Introductory Chapter: Cavitation - An Overview of New Research Results

Wojciech Borek, Tomasz Tański and Mariusz Król

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1. Introduction

Cavitation is one of the very well-known phenomena of the destruction of engineering materials working in water conditions or any other kinds of liquids at variable pressure value. Better understanding of all aspects related to cavitation wear will allow for more thoughtful analysis in the selection of innovative engineering materials additionally protected by various technologies or techniques in the field of surface engineering and optimization of the design of constructional elements used in the cavitation environment in such industries as river and sea transport; machining and cutting of hard metals; surface cleaning of various materials; chemical and petrochemical processes, e.g. emulsification or depolymerization; and liquid sterilization processes and also in methods used in esthetic medicine or in heating engineering, where cavitation processes are at the stage of initial investigations. This book intends to provide the reader, not only for students but also for professional engineers who are working in the industry as well as to specialists, a comprehensive overview of the state-of-the-art in new trends, research results on issues related with cavitation, cavitation wear and the ability to protect newly developed structural elements against the action of the cavitation environment.

When designing the individual components of machines or entire devices, one must draw special attention to the resistance of the elements working there, to tribological damages like mechanical, fatigue, adhesion, abrasion, hydrogen and other damages as well as to non-tribological damages like corrosion, diffusion, cavitation, erosion, ablation and many others. Considering the mechanisms mentioned above, cavitation erosion and cavitation wear are often ignored during engineering design, the dual character of which has an effect on the economics and development of particular fields of the economy in the negative and positive sense. Cavitation is generally described as a phenomenon consisting of implosion of gas bubbles in liquid, with such bubbles formed because of a rapidly falling pressure causing the creation of shock waves with the length of 0.1–0.2 mm and the speed of several 100 m/s, destroying local surfaces of elements and causing deep cavitation pits and craters [1–3].

The most effective way to weaken the effect of cavitation in flow systems is to use innovative materials resistant to cavitation wear. Also based on the results described by T. Linek in chapter of this book "Effects of Applying WC/C Protective Coating on Structural Elements Working in Cavitation Environment" can be concluded that the application of special low-friction protective coatings like WC/C coating deposited PVD method allows to reduce costs in association with the selection of engineering materials for a substrate of constructional elements working in a cavitation wear environment [4].

Cavitation is also present on components made from various engineering materials, but the usage of ceramic materials in the applications endangered by intensive cavitation could limit erosion phenomena; such approach was described in detail in the second chapter of this book. These materials were oxide ones: α-alumina, tetragonal zirconia and two composites selected from alumina/zirconia system. Otherwise, non-oxide materials like silicon carbide and silicon nitride were tested. The significant variety in cavitation wear mechanisms for all studied materials was recognized. Alumina was degraded by eliminating the whole grains from the large surface dominated by cavitation effect. Degradation of zirconia proceeded locally, along ribbon-like paths of removed grains. Cavitation wear of composites was strongly dependent on the residual stress state in the material. Alumina/zirconia composite with compressive stresses in the matrix presented a significant increase of cavitation resistance. Degradation of silicon nitride proceeded by selective degradation of glassy phase present on grain boundaries. Silicon carbide degradation proceeded by large grains fragmentation [5–8].

In the next chapter written by Toshihiko Yoshimura, Kumiko Tanaka and Masataka Ijiri, the methods and their results of processing particles by cavitation were introduced. Titanium oxide particles were treated by waterjet cavitation (WJC)-generated and multifunction cavitation (MFC) using an ejector nozzle. The basic features of multifunctional cavitation were theoretically and experimentally evaluated. Multifunctional cavitation showed the ability to perform nanolevel hot working at the surface of the material, modifying the surface morphology and the electrochemical state of the surface by hot spot melting [9, 10].

