Preface

This book is devoted to cavitation erosion. It provides a comprehensive review of the phenomenon and the state of the art of the research in cavitation erosion.

In brief, cavitation is the formation of vapor bubbles in a liquid flow due to local low pressures. After an initial growth phase in the low pressure (or high velocity) regions, cavitation bubbles collapse in the regions of pressure recovery. When the collapses occur repeatedly close to a solid boundary, they may induce wear and erosion. After some incubation period, material loss can increase steadily with the exposure time.

Cavitation erosion involves both liquid flow and material properties. On the liquid side, cavitation erosion depends upon the "aggressiveness" of the cavitating flow, defined in terms of the frequency and intensity of the collapses. On the material side, it depends upon the material properties which govern the response of the boundary to the cavitating flow. The actual damage will be the result of the competition between the cavitation intensity and the material strength.

Material strength may be characterized by conventional properties such as hardness, strain energy, or ultimate resilience. Correlations between cavitation erosion (typically mass loss) and material properties are unfortunately far from being universal and are generally valid only within a given class of materials and cavitation intensities. This is the reason why researchers have recently attempted to develop analytical techniques as opposed to correlative techniques.

Thanks to their built-in physical information, analytical techniques open the way for numerical predictions of cavitation damage with limited recourse to erosion tests. These techniques are made increasingly more possible due to the recent increase in computational power and resources. An overview of the founding principles of analytical methods of cavitation erosion prediction is provided in this book.

In principle, analytical techniques in cavitation erosion are very similar to conventional approaches in structural mechanics which consist of identifying the loads applied to a structure and computing the behavior of the structure under these mechanical loads using the material properties. However, there are many challenges in making this ideal approach effective in cavitation erosion.

The loading conditions in a cavitating flow are quite complex. Even for a single collapsing bubble, the impact load is still largely uncertain because of its extreme features in amplitude, frequency, and size. The situation is further complicated in real cavitating flows by a large spectrum of bubbles of various characteristics possibly interacting with each other. The response of the material to the distribution of impact loads on the boundary is also a major source of difficulties since complex mechanical and metallurgical phenomena are involved within the material, including fatigue and fracture. In spite of all the difficulties, significant progress has recently been made in the development of analytical techniques which offer the most promising option for cavitation erosion prediction.

In an attempt to address these challenges more effectively, an international collaborative project was initiated with the support of the U.S. Office of Naval Research (ONR) and ONR Global Naval International Cooperative Science and Technology Opportunity Program (NICOP program) during 2009–2012. The participating organizations were the Laboratory of Geophysical and Industrial Flows (LEGI, Grenoble, France), the Swiss Federal Institute of Technology (EPFL, Lausanne, Switzerland), DYNAFLOW, INC. (USA), the Naval Surface Warfare Center, Carderock Division (USA), and the Naval Research Laboratory (USA).

As part of this project, the International Workshop on Advanced Experimental and Numerical Techniques for Cavitation Erosion Prediction was held in Grenoble during 1–2 March 2011, supported by ONR Global. The objectives of the Workshop were to provide an informal forum to researchers currently involved in cavitation erosion research, to share the knowledge, and identify unresolved issues in understanding the phenomena, thus providing insights into analytical approaches. More than 40 experts in cavitation erosion participated and 17 technical papers were presented.

This book consists of two parts. Part I (Chaps. 1–7) was jointly written by the NICOP project team members; G. L. Chahine (DYNAFLOW, INC.), J.-P. Franc (LEGI) and A. Karimi (EPFL), summarizing the major accomplishments of the project. Part II (Chaps. 8–16) consists of selected papers presented at the International Workshop in Grenoble.

The fundamental principles of analytical techniques are presented in Part I of this book. The guiding thread throughout Part I is the concept of impact load defined as the elementary loading conditions resulting from the collapse of a cavitation bubble.

