



# Erosion and erosion–corrosion of Al-brass alloy: Effects of jet velocity, sand concentration and impingement angle on surface roughness



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Received 1 October 2016; accepted 31 December 2016

**Abstract:** Effects of jet velocity, sand concentration and impingement angle on the surface roughness of Al-brass alloy were investigated after erosion and erosion–corrosion tests. The tests were performed using a jet impingement rig. The eroded surfaces were characterized using 2-D and 3-D surface profilometry and scanning electron microscopy (SEM). The results showed that there was an increase in the surface roughness of the erosion–corrosion samples as sand concentration was increased to 1, 5 and 10 g/L at jet velocities of 9, 6 and 3 m/s, respectively. However, the surface roughness decreased with a further increase in sand concentration. This decrease in the surface roughness was attributed to the higher work hardening of the surface, rebounding or blanketing effect and very high frequency of the impacts at the higher sand concentrations. The surface roughness increased as the jet velocity increased. The results also showed that the change in the surface roughness with impingement angle was not significant at two jet velocities of 3 and 6 m/s. However, at a higher jet velocity of 9 m/s, formation of ripples on the erosion surfaces at oblique angles resulted in a higher surface roughness as compared with the normal impingement angle.

**Key words:** Al-brass; erosion–corrosion; surface topography; sand concentration

## 1 Introduction

Impingement of slurry on the surface of materials could damage the surfaces during the erosion–corrosion process. A single particle impact would generate a scratch or crater with raised lips on the surface [1]. This could change the surface roughness of the material, which is an important parameter in the erosion–corrosion resistance of alloys. Increasing the surface roughness would increase the corrosion rate during the erosion–corrosion process (i.e., erosion-enhanced corrosion) due to the higher effective surface area of the eroded surfaces [2]. Indeed, the increase in surface roughness through multiple particle impacts could result in formation of various micro-galvanic sites, which may increase the corrosion rate [3]. SASAKI and BURSTEIN [4] have suggested that the surface roughness generated by the erosion lowered the pitting potential, hence may be responsible for the enhanced pitting of the metal during erosion–corrosion. Surface roughness could also increase the material removal rate due to the erosion

mechanisms [5]. Heat transfer, an important parameter in the heat exchanger tubes, is another important parameter that may be affected by the surface roughness [6].

ZHENG et al [7] have studied the surface roughness of 304 stainless steel and a Fe-based amorphous coating to determine the critical flow velocity during erosion–corrosion. They showed that at the velocities above the critical flow velocity, the surface roughness increased rapidly with increasing the flow velocity. Higher surface roughness of 304 stainless steel specimens at higher jet velocities and higher testing times has also been indicated by NGUYEN et al [8]. JI et al [9] have shown that the surface roughness values of the eroded surfaces were inversely related to the hardness of tested materials. The change in the surface roughness of cavitation erosion–corrosion samples was studied by RYL et al [10] using electrochemical impedance spectroscopy (EIS) technique. In another research, the lower surface roughness of Pd–Co film was considered as a reason for its lower erosion–corrosion rate as compared with Pd–Cu film [11].

Jet velocity, sand concentration and impingement

angle are the most important factors in the erosion–corrosion behaviors of materials [11,12], which could also affect the surface roughness of the eroded surfaces. To our knowledge, there have not been many studies on the effect of erosion–corrosion parameters on the surface roughness. In this work, the surface roughness of Al-brass alloy was examined after pure erosion (i.e., with cathodic protection) and erosion–corrosion tests in various conditions. The alloy has been extensively used in condensers and heat exchangers that may be exposed to the erosion–corrosion degradation [13]. The mechanisms of the change in the surface roughness of the alloy by each factor (i.e., jet velocity, sand concentration and impingement angle) were also characterized.

## 2 Experimental

Al-brass alloy with a composition of Cu–19.2%Zn–2.3%Al–0.1%As was melted in a resistance furnace and cast in an iron mold. The cast ingot with a thickness of 14 mm was solution annealed in a muffle furnace at 750 °C for 4 h and then cold rolled into a thickness of 8 mm. Finally, the obtained strips were annealed at 550 °C for 2 h. Erosion–corrosion samples, 5 mm in diameter and 7 mm in length, were wire-cut from the annealed strips. The erosion and erosion–corrosion surfaces, i.e., the circles at the ends of all cylindrical specimens were polished to an average roughness ( $R_a$ ) of about  $(0.12 \pm 0.02) \mu\text{m}$ .

