Cavitation dynamics on laser-textured surfaces

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Abstract

This study examines hydrodynamic cavitation behavior on laser-textured surfaces. Cavitation dynamics was investigated on stainless steel cylinders with 10 mm in diameter. Their surfaces were modified by direct laser texturing (DLT) with a nanosecond fiber laser (wavelength of 1060 nm). A highly-polished cylinder was used as a reference. Cavitation characteristics behind circular cylinders were monitored simultaneously by high-speed visualization and high frequency pressure transducer. Comparison at similar cavitation numbers proves, that cavitation characteristics differ significantly between different micro-structured surfaces. In some cases, cavitation extent decrease in comparison with reference – a highly polished cylinder.

Keywords: cavitation; laser texturing; fluid dynamics; surface engineering

Introduction

Cavitation as a physical phenomenon is relatively well known, and has been studied intensively since the end of 19th century on behalf of avoiding, preventing or predicting cavitation on turbine machinery. Nowadays cavitation is not considered exclusively as a negative effect of a local pressure drop in a liquid, but it can be also used as an alternative technology in various processes, such as water treatment [1]. Nevertheless, when one studies cavitation phenomena to avoid or to use them, it is preferable to know them in details. Most of the study usually considerate how basic body geometry influences on cavitation characteristics. Also scale effects on cavitation dynamics [2] have been studied, while no study with direct-laser-textured (DLT) surfaces has been performed yet to observe cavitation characteristics. The main aim of this contribution is to study, how surface properties influence on cavitation dynamics. Therefore, we used 10 mm long stainless steel cylinders with diameter of 10 mm. Their surfaces were modified by (DLT) with a nanosecond fiber laser. Several recent studies [3,4,5] have shown that DLT can be used for surface functionalization, since it influences on surface topography and also on surface wettability - immediately after DLT, the textured surfaces become superhydrophilic and after some time the transition to superhydrophobic state may occurs.

Experimental set-up

Experiments were performed in a closed loop cavitation tunnel (Figure 1a) at the Faculty of Mechanical Engineering, University of Ljubljana. For water circulation in cavitation tunnel a 4.5 kW pump is installed, which enables the variation of rotation frequency via frequency controller to control the flow rate. The water flows through the upstream reservoir into the test section and through the downstream reservoir back into the pump. The main purpose of the two reservoirs is to eliminate the pump pulsation and to avoid potential small bubbles to enter into the test section. The upstream reservoir can be also used to raise the fluid temperature with an electric heater installed, while downstream reservoir enables a cooling system with separated cooling loop, connected to the tap water system. Two valves are installed upstream and downstream of the test section, which enables the additional control of the flow rate and easy and fast disconnection of the test section from the main loop. The flowrate is monitored by an electromagnetic flowmeter ABB WaterMaster. Temperature of the fluid is monitored by Pt100, installed into the downstream reservoir, while pressure is monitored at the test section by ABB absolute and differential pressure transducers. The test section (Figure 1b) is made out of transparent acrylic glass, which enables to observe cavitation phenomena from different angles. Cavitation was observed on the 10 mm long stainless steel cylinders with diameter of 10 mm and modified surfaces by direct laser texturing, with a nanosecond fiber laser. The cylinders were installed horizontally, perpendicular to the flow direction.

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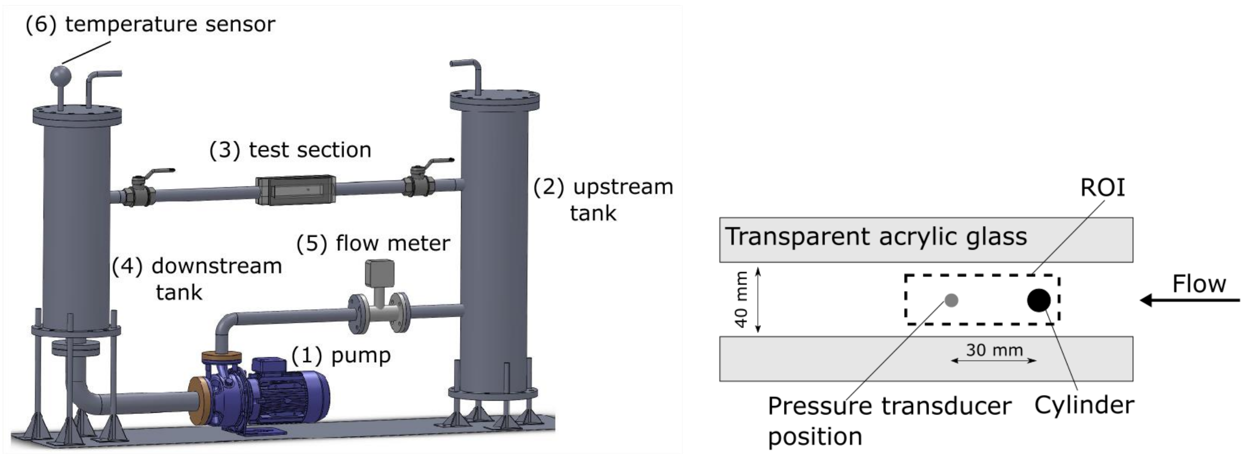

Figure 1: Cavitation tunnel (left - a) and test section (right – b).

