A Comparison of the Properties of Corrosion-Resistant Alloys and Titanium: An Aid for Specifying Cost Effective Materials for Demanding Applications

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Commercially pure (C.P.) titanium and titanium alloys offer excellent resistant to many commonly encountered corrosive media. However, these materials are currently in very limited supply. Thus, designers are being forced to consider alternate corrosion-resistant materials. Nickel-chromium-molybdenum corrosion-resistant alloys such as INCONEL alloys C-276, 22, and 686 and INCOLOY alloy 27-7MO are excellent candidates for this purpose. For comparison purposes, data describing competitive alloys Allegheny Ludlum AL6XN, Krupp VDM alloys 31 and 59, and Haynes Hastelloy C-2000 are included.

Relative cost, localized corrosion resistance, general corrosion resistance and marine corrosion data are provided in Table 1. Chemical composition, mechanical properties, density and specification information are presented in Table 2.

Information describing all the alloy products manufactured by Special Metals is available on the company websites, www.specialmetals.com and www.specialmetalswelding.com.

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Table 1

A Comparison of the Aqueous Corrosion Resistance of Several Alloys in Various Applications

Application / Test Environment	INCOLOY 25-6MO	Alloy AL6XN	Alloy 31	INCOLOY 27-7MO	INCONEL C-276	Alloy C-2000	INCONEL 22	Alloy 59	INCONEL 686	Ti Gr. 2
General										
% Nickel - % Molybdenum	25Ni-6Mo	24Ni-6Mo	31Ni-6Mo	27Ni-7Mo	57Ni-16Mo	57Ni-16Mo	58Ni-13Mo	59Ni-16Mo	57Ni-16Mo	-
Cost Ratio (relative to alloy 25-6MO)	**1**	**1**	**1.4**	**1.1**	**2.0**	**2.3**	**2.1**	**2.3**	**2.3**	**2.1**
Localized Corrosion										
Pitting Resistance Equivalency No[1]	35.8	36.4	42.6	43.0	45.2	47[2]	46.5	47	50.8	N/A
Critical Pitting Temp (ASTM G48C)	70°C	70-75°C	75°C	>85°C	>85°C	>85°C	>85	>85°C	>85	N/A
Critical Crevice Temp (ASTM G48D)	35°C	35°C	45°C	50°C	50°C		75		>85	N/A
Critical Pitting Temp ("Green Death")	60°C	65°C	55C	80°C	> Boiling	110°C	>120°C		>135°C	N/A
Critical Crevice Temp ("Green Death")	45°C	50°C	50°C	65°C	90°C	<125°C	120°C	130°C	135°C	N/A
General Corrosion - mpy										
1% HCl @ 60C	0			0	0		0		0	0.6
1% HCl @ Boiling	218		1.5	1.3	6.5		2.7		2	23
2% HCl @ Boiling	>50	>50	>50	>50	50	3.5	60	5	7	
3% HCl @ 60°C	>50			<5	<1		<1		<1	39
5% HCl @ 50°C	45	64	<1	<1	0.5		<1		<1	
5% HCl @ 60C	88			70	1		<1		1	118
5% HCl @ 65C	>50	>50		>50	12	8	<1		<1	
15% HCl @ 35°C, Aerated	<50			20	<5		5		<5	94
10% H_2SO_4 @ 90°C	33	>5	1	1	<1	<1	1	<1	<1	
10% H_2SO_4 @ 35C, Aerated	<5	<5	<5	<5	<5		<5		<5	47
40% H_2SO_4 @ 35C, Aerated	<5	<5	<5	<5	<5		<5		<5	335
95% H_2SO_4 @ 50°C	18	29	13	14	<1		<1		<1	
80% H_2SO_4 @ 93°C	>20	>20	>20	>20	24	47		88	29	
10% H_2SO_4 + 2% HCl @ 50°C	29	42	18	<1	<1					
10% H_2SO_4 + 10,000 ppm Cl^- @ 65°C	26			<0.5	0.5		<0.5		<0.5	479
10% H_2SO_4 + 1,000 ppm Cl^- @ 65°C	26			0	1		<0.5		<0.5	
98% H_2SO_4 + 1,000 ppm Cl^- @ 65°C	57			49						
Resistance to hydrogen embrittlement and hydriding	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Poor

1 - PREN = %Cr + 1.5 (%Mo + %W) + 30 (%N) 2 – Actual pitting resistance is lower due to copper content

