# INCONEL® alloy 686
# The Corrosion-Resistant Alloy for the 21st Century

Multi-purpose pharmaceutical vessel manufactured in 40mm thick INCONEL alloy 686 plate.

INCONEL alloy 686 (UNS N06686) is the most highly alloyed corrosion-resistant alloy commercially available today. The alloy is available in all standard product forms including plate, sheet, strip, pipe, tube, rod, bar, forging stock, and matching composition welding products. The alloy has full specification coverage from ASTM, ASME, VdTÜV, and NACE MR0175.

Alloy 686 is a low-carbon, nickel-chromium-molybdenum-tungsten advanced corrosion-resistant alloy that offers outstanding resistance to oxidizing, reducing, and mixed acid environments including those containing halides. The alloy is resistant to seawater and other marine environments. Thus, alloy 686 is widely used in the chemical processing, marine, and air pollution control (flue gas desulfurization) industries. The alloy's resistance to a diverse number of environments makes it a candidate for many aggressive aqueous environments. This document is written to help design and maintenance engineers evaluate materials and compare the corrosion resistance of alloy 686 with the other corrosion-resistant alloys currently available.

Additional information describing INCONEL alloy 686 or any of the alloys manufactured by Special Metals Corporation is available on the SMC website, www.specialmetals.com.

## Chemical Composition

The typical chemical compositions of the corrosion-resistant alloys to be compared are reported in Table 1. Limiting chemical compositions for purchasing purposes will be found in the appropriate society specifications (e.g., ASTM, ASME, SAE / AMS, VdTÜV, etc.)

**Table 1** - Typical Chemical Composition of Corrosion-Resistant Alloys

| Alloy | UNS No. | Ni | Cr | Mo | Cu | W | N |
|---|---|---|---|---|---|---|---|
| INCOLOY alloy 25-6MO | N08926 | 25 | 20 | 6.5 | 1 | - | 0.20 |
| INCONEL alloy 625 | N06625 | Bal | 22 | 9 | - | - | - |
| INCONEL alloy C-276 | N10276 | Bal | 16 | 16 | - | 3.5 | - |
| INCONEL alloy 22 | N06022 | Bal | 22 | 14 | - | 3.2 | - |
| Hastelloy C-2000 | N06200 | Bal | 23 | 16 | 2 | - | - |
| VDM 59 | N06059 | Bal | 23 | 16 | - | - | - |
| INCONEL alloy 686 | N06686 | Bal | 21 | 16.3 | - | 3.9 | - |

## Types of Corrosion

There are many types of corrosive attack. The attack encountered will be dependent upon the conditions to which the alloy component is exposed. A discussion of the types of corrosion commonly encountered in the process industries may be found in the SMC publication "High-Performance Alloys for Resistance to Aqueous Corrosion" available on the SMC website, www.specialmetals.com.

### Resistance to General Corrosion

General corrosion, an even, uniform attack of the alloy surface, is the most commonly encountered form of corrosion. This type of attack is predictable, which allows effective estimation of the life of components. The corrosion rate is significantly affected by the concentration of the corrosive medium, the presence of contaminants in the medium, and temperature. The data presented in Table 2 allow comparison of materials in various media and conditions. Iso-corrosion diagrams for alloy 686 in hydrochloric and sulfuric acids are presented as Figures 1 and 2, respectively.

**Table 2** - Comparative Corrosion Rates (mpy)[b] in Acidic Media

| Alloy | 1.5% HCl Boiling | 80% $H_2SO_4$ 93°C | 90% $H_2SO_4$ °93C | FGD 1[a] 80°C | FGD 2[a] 105°C |
|---|---|---|---|---|---|
| INCOLOY alloy 25-6MO | 218 | >100 | >100 | 199 | N/A |
| INCONEL alloy 625 | 350 | >100 | >100 | 187 | N/A |
| INCONEL alloy C-276 | 32 | 24 | 18 | 51 | 238 |
| INCONEL alloy 22 | <2 | 69 | 20 | 40 | 279 |
| Hastelloy C-2000 | 5 | 47 | 15 | 24 | |
| VDM alloy 59 | 2 | 88 | 72 | 47 | 308 |
| INCONEL alloy 686 | 2 | 29 | 8 | 23 | 274 |

