Combined silt and cavitation erosion resistance of nanoparticle reinforced polyurethane coatings on 16Cr-5Ni Martensitic stainless steel substrate

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Long Abstract

Introduction

Among all the renewable energy sources available, hydropower is considered as the most promising source of energy. A major challenge for hydropower development, specific to the Himalayan region, is the withdrawal of clean water from sand-laden rivers and cavitation damages, which leads to unexpected shutdowns and unplanned maintenance of hydroturbines. There are some preliminary results showing that cavitation erosion enhances in silt environment due to more nucleating sites [1]. Erosion due to individual effect and synergic effect of silt and cavitation are more complex which cause serious degradation and are unsolved problem in hydraulic machines [2, 3].

Most of hydropower plants are run-of-river schemes and situated in steep hilly terrains. Due to high cost, effective sediment settling systems remove only coarser particles (>300 µm) [4]. More than 90% of silt is quartz which causes severe silt erosion [5]. Mann and Arya [6] reported that silt erosion causes a huge loss every year due to drop in efficiency and repairs.

One of the detrimental effects of cavitation in hydraulic machinery is cavitation erosion. The violent process of cavity collapse takes place in a very short time of about few microseconds and could result in the emission of large amplitude shock waves, as demonstrated by Avellan and Farhat [7]. A high-speed liquid micro-jet directed towards the boundary can also occur in cavities collapsing close to a solid surface [8]. The impingement pressure caused by the cumulative collapse of bubbles was estimated in the literature to be in the order of 900 MPa which can lead to locally strain hardening and an eventual fatigue failure of ductile materials, or to crack propagation in brittle materials as demonstrated by Hammit [9] and Arndt [10].

Of all the methods suggested to reduce silt and cavitation-induced damage [5], we have adopted development of novel coating of materials to increase the erosion resistance. 13Cr-4Ni martensitic stainless steel (MSS), commonly used in hydroturbines due to its good mechanical properties and sufficient corrosion resistance. However, this material is considerably less resistant to cavitation erosion and silt erosion due to excessive silt entrained with in the water. Therefore, in this study, we have used 16Cr-5Ni MSS as base material, due to its superior impact strength, tensile strength and mechanical properties compared with 13Cr-5Ni MSS [11]. Further, we have used polyurethane (PU) coating for its high elasticity and damping characteristics with addition of B_4C and SiC nanoparticle inserts in the PU [12]. There are few, if any, publications exploring the effect of hard ceramic particles (such as B_4C and SiC) on the silt and cavitation wear resistance of PU coatings and their synergy.

1. Methods

There are several erosion test methods are exist to study individual effects of silt and cavitation erosion by either ASTM or non-standard test rigs. However, to the best of our understanding, the synergy between silt and cavitation erosion behaviors cannot be simulated through these apparatus. To overcome such shortcoming we developed a submerged silt and cavitation erosion apparatus,

where the slurry jet impinges upon a stationary submerged specimen, and focused ultrasonic transducer is used for cavitation erosion studies.

To enhance silt and cavitation erosion resistance of 16Cr-5Ni steel, in our full-length paper, we are going to present:

- Description of a new test set up to explore possibility of synergetic effect of silt and cavitation erosion mechanisms.
- Comparison of silt, cavitation and combined silt and cavitation erosion characteristics obtained using this experimental test facility.
- Demonstration of enhanced erosion in case of combined silt and cavitation studies when compared with stand-alone silt or cavitation rates.
- Based on the findings of the work on polyurethane coatings, following comments can be made:
  - The coatings with B_4C nanoparticles have higher wear resistance than those with SiC.
  - An interesting finding from the results is that there is an optimum amount of nanoparticles (20 wt% B_4C and 10 wt% SiC) at which mass removal is the minimum with respect to silt erosion and (10 wt% B_4C and 2 wt% SiC) with respect to cavitation erosion.
  - These observations are explained in terms of surface characteristics of coatings as brought out by a combination of measurements including SEM images as well as roughness measurement.

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