Wear 346-347 (2016) 78–86

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Hydrodynamic cavitation damage in water at elevated temperatures

Matevž Dular

University of Ljubljana, Askerceva 6, 1000 Ljubljana, Slovenia

ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form
5 November 2015
Accepted 9 November 2015
Available online 18 November 2015

Keywords:
Cavitation
Erosion
Thermodynamic effect
Model
Thermodynamic parameter

ABSTRACT

In the present study we show experimental campaign where cavitation erosion in water at different temperatures was investigated. In contrary to other studies, where cavitation is generated by ultrasound, we employed hydrodynamic cavitation, which more closely resembles the conditions in applications – it is known that the results obtained by ultrasonic cavitation can be misleading. The tests were performed in a radial flow test-section, which can generate very aggressive type of cavitation. Polished aluminum samples were used to investigate the damage. Temperatures in the range between 30 and 100 °C were investigated.

We found out that the temperature of the water significantly influences the cavitation aggressiveness – maximum aggressiveness was found at 60 °C.

In the last part of the work two theories were developed and tested. Micro-jet approach correctly predicted the trend but the influence of the temperature was marginal. On the other hand, the theory of the spherical bubble collapse with consideration of thermodynamic effects of cavitation produced a very good agreement to the experiments.

1. Introduction

Cavitation is a phenomenon characterized by vapor generation and condensation in high-speed liquid flows. It frequently occurs in industrial configurations such as rotating machinery, injectors, and other hydraulic devices. Most of the time it is accompanied by effects like vibrations, increase of hydrodynamic drag, changes in the flow hydrodynamics, noise, erosion, light effects such as sonoluminescence, and also thermal effects [1,2].

Thermodynamic effects become significant only when the critical-point temperature is close to the operating temperature of the fluid, as in the case of cryogenic fluids [3]. Therefore, the understanding and the prediction cavitation effects in such cases is crucial in many applications; for example the turbopumps for liquid hydrogen LH2 and oxygen LOX in space launcher engines need to have an inducer rotor installed upstream from the main impellers, in order to achieve high suction performance [4]. The inducer is designed to operate in moderate cavitating conditions, hence a minimum pressure level in the tanks must be ensured, in order to avoid the occurrence of large sheet cavities on the blades, which are often associated with large-scale instabilities. Particularity well known is the failure of the Japanese H-II rocket due to rotating cavitation in the LH2 turbopump [5]. The new generation of rocket engines will also feature the possibility of re-ignition while in orbit, hence long term operation of LH2 and LOX turbopumps under cavitation conditions is becoming an issue.

A wide range of studies related to various aspects of the cavitation erosion problem – bubble dynamics, model development, CFD prediction, material testing etc. – have been performed in the past [6–12]. They all aim at improving the physical understanding of the phenomenon. Yet it seems, that with every new step we find new phenomena and physical background, which prove that cavitation erosion process is even more complex and its prediction even more elusive [13].

The effects of medium temperature on the aggressiveness of cavitation erosion were studied as early as 1960's and 70's when Garcia and Hammitt [14], Young and Johnston [15] and Plesset [16] conducted vibratory tests. They have concluded that the decrease in the damage observed at higher temperatures can be attributed to either the increase in vapor pressure or the fact that the condensation driven collapse of a bubble at a higher temperature is slower, since more heat needs to be conducted into the surrounding fluid as a result of higher vapor density-when the temperature and pressure of the uncondensed vapor are raised, they arrest the bubble collapse, decrease collapse pressures and consequently damage.

More recently the effects of medium and its temperature on acoustic cavitation aggressiveness were studied by Hatori [17,18]. While they show that both play significant role in the process, few

E-mail address: matevz.dular@fs.uni-lj.si

http://dx.doi.org/10.1016/j.wear.2015.11.007
0043-1648/

conclusions on the physical background of the measured results are provided.

In contrary to other studies, where cavitation is generated by ultrasound, we employed hydrodynamic cavitation, which more closely resembles the conditions in space propulsion applications. Cavitation aggressiveness on aluminum samples in water with different temperatures (from low to significant level of thermodynamic effects) was observed. In the discussion we derive a bubble dynamics model, which explains the dependency between the temperature of the medium (its thermodynamic parameter Σ [19]) and cavitation aggressiveness.