[a] Test medium designed to simulate that found in a wet limestone flue gas desulfurization air pollution system for high-sulfur coal-fired electric power generation utilities:
FGD 1: 60% $H_2SO_4$ + 2.5% HCl + 0.2% HF + 0.5% flyash at 80°C
FGD 2: 70% $H_2SO_4$ + 2.5% HCl + 0.2% HF at 105°C

[b] mpy can be converted to mm/a by multiplying by 0.0254

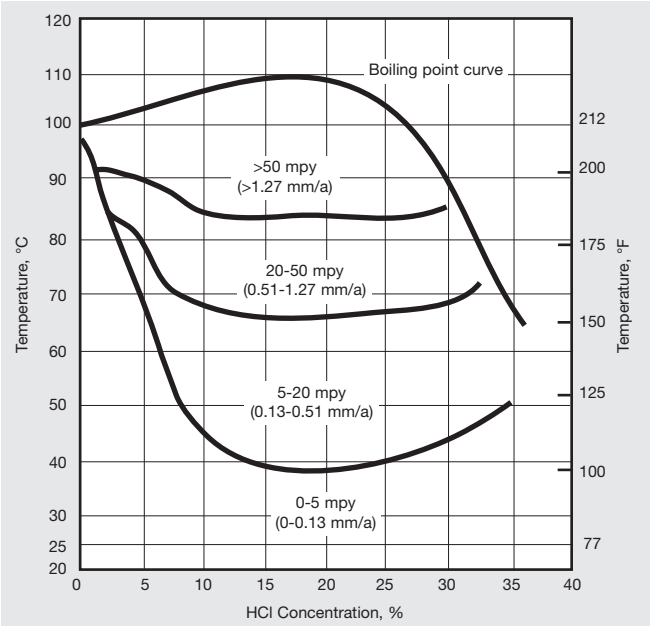


**Figure 1.** Iso-corrosion chart for INCONEL alloy 686 in hydrochloric acid.

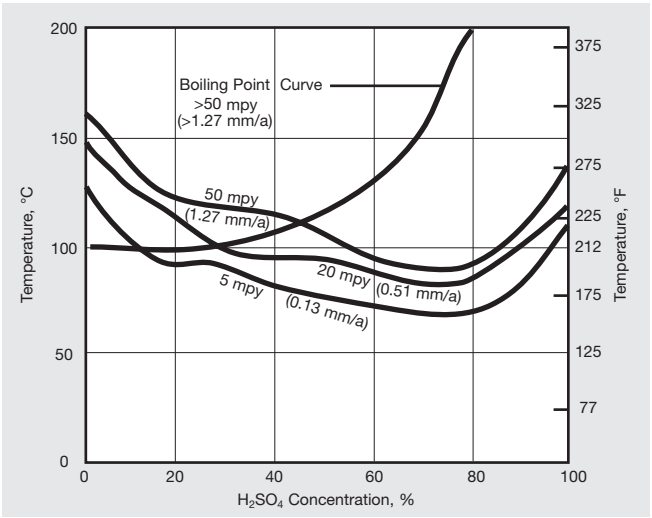


**Figure 2.** Iso-corrosion chart for INCONEL alloy 686 in sulfuric acid.

## Resistance to Localized Corrosion

Localized attack, pitting and crevice corrosion, can occur very quickly and lead to premature, unexpected failure. While the general attack of the surface of the component may be very light, a single pit may propagate through the thickness of the part causing leakage and failure. Crevice corrosion, as the name implies, takes place within the crevices formed by overlapping sections of metal or under tightly adhering deposits.

The Pitting Resistance Equivalency Number (PREN) is a means of comparing the relative resistance of alloys to localized corrosion. Alloys with higher PREN values would be expected to offer superior corrosion resistance to alloys with lesser values. Values for PREN are calculated from the chemical composition of the alloy. Several equations are used to calculate PREN values. Those reported in Table 3 were calculated using the typical composition values in Table 1 and an equation developed to be applicable to the range of corrosion-resistant alloys reported in the table.

