Comparative Analysis of Cavitation Resistance of Deposited/Sprayed Layers of Carbides, Stainless Steels and Metastable Austenite

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Abstract. The cavitation erosion resistance of deposited/sprayed layers prepared by thermal spraying and welding processes was evaluated using a new principle of ultrasonic vibratory testing [1]. A high velocity air fuel thermal spraying process (HVAF), gas tungsten arc welding (GTAW or TIG), and shielded metal arc welding (SMAW) were used to prepare the deposit deposited/sprayed layers. The WC-10Co4Cr powder was deposited on 20X13 stainless steel, while E308L-17 welding filler electrode, 06X19H9T welding solid wire, and Fe-Cr-Al-Ti cored wire (known as PPM-6) were deposited on AISI 316L stainless steel. For all materials, the curves of volume loss as a function of testing time were plotted. The obtained results showed that the deposited layers of PPM-6 metastable austenite steel prepared by TIG welding process was exhibited a higher resistance to cavitation erosion than the others. The maximum volume loss of PPM-6 steel was about 0.31 mm³, whereas the volume loss for the other materials was of 5-20 times high.

1. Introduction
Metallic machinery components are known to be subjected to different kinds of wear and corrosion during the operation. This causes the components to deteriorate, in particular, the functional surfaces due to their direct contact with the surrounding environment. The components working in aqueous environments are frequently exposed to a kind of surface damage termed as "CAVITATION", which is considered as a special form of wear. Cavitation wear or erosion has been recognized as one of the main problems that may occur in the equipment of fluid-handling systems such as hydraulic turbines, pump impellers, valves, and marine ship propellers [2-5]. The damage caused by cavitation erosion leads to economic loss; reduction of operational performance efficiency; increase vibration, maintenance operations, downtime, and repair costs [6-8]. Thus, it is mainly necessary to protect the metallic surfaces or repair them by high-grade materials to avoid or at least reduce the cavitation impacts so as not to be vulnerable to failure and/or to prolong their operational lifetime.
The cavitation damage is basically occurred as a result of formation and frequent violent collapse of cavitation bubbles (cavities) in a liquid due to rapid changes in local liquid pressure at a relatively constant temperature. High-pressure shock waves and liquid micro-jets may be produced during the collapse of cavitation bubbles, resulting in plastic deformation, fatigue, and, consequently, material loss [9-11]. The shock wave pressure emitted during the collapse process can reach as high as 1.5 GPa [12, 13]. The velocities of liquid micro-jets exceed 120 m/s when cavitation damage is caused [14-16].

The aim of this research is to evaluate the cavitation erosion resistance of deposited/sprayed layers prepared by thermal spraying and welding processes for three groups of materials: carbides, stainless steels, and metastable austenite steel.

2. Development of cavitation erosion testing apparatus

Figure 1 shows a schematic diagram of the developed cavitation testing installation used to evaluate the cavitation erosion resistance of materials [1]. This installation is an easy-to-use apparatus that provides stable test results of cavitation erosion. As shown in figure 1, the test specimen (no. 4) is fixed at the end of horn (no. 3), and the gap between the specimen and the nozzle of liquid (no. 5) is regulated within the limits providing a cavitation effect, varied from 1 to 3 mm. The tank (no. 13) is filled with the test liquid, which is controlled by the valve (no. 14). The liquid is transported by the hose (no. 15) to the nozzle supported by the base (no. 7). From the nozzle (no. 5), the liquid flows upward to be in contact with the test specimen. A large number of cavitation bubbles form in the liquid under the action of ultrasonic vibrations between the test specimen and the nozzle of liquid. The liquid goes down to the container (no. 10) by the hose (no. 9). When the liquid in the container reaches a certain level, the water pump is automatically switched on and pushes the liquid through the hose (no. 12) to the tank. The control unit (no. 16) is used to control the on/off process of the water pump. Figure 1(a) shows a close up view of the installation setup. Water was used as a test liquid and a certain voltage (12 V) has been applied with water to accelerate the cavitation erosion and give a combined mechanical-electrochemical effect. Figure 1(b) shows the voltage applying to the cavitation test. The test specimens were prepared according to the requirements of ASTM standard G32-10 [17]. Figure 1(c) shows the design of test specimen. The cavitation test conditions adjusted here are: frequency of vibration of 20±0.1 kHz, peak-to-peak amplitude of 55±3µm, and the power of the ultrasonic generator of 500 W.

