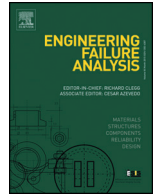




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# Cavitation erosion and erosion-corrosion resistance of austenitic stainless steel by plasma transferred arc welding

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## ABSTRACT

41WC-36Ni7.5CrSiB (Colmonoy75) and NiCrBSiW (Colmonoy88) alloy coatings were synthesized on 316 L stainless steel by plasma transferred arc welding, aiming at improving cavitation erosion and erosion-corrosion resistance. The microstructure, chemical composition, phase constituents and microhardness were determined by using SEM, EDS, XRD and microhardness tester. The cavitation erosion and erosion-corrosion experiments of the coatings were investigated using an ultrasonic vibrator and a jet erosion testing measurement in 3.5 wt% NaCl solution, respectively. Experimental results showed that the coatings with few pores, cracks or other defects could be obtained. The microstructure of the Colmonoy75 and Colmonoy88 coatings exhibited cellular dendrite and irregular blocky phases. The two coatings were composed of  $\gamma$ -Ni solid solution and WC particles, while the formation mechanism of WC was different. In the cavitation erosion and erosion-corrosion tests, the cumulative volume losses of the two coatings were much lower than that of the substrate. Colmonoy88 coating exhibited a better resistance to cavitation erosion and erosion-corrosion than Colmonoy75 coating. The cavitation erosion and erosion-corrosion resistance of the Colmonoy75 coating could reach about 3 times and 8 times that of 316 L substrate, while the Colmonoy88 coating could reach about 12 times and 31 times that of 316 L substrate, respectively. The improvement in the cavitation erosion and erosion-corrosion resistance for Colmonoy88 coating could be attributed to the fact that the in situ synthesized WC particles increased the cavitation erosion and erosion-corrosion resistance by providing an anchoring effect on the solid solutions to hinder the nucleation and propagation of cracks.

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## 1. Introduction

Stainless steel engineering components, such as water pumps, experience cavitation and erosion-corrosion which result in detrimental effects and premature failure. The 316 L stainless steels are used in hydraulic systems due to their good corrosion resistance in a series of severe corrosive environments, such as sea water. However, the microhardness of 316 L stainless steel is ~200 HV. Low hardness usually corresponds to the low cavitation erosion and erosion-corrosion resistance, 316 L stainless steel cannot meet the service requirements in liquid and slurry environments [1–6]. As the cavitation erosion and erosion-corrosion

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resistance is a surface phenomenon, surface modification provides an effective method to solve these problems and prolong its service life [7,8].

Cavitation erosion is a degradation of the surface, due to small bubbles or cavities formed resulting from the rapidly changed pressure in the liquid. These bubbles can collapse near the component's surface at a high frequency, imploding violently, producing shock waves and micro-jets [9]. Some studies indicated that shock wave and micro-jet mechanisms worked together on the surface of components [10]. The shock wave and/or micro-jet repeatedly impact component's surface leading to pits, plastic deformation and eventually mass removal of the coatings. When components undergo an intense cavitation erosion process, the density of pits is high enough to result in a porous matrix or a destroyed the component.

Erosion-corrosion, also known as wear corrosion, is a material removal process caused by moving two-phase fluid at high velocity. Erosion-corrosion is a form of mutually reinforcing synergy of erosion and electrochemical corrosion processes [11]. Therefore, the erosion-corrosion is much more severe than the summation of pure erosion and corrosion. Erosion-corrosion problems are especially important in oil production systems, hydroelectric power plants, mining industries and desalinization plants. The erosion-corrosion process can be very destructive on hydraulic systems and components, and may result in serious problems such as material removal, leading to a drastic decrease of component efficiency.