Table 1 (continued)

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Application / Test Environment	INCOLOY 25-6MO	Alloy AL6XN	Alloy 31	INCOLOY 27-7MO	INCONEL C-276	Alloy C-2000	INCONEL 22	Alloy 59	INCONEL 686	Titanium Grade 2
Marine (max depth of attack in mm)										
30°C Seawater, 60 days, crevice test	---	0.01	---	No Attack	0.02	---	---	---	---	---
Boiling Saturated (26%) NaCl	Crevice Attack	---	---	No Attack	No Attack	---	No Attack	---	No Attack	Attack[3]
Boiling pH 1 Saturated NaCl	---	---	---	5	<1	1	2.5	<1	0	---

3 – Incipient crevice attack at discoloration

Table 2

Physical and Mechanical Properties of Nickel Containing Alloys and Titanium

Physical & Mechanical Properties	INCOLOY 25-6MO	Alloy AL6XN	Alloy 31	INCOLOY 27-7MO	INCONEL C-276	Alloy C-2000	INCONEL 22	Alloy 59	INCONEL 686	Titanium Grade 2
Density										
lb/cu.in.	0.290	0.291	0.293	0.289	0.321	0.307	0.311	0.31	0.315	0.163
g/cu. cm.	8.03	8.06	8.1	8.02	8.89	8.50	8.61	8.6	8.73	4.51
Mechanical Properties At Room Temperature										
Specification – ASTM	B625,A240	A240	B625	A240	B575	B575	B575	B575	B575	B348
Minimum UTS - ksi	94	100	94	112	100	100	100	100	100	50
Minimum 0.2%YS - ksi	43	45	40	52	41	41	45	45	45	40
Minimum Elong. - %	35	30	40	40	40	45	45	45	45	20
Limiting Chemical Composition										
Specification - ASTM	B625, A240	A240	B625	A240	B575	B575	B575	B575	B575	B348
Nickel	24.0-26.0	23.5-25.5	30.0-32.0	26.0-28.0	Balance	Balance	Balance	Balance	Balance	---
Chromium	19.0-21.0	20.0-22.0	26.0-28.0	20.5-23.0	14.5-16.5	22.0-24.0	20.0-22.5	22.0-24.0	19.0-23.0	---
Molybdenum	6.0-7.0	6.0-7.0	6.0-7.0	6.5-8.0	15.0-17.0	15.0-17.0	12.5-14.5	15.0-16.5	15.0-17.0	---
Tungsten	---	---	---	---	3.0-4.5	---	2.5-3.5	---	3.0-4.4	---
Copper	0.5-1.5	0.75 max	1.0-1.4	0.5-1.5	---	1.3-1.9	---	0.50 max	---	---
Iron	Balance	Balance	Balance	Balance	4.0-7.0	3.0 max	2.0-6.0	1.5 max	2.0 max	0.30 max
Manganese	2.0 max	1.00 max	2.0 max	3.00 max	1.0 max	0.5 max	0.50 max	0.5 max	0.75 max	---
Vanadium	---	---	---	---	0.35 max	---	0.35 max	---	---	---
Titanium	---	---	---	---	---	---	---	---	0.02-0.25	Balance
Cobalt	---	---	---	---	2.5 max	2.0 max	2.5 max	0.3 max	---	
Carbon	0.02 max	0.030 max	0.015 max	0.020 max	0.01 max	0.010 max	0.015 max	0.010 max	0.01 max	0.08 max
Nitrogen	0.15-0.25	0.18-0.25	0.15-0.25	0.3-0.4	---	---	---	---	---	0.03 max
Silicon	0.5 max	1.00 max	0.3 max	0.5 max	0.08 max	0.08 max	0.08 max	0.10 max	0.08 max	---
Sulfur	0.01 max	0.030 max	0.010 max	0.01 max	0.03 max	0.010 max	0.02 max	0.010 max	0.02 max	---
Phosphorus	0.03 max	0.040 max	0.020 max	0.03 max	0.04 max	0.025 max	0.02 max	0.015 max	0.04 max	---
Hydrogen	---	---	---	---	---	---	---	---	---	0.015 max
Oxygen	---	---	---	---	---	---	---	---	---	0.25 max
Residual Elements (each element)	---	---	---	---	---	---	---	---	---	0.1 max
Residual Elements (total)	---	---	---	---	---		---	---	---	0.4 max