After a general introduction to cavitation and cavitation erosion (Chap. 1) and a description of typical laboratory testing methods of cavitation erosion (Chap. 2), the early stage of erosion (the incubation period) is analyzed in detail in Chap. 3. This chapter is focused on the elementary damage—a cavitation erosion pit—that results from a single cavitation impact load and provides a technique for estimating the impact load amplitude from the material properties. A statistical analysis of pits and associated impact loads is also provided for a typical cavitating flow.

Chapter 4 is devoted to the measurement of impact loads by means of pressure sensors. Distribution of impact loads in terms of amplitude and time duration are discussed as well as scaling laws followed by the impact load spectra.

The advanced stages of erosion are presented in Chap. 5. They are characterized by material removal and mass loss which result from the repetitive loading of the material surface.

Chapter 6 offers an insight into the potential of numerical methods to compute the impact load resulting from the collapse of a cavitation bubble and the formation of a permanent pit in the case of an elastic–plastic material using a fully coupled fluid–structure interaction approach.

Finally, Chap. 7 addresses the modeling of the advanced stages of erosion. A simple model of the response of a ductile material to successive impact loads is provided which makes it possible to estimate the erosion rate.

Part II is devoted to a selection of papers (each presented in a chapter) representative of the state-of-the-art research in cavitation erosion. Chapters 8–12 deal with experimental aspects, whereas Chaps. 13–16 are devoted to numerical aspects.

Chapter 8 by G. Bark and R. E. Bensow (Chalmers University of Technology, Sweden) presents various concepts of the specific hydrodynamic processes controlling cavitation erosion on marine propellers with a special emphasis on the concept of focusing of collapse energy.

The dynamics of sheet and cloud cavitation in a Venturi-type test section (converging–diverging 2D nozzle) is more specifically studied using a copper layer placed in the diverging section by P. F. Pelz, T. Keil, and G. Ludwig (Technical University of Darmstadt, Germany) in Chap. 9, whereas Chap. 10 by M. Dular (University of Ljubljana, Slovenia) confirms the strong correlation between the dynamics of cavitation structures and the erosion damage on copper-coated hydrofoils.

In Chap. 11, recent investigations in cavitation erosion conducted at the University of Fukui (Japan) are presented by S. Hattori. They include the effect of temperature, erosion in liquid metals, and prediction of erosion based on impact load measurements.

Chapter 12 is devoted to erosion by a submerged cavitating jet with a special emphasis on the effect of the nozzle geometry on the flow aggressiveness. This chapter was prepared by S. Nishimura, O. Takakuwa, and H. Soyama from Tohoku University (Japan).

The next Chaps. 13–16 address modeling and simulation issues in cavitation erosion in pumps, propellers, and hydrofoils. Using a bubble flow model, M. Fukaya (Hitachi, Japan) was able to numerically assess the cavitation intensity in a centrifugal pump and also the compressive residual stresses in a sample exposed to a cavitating jet in Chap. 13.

A compressible Euler model including shock developed by S. J. Schmidt, M. S. Mihatsch, M. Thalhamer, and N. A. Adams (Technical University of Munich, Germany) is presented in Chap. 14 to predict bubble cloud collapses and resulting peak pressures responsible for cavitation erosion. This chapter showed promising results indicating a possibility of practical applications of the tool to predict cavitation erosion susceptibility.

Modeling and simulation of bubble cloud dynamics is also the subject of Chap. 15 by G. L. Chahine, C.-T. Hsiao, and R. Raju (DynaFlow, Inc., USA). The first part of this chapter deals with cavitation dynamics on a rotating propeller using a Eulerian–Lagrangian approach with special emphasis on scaling of pressure loading. The second part focuses on the modeling of bubble cloud and shows the significance of tuning between the bubble cloud characteristics and the pressure field that is essential to generating very high cavitation impulsive load.

Part II ends with a presentation of numerical simulations of shock emission by bubble collapse near a rigid surface in Chap. 16 by E. Johnsen (University of Michigan, USA) with potential applications to shock wave lithotripsy and the spallation neutron source.

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