The dynamical behavior of the bubble in the nearest area of a solid wall has crucial and practical importance for the discovery of the industrial application of ultrasonic cavitation. Cavitation bubble collapsed and it produced micro-jet on a solid wall. Prediction and controlling of micro-jet process are a challenge due to complicated mechanisms of collapse of cavitation bubbles under the ultrasonic field. To determine the interaction of microjet of the key parameters that affect the acoustic cavitation, it is important to correctly identify what is the growth rate of individual bubbles and collapsing near the rigid boundary in the water. The results of numerical analysis described in the next chapter of this book show that the bubble under the rigid boundary has a lower maximum radius and a longer collapse time than the bubble under the free boundary, which indicates that the rigid boundary has an inhibition effect for ultrasonic cavitation. The velocity of the bubble collapse decreases with the increase of the initial radius of the bubble, and it rises with the increase of the dimensionless distance from the bubble to the solid wall. However, the velocity of the bubble collapse under the rigid boundary can increase first and then decrease. Therefore, it can be considered that the bubble model and its connection with the microjet have a specific reference value in theory, which gives an implication for further understanding the dynamics of cavitation bubbles on the solid wall induced by the ultrasonic field [11, 12].

Not only cavitation is a very dangerous phenomenon for engineering materials working in the aquatic environment but also erosion is important. Prediction of erosion is interesting in many aspects because it can be used to predict further remedial work and helps to understand the basic phenomenon of erosion. The prediction of erosion can be achieved by clearly defining and understanding the erosion strength of the target surface. Being a function of many independent variables, the problem of erosion prediction can be examined by introducing appropriate dimensionless numbers. The erosion of the blades of the last-stage steam turbines is a well-known problem in the turbine industry. Structural damage and loss of performance are common problems associated with erosion. Understanding of phenomenon leading to low-pressure blade erosion, erosion protection and erosion prediction have been the issues in many scientific research and interest in the steam turbine manufacturing community from the beginning of the nineteenth century. Resistant materials to erosion can be presented by its physical and mechanical properties. In materials with the same metallurgical structure, the resistance to erosion increases with the hardness of the surface [13].

Innovative engineering materials are manufactured and shaped in various technological processes aimed at controlling their microstructure and thus obtaining materials with special mechanical, physical and chemical properties, and not only. In corrosion science, this concept is used to induce better corrosion resistant to various engineering materials in corrosive environments. In the next chapter of this book, the effect and role of NCI, NAB and Monel 400 microstructures on their cavitation erosion behavior were studied. The cavitation erosion of NCI, NAB and Monel 400 in seawater under cavitation conditions of 20 kHz resulted mainly from the mechanical action of collapsing bubbles on the surface of the samples. The initiation of cavitation damage for NCI was at the graphite/ferrite interface due to microgalvanic activity and mechanical factors. For NAB, the α phase was selectively attacked at the interfaces with the intermetallic κ precipitates. The corrosion of the Monel 400 alloy began mainly within and around the grain boundaries, annealing twins and second phase particles leading to metal loss [14].

In this next chapter, interfacial characteristics and erosion-corrosion mechanism of directionally solidified (DS) Fe-B alloy with various Fe2B lamellar distributions in flowing zinc were investigated. The obtained results indicate that the formation of adhesive interfacial film depends not only on erosion time and Fe2B lamellar distribution but also on epitaxial ζ accumulation determined by the influence of zinc flow. In the meantime, microturbulence of flowing zinc can result in the formation of slip bands and erosion holes on ζ-FeZn13 surface. The flow-induced localized corrosion appears to accelerate the erosion-corrosion damage of interfacial adhesive film structure and morphology that reveals the mechanism of erosion of the liquid metal [15].

Research on the phenomena of cavitation wear is very important; the possibility of implementing the obtained research results to build mathematical models is also significant. In the last chapter of this book, authors study cavitation without end-leakage effects, the pre-in cipience contiguous fluid film solution is given by the Sommerfeld solution with the ambient state and is reduced to the π-film, and the issue of post-incipience evolution is reduced to an appropriate interpretation of a suitably defined evolution time. To treat cavitation with allowance for end-leakage effects, computation of the pre-incipience contiguous film requires a two-dimensional adaptation of the Sommerfeld solution with a consistent spline interpolation scheme, and treatment of Olsson's interphase condition is quite elaborate [16].

Author details

Wojciech Borek*, Tomasz Tański and Mariusz Król

*Address all correspondence to: wojciech.borek@polsl.pl

Faculty of Mechanical Engineering, Silesian University of Technology, Institute of
Engineering Materials and Biomaterials, Gliwice, Poland

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