Erosion and erosion–corrosion tests were performed using a slurry impingement rig. The details of the rig were described elsewhere [14]. The used slurry consisted of distilled water, 35 g/L NaCl and 0–90 g/L  $\text{SiO}_2$  particles with average size of 250–500  $\mu\text{m}$ . Figure 1 shows the morphology of  $\text{SiO}_2$  particles used in the current work. The tests were carried out under various impingement angles between 20° and 90° at three jet velocities of 3, 6 and 9 m/s for 30 min. The erosion–corrosion tests were performed at the open circuit potential (OCP). The pure erosion tests were carried out by applying a cathodic protection potential using a 302 N Autolab potentiostat/galvanostat coupled to the erosion–corrosion rig. For the pure erosion tests, the OCP of the alloy was measured in the first 60 s of each test and the voltage of specimen was then shifted –1000 mV to the obtained OCP. The counter and reference electrodes were graphite and saturated Ag/AgCl in a capillary, respectively.

The erosion and erosion–corrosion surfaces were characterized using a scanning electron microscope (SEM) equipped by an energy dispersive X-ray spectrometer (EDS). The surface roughness ( $R_a$ ) of the samples was also measured using a T–8000

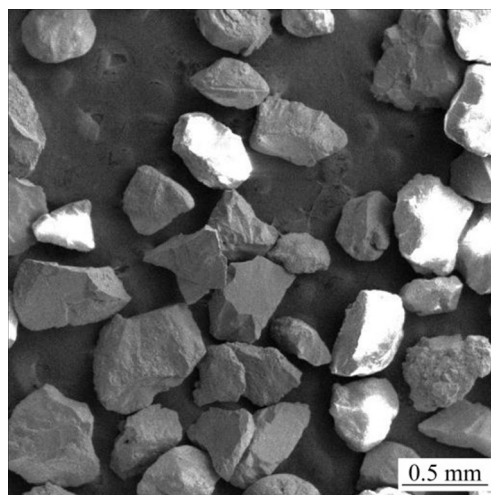


Fig. 1 SEM micrograph of eroding  $\text{SiO}_2$  particles

Hommelwerke surface profilometer. Measurements were performed in a total length of 3 mm on the eroded surfaces using a standard cut-off length of 0.8 mm. The reported values for  $R_a$  were the average roughness of at least three measurements for each sample. The 3-D topography of some eroded surfaces was also obtained by scanning an area of 2 mm  $\times$  2 mm of the surfaces using the surface profilometer. The distance between the line scans was set to be 10  $\mu\text{m}$ . In the case of oblique impingement angles, the roughness measurements were performed longitudinal to the particle impact direction on the eroded surfaces.

## 3 Results and discussion

The surface roughness of Al-brass samples after erosion and erosion–corrosion tests at three jet velocities of 3, 6 and 9 m/s as a function of particle concentration under an impingement angle of 90° is shown in Fig. 2. Almost a same trend was shown with a little change in the surface roughness for erosion (E) and erosion–corrosion (EC) samples at various jet velocities. Increasing the sand concentration resulted in an initial increase in the surface roughness of the samples followed by a decrease at the higher sand concentrations. At a jet velocity of 9 m/s, the maximum surface roughness for both erosion and erosion–corrosion samples occurred at a low sand concentration of 1 g/L. Adding 1 g/L  $\text{SiO}_2$  particles in the solution has boosted the surface roughness from a value of 0.12  $\mu\text{m}$  (in the flow corrosion, i.e., with 0 g/L sand concentration) to 0.64  $\mu\text{m}$ . Further increase in the sand concentration lowered the surface roughness to a value of about 0.3  $\mu\text{m}$  at sand concentration of 90 g/L.

Comparing the surface roughness of the alloy at two jet velocities of 6 and 9 m/s in Fig. 2 revealed that the maximum surface roughness ( $R_a$ ) was shifted from sand

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