**Table 3.** Resistance to Localized Corrosion

| Alloy | UNS No. | PREN[a] | CCT (°C)[b] |
|---|---|---|---|
| INCOLOY alloy 25-6MO | N08926 | 35.8 | <50 |
| INCONEL alloy 625 | N06625 | 40.8 | 65 |
| INCONEL alloy C-276 | N10276 | 45.3 | 90 |
| INCONEL alloy 22 | N06022 | 47.8 | 125 |
| Hastelloy C-2000 | N06200 | 46.0 | 125 |
| VDM alloy 59 | N06059 | 47.0 | 135 |
| INCONEL alloy 686 | N06686 | 51.3 | 140 |

[a] PREN = %Cr + 1.5(%Mo + %W + %Nb) + 30(%N) - 0.5% Cu
[b] Critical Crevice Temperature in Green Death solution (11.9% $H_2SO_4$ + 1.3% HCl + 1% $FeCl_4$ + 1% $CuCl_2$)

The critical crevice temperature (CCT) is a test designed to compare the resistance of alloys to localized (crevice) attack in a given medium. Commonly used test procedures are defined in ASTM G 48. The CCT of various alloys in the "Green Death" test medium is presented in Table 3. The depth of attack as a function of temperature is seen in Figure 3.

## Welding

Since weldments are cast structures, they often behave differently in corrosive environments than wrought products of the same composition. Nickel-chromium-molybdenum weldments suffer from elemental segregation during solidification. Higher melting elements such as molybdenum and tungsten solidify before lower melting elements such as nickel and chromium. Thus there are elemental gradients across the components of the welds. Since there are variations in composition, the various sections of the weld respond differently to corrosive media. Those sections depleted of alloying elements normally corrode preferentially to those that are enriched in alloying elements. To counter this affect, when possible, more highly alloyed welding products are used to join corrosion resistant alloys. For example, INCONEL alloy 22 and 625 welding products are commonly used to join molybdenum-bearing austenitic stainless steels ( e.g, grades 316 and 317), super-austentic stainless steels such as INCOLOY alloy 25-6MO, and lesser alloyed nickel-base corrosion-resistant alloys such as INCOLOY alloys 825 and 020 and INCONEL alloy G-3. In a similar manner, alloy 686 welding products, INCO-WELD Filler Metal 686CPT and INCO-WELD Welding Electrode 686CPT, may be used to weld corrosion-resistant alloys such as INCONEL alloys 22 and C-276, Hastelloy C-22 and C-2000 alloys, and VDM alloy 59. Figure 4 demonstrates the superior corrosion resistance of the 686CPT welds compared to those deposited with matching composition welding products in these alloys. Since alloy 686 is the most highly alloyed material available, it must be welded with the matching composition welding products (686CPT). It is seen in Figure 4 that the alloy 686CPT weldments in alloy 686 base metal exhibit full resistance to the environment. Additional information on welding can be found on the Special Metals websites, www.specialmetals.com and www.specialmetalswelding.com.

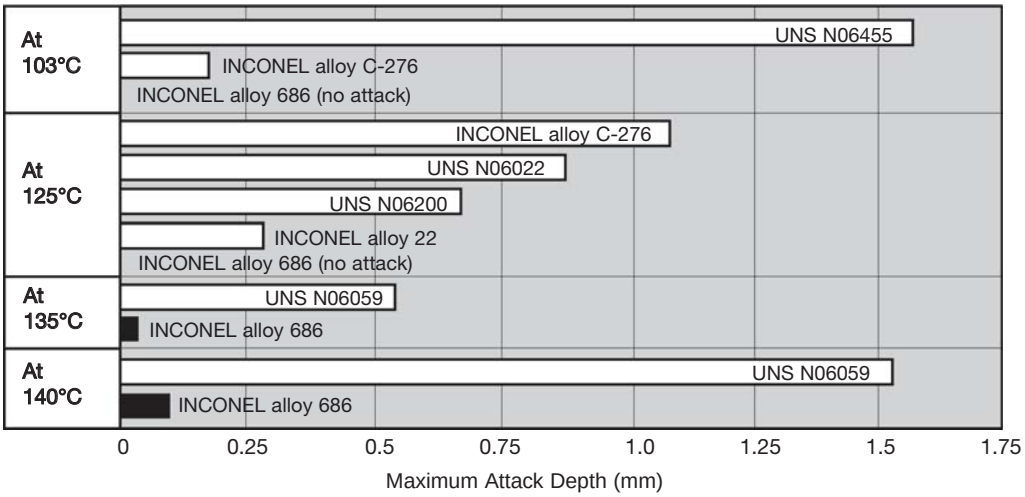


**Figure 3.** Relative resistance of nickel base alloys to crevice corrosion as a function of temperature in "Green Death" solution (11.9% $H_2SO_4$ + 1.3% HCl + 1.0% $FeCl_3$ + 1.0% $CuCl_2$). Special Metals laboratory test data.

