TECHNICAL MEMORANDUM WHOI-4-72

Woods Hole Oceanographic Institution

HANDBOOK OF OCEANOGRAPHIC ENGINEERING MATERIALS

VOLUME I - METALS AND ALLOYS

Stephen C. Dexter

TECHNICAL MEMORANDUM
Prepared for the Department of Commerce under NOAA, Grant No. 2-35252.

WOODS HOLE, MASSACHUSETTS 02543

WHOI-4-72

HANDBOOK OF OCEANOGRAPHIC ENGINEERING MATERIALS

VOLUME I - METALS AND ALLOYS

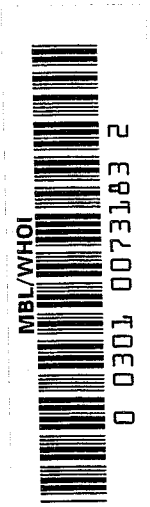
Prepared by

Stephen C. Dexter

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

December 1972

TECHNICAL MEMORANDUM
Prepared for the Department of Commerce under NOAA, Grant No. 2-35252.



Preface

This handbook is intended to serve as an aid in materials selection to Oceanographic engineers and designers. As such it is intentionally limited to materials that may be used advantageously in the marine environment. The complete handbook will eventually appear in two volumes:

Volume I: Metals and Alloys
Volume II: Non-metallic Materials

The data presented in this handbook should be of considerable assistance in optimizing materials selection with regard to mechanical, physical and chemical properties; corrosion resistance; fabricability; availability and cost for sea water applications. Caution should be exercised, however, in applying this data to critical design calculations. In many cases the data presented here represent the extremes of the range of a given property that the material of interest is capable of exhibiting. Thus, the data presented herein should always be supplemented by more detailed information from the materials supplier on the properties of the chosen material in the specific form in which it will be used.

Table of Contents

Introduction to Volume 1 1

Part A

Density 2

Elastic Modulus 3

Approximate Yield Stress 4

Specific Stiffness 5

Specific Strength 6

Strength per unit Weight per unit Cost 8

Corrosion Potential in Flowing Sea Water 10

General Sea Water Corrosion Behavior 11

Approximate Cost 13

Part B

Aluminum Alloys 14

Copper Alloys 27

Nickel Alloys 46

Iron and Steel 54

Stainless Steels 70

Titanium 84

Magnesium and Zinc 86

Index of Materials Listed in Part B 88

Introduction to Volume I - Metal and Alloys

Volume I consists of two sections. Part A is a series of tabulations of metallic materials ranked according to selected mechanical and physical properties, corrosion resistance, and cost. Part B consists of one page of more detailed data on each of the materials covered. Composition, mechanical and physical properties, corrosion resistance, forms available, fabricability, typical uses and base cost are treated for each material. In this section the materials are grouped into alloy classes according to the base metal of the alloy.

PART A

DENSITY

Alloy	in Sea Water ρ_{sw} (lb/in^3)	in Air ρ (lb/in^3)	Alloy	in Sea Water ρ_{sw} (lb/in^3)	in Air ρ (lb/in^3)
Hastelloy C	.286	.323	431 Stainless Steel	.243	.280
90-10 Cu-Ni CDA 706	.286	.323	Titanium	.126	.163
80-20 Cu-Ni CDA 710	.286	.323	6-4 Titanium	.123	.160
70-30 Cu-Ni CDA 715	.286	.323	7178 Aluminum	.065	.102
OFHC Copper CDA 110	.285	.322	7075 Aluminum	.064	.101
Monel 400	.282	.319	7079 Aluminum	.062	.099
Phosphor Bronze 10% CDA 524	.280	.317	3003 Aluminum	.062	.099
Red Brass CDA 230	.279	.316	6061 Aluminum	.061	.098
Nickel Silver CDA 752	.279	.316	1100 Aluminum	.061	.098
Silicon Bronze CDA 655	.271	.308	5005 Aluminum	.061	.098
Cartridge Brass CDA 260	.271	.308	5050 Aluminum	.060	.097
Inhibited Admiralty CDA 443	.271	.308	5052 Aluminum	.060	.097
Monel K 500	.269	.306	5083 Aluminum	.059	.096
Inconel 625	.268	.305	5086 Aluminum	.059	.096
Inconel 600	.267	.304	5456 Aluminum	.059	.096
Naval Brass CDA 464	.267	.304	Magnesium	.026	.063
Muntz Metal CDA 280	.266	.303			
Mn-Bronze CDA 675	.265	.302			
Be-Copper CDA 172	.261	.298			
Inconel X-750	.261	.298			
Inconel 718	.259	.296			
Hastelloy F	.258	.295			
Incoloy 825	.257	.294			
Maraging Steels	.253	.290			
300 Series Stainless Steels	.253	.290			
Alloy 20 Cb	.253	.290			
22-13-5 Stainless Steel	.248	.285			
HY-80 Steel	.247	.284			
HY-100 Steel	.247	.284			
Plain Carbon Steels	.246	.283			
HSLA Steels	.246	.283			
Al-Bronze D CDA 614	.244	.281			
17-4 PH Stainless	.243	.280			
410 Stainless Steel	.243	.280			

