - the best from the anti-cavitation protection point of view - of laser modified surface is still unresolved.
Assessment of cavitation erosion resistance of materials can be done by comparison of erosion curves (volume loss in time and volume loss rate in time) for different materials [1]. However investigations of materials, to determine such relationships, are labor-consuming and very expensive. In recent years many authors try to determine cavitation erosion resistance of materials observing their cavitation behaviors in the initial stage of erosion [2,3].

The topic of this paper is the research relationship between microstructure of laser alloyed of C45 mild carbon steel and its cavitation resistance. The relationship was determined in the initial stage of erosion. As a property characterising the cavitation erosion resistance of processed surface layers have been proposed resistance of surface to plastic deformation under cavitation loading.

2. EXPERIMENTAL PROCEDURES

Samples for investigations in shape of cylinder (30 x 8 mm) were made of mild carbon steel of the grades: 0.45 % C, 0.65 % Mn, 0.25 % Si, max. 0.3 % Cr, max. 0.3 % Ni, max. 0.3 % Cu, 0.04 % P, 0.04 % S. Next powders of alloying elements were mixed with natrium water glass and the layer was placed on the sample's surfaces by pasting. Subsequent laser surface melting of the layer gave a surface metal matrix composite. Continuous work CO_2 laser TRIUMPH TLF 6000 was used as a power source. During the experimental runs the samples were moved across the laser beam along single 1 cm wide path. 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. The average data on the chemical constitution of the investigated samples detected by electron dispersive spectroscopy is presented in Table 1. The depths of alloyed surface layers were not uniform due to power distribution on the cross section of laser beam. The alloying of mild carbon steel by laser beam created surface layers of good bonding to the substrate.

Table 1.
Chemical composition and microstructures of the processed surface layers

Samples designation	Actual-post processing-chemical composition wt. %								Microstructure	Maximal thickness of the alloyed layers [mm]
	Ni	Cr	Mn	Co	Mo	Nb	Fe	C		
45-2	6.4	19.4	10.8	-	-	1.8	61.2	0.45	austenite+carbides	0.4
45-3	9.0	-	-	4.4	3.1	-	83.4	0.45	martensite+austenite	0.5
45-4	-	3.9	-	5.9	1.8	-	88.3	0.45	martensite+carbides	0.3

Before emplacing the samples into the rotating disk, the grinding and polishing of their surfaces were done.

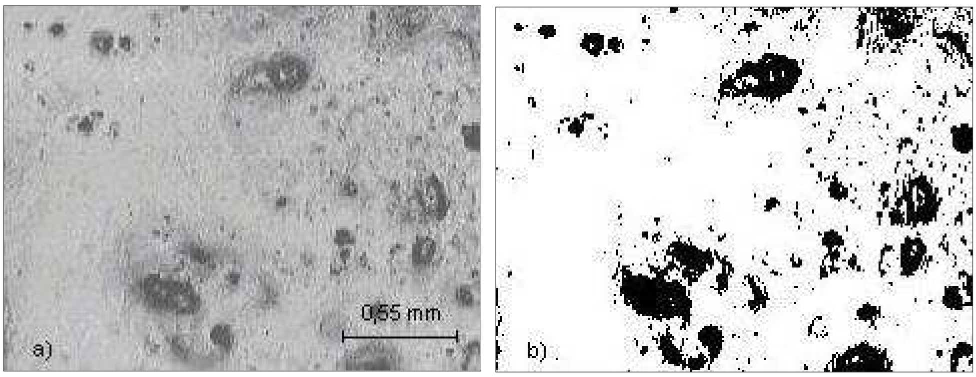

Figure 1. Monochromatic picture of deformed surface – a) and the same picture after binarisation with threshold 150 – b)

After laser alloying samples were subjected to cavitation loading at the rotating disk facility [4]. The tests were performed in runs 3-5 min long following one after another, lasting 40 minutes in total. After each run, the plastic deformation on the processed surfaces (see Fig. 1), caused by cavitation loading was defined. The procedures of calculation of resistance of processed surface to plastic deformation under cavitation loading using an image analysis of monochromatic picture of eroded surface have been elaborated. Relative plastic deformation was defined as a black area fraction in a binary image of eroded surface. The binary image was obtained by binarisation of monochromatic picture with threshold 100 (Fig. 1). It means that every pixel of a monochromatic picture was changed to black if its brightness on the monochromatic picture was lower than 100 in the opposite case the pixel was changed to white (monochromatic picture i.e. eight-bit picture has $2^8 = 256$ levels of gray). Cavitation resistance of laser processed materials has been calculated on the surface of about 4 mm^2 on which cavitation intensity was constant.

