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Photothermal Investigation of Cavitation Wear Protecting NiTi-Coatings

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Photothermal radiometry was applied to investigate the effect of abrasion by cavitation on steel which was supplied with a wear protecting NiTi film. Phase and amplitude data from areas on the sample which where damaged differently by the cavitation effect indicate the appearance of a three layer structure with the cavitation treatment. With cavitational impact the thermal diffusion time of the first layer decreases and an interfacial layer emerges which is identified as a surface region of the steel substrate which has undergone a stress induced transformation from an austenite to a martensite structure.

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1. Introduction

When a volume of liquid is subjected to a sufficiently low pressure, it may rupture and form a cavity. This phenomenon is termed cavitation inception and can occur behind the blade of a rapidly rotating propeller or on any surface vibrating in liquids with sufficiently large amplitude and acceleration. Vapour gases evaporate into the cavity from the surrounding medium, thus the cavity is not a perfect vacuum but has a relatively low gas pressure. Such a low pressure cavitation bubble in a liquid will begin to collapse due to the higher pressure of the surrounding medium [1]. As the bubble collapses, the pressure and temperature of the vapor within will increase. The bubble will eventually collapse to a minute fraction of its original size: As a consequence the gas will dissipate into the sourrounding liquid by a violent mechanism realising an intense accoustic shock wave which can destruct the surface of the moving blade.

Therefore, cavitation has a serious impact on the lifetime of turbine blades or rotating propellers in liquids. A possibility to reduce the impact of the cavitation effect is to cover the blade with a film of pseudo-elastic NiTi. The energy or at least a part of the energy produced by the collapsing bubble will be dissipated by the hysteresis loop of the NiTi film. Under the impact of the cavitation energy the protecting film will be driven elastically from the martensite state to the austenite state and back. Presuming a good contact at the interface NiTi film and blade material the lifetime of turbine blade may be increased markedly.

Here we report on photothermal infrared radiometry (PTR) studies of cavitation damages of coated hard metals.

2. Experimental

NiTi of nearly equi-atomic composition was deposited by sputter technique on the steel blade material. The thickness of the deposited NiTi film was about 10 μm. For the cavitation damage tests a commercial ultrasonic equipment was used [1]. The sonotron which was run at a frequency of 20 kHz was placed some

Fig. 1. Sample with positions of measurements. From top to bottom: non damaged, moderately damaged and strongly damaged areas on the NiTi film.

mm before the sample. The cavitation treatment lasted up to about 12 h. Figure 1 shows a photograph of the sample with the differently damaged areas. The surface damages of the charged areas were imaged by scanning electron microscopy. The surface and subsurface thermal transport properties were investigated as a function of position by photothermal IR-radiometry (PTR). For the excitation of the thermal waves in the sample, the beam of an argon ion laser with a beam power of up to 600 mW and a diameter of about 2 mm is intensity-modulated with the help of an acousto-optical modulator in the frequency interval between 0.1 Hz and 50 kHz.

3. Results and discussion

3.1. Frequency dependent signal phases

The normalized PTR phases exhibit a frequency dependence which points towards a layer structure (Fig. 2). The theoretical curves are adjusted to the experimental points based on a three-layer model. Details will be published elsewhere. The main features of the frequency dependence can be understood already in the

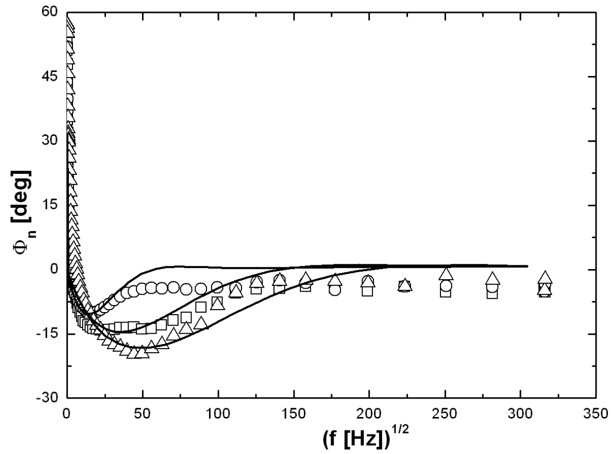

Fig. 2. Variation of the normalized phase as a function of the square root of the modulation frequency as measured at the three positions on the sample with NiTi protection layer as shown in Fig. 1. The theoretical curves are results of an adjustment of a three--layer model to both the phase and amplitude data of the non damaged area (circles), the moderately damaged area (squares) and the strongly damaged area (triangles).