ELASTIC MODULUS

Alloy	Tension, E, x 10^6 psi	Shear, G, x 10^6 psi
Inconel X-750	31	11
Inconel 600	30	11
Plain Carbon Steels	30	
HY 80 & HY 100	30	
HSLA Steels	30	
310 Stainless Steel	30	
Inconel 625	29.8	11.4
Hastelloy C	29.8	
Inconel 718	29	11.2
Hastelloy F	29	
Maraging Steels	29	
410 & 431 Stainless	29	
17-4 PH Stainless	28.5	12.7
22-13-5 Stainless Steel	28	10.1
300 Series Stainless Steels	28	12.5
Alloy 20 Cb	28	11
Incoloy 825	28	
Monel 400 and K 500	26	9.5
70-30 Cu-Ni CDA 715	22	8.3
80-20 Cu-Ni CDA 710	20	
CDA alloys 172, 706, 614, 752	18	6.7 to 7.0
CDA alloys 110, 230	17	6.4
6-4 Titanium	16.5	6.1
CDA alloys 443, 260, 524	16	6
Titanium	15	6.5
CDA alloys 655, 675, 280, 464	15	5.6
Aluminum alloys 7075, 7079, 7178	10.4	3.9
Aluminum alloys 5083, 5086	10.3	3.83
5052 Aluminum	10.2	3.75
Aluminum alloys 1100, 3003, 5005, 5050, 5456, & 6061	10	3.75

APPROXIMATE YIELD STRESS,[a] σ_y

Alloy	Range High 1000 psi	Range Low 1000 psi
Maraging 300	340*	110
Maraging 250	280*	110
Maraging 180	210	110
Monel K 500	195	40
Be-Copper CDA 172	190	20
17-4 PH Stainless	185	110
HY-180 Steel		180
Inconel 600	175	25
Inconel 718	174	
6-4 Titanium	155	120
431 Stainless	155	95
410 Stainless	145	35
1080 Steel	142	70
HY-140 Steel		140
Inconel 625		53
Inconel X-750	138	
Monel 400	130	25
1095 Steel	120	74
Phosphor Bronze 10% CDA 524	116	26
HY-100 Steel	115*	100
HY-80 Steel	98*	80
Nickel Silver CDA 752	90	25
22-13-5 Stainless	86	60
1040 Steel	86	62
Titanium	85	25
70-30 Cu-Ni CDA 715	79	18
7178 Aluminum	78	15
80-20 Cu-Ni CDA 710	75	
7075 Aluminum	73	15
Inhibited Admiralty CDA 443	72	13
Silicon Bronze CDA 655	70	21

Alloy	Range High 1000 psi	Range Low 1000 psi
7079 Aluminum	68	
Naval Brass CDA 464	66	25
Cartridge Brass CDA 260	65	17
Red Brass CDA 230	63	10
Mn Bronze CDA 675	60	30
HSLA Steels	60	40
Hastelloy C	58	50
6061 Aluminum	57	8
90-10 Cu-Ni CDA 706	57	16
Al-Bronze D CDA 614	55	30
7039 Aluminum	50	
OFHC Copper CDA 110	50	10
Muntz Metal CDA 280	50	17
1020 Steel	48	
Hastelloy F	47	37
310 Stainless	45	40
5456 Aluminum	43	23
304 Stainless	42+	35
316 & 316 L Stainless	42+	30
5083 Aluminum	41	21
302 Stainless	40+	35
317 Stainless	40	35
347 Stainless	40	35
Alloy 20 Cb	40	35
5052 Aluminum	37	13
5086 Aluminum	37	17
304 L Stainless	35+	28
5050 Aluminum	29	8
5005 Aluminum	28	6
3003 Aluminum	27	6
1100 Aluminum	22	5

a) except where noted, values represent the high and low side of a range of typical values.

* value given is for compressive loading. Tensile yield is about 15% lower.

\+ Usually used in this condition. Can be strengthened by cold working.

SPECIFIC STIFFNESS

Alloy	in Sea Water $\frac{E}{\rho_{sw}} \times 10^6$ in.	in Air $\frac{E}{\rho} \times 10^6$ in.
5083 & 5086 Aluminum	175	107
5052 Aluminum	170	105
5456 Aluminum	170	104
7079 Aluminum	168	105
5050 Aluminum	167	103
6061, 5005, & 1100 Aluminum	164	102
7075 Aluminum	163	103
3003 Aluminum	162	101
7178 Aluminum	160	102
6-4 Titanium	134	103
Plain Carbon Steels	122	106
HY-80 & HY-100	122	106
HSLA Steels	122	106
HY-140 & HY-180	122	106
410, 431, & 310 Stainless	119	104
Inconel X-750	119	104
Titanium	119	92
17-4 PH Stainless	117	102
Maraging 180, 250, 300 Steel	115	100
22-13-5 Stainless	113	98
Inconel 600, 718, & Hastelloy F	112	99
Inconel 625	111	98
300 Series Stainless Steels	111	97
Alloy 20 Cb	111	97
Incoloy 825	109	95
Hastelloy C	104	92
Monel K 500	97	85
Monel 400	92	82
70-30 Cu-Ni CDA 715	77	68
Al-Bronze D CDA 614	74	64
80-20 Cu-Ni CDA 710	70	62
Be-Copper CDA 172	69	60
Nickel Silver CDA 752	65	57
90-10 Cu-Ni CDA 706	63	56
Red Brass CDA 230	61	54
Copper Alloys 110, 260, 280, 443, 464, 524, 655, & 675	55-60	49-53

SPECIFIC STRENGTH [a]

