



# Comparative study of erosion–corrosion performance on a range of stainless steels

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## ABSTRACT

Erosion–corrosion is one of the most severe types of material deterioration that occur in hydraulic machinery. Corrosion resistant alloys perform well in some marine applications. These materials do have their limitations, though, and for this reason a comparison of their performances is significant. This study focuses on the assessment of the relative behaviour of four different types of stainless steel (UNS S31600, UNS S32760, UNS S42000, and UNS S17400) in erosion–corrosion environments. The study was expanded to include a carbon steel (UNS G10400). Test pieces have been investigated in a submerged jet impingement apparatus in 3.5% NaCl solution with suspended solid particles at temperatures of 30–35 °C. In situ corrosion monitoring was also undertaken and the influence of the application of cathodic protection was studied. This facilitated assessment of the relative roles of erosion, corrosion and synergy on the overall degradation processes. A variety of examination techniques were utilised (i.e. mass loss, surface profiling, microscopy) in order to obtain detailed information on those different modes of attack. Differences between stainless steels and carbon steel were observed and the superduplex stainless steel exhibited the best performance of the four types of stainless steel investigated herein.

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## 1. Introduction

Erosion–corrosion is a material deterioration phenomenon that occurs in hydraulic machinery that handles aggressive slurries. Many industries attempt to mitigate this challenging feature by modifying the design of components and/or by selecting more erosion–corrosion resistant materials. The latter strategy often involves the selection of corrosion resistant alloys (CRAs), which exhibit good performance in many environments instead of using coating techniques to shield vulnerable materials such as carbon steels even if this increases the initial cost.

An important attribute of the group of materials known as stainless steels is their capacity to resist high flow rates of many aqueous fluids. This contributes to the selection of various types of stainless steel in many engineering applications. Numerous studies have demonstrated that stainless steels display good erosion–corrosion performance under solid-free liquid impingement conditions [1,2]. This good behaviour is due to the ability of its chromium-rich, oxide passive film to resist breakdown even in rapidly flowing liquids and relatively high temperatures (up to 60 °C) [3].

It is well known [4] that the durability of stainless steels decreases when suspended solids are present in the flowing liquid. On account of the diversity in composition, metallurgical structure and mechanical properties in stainless steels, it is of interest to compare the erosion–corrosion behaviour of a range of such materials under these more aggressive conditions.

Many past investigations, however, have focused on individual grades of stainless steel, such as the standard austenitic UNS S31600/31603 [5–9] and similar austenitic stainless steel UNS S30400 [10–12]. When more than one stainless type has been studied they have usually comprised comparing two grades. Examples of such work are studies of UNS S31600 versus superaustenitic stainless steel [13,14], comparison of austenitic UNS S30400 with martensitic UNS S42000 [15], martensitic UNS S41000 against UNS S32760 [16] and duplex/superduplex versus UNS 31600 [17,18]. Some of these researchers have also demonstrated the superior erosion–corrosion resistance of stainless steels over carbon steels [16,17,19,20].

Another important feature, of many studies of the erosion corrosion behaviour of stainless steels (and other materials), has been the application of cathodic protection (CP) for the assessment of the potential benefits of the material durability and also in unravelling of erosion corrosion mechanisms [13,14,17,21].

The current study comprised a comparative investigation of four types of stainless steel under solid/liquid impingement conditions in a saline environment. The objectives of this study were firstly to

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obtain any evidence of the different performances of these four types of stainless steel, which might impact on material selection for the Offshore and Oil and Gas Industry. Also, the aim was to ascertain the extent to which the different metallurgical structures and chemical compositions of the steels influence the fundamental mechanisms of erosion–corrosion. A medium carbon steel was also included in the programme as a low-corrosion-resistant comparator. The testing environment has included free erosion corrosion conditions and also experiments involving the application of cathodic protection.

## 2. Materials under study and experimental methodology

The steels, that were considered in this study, were an austenitic stainless steel (UNS S31600), two martensitic stainless steels (UNS S42000 and precipitation hardened martensitic UNS S17400), a superduplex stainless steel (UNS S32760) and a medium carbon steel (UNS G10400). The nominal compositions of all the studied steels are presented in Table 1.

Micro-structural analysis, with an Olympus GX51 microscope, was completed prior to testing to identify the different structures of the steels. Figs. 1–5 display the structures of the steels after polishing to 3  $\mu\text{m}$  diamond and either etching in Nital (for the carbon steel) or electrolytic etching with 10% oxalic acid for the stainless steels.

Also, a macro-hardness tester, Vickers MAT31 was used to obtain the hardness values with 5 kgf load, shown in Table 2, for each grade of steel.