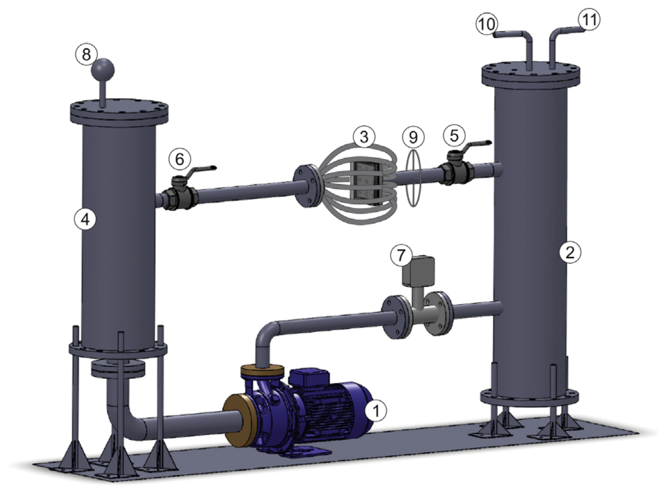

Fig. 1. Cavitation test-rig.

The present study is a step towards evaluation of erosion in cryogenic liquids under a scope of the continuous work for the European Space Agency (ESA).

2. Experiment

Cavitation tests were performed in a small cavitation tunnel at the Laboratory for Water and Turbine Machines, University of Ljubljana. The geometry was adopted from the facility at the LEGI Grenoble [9,20].

2.1. Test-rig

The cavitation tunnel (Fig. 1) has a closed circuit which enables to vary the system pressure and consequently the cavitation number (Eq. (1)), defined as the difference between the reference pressure p_∞ (measured 35 mm upstream of the test-section) and vapor pressure p_v (at system temperature T) divided by the dynamic pressure (defined by the fluid density ρ and the flow velocity v at the inlet into the section):

$$\sigma = \frac{p_\infty - p_v}{1/2 \rho v^2}. \tag{1}$$

A 4.5 kW pump (1) enables the variation of the rotation frequency in order to set the flow rate. Downstream of the pump, a partially filled tank (2) is installed for water heating and for damping the periodical flow rate and pressure fluctuations. Cavitation and its effects are observed in a test Section (3). The water enters the section axially through the nozzle and exits it by 8 flexible pipes. The tank further downstream (4) is used for cooling of the circulation water-a secondary cooling water loop is

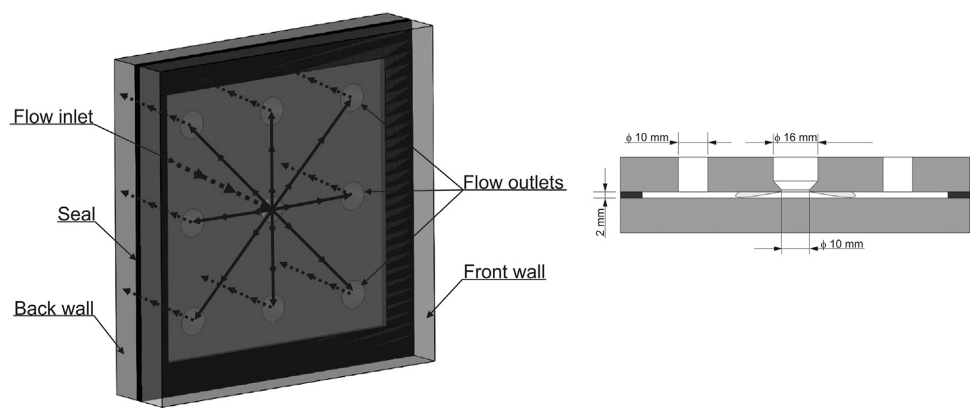

Fig. 2. Test section design with indicated general flow pattern.

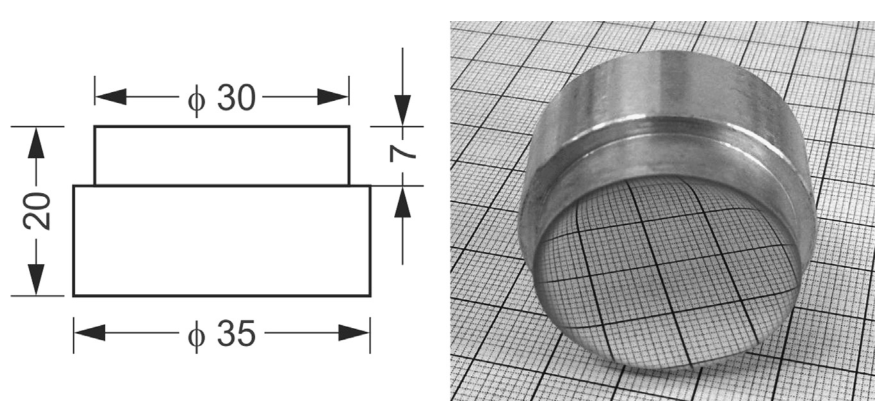

Fig. 3. Dimensions of the specimen (in mm) and its picture prior to the exposure to cavitation.