Alloy	in Sea Water $\frac{\sigma_y}{\rho_{sw}}$ x 1000 in.	in Air $\frac{\sigma_y}{\rho}$ x 1000 in.
6-4 Titanium	1260	968
Maraging 300 Steel	1200*	1044
7178-T6 Aluminum	1200	765
7075-T6 Aluminum	1142	723
Maraging 250 Steel	1108*	925
7079-T6 Aluminum	1097	687
Maraging 180 Steel	830	724
7039 Aluminum	806	505
17-4 PH Stainless	762	661
5456 Aluminum	729	448
HY-180 Steel	729	634
Be-Copper CDA 172	728	638
Monel K 500	725	638
5083 Aluminum	695	426
Titanium	675	522
Inconel 718	672	588
Inconel 600	656	576
6061-T6 Aluminum	656	408
431 Stainless	639	554
5086 Aluminum	627	385
5052 Aluminum	616	381
410 Stainless	597	518
1080 Steel	578	503
HY-140 Steel	567	494
Inconel X-750	518	453
1095 Steel	488	425
5050 Aluminum	484	299
HY-100 Steel	466*	370
Monel 400	461	408
5005 Aluminum	459	286
3003 Aluminum	435	273
Phosphor Bronze 10% CDA 524	414	366
Inconel 625	411	361
HY-80 Steel	397*	310
1100 Aluminum	361	225
1040 Steel	345	301
22-13-5 Stainless	343	298
Nickel Silver CDA 752	323	285
70-30 Cu-Ni CDA 715	276	244
Inhibited Admiralty CDA 443	266	234
80-20 Cu-Ni CDA 710	262	232
Silicon Bronze CDA 655	258	227
Naval Brass CDA 464	247	217
HSLA Steels	244	212
Cartridge Brass CDA 260	240	211

Mn Bronze CDA 675	226	199
Red Brass CDA 230	226	199
Al-Bronze D CDA 614	226	196
Hastelloy C	203	180
90-10 Cu-Ni CDA 706	199	177
1020 Steel	195	170
Muntz Metal CDA 280	188	165
Hastelloy F	182	159
310 Stainless	178	155
OFHC Copper CDA 110	176	155
Incoloy 825	175+	153
316 Stainless and 316 L	166+	145
304 Stainless	166+	145
317 Stainless	158+	138
347 Stainless	158+	138
302 Stainless	157+	138
304 L Stainless	139+	121
Wrought Iron	120	105

a) except where noted, values represent the highest yield strength from a range of typical values divided by the appropriate density.

*These values are based on the yield strength in compression. Tensile yield strengths are about 15% lower.

+This value is for the annealed condition in which these alloys are usually used. The value will be much higher for the cold worked material.

STRENGTH PER UNIT WEIGHT PER UNIT COST (S/W/C)[a,b]

Material	S/W/C ($\$^{-1}$)	Material	S/W/C ($\$^{-1}$)
7178 Aluminun	16,194	347 Stainless (3000,000 psi)	2,343
7075 Aluminum	15,634	316 Stainless (300,000 psi)	2,130
7079 Aluminum	15,517	HY-140 Steel	1,912
6061 Aluminum	13,437	310 & 317 Stainless (300,000 psi)	1,674
1080 Steel	11,732	431 Stainless Steel	1,641
7039 Aluminum	11,410	410 Stainless Steel	1,637
5456 Aluminum	10,836	MA 300 Steel	1,328
5083 Aluminum	10,332	MA 250 Steel	1,250
1095 Steel	9,915	22-13-5 Stainless Steel cold drawn to 300,000 psi	1,219
5086 Aluminum	9,324	6X Stainless 300,000 psi	1,171
5052 Aluminum	9,016	MA 180 Steel	1,094
1040 Steel	7,106	17-4 PH Stainless Steel	870
5050 Aluminum	7,066	Inhibited Admiralty CDA 443	628
5005 Aluminum	6,601	P-Bronze 10% CDA 524	578
3003 Aluminum	6,161	Cartridge Brass CDA 260	546
1100 Aluminum	5,186	Naval Brass CDA 464	545
HSLA Steels	4,957	6-4 Titanium	539
1020 Steel	3,966	Nickel-Silver CDA 752	516
HY-80 Steel	3,213	MN-Bronze A CDA 675	503
HY-100 Steel	3,142	Unalloyed Titanium	500
302 & 304 Stainless Steel cold drawn to 300,000 psi	2,604	Monel K-500	481
4130 & 4140 Steel	2,582	Silicon Bronze A CDA 655	481

Material	S/W/C ($\$^{-1}$)	Material	S/W/C ($\$^{-1}$)
Red Brass CDA 230	455	OFHC Copper CDA 110	305
Inconel 600	446	304L Stainless (annealed)	304*
Al-Bronze D CDA 614	436	347 Stainless (annealed)	301*
Muntz Metal CDA 280	426	90-10 Cu-Ni CDA 706	300
Be-Copper CDA 172	423	316 & 316L Stainless (annealed)	298*
Hy-180 Steel	421	310 Stainless (annealed)	251*
Inconel 625	381	317 Stainless (annealed)	223*
Inconel 718	371	6X Stainless (annealed)	164*
304 Stainless (annealed)	364*	Hastelloy C-276	30
80-20 Cu-Ni CDA 710	355		
22-13-5 Stainless (annealed)	350*		
302 Stainless (annealed)	347*		
70-30 Cu-Ni CDA 715	342		
Monel 400	341		
Inconel X-750	338		

a) The S/W/C factor is a figure of merit for a tensile specimen .5" in diameter with a 2" gage length obtained as follows:

$$\frac{\text{load at yield (lbf)}}{\text{weight in sea water of gage section (lbf)} \times \text{cost of gage section (\$)}} = \text{S/W/C } (\$^{-1})$$

b) Unless otherwise noted the yield strength used is the maximum obtainable for each material.