frame of a two-layer structure [2]. The minimum displayed by the signal phase as a function of modulation frequency provides information on the layer properties. In the frame of a simple two-layer model the thermal diffusion time of the layer $\tau_s = d_s^2/\alpha_s$ is determined by the modulation frequency f_{extr} where the minimum occurs and the phase shift at the minimum [2]. Here d_s is the thickness of the layer and α_s the thermal diffusivity of the layer [3]. As τ_s is proportional to the inverse of f_{extr}, a decrease in the layer thickness will lead to a shift of the minimum to higher modulation frequencies. This obviously happens when the NiTi film is subjected to the cavitational abrasion (Fig. 2). Making the hypothetical assumption that the thermal difussivity of the NiTi layer has not changed during the cavitational impact, the thickness of the protection film is reduced by about 40% for the damaged and by about 65% in the strongly damaged region. The deepening of the phase shift at minimum with cavitation treatment, however, shows that in addition to the thickness also the thermal properties change as the magnitude of the phase shift at minimum correlates with the ratio e_s/e_b where e_s is the effusivity of the layer and e_b that of the substrate apart from a factor due to the different optical properties of the sample and the normalizer. The experimental points in Fig. 2 do not reach the asymptotic value of 0° at high frequencies as indicated by the theoretical curves. A possible reason for this observation may be roughness effects.

3.2. Frequency dependent signal amplitudes

The reciprocal of the amplitude normalized with that of sigradur is proportional to the effusivity for an infinite solid or to the ratio of effusivities of subsequent layers for a layered system [3]. The appearance of a maximum in the frequency dependent inverse nomalized amplitude (Fig. 3) yield evidence of a third layer which is developing with the strength of the cavitation impact. The origin

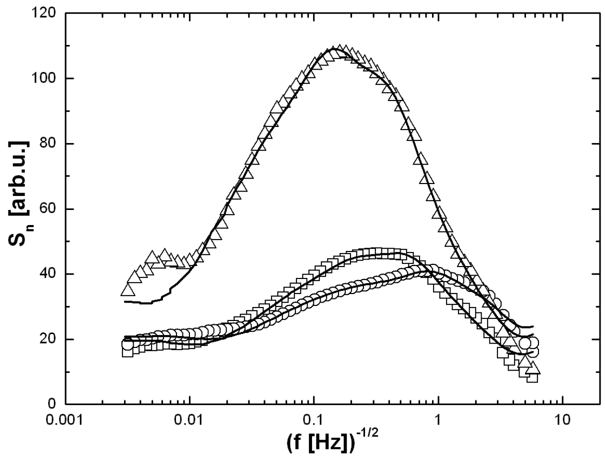

Fig. 3. Variation of the inverse normalized amplitude as a function of the inverse square root of the modulation frequency measured at the three positions on the sample as shown in Fig. 1. The theoretical curves are results of an adjustment of a three-layer model to both the phase and amplitude data of the non damaged area (circles), the damaged area (squares) and the strongly damaged area (triangles).

of this third layer may be partly due to delamination and to a modification of the steel substrate at the interface due to the mechanical impact where the latter is supported by the results of electron microscopic studies. Under axial pressure the surface near areas of the steel can undergo a structural transition from the austenite to the martensite state. Adjustment of the amplitude and phase data yields the thermal parameters for the three-layer system consisting of a surface layer, an interfacial layer and the bulk substrate. The obtained parameters clearly point towards a stress induced modification of the thermal parameters of the protecting NiTi layer and of the interfacial region between protecting layer and steel substrate.

4. Conclusion

Frequency dependent photothermal radiometry has proven to be a suited tool to explore locally the impact of cavitational abrasion on the thermal properties of steel samples covered by a NiTi protective layer. Using a sonotron cavitation, induced damages were induced on different positions of the same sample. The frequency dependence of the phase and amplitude signals measured in the thermal reflection configuration yield evidence of the modification of the thermal properties of both the protecting NiTi layer and of the steel substrate at the interface. These modifications increase with cavitational impact. Proceeding from the results of electron microscopy studies the appearance of an interface layer is attributed to a stress induced structural martensitic transition of the surface near region of the steel substrate.

Acknowledgments

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