The erosion–corrosion performance was assessed as follows:

- 1) Mass loss tests were carried out under solid/liquid impingement under free erosion–corrosion conditions as well as with the application of cathodic protection which isolated the mechanical damage.
- 2) Potentiodynamic anodic polarisation experiments were conducted in solid/liquid impingement and under static conditions to evaluate the pure electrochemical processes.
- 3) Post-experimental analysis was facilitated initially with the Olympus GX51 microscope to review the surface in more detail. Alicona Infinite Focus equipment was used to determine the wear scar depths. Also, a Mitutoyo SurfTest SV 2000 machine was employed for the surface roughness evaluation in different regions of the post-test surface.

The erosion–corrosion experiments were carried out using a circulating closed loop rig (Fig. 6). The duration of the tests was 30 min. The nozzle diameter was 3 mm and the slurry, which consisted of 3.5% NaCl and sand particles, impinged at 24 m/s velocity perpendicular to the specimen surface. The silica sand particles used in this study possesses hardness of 1160HV with spherical shape, as shown in Fig. 7. The sand concentration, which was measured directly under the nozzle, was  $200 \pm 20$  mg/l. Table 3 represents the sand particle size distribution. The testing temperature range was 30–35 °C. The specimens, of 3.8 cm diameter, were ground on 220, 500, 800, 1200 SiC grit papers, and achieved 0.07  $\mu\text{m}$

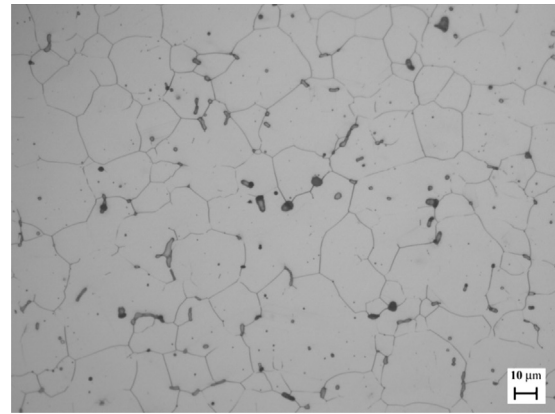


Fig. 1. Austenitic grain structure with  $\delta$ -ferrite valleys at grain boundaries (dark spots) in the UNS S31600.

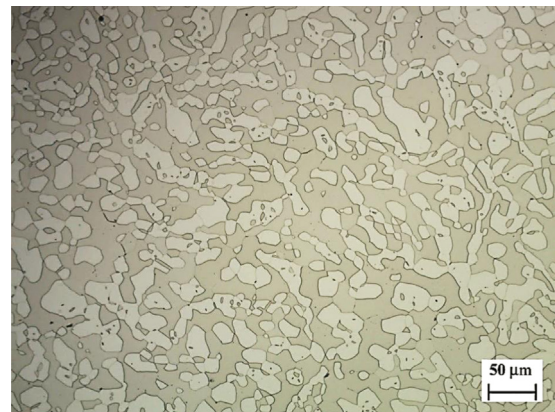


Fig. 2. Ferrite matrix and austenite grains in UNS S32760.

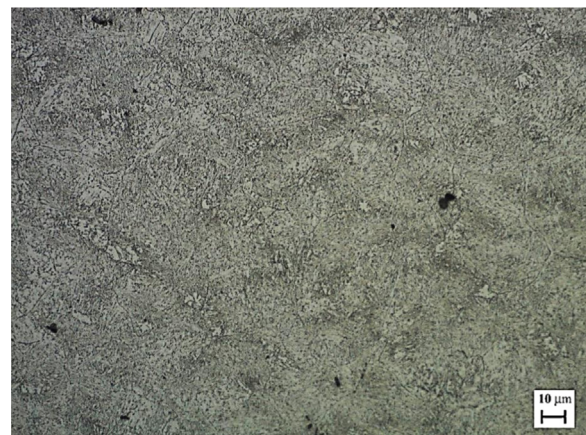


Fig. 3. Tempered martensitic structure in UNS S42000.

Table 1  
Nominal composition of the steels.

Material	C%	W%	Cr%	Ni%	Mo%	S%	Mn%	Cu%	Si%	N%	Nb+Ta%
UNS S31600	0.08		17.5	12	2.5	< 0.03	< 2		< 0.75	< 0.1	
UNS S32760	0.03 Max	0.75	25	7	3.5	< 0.01	1 Max	0.75		0.25	
UNS S42000	< 0.15		13			< 0.03	< 1		< 1		
UNS S17400	< 0.07		16.5	4		< 0.03	< 1	4	1		0.3
UNS G10400	0.40					0.05	0.75				

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