

From 6Mo to Ni-Base – Characterizing the Corrosion Performance of Two Important Material Groups

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ABSTRACT

Over the years, the gap between stainless steels and Ni-base alloys has become increasingly diffuse, not only in terms of chemical composition but also when considering performance in corrosive service conditions. While Ni-base alloys can sometimes be considered the safe choice, alternatives with a lower nickel content are often more cost efficient. Due to advances in material technology and the always-increasing knowledge about material performance, high-alloyed stainless steels can indeed be attractive and competitive materials of choice for highly corrosive service conditions.

This work focuses on characterizing various high-alloyed stainless steels and Ni-base alloys in terms of localized corrosion performance, as well as uniform corrosion performance in chloride contaminated sulfuric acid. Corrosion data will be presented to demonstrate differences and similarities between these material groups, and between individual grades. This knowledge can be used to make better-informed decisions when selecting materials for highly corrosive applications.

Key words: Acids, corrosion resistant materials, stainless steel, pitting

INTRODUCTION

Stainless steels and Ni-base alloys are often considered as construction materials in applications where highly corrosive conditions are expected. High levels of halides, low pH and high temperatures are factors that often contribute to the selection of such materials.

Ten different alloys have been included in this work, representing a range of highly alloyed stainless steels and Ni-base alloys. The purpose has been to evaluate the corrosion resistance of stainless steels with alloying content in the 6Mo range or higher, and competing Ni-base materials. The austenitic grade N08904 and two super-duplex grades have also been included for reference.

Material groups

The main characteristics of the selected materials are described in the following section. The description of each material group is in no way exhaustive or definite – it is meant as a brief overview of some commonly used materials, with the focus on the grades that are included in this work.

6Mo grades

This material group is often a go-to choice for applications where the corrosion resistance of standard austenitic grades is not sufficient. 6Mo is not a single grade, nor is it a clearly defined group of grades, but it commonly refers to highly alloyed austenitic stainless steels with a molybdenum content of roughly 6 weight%.¹ Other common characteristics are chromium and nickel contents of around 20% and a nitrogen content of approximately 0.2%. The two grades 254 SMO[†] (UNS S31254) and 6XN[†] (UNS N08367 / N08926) are similar in terms of composition, with the most significant difference being the higher nickel content of the latter.

UNS N08904

Similar to the 6Mo grades, 904L[†] (UNS N08904) is a highly alloyed austenitic grade. The main difference from the 6Mo grades is the lower molybdenum content, the exclusion of nitrogen as an alloying element and higher levels of copper.

Super-duplex

Grades from this material group can be attractive alternatives to the 6Mo grades. The corrosion resistance is similar in many environments, while the duplex grades offer higher mechanical strength and better price stability (the latter due to the lower nickel content).² Two super-duplex grades have been included in this work – SDX 2507[†] (UNS S32750) and SDX 100[†] (UNS S32760). Compared to the included 6Mo grades, these two contain a higher content of chromium, lower content of nickel and molybdenum, and a slightly higher content of nitrogen. The main difference between the two super-duplex grades is the inclusion of tungsten as an alloying element in S32760.

UNS S32654 and UNS N08031

654 SMO[†] (UNS S32654) and Alloy 31[†] (UNS N08031) are two highly alloyed austenitic alloys that fall between the Ni-base alloys and 6Mo grades in alloying content. These two grades are similar to the 6Mo grades in utilizing high levels of chromium, molybdenum and nitrogen for their corrosion resistance. For these grades, however, the levels have been pushed even further – especially the chromium content in N08031 and the molybdenum and nitrogen content in S32654. Additionally, N08031 contains a high amount of nickel (31%) compared to the previously described materials.

Ni-base alloys

For the most corrosive conditions, where even the 6Mo or super duplex grades do not suffice, Ni-base alloys are often considered. This is a large group of materials with the common attribute of having nickel as the dominating alloying element. Many of the available Ni-base alloys are specialized for

[†] Trade name

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niche environments and usage areas. In this work, three widely used and established grades have been investigated – Alloy 825[†] (UNS N08825), Alloy 625[†] (UNS N06625) and Alloy C-276[†] (UNS N10276). These three alloys have very different compositions, the most striking difference being the molybdenum contents of approximately 3%, 9% and 16%, respectively, as well as the nickel contents. With the significant differences in alloying content in mind, these should be treated as different alloys and do not necessarily share the same similarities as other alloys within the same material group.

Corrosion resistance of grades within the 6Mo to Ni-base range

The corrosion performance of such a wide range of materials is a vast topic that cannot be fully covered in any one paper. In the following section, however, a brief overview of the resistance to some of the most commonly encountered corrosion types will follow.

Pitting and crevice corrosion resistance

Most of the materials within these groups offer very good resistance to localized corrosion types, such as pitting and crevice corrosion. 6Mo grades are commonly used in applications where high chloride resistance is required, such as sea water exposure at moderate temperatures.^{1,3} For many applications, the significant step up in corrosion resistance compared to standard grades is sufficient. However, in the most aggressive cases, typically characterized by some combination of high chloride content, high temperature, low pH and aggressive crevices, the 6Mo family may not offer sufficient resistance. For such applications, high-alloyed Ni-base grades such as N06625 or N10276 are often considered. An alternative option is to use grades such as S32654 and N08031, which have been shown to offer similar, or sometimes higher, resistance to pitting and crevice corrosion.^{4,5}

Stress corrosion cracking

In stainless steels and Ni-base alloys the resistance to stress corrosion cracking is strongly connected to alloying content of nickel. With roughly 20% nickel, or more, the 6Mo grades have excellent resistance to stress corrosion cracking. In laboratory tests, they pass many standardized tests that standard grades are known to fail³.

In the most extreme conditions, though, the 6Mo grades may be susceptible to stress corrosion cracking. This may occur in highly concentrated boiling chloride solutions⁶. Similarly, unfavorable conditions with high temperatures, chloride contents and the presence of hydrogen sulfide may occur in the oil and gas industry. In such cases a grade with higher Ni-content is likely to perform better. For the latter case, the environmental limits for different materials are described in ISO 15156-3^{(1),7}.

Uniform corrosion in acids

While most grades within the 6Mo to Ni-base range offer some level of resistance to the most commonly encountered acids, the temperature and concentration limits for satisfactory corrosion resistance vary significantly depending on both acid type and grade of material. Different alloying elements have different effects on the corrosion resistance depending on acid type and concentration. Comparing stainless steels to Ni-base grades, the strength of and reliance on passivity may be very different, as may the corrosion rates in the active state.⁸

For reliable material selection, corrosion data for the given acid environment must be consulted. In this work, the performance of the previously discussed alloys in 20% sulfuric acid has been investigated. Several temperatures and different levels of chloride contamination have been evaluated to see how the different materials respond when conditions are made gradually more aggressive. In addition to this, localized corrosion testing has been performed to evaluate resistance to pitting and crevice corrosion.

[†] Trade name

(1) International Organization for Standardization, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland

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