* This is the condition in which these materials are normally used.

APPROXIMATE CORROSION POTENTIAL IN FLOWING SEA WATER[a] vs. SATURATED CALOMEL ELECTRODE

Alloy	Potential (volts)	Alloy	Potential (volts)
Magnesium	-1.6	431 Stainless Steel (passive)	-0.22
Zinc	-1.0	70-30 Cu-Ni CDA 715	-0.21
Aluminum 7079	-0.87	OFHC Copper CDA 110	-0.20
Aluminum 5456	-0.87	Inconel 600 (passive)	-0.17
Aluminum 5083	-0.87	Monel 400	-0.11
Aluminum 5086	-0.85	Monel K 500	-0.11
Aluminum 5050	-0.84	Inconel 625	-0.10
Aluminum 5052	-0.84	Inconel 718	-0.10
Aluminum 5005	-0.84	Inconel X750	-0.10
Aluminum 1100	-0.83	Incoloy 825	-0.10
Aluminum 3003	-0.83	Alloy 20 Cb	-0.10
Aluminum 6061	-0.83	Titanium	-0.10
Aluminum 7075	-0.81	6-4 Titanium	-0.10
Plain Carbon Steels	-0.65	300 Series Stainless Steels	
HY-80 Steel, cast iron	-0.62	(passive)	-0.09
HSLA Steels	-0.60	22-13-5 Stainless	
Maraging Steels	-0.50	6X Stainless	
300 Series Stainless Steels (active)	-0.50	Hastelloy C	-0.08
410 & 431 Stainless (active)	-0.50		
Inconel 600 (active)	-0.40		
Cartridge Brass CDA 260	-0.37		
Red Brass CDA 230	-0.37		
Al-Bronze D CDA 614	-0.37		
Mn-Bronze CDA 675	-0.32		
Muntz Metal CDA 280	-0.32		
Naval Brass CDA 464	-0.32		
Inhibited Admiralty CDA 443	-0.30		
410 Stainless Steel (Passive)	-0.30		
90-10 Cu-Ni CDA 706	-0.28		
Silicon Bronze CDA 655	-0.27		
80-20 Cu-Ni CDA 710	-0.25		

a) This value represents the approximate mid point of a range of corrosion potentials.

GENERAL SEA WATER CORROSION BEHAVIOR

Types of Attack Suffered

Alloy	General Rating	Uniform	Pitting, Crevice etc.	Stress Corrosion Cracking (SCC)	Hydrogen Embrittlement	Comments
Hastelloy C-276	Inert					Highly resistant to all types of attack in sea water for long periods
6-4 Titanium	"			x*		
Pure Titanium	"			x*		
Inconel 625	Excellent		slight#			
Alloy 20Cb	"		slight#			
22-13-5 Stainless	"		slight#	x*		
6X Stainless	"		slight#			
Inconel 718	Good		x			No attack at vel. > 3 fps good in corrosion fatique
Inconel X-750	"		mild			Immune to Cl^-SCC
Incoloy 825	"		slight			No attack if vel. > 5 fps good resistance to Cl^-SCC
316 & 316L Stainless	"		slight	x*		
Inconel 600	"		mild			Immune to Cl^-SCC
Monel 400 & K 500	"	x	x			No attack if vel. > 5 fps
70-30 Cu-Ni CDA 715	"	<1. MPY				OK up to 15 fps. Sulfur and H_2S are detrimental.
Other 300 series Stainless	Fair		severe	x*		Especially under fouling deposits
17-4 PH Stainless	"		x			Weld bead attack
80-20 Cu-Ni CDA 710	"	1.25 MPY				OK up to 12 fps. Sulfur & H_2S are detrimental.
90-10 Cu-Ni CDA 706	"	1.5 MPY				OK up to 10 fps. Sulfur & H_2S are detrimental.
Be-Cu CDA 172	"	x				
Naval Brass CDA 464	"	<2.5 MPY				Dezincification
Inhibited Adm. CDA 443	"	<2.5 MPY	slight			

Al-Bronze D CDA 614	Fair	<2 MPY	x			Dealuminumization
Si Bronze CDA 655	"	<2 MPY				OK up to 3 fps.
Mn Bronze CDA 675	"	<3 MPY				Dezincification
Phosphor Bronze CDA 524	"	x	x			
Nickel Silver CDA 752	"	x		x		
6061 Aluminum	"		x	in T4		Best of Aluminum Alloys
5456, 5086, & 5083 Al	"		x			
410 & 431 Stainless	"		x			Especially under fouling deposits.
Red Brass CDA 230	Poor	<2 MPY		slight		Dezincification
Cartridge Brass CDA 260	"	2 to 3 MPY		slight		Dezincification
5052, 5050, & 5005 Al	"		x			
HSLA Steels	"	.5-5.0 MPY	slight			
Muntz Metal CDA 280	"	2 to 3 MPY	x	x		
1100, 3003 Aluminum	"		x			
OFHC Copper CDA 110	"	1 to 3 MPY				Accelerated if vel. >3 f
Plain Carbon Steels	"	10-15 MPY	slight		x	<5 MPY after 5 years
Quenched and tempered Alloy Steels	"	<3 MPY		x+	x+	
Maraging Steels	"	<3 MPY		x	x	
7178 Aluminum	very poor		severe			Not used without protection.
7039 Aluminum	very poor		severe			Not used without protection.
7075 & 7079 Al	"		severe			Not used without protection.