3. RESULTS AND DISCUSSION

The series of cavitation erosion curves (i.e. time variations of plastic deformation) are presented in Fig. 2. Cavitation erosion curves is not monotonic for sample 45-2 because of the pits overlapping.

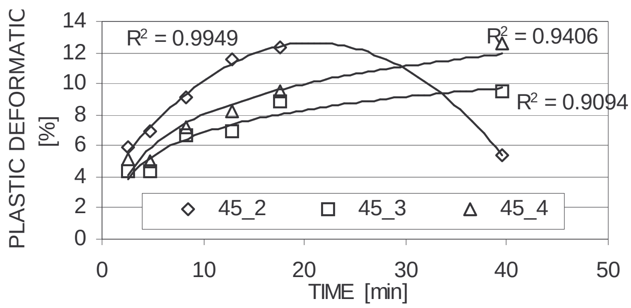

Figure 2. Dependence of plastic deformation on time

Resistance to plastic deformation of surface under cavitation loading can be defined as :

$$R = \frac{1}{\int_0^T z(t)dt} \tag{1}$$

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

Relative quantification of the materials wear resistance can be done by direct comparisons of their R and their susceptibility to brittle cracking, because stresses within the material, due to cavitation loading, can relax by plastic deformation or/and by cracking. Relative resistance to plastic deformation under cavitation loading for all investigated samples is presented on Fig. 3. How result from this graph sample 45-3 was less susceptible to plastic deformation. Results of microscopic investigations indicate that for sample 45-2 relaxation of cavitation stresses proceeds not only by plastic strain but also by micro cracks in strengthened surface layer up to the depth 0,15 mm. Microcracs, due to cavitation loading, start to propagate from places of grain boundary interception by the slip lines, in places of chromium carbides occurrences, and develop mainly along grain boundaries.

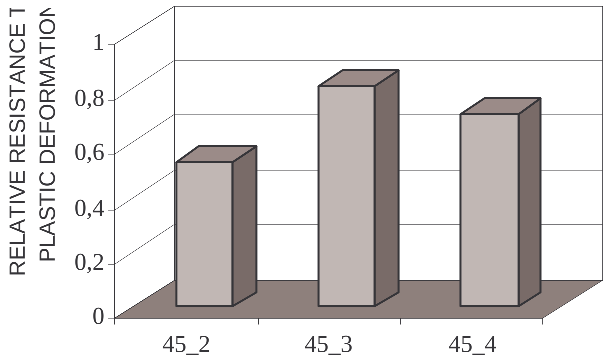

Figure 3. Relative resistance to plastic deformation measured for time T=20 min

The case of sample 45-3 is opposite. Microstructure of this sample was designed to get martensite and austenite. Austenite skeleton, susceptible to work hardening, was filled with hard martensite. This kind of microstructure is very erosion resistant. It is the case, because hard martensite can resist high stresses and softer austenite contributes an increase in strain hardening and high impact toughness.

Microstructure of the sample 45-4 consists of hard skeleton of carbides filled with softer martensite. Strain hardening degree for this sample reached the level of 13 % and was even better than strain hardening in the sample 45-2. It could be linked to hardness of HAZ which was softer than surface layer. This hard microstructure of the surface layer (900 μHV0.2) was not very resistance to crack formation. For this alloyed surface layer, the highest crack propagation rates occur under the loading. Such microstructure does not guarantee high resistance in advanced stage of cavitation erosion.

4. CONCLUSION

The results indicate that better cavitation erosion resistance is achieved if steel microstructures is susceptible to strain hardening e.g. due to content of some amount of austenite, or in the complex microstructures with matrix of high impact toughness.

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