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Erosion-corrosion characteristics of spark plasma sintered pure nickel in simulated mine water

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ABSTRACT

This study estimates the impact of shear stress and solid particles on the erosion-corrosion behaviour of spark plasma sintered pure nickel in simulated mine water. Rotating cylinder electrode system was employed to carry out the erosion-corrosion tests by weight-loss and electrochemical measurements. Corroded coupons were examined with the aid of microscope to assess the surface morphology. The gravimetry data was inconsistent with both weight gain and weight loss recorded. The impact of the hydrodynamic parameters was correlated with the pitting resistance and re-passivation behaviour of the sintered nickel, while the morphology results showed minimal general attack and severe localised corrosion.

1. Introduction

Resurgence in the research involving nickel is due primarily to its vast applications as a result of its good properties second to iron [1]. Nickel has an added advantage of exhibiting better corrosion behaviour which is attributed to passive film formation on its surface. Sato and Kudo [2] cited several efforts that have been deployed to understand the mechanism of nickel passivation in acidic, near neutral, and alkaline solutions. In this work, simulated mine water with pH in the range of near neutral solution was employed. Due to the strategic importance of the mining industry to the global economy and coupled with the need to reduce cost of production in mineral processing vis-à-vis robust materials selection and process design; it was on this bases, that the pure nickel was produced via spark plasma sintering unlike previous studies which utilised wrought in form of plate, sheet, bar, rod, tube, and electrolytic pure nickel among other techniques [3,4].

Understandably, mining environment encompasses solution having solid particles and this introduced the concept of erosion-corrosion which is regarded as the interaction of mechanical and electrochemical factors [5,6]. It is also known that erosion-corrosion is associated with unacceptable degradation rate [7] which makes the control and prevention very important. Most researches in erosion-corrosion monitoring focusses on determining the erosion-corrosion, the components of erosion, corrosion and their synergistic interactions via gravimetric, electrochemical, microscopy, and even modelling among others [5–9]. Recently, there is a study showing the impact of shear stress and solid particles on the erosion-corrosion in oilfield environment through the integration of profilometry and gravimetric measurements [10]. This study uses total mass loss and various electrochemical approaches such as open circuit potential (OCP), potentiodynamic polarization and cyclic potentiodynamic polarization methods.

Noticeably, most of the reported studies [2–4] on nickel generally focussed on its anodic polarization characteristics and virtually none described the effects of flow rates on the nickel material. However, one of the most recent available works on the flow induced corrosion of nickel in hot H_2SO_4 was carried out using a rotating cylinder electrode (RCE) and it was concluded that the corrosion is mass transfer rate determining process [11]. RCE hydrodynamics parameters are well characterised [12] with the shear stress for calculated and measured values almost in agreement.

In spite of huge available research on the polarization measurements of nickel in corrosive environments [2–4,8,13,14], this work relates the erosion-corrosion behaviour of sintered pure nickel with repassivation, pitting and passive potentials. Hence, the primary aim of this work is to study the impact of shear stress and solid particles on the erosion-corrosion characteristics of spark plasma sintered nickel products in simulated mine water. Another goal is to correlate the hydrodynamics parameters with the pitting corrosion data. This was achieved by employing three independent corrosion monitoring techniques, namely; total mass loss, potentiodynamic polarization and

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Table 1
Composition of simulated mine water used in this study.

Salt	Concentration (mg/L)
Na_2SO_4	1237
$Cacl_2$	1038
$MgSO_4$	199
NaCl	1380

Table 2
The hydrodynamic parameters used for the tests.

S/N	Rotating speed (rpm)	Velocity (m/s)	Reynold number	Shear stress (Pa)
1	500	0.4	5870	7
2	1500	1.0	17315	50
3	2500	2.0	28761	110
4	4000	3.0	40353	200
5	5000	4.0	57668	360

Table 3
The total mass loss for the sintered nickel samples after 4 h exposure in simulated mine water.

Shear stress (Pa)	FIC (µg)			EC (µg)		
7	80	70	410	120	+90	+80
50	+40	10	+10	+260	30	190
110	250	+90	20	+100	10	2080
200	740	30	+90	6210	350	1490
360	70	400	40	+50	230	+380

+ indicates mass gain.

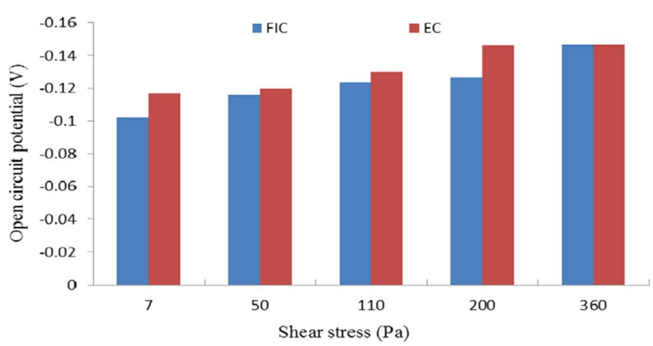

Fig. 1. The effect of open circuit potentials (OCP) at various shear stress with and without solid particles.

cyclic potentiodynamic polarization.