* In hot Cl^- environments

\+ HY-140 and HY-180 are much more resistant than HY-80

\# Under extreme conditions

APPROXIMATE COST

Alloy	$/lb High	$/lb Low
Hastelloy C-276	11.65*	5.50
6-4 Titanium	9.50*	4.50
Pure Titanium	5.35*	4.00
Inconel 625	3.65*	3.25
Inconel 718	3.50*	3.00
Be-Copper CDA 172	3.30+	
Inconel X-750	3.00*	2.60
Monel K-500	2.80*	2.50
Inconel 600	2.75*	2.30
Incoloy 825	2.50*	2.00
Monel 400	2.40*	2.00
22-13-5 Stainless	2.00*	1.50
6X Stainless	2.00†	1.50
17-4 PH Stainless	1.80*	1.25
70-30 Cu-Ni CDA 715	1.41+	
317 Stainless	1.40*	1.05
310 Stainless	1.40*	1.05
80-20 Cu-Ni CDA 710	1.29+	
Phosphor Bronze 10% CDA 524	1.28+	
90-10 Cu-Ni CDA 706	1.16+	
Nickel Silver CDA 752	1.12+	
316 L Stainless	1.10*	0.80
Al-Bronze D CDA 614	1.06#	
OFHC Copper CDA 110	1.01+	
347 Stainless	1.00*	0.80
316 Stainless	1.00*	0.75
Silicon Bronze CDA 655	0.99+	
7075 Aluminum	0.92*	0.60
304 L Stainless	0.90*	0.60
304 & 302 Stainless	0.90*	0.50
Red Brass CDA 230	0.89+	
Mn-Bronze CDA 675	0.85+	
Naval Brass CDA 464	0.85+	
Muntz Metal CDA 280	0.83Δ	
Cartridge Brass CDA 260	0.81+	
431 Stainless	0.80*	0.42
Inhibited Admiralty CDA 443	0.78#	
Aluminum Alloys: 1100, 3003, 5005, 5050, 5052, 5083, 5086, 5456, 6061, 7039, 7079, 7178	0.57+	0.51
Plain Carbon Steels	0.10*	0.06
HSLA Steels	0.10*	0.06

*This price range includes extras for quantity, cutting, temper, etc. and a variety of product forms

+This price is for 1/4" plate before extras. Thicker plate will be less. other forms slightly more or less.

†This alloy is still experimental so the price is not set firmly.

#This price is for 1" O.D. tubing with .049" wall thickness.

ΔThis price is for thin sheet architectural products.

PART B

MATERIAL: Aluminum Alloy 1100 (Commercially Pure)

NOMINAL COMPOSITION: 1.0 Si + Fe, .2 Cu, .1 Zn, .05 Mn, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .098 lb/in^3; in sea water, ρ_{sw} = .061 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 22.5 x 10^{-6} in/in/°C

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Hard
.2% Yield Strength σ_y	(1000 psi)	5	17 (H 14)	22 (H 18)
Tensile Strength σ_u	(1000 psi)	13	18 (H 14)	24 (H 18)
Shear Strength γ	(1000 psi)	9	11 (H 14)	13 (H 18)
Elongation	(% in 2 inches)	35 to 45	9 to 20	5 to 15
Hardness	(Brinell)	23	32	44 (Rockwell H 85)

Fatigue limits: 5,000 to 9,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.83 (.1N Calomel scale)

Types of Corrosion Suffered: pitting, edge and crevice corrosion

Typical Corrosion Rate Ranges:

USES: Applications requiring very good formability and corrosion resistance, low strength

Forms available: wire, rod, bar, tube, sheet, plate, extruded shapes

Fabricability: Easily welded but machining a smooth surface is difficult

MATERIAL: Aluminum Alloy 3003

NOMINAL COMPOSITION: 1.2% Mn, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .099 lb/in^3; in sea water, ρ_{sw} = .062 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 22.2 x 10^{-6} in/in/°C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	H (14)	H (18)
.2% Yield Strength σ_y	(1000 psi)	6	21	27
Tensile Strength σ_u	(1000 psi)	16	22	29
Shear Strength γ	(1000 psi)	11	14	16
Elongation	(% in 2 inches)	30 to 40	8 to 16	4 to 10
Hardness	(Brinell)	28	40	55

Fatigue limits: 7,000 to 10,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.83v (.1N Calomel scale)

Types of Corrosion Suffered: pitting (scattered and deep), edge and crevice corrosion; susceptible to intergrannular corrosion in H 14 temper

Typical Corrosion Rate Ranges: pitting up to 85 mills deep in 1000 days at 5,300 ft.