3. Materials and depositing/spraying methods

Three groups of materials, namely carbides (WC-10Co4Cr); stainless steels (E308L-17 and 06X19H9T); and metastable austenite steel Fe-Cr-Al-Ti (PPM-6), were used as depositing/spraying materials and tested using the developed ultrasonic vibratory testing. The chemical compositions of all materials are shown in table 1. The WC-10Co4Cr powder (coded 2W101-2510) with grain size of -25 +10, which is fabricated by C&M Technologies GmbH, Germany, was sprayed by thermal spraying process HVAF (SB9500-gun, Uniquecoat Technologies, VA, USA) towards the 20X13 stainless steel substrate with final thickness of coating layer of 230 ± 20 µm. The spraying parameters are as follows: air pressure 0.61 MPa, spraying distance 150 mm, main fuel gas–propane (1) 0.58 MPa, secondary fuel gas–propane (2) 0.45 MPa, carrier gas flow rate–nitrogen 68 L/min, Powder feed rate 200 g/min, and traverse speed of the gun 1.0 m/s. Propane 1 was used as a main fuel gas, and propane 2 was used to increase the heating of the mixture in the combustion chamber. Stainless steels and metastable austenite steel are deposited by welding processes on AISI 316L stainless steel substrate. The two welding filler wires (PPM-6 and 06X19H9T) were deposited by a gas tungsten arc welding process (GTAW or TIG) with current of 90-120 A, voltage 12 V, and feeding of argon 12-15 L/min. The E308L-17 welding filler electrode was deposited by a shielded metal arc welding process (SMAW) with current 70-75 A and voltage of 25 V. The final thickness of the deposited layers was approximately 4 ± 0.5 mm.
Figure 1. Schematic diagram of the developed ultrasonic cavitation testing: 1 ultrasonic generator; 2 ultrasonic transducer; 3 horn (waveguide); 4 test specimen; 5 nozzle; 6 container; 7 base; 8 movable table; 9 hose; 10 container for storing the test liquid temporarily; 11 water pump; 12 hose, 13 test liquid tank; 14 liquid flow control valve; 15 hose, 16 water pump controller.
**Table 1.** Chemical compositions of all tested materials (wt. %).

| Material     | C (wt. %) | Co | Cr (wt. %) | Ni | Si (wt. %) | Mn | Al | P (wt. %) | S (wt. %) | Ti (wt. %) | Nb (wt. %) | Mo | W (wt. %) | Fe |
|--------------|-----------|----|------------|----|------------|----|----|----------|-----------|------------|------------|----|-----------|----|
| 20X13        | 0.16-0.25 | 12.0-20 | ≤ | ≤ | ≤ | 0.03 | ≤ | ≤ | - | - | - | 20 | Bal. |
| AISI 316L    | ≤ | 16.5-18.0 | 10.0-13.0 | 0.75 | 2.00 | 0.04 | ≤ | 0.03 | - | - | 2.0 | 2.5 | Bal. |
| WC-CoCr      | 5.34 | 9.91 | 3.94 | 0.07 | - | - | - | - | - | - | - | - | Bal. 0.07 |
| 06X19H9T     | ≤ | 18.0-20.0 | 8.0-10.0 | 0.40-1.00 | - | ≤ | ≤ | Min | - | - | - | - | Bal. |
| PPM-6        | 0.6 | 8.0 | - | - | - | 1.5 | - | - | 1.0 | - | - | Bal. |

4. Results and discussion
The ultrasonic vibratory tests were conducted for all the studied materials by applying a combination of mechanical-electrochemical interaction (water-voltage). The cavitation erosion resistance of all materials are shown in figure 2, which represents the relationship between the cumulative volume loss and cavitation exposure time. The comparison between the tested materials is based on the volume loss instead of the mass loss because the WC-10Co4Cr has a different density compared to steels. The densities adopted for the WC-10Co4Cr coating and all types of steels were 12.5 g/cm³ [18] and 7.8 g/cm³, respectively. It can be easily noticed that the metastable austenite steel PPM-6 has the highest resistance to cavitation erosion, since the maximum volume loss at the end of cavitation test was about 0.31 mm³, whereas the volume loss for the other materials was of 5-20 times high. This might be attributed to structural transformations occurring in deposited layers of PPM-6 steel under the cavitation loading. Figure 3 represents the cavitation resistance of all materials relative to PPM-6 steel. The explanations of these results will be a subject of further investigations.

![Figure 2. The cumulative cavitation volume loss of the all tested materials.](image-url)
5. Conclusions
1. The cavitation experiments of deposited/sprayed layers prepared from WC-10Co4Cr powder, E308L-17 stainless steel, 06X19H9T stainless steel, and PPM-6 metastable austenite steel were conducted by using the developed ultrasonic cavitation testing. The PPM-6 steel was exhibited higher cavitation erosion resistance than the other materials, since the maximum volume loss at the end of cavitation test was about 0.31 mm³, whereas the volume loss for the other materials was of 5-20 times high.

2. Additional studies regarding the effect of structural transformations in deposited layers of PPM-6 steel on the cavitation erosion resistance should be made, and study the reasons for the increased cavitation resistance of these layers in comparison with HVAF coatings.

6. References
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**Acknowledgement**

This work was done within the state order of IMP UB RAS on the subject no. AAAA-A18-118020190116-6, within the state order of IMP UB RAS on the subject “Laser”, and IES UB RAS on the subject no. AAAA-A18-118020790147-4. The present study was supported by IRA-SEM 2019 II, project No. 66316.