2. Experimental procedure

The starting material was pure Ni (99.8% purity and APS 4–7 µm) supplied by Goodfellow Metals, Cambridge. Sintering process was carried out by using an automated spark plasma sintering machine (model HHPD-25, FCT, GmbH Germany). Charge calculation was used to determine the appropriate quantity of Ni powder needed to fabricate a 20 mm diameter product. The powder is then poured into a graphite die, compacted and placed in the sintering chamber. In order to protect the sintered products, graphite sheets were used to shield the powders from the die, upper and lower punches [15]. The pure nickel was sintered in vacuum while the sintering temperature, heating rate, holding time and pressure were fixed at 850 °C, 150 °C/min, 5 min and 30 MPa respectively.

The sintered products were machined via electrical discharge machining (EDM) technique into an RCE sample configuration which

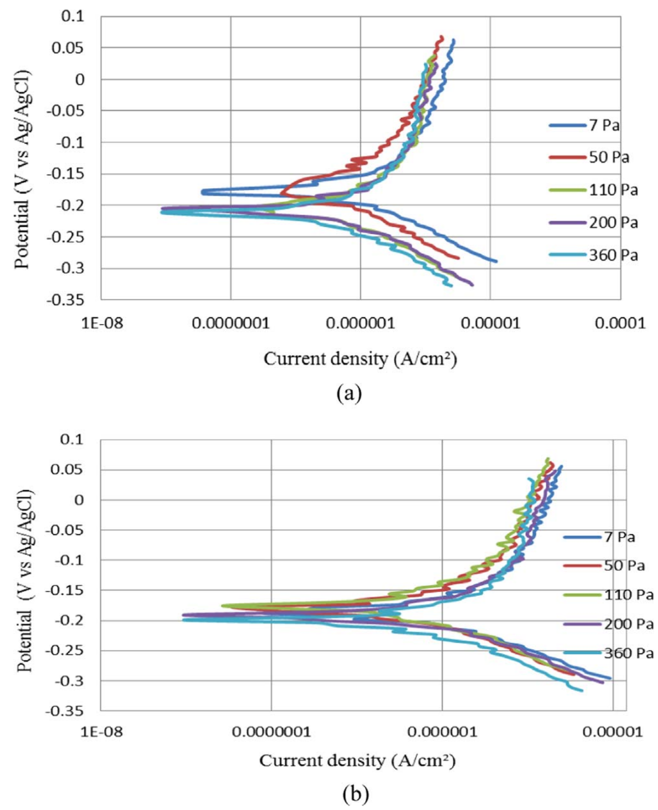

Fig. 2. The tafel plots used to derive corrosion current density for the sintered nickel samples immersed in simulated mine water at various flow rates (a) (FIC (b) EC.

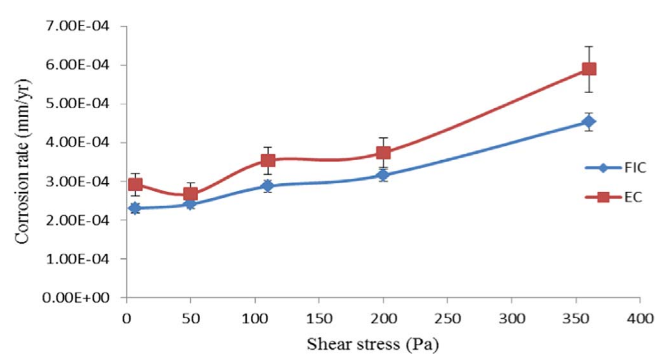

Fig. 3. The corrosion rate for the sintered nickel samples in flow induced corrosion and erosion corrosion conditions.

is cylindrically shaped (15 mm diameter, 8.1 mm height and 7.35 cm^2 area). Metallurgical preparation of the sintered samples includes mechanically grinding and polishing with ATM's Saphire 520 metallographic grinder and polisher using 1200 silicon carbide paper. Thereafter, the samples were polished using 6 µm diamond suspensions for 5 min at a speed of 450 rpm and fine polishing was achieved using 1 µm diamond suspension on a polishing cloth at a speed of 250 rpm, until all the scratches had been removed. Subsequently the samples were degreased with acetone, rinsed with distilled water and dried with compressed air.

Tests were conducted in simulated mine water (SMW) without solid loading for flow-induced corrosion (FIC) and with the addition of 5 g/L of sand to create an erosion-corrosion environment (EC). Round silicon sand particles were used in these studies with an average diameter of 250 µm. Table 1 shows the chemical composition of the simulated mine water prepared according to Hango et al. 2005 [16] and the measured pH was 6.0.