USES: Similar to 1100 in corrosion resistance but higher strength. Mostly architectural uses, hardware, and piping

Forms available: tube, sheet, & plate

Fabricability: Readily weldable but more difficult to machine than the 2000 series Al-alloys

MATERIAL: Aluminum Alloy 5005

NOMINAL COMPOSITION: 0.8% Mg, balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .098 lb/in^3; in sea water, ρ_{sw} = .061 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 23.8 x 10^{-6} in/in/° C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Hard
.2% Yield Strength σ_y	(1000 psi)	6	22 (H 14)	28 (H 18)
Tensile Strength σ_u	(1000 psi)	18	23 (H 14)	29 (H 18)
Shear Strength γ	(1000 psi)	11	14 (H 14)	16 (H 18)
Elongation	(% in 2 inches)	30	6 (H 14)	4 (H 18)
Hardness	(Brinell)	28	41 (H 34)	51 (H 38)

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: pitting, edge and crevice corrosion

Typical Corrosion Rate Ranges:

USES: Similar to 3003

Forms available: wire, rod, sheet, plate & foil

Fabricability: Similar to 3003

MATERIAL: Aluminum Alloy 5050

NOMINAL COMPOSITION: 1.4% Mg, balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .097 lb/in^3; in sea water, ρ_{sw} = .060 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 22.8 x 10^{-6} in/in/° C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	H 34	H 38
.2% Yield Strength σ_y	(1000 psi)	8	24	29
Tensile Strength σ_u	(1000 psi)	21	28	32
Shear Strength γ	(1000 psi)	15	18	20
Elongation	(% in 2 inches)	24	8	6
Hardness	(Brinell)	36	53	63

Fatigue limits: 12,000 to 14,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.84v (.1N Calomel scale)

Types of Corrosion Suffered: pitting, edge and crevice corrosion

Typical Corrosion Rate Ranges:

USES: sheet, trim, coiled tubing, builders hardware

Forms available: wire, rod, bar, tube, sheet, & plate

Fabricability: Similar to 3003

MATERIAL: Alluminum Alloy 5052

NOMINAL COMPOSITION: 2.5 Mg, .25 Cr, balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .097 lb/in^3; in sea water, ρ_{sw} = .060 lb/in^3

Coefficient of Thermal Expansion (-50 to 100^{o}C) = 23.0 x 10^{-6}in/in/^{o} C

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	(H 34)	(H 38)
.2% Yield Strength σ_y	(1000 psi)	13	31	37
Tensile Strength σ_u	(1000 psi)	28	38	42
Shear Strength γ	(1000 psi)	18	21	24
Elongation	(% in 2 inches)	25 to 30	10 to 14	7
Hardness	(Brinell)	47	68	77

Fatigue limits: 16,000 to 20,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.84v (.1N Calomel scale)

Types of Corrosion Suffered: edge and crevice corrosion

Typical Corrosion Rate Ranges:

USES: Applications requiring good corrosion resistance & high fatigue strength. Fuel lines & tanks, sheet metal work etc.

Forms available: wire, rod, bar, tube, sheet & plate, fasteners, rivets

Fabricability: Similar to 3003

MATERIAL: Aluminum Alloy 5083

NOMINAL COMPOSITION: 4.5 Mg, 0.7 Mn, .2 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .096 lb/in^3; in sea water, ρ_{sw} = .059 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 23.4 x 10^{-6} in/in/°C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10.3 x 10^6 psi

b) Shear G = 3.83 x 10^6 psi

Property	Condition →	Annealed	H 113	H 343
.2% Yield Strength σ_y	(1000 psi)	21	33	41
Tensile Strength σ_u	(1000 psi)	42	46	52
Shear Strength γ	(1000 psi)	25	28	30
Elongation	(% in 2 inches)	22	16	8
Hardness	(Brinell)	67	82	92

Fatigue limits: 23,000 psi (H 113) @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.87v (.1N Calomel scale)

Types of Corrosion Suffered: pitting (scattered and deep), edge and crevice corrosion; susceptible to intergrannular attack in H 113 temper

Typical Corrosion Rate Ranges: pitting up to 55 mills deep after 123 days at 5640 ft

USES: Marine superstructures and applications requiring a weldable, moderate strength alloy with good corrosion resistance

Forms available: bar, sheet & plate, extrusions & structural shapes

Fabricability: weldable but difficult to machine

MATERIAL: Aluminum Alloy 5086

NOMINAL COMPOSITION: 4.0 Mg, .5 Mn, .1 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .096 lb/in^3; in sea water, ρ_{sw} = .059 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 23.9 x 10^{-6} in/in/° C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10.3 x 10^6 psi

b) Shear G = 3.83 x 10^6 psi

Property	Condition →	Annealed	H 112	H 34
.2% Yield Strength σ_y	(1000 psi)	17	19	37
Tensile Strength σ_u	(1000 psi)	38	39	47
Shear Strength γ	(1000 psi)	23	23	28
Elongation	(% in 2 inches)	22	14	10
Hardness	(Brinell)	60	64	82

Fatigue limits: 21,000 to 23,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.85v (.1N Calomel scale)

Types of Corrosion Suffered: pitting, edge & crevice corrosion; susceptible to intergrannular attack in H 34 temper

Typical Corrosion Rate Ranges: pitting up to 70 mills deep and crevice corrosion up to 100 mills deep after 1064 days at 5,300 ft.

USES: weldings, marine tanks, trucks and trailers

Forms available: rod, bar, sheet & plate, extrusions & structural shapes

Fabricability: weldable but difficult to machine

MATERIAL: Aluminum Alloy 5456

NOMINAL COMPOSITION: 5.25 Mg, .8 Mn, .1 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .096 lb/in^3; in sea water, ρ_{sw} = .059 lb/in^3

Coefficient of Thermal Expansion (-50 to 100^{o}C) = 23.0 x 10^{-6}in/in/^{o} C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	H 321	H 343
.2% Yield Strength σ_y	(1000 psi)	23	37	43
Tensile Strength σ_u	(1000 psi)	45	51	56
Shear Strength γ	(1000 psi)	27	30	33
Elongation	(% in 2 inches)	24	16	8
Hardness	(Brinell)	70	90	94

Fatigue limits: 22,000 to 24,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.87v (.1N Calomel scale)

Types of Corrosion Suffered: pitting, edge and crevice corrosion.
Susceptible to intergrannular attack in H 343 temper or as welded H 321

Typical Corrosion Rate Ranges: pitting up to 50 mills deep after 1064 days at 5,300 ft.