Experiments were performed sequentially under the same operating conditions (Table 1) for all five specimens-cylinders, labeled S1-S5. The flowrates were chosen based on visual perception, where the initial flowrate determines initial cavitation on the reference specimen. Flowrates, inlet pressures and flow temperatures were monitored and controlled, to ensure the same cavitation numbers for specific measurement points, by all specimens.

Measurement point	Flowrate [L/min]	Pressure [kPa]	cav. number [ ]
A	163	94	2.2
B	182	91	1.7
C	197	92	1.5
D	212	93	1.3
E	231	92	1.1

Table 1: Operating conditions.

Cavitation characteristics behind circular cylinders were monitored simultaneously by high-speed visualization and high frequency pressure transducer. Visualization was performed by high-speed camera Fastec HiSpec4 at 15,000 fps and resolution of 464×164 pixels. High power LED illumination allowed to set shutter time down to 10µs, at medium opened aperture. Pressure oscillations were measured by PCB 113B28 pressure transducer at 1MHz via DAQ NI USB 6351 measurement card.

Cylinder surface texturing

As a reference sample we used a highly-polished surface (S1). Additionally, we prepared 4 different DLT samples (S2-S5). Their surfaces were textured by using a fiber laser (SPI Lasers, Ltd., G4, SP-020P-A-HS-S-A-Y), radiating pulses with a wavelength of 1060 nm, an average power of 10 W, pulse frequency of 50 kHz, and pulse duration of 28 ns. The spot size in a focal position equaled 0.03 mm. To process the whole surface of cylinders, they were mounted on a rotational motorized stage with an angular resolution of 0.005°. For all DLT-samples (with exception of S3) the laser beam was delivered in lines, parallel to symmetrical axis of the cylinder with scanning velocity of 300 mm/s. SEM micrographs of all samples after DLT are shown in Figure 2. In case of highly porosity surface (S2), the distance between two successive scanning lines, so called scan line separation Δy, equaled 25 µm. The micro-channels in S4 and S5 are 100 µm wide and were performed by engraving at four different angles (0°, 18°, 45°, 72°) and Δy = 10 µm. On sample S4, the micro-channels are separated by 200 µm, while on S5 this distance equals 500 µm. In sample's surface S3 we drilled micro-holes with diameter of 40 µm, that are separated by 200 µm Here, each hole was drilled by 1,000 pulses.

After DLT, all textured samples were superhydrophilic in a saturated Wenzel regime (a static contact angle equaled 0°), similar as in Ref. [5].

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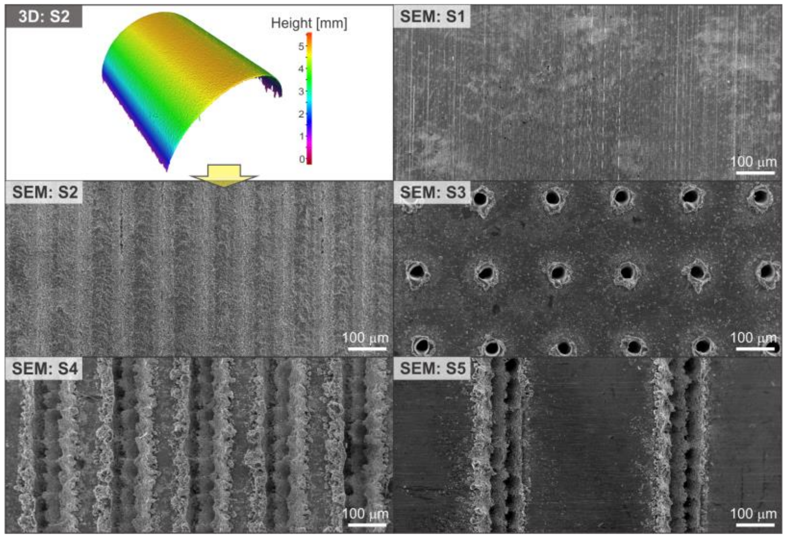

Figure 2: 3D scan and SEM micrographs of DLT surfaces.

Results

Figure 3 presents averaged cavitation extents behind the circular cylinder, while Figure 4 presents standard deviation, calculated based on visualization, for five different measurement points and five different specimens. One can see that cavitation grows with decreasing the cavitation number by all specimens. Notice that the results in Figures 3 and 4 are presented at different color bar scales for individual measurement point, due to better visual perception. Each measurement point has the same color bar scale for all five specimens. The flow is from right to left.

It is clearly visible, that cavitation differs between five specimens, by the same cavitation number (Figures 3 and 4). By S2 cavitation first appears at lower cavitation number in comparison with reference (S1). It is also clearly demonstrated, that by S3 cavitation appears in different shape as by S1, i.e., it is more compressed and centered behind the cylinder. By S4 and S5 cavitation extent is more significant in comparison with the reference, but differs in shape.