The hardness, cavitation erosion and erosion-corrosion resistance of low-cost steel substrates can be improved by surface modification [12–15]. A series of surface treatments are used in studying cavitation erosion and erosion-corrosion resistance, such as laser surface alloying, and high-velocity oxygen-fuel (HVOF) spraying and plasma spray or plasma transferred arc (PTA) welding [16–18]. Among various surface modification technologies, the alloy coatings prepared by plasma transferred arc welding have drawn amounts of attention [19–22]. In addition, in situ synthesis phenomenon occurs during surface modification, which was proved to be an efficient method to produce in situ ceramic particles reinforced coatings.

During in situ synthesis process, reinforced particles are synthesized in the metallic matrix by metallurgical reaction between elements or between the elements and compounds during the fabrication process [23]. And the excellent wear resistance of coatings with in situ reinforced particles was obtained [24,25]. The influence of the in situ particles and alloying element on the properties of coatings was reported by Li et al. and Corujeira Gallo et al. [26,27]. But few studies focus on the cavitation erosion and erosion-corrosion performances of in situ particles reinforced Ni-based alloy coating.

Among various ceramic particulates, WC particulate is widely used in Ni-based and Co-based composite coatings as reinforcing phases due to its high hardness and excellent wear resistance [28,29]. However, it is found that the reinforcement effect of WC particles on the cavitation erosion and erosion-corrosion resistance was rarely investigated. In this study, 41WC-36Ni7.5CrSiB (Colmonoy75) and NiCrBSiW (Colmonoy88) alloy powders were deposited on 316 L stainless steel by PTA welding, respectively. The cavitation erosion and erosion-corrosion resistance of Colmonoy75 and Colmonoy88 alloy coatings with WC reinforcing phases will be discussed, aiming at comparing the cavitation erosion and erosion-corrosion resistance of Colmonoy75 and Colmonoy88 alloy coatings. The effect of in situ WC particles in Colmonoy88 alloy coating on the cavitation erosion and erosion-corrosion resistance was also investigated.

## 2. Experimental procedure

### 2.1. Materials and test specimens

The substrate material used in this work was 316 L stainless steel in the form of plate having a dimension of 400 mm × 300 mm × 20 mm. The nominal chemical composition of 316 L stainless steel was in wt%: ≤0.03% C, ≤1% Si, ≤2% Mn, 0.03% Si, 0.045% P, 16–18% Cr, 10–14% Ni, 2–3% Mn, and Fe balance. The substrate was ground with 600 SiC paper to remove surface oxides or contaminants and then sandblasted to increase surface roughness for enhancing powder adhesion. Colmonoy75 alloy and Colmonoy88 alloy powder were used as the coating material. The nominal chemical composition of Colmonoy75 alloy and Colmonoy88 is given in Table 1. Before surfacing, the Colmonoy75 and Colmonoy88 alloy powder was dried in an oven at 150 °C for 2 h. Within a range of optimisation runs, the optimized process parameters were obtained as presented in Table 2, under which good quality coatings could be achieved.

A metallurgical cross section of the samples was prepared and etched with 30 mL HCl + 10 mL HNO<sub>3</sub>. The microstructure and chemical compositions of the samples were investigated using a scanning-electron microscope (SEM, S-3400 N), equipped with an energy-dispersive spectrometer (EDS). The phase constituents were identified using a X-ray diffractometry (XRD, XRD-7000) at a scanning speed of 4° min<sup>-1</sup>, ranging from 20° to 100° and a voltage of 40 kV and a current of 30 mA, using Cu K<sub>α</sub> radiation. The vickers microhardness of Colmonoy75 and Colmonoy88 alloy coatings was measured using a HVS-1000 Vickers hardness tester with a load of 2 N and a duration time of 15 s, measuring three sets of data at each region and then taking the average.

**Table 1**  
Chemical compositions of Colmonoy75 and Colmonoy88 alloy powders.

Elements	B	C	Co	Cr	Fe	Si	W	Ni
Colmonoy75	1.4	2.9	6.0	7.5	2.5	2.4	41.4	Bal.
Colmonoy88	3.0	0.6	0	15	3.5	4.0	15.5	Bal.

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