USES: welded structural applications - ship hulls

Forms available: rod, bar, tube, pipe, sheet & plate, structural shapes

Fabricability: weldable by inert arc but difficult to machine

MATERIAL: Aluminum Alloy 6061

NOMINAL COMPOSITION: 1.0 Mg, .6 Si, .25 Cu, .20 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .098 lb/in^3; in sea water, ρ_{sw} = .061 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 23.0 x 10^{-6} in/in/°C

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 10 x 10^6 psi

b) Shear G = 3.75 x 10^6 psi

Property	Condition →	Annealed	T6	T9
.2% Yield Strength σ_y	(1000 psi)	8	40	57
Tensile Strength σ_u	(1000 psi)	18	45	59
Shear Strength γ	(1000 psi)	12	30	33
Elongation	(% in 2 inches)	25	12	12
Hardness	(Brinell)	30	95	

Fatigue limits: 9,000 to 14,000 psi at 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: ppt hardening (Mg_2Si) & work hardening. Solution heat treat at 520 to 540° quench & ppt at 175°C 6 to 10 hr.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.83v$^+$ (.1N Calomel scale)

Types of Corrosion Suffered: pitting, edge and crevice corrosion. Susceptible to intergrannular attack in T6 condition and SCC in T4 condition.

Typical Corrosion Rate Ranges: few deep pits up to 75 mills after 1064 days at 5300 ft.

USES: General marine usage

Forms available: wire, rod, bar, tube, pipe, sheet & plate, fasteners, rivets, extrusions & forgings.

Fabricability: Weld areas will be weak unless subsequently heat treated. More readily machined than 5000 series alloys

$^+$in T6 Condition (-0.80v in T4 condition)

MATERIAL: Aluminum Alloy 7039

NOMINAL COMPOSITION: 2.8 Mg, 4 Zn, .25 Mn, .20 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .099 lb/in^3; in sea water, ρ_{sw} = .062 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6}in/in/°

Poissons Ratio = .33

Elastic Modulus in a) Tension E = x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	T 61	
.2% Yield Strength σ_y	(1000 psi)		50	
Tensile Strength σ_u	(1000 psi)	32	60	
Shear Strength γ	(1000 psi)		27	
Elongation	(% in 2 inches)		13	
Hardness	(Brinell)		123	

Fatigue limits:

Impact Strength:

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: severe pitting, edge & crevice as well as exfoliation attack; also intergrannular corrosion in T6 condition. Do not use without anodizing & cathodic protection.

Typical Corrosion Rate Ranges: Pitting up to 60 mills deep after 200 days at 2340 ft.

USES: welded cryogenic applications

Forms available: sheet & plate

Fabricability: weldable & machines about like 6061-T6. lower strength than the other 7000 series Al alloys but better sea water corrosion resistance.

MATERIAL: Aluminum Alloy 7075

NOMINAL COMPOSITION: 5.6 Zn, 2.5 Mg, 1.6 Cu, .3 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .101 lb/in^3; in sea water, ρ_{sw} = .064 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 23.0 x 10^{-6} in/in/° C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10.4 x 10^6 psi

b) Shear G = 3.9 x 10^6 psi

Property	Condition →	Annealed	T6	
.2% Yield Strength σ_y	(1000 psi)	15	73	
Tensile Strength σ_u	(1000 psi)	33	83	
Shear Strength γ	(1000 psi)	22	48	
Elongation	(% in 2 inches)	17	11	
Hardness	(Brinell)	60	150	

Fatigue limits: 23,000 psi @ 5 x 10^8 cycles in T6

Impact Strength:

Strengthening Mechanism: ppt hardening Solution heat treat 1 hr @ 460° to 500°C, quench, ppt at 120°C 24 hr.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.81v$^+$ (.1N Calomel scale)

Types of Corrosion Suffered: severe pitting, edge & crevice corrosion as well as exfoliation attack and some intergrannular attack in T6 condition. Use with protection only.

Typical Corrosion Rate Ranges:

USES: Applications requiring high specific strength in sea water

Forms available: wire, rod, bar, tube, sheet & plate, extrusions & forging

Fabricability: Machinability is comparable to 6061 but welding is difficult in T6 condition

$^+$

MATERIAL: Aluminum Alloy 7079

NOMINAL COMPOSITION: 4.3 Zn, 3.3 Mg, .6 Cu, .2 Mn, .2 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .099 lb/in^3; in sea water, ρ_{sw} = .062 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 23 x 10^{-6} in/in/°C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10.4 x 10^6 psi

b) Shear G = 3.9 x 10^6 psi

Property	Condition →	Annealed	T 6	
.2% Yield Strength σ_y	(1000 psi)		68	
Tensile Strength σ_u	(1000 psi)		78	
Shear Strength γ	(1000 psi)		45	
Elongation	(% in 2 inches)		14	
Hardness	(Brinell)		145	

Fatigue limits: 23,000 psi at 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: ppt hardening. Solution heat treat 1 hr. @ 435° to 450°C ppt at 120°C 48 hr.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.87v (in T6 temper) (*.1N Calomel Scale)

Types of Corrosion Suffered: severe pitting, crevice exfoliation and intergrannular attack. Use with protection only.