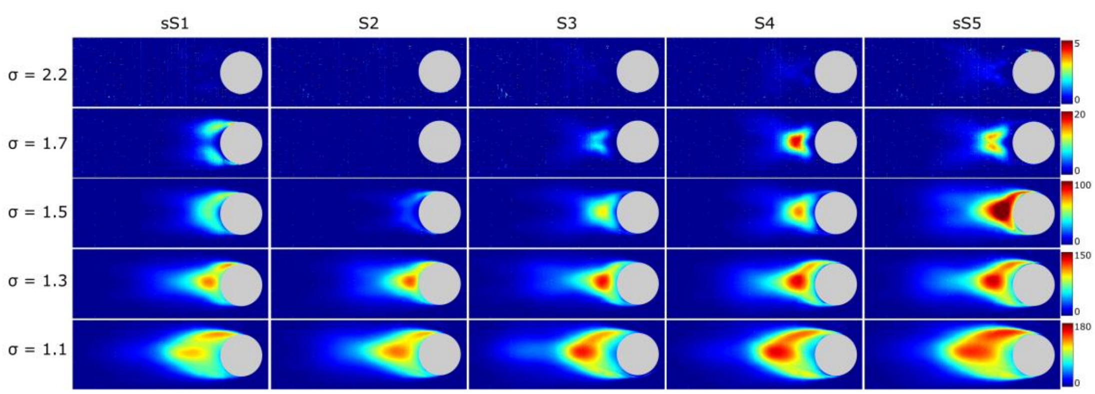

Figure 3: Averaged cavitation extents, based for a period of time of 0.67 s.

Observing standard deviations reveals that in case of S2, no cavitation dynamics is taking place till cavitation number decreases to 1.5. It is demonstrated that in all other cases (S1, S3, S4, and S5) strong cavitation dynamic is present from initial cavitation state. Comparing cavitation dynamics at cavitation numbers 2.2 and 1.7 shows, that in case of laser-textured specimens, strong cavitation dynamic is present more at the center, behind the cylinder, while in case of polished specimen (S1) dynamics are present more at the upper and lower side of the cylinder.

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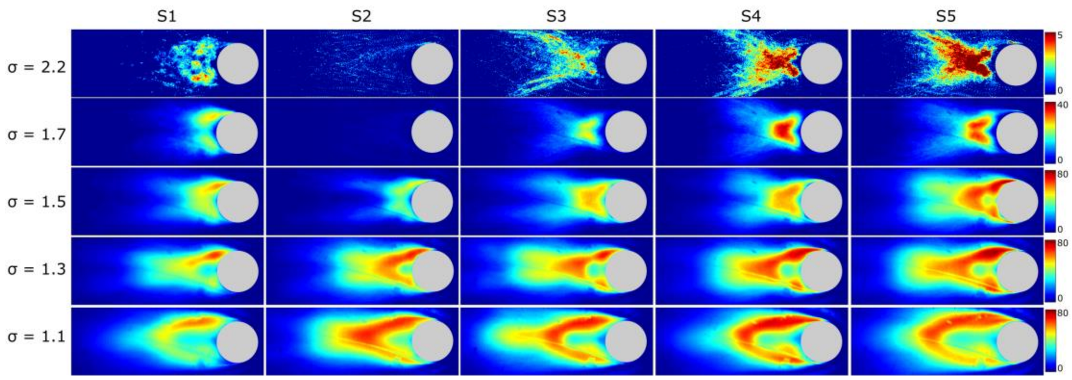

Figure 4: Calculated standard deviation, based on visualization for a period of time of 0.67 s.

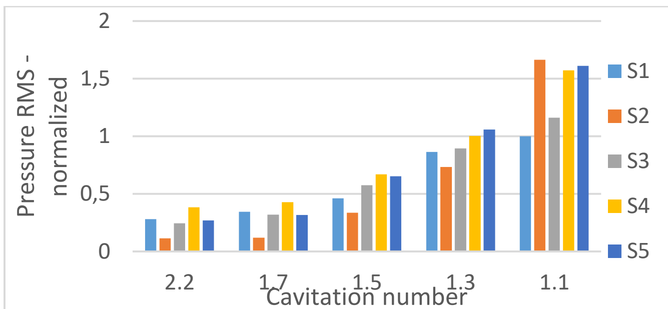

Figure 5: Pressure RMS values, normalized on S1.

Figure 5 presents RMS pressure values for all measurement points, by all specimens. Values are normalized with the S1 value at cav. number 1.1. It is shown, that in case of S2, pressure pulsations are weaker than in case of S1, which corresponds with results from visualization. Pressure pulsation by S3 are very similar in comparison with S1, while in case of S4 and S5 pressure pulsations are stronger.

Conclusion

This study clearly demonstrates that cavitation on the same basic geometry (circular cylinder, 10 mm in diameter) can be controlled by surface engineering, using nanosecond fiber-laser texturing. If appropriate laser-texturing parameters are chosen, cavitation can be decreased or initial cavitation can be shifted to lower cavitation numbers. The presented results, therefore, reveal that direct laser texturing on the exposed surfaces is offering a potential of reducing the risk of cavitation to appear or eventually reducing the cavitation extent and consequently the cavitation erosion.

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