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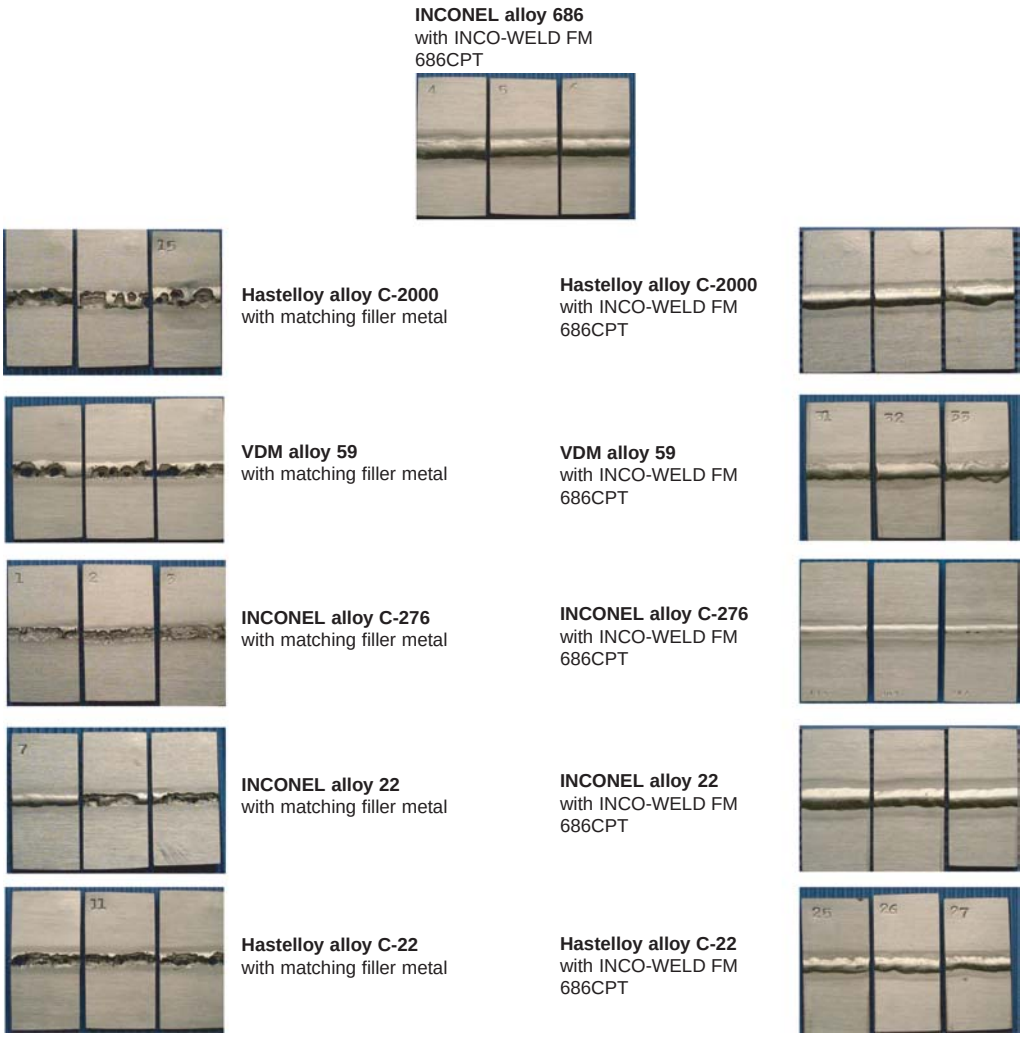


**Figure 4.** Corrosion resistance of weldments in corrosion-resistant alloys in boiling Green Death test medium.

## Availability

INCONEL alloy 686 is manufactured by Special Metals Corporation in all common product forms. Commercial inquiries may be submitted to any Special Metals office or on our website. Alloy 686 products are available from stock from Corrosion Materials, Inc. (www.corrmatls.com) and BIBUS Metals AG (www.bmag.bibus.ch).

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