Typical Corrosion Rate Ranges: random pitting 50 to 60 mills in 200 days at 2340 ft.

USES: High strength in heavy sections

Forms available: sheet & plate, extrusions & forgings

Fabricability: Welding is difficult , machining comparable to 6061

MATERIAL: Aluminum Alloy 7178

NOMINAL COMPOSITION: 6.8 Zn, 2.7 Mg, 2.0 Cu, 0.3 Cr, Balance Al

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .102 lb/in^3; in sea water, ρ_{sw} = .065 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 13 x 10^{-6} in/in/°F

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 10.4 x 10^6 psi

b) Shear G = 3.9 x 10^6 psi

Property	Condition →	Annealed	T6	
.2% Yield Strength σ_y	(1000 psi)	15	78	
Tensile Strength σ_u	(1000 psi)	33	88	
Shear Strength γ	(1000 psi)	22	52	
Elongation	(% in 2 inches)	15	10	
Hardness	(Brinell)	60	160	

Fatigue limits: 22,000 psi @ 5 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: pptn hardening. Solution heat treat 1 hr @ 460° to 500°C, ppt @ 140°C 26 hr.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: pitting, edge & crevice corrosion and intergrannular attack in T6 condition. Use with protection only.

Typical Corrosion Rate Ranges: Similar to 7079 but less severe pitting up to 50 mills in 1064 days at 5,300 ft.

USES: Applications requiring high specific strength and better corrosion resistance than 7075 and 7079.

Forms available: rod, bar, sheet & plate, extrusions

Fabricability: similar to 7075 and 7079

MATERIAL: Electrolytic Tough Pitch Copper CDA 110

NOMINAL COMPOSITION: 99.90 Cu, 0.04 Oxygen

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .322 lb/in^3; in sea water, ρ_{sw} = .285 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 16.8 x 10^{-6} in/in/°C

Poissons Ratio = 0.33

Elastic Modulus in a) Tension E = 17 x 10^6 psi

b) Shear G = 6.4 x 10^6 psi

Property	Condition →	Annealed	Full Hard	
.2% Yield Strength σ_y	(1000 psi)	10	50	
Tensile Strength σ_u	(1000 psi)	32	55	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	45 to 55	6 to 20	
Hardness	(Rockwell F)	40	90	

Fatigue limits: 11,000 to 13,000 psi @ 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.20v

Types of Corrosion Suffered: uniform only

Typical Corrosion Rate Ranges: up to 1.5 MPY below 2,000 ft., about 1-3 MPY in surface water, greatly accelerated if velocity is above 3 fPS

USES: low strength architectural & electrical applications

Forms available: wire, rod, bar, tube, pipe, sheet & strip & plate, shapes

Fabricability: highly formable, machinability index 20 (free cutting brass is 100)

MATERIAL: Beryllium Copper CDA 172

NOMINAL COMPOSITION: 1.90 Be, .2 Co, Balance Cu

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .298 lb/in^3; in sea water, ρ_{sw} = .261 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 16.7 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 18 x 10^6 psi

b) Shear G = 7 x 10^6 psi

Property	Condition →	Annealed	Fully work Hardened	Heat treated & 75% Cold Worked
.2% Yield Strength σ_y	(1000 psi)	20-35	100-150	150-190
Tensile Strength σ_u	(1000 psi)	60-80	100-150	195-205
Shear Strength γ	(1000 psi)	50-60	90-100	90-100
Elongation	(% in 2 inches)	35-50	2-8	1-2
Hardness	(Rockwell)	B50-65	B88-103	C36-42

Fatigue limits: 32,000 to 42,000 psi @ 10^8 cycles

Impact Strength:

Strengthening Mechanism: ppt hardening & work hardening. Solution heat treat 1 hr @ 790°C, ppt 3 hr @ 315°C or 2 hr if previously cold worked.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: mostly uniform

Typical Corrosion Rate Ranges:

USES: Parts requiring good corrosion resistance, high strength & electrical conductors. springs, bushings, bearings, cams, electrical contacts

Forms available: wire, rod, bar, tube, pipe, sheet, shapes

Fabricability: machinability index 20 to 40 (free cutting brass = 100)

MATERIAL: Red Brass CDA 230

NOMINAL COMPOSITION: 85 Cu, 15 Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .316 lb/in^3; in sea water, ρ_{sw} = .279 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 18.7 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 17 x 10^6 psi

b) Shear G = 6.4 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Spring
.2% Yield Strength σ_y	(1000 psi)	10	49	63
Tensile Strength σ_u	(1000 psi)	39	57-72	84-105
Shear Strength γ	(1000 psi)	31	37-43	46-54
Elongation	(% in 2 inches)	48	8-12	3
Hardness	(Rockwell)	F56	B65	B86

Fatigue limits: 20,000 psi at 3 x 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.37v

Types of Corrosion Suffered: uniform & slight dezincification and SCC

Typical Corrosion Rate Ranges: up to 2 MPY in surface water

USES: multiple

Forms available: wire, tube, pipe, strip & sheet, fasteners

Fabricability: machinability index 30

MATERIAL: Cartridge Brass CDA 260

NOMINAL COMPOSITION: 70 Cu, 30 Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .308 lb/in^3; in sea water, ρ_{sw} = .271 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 19.9 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 16 x 10^6 psi

b) Shear G = 6 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Spring
.2% Yield Strength σ_y	(1000 psi)	11	52	65
Tensile Strength σ_u	(1000 psi)	44	62	94-130
Shear Strength γ	(1000 psi)	31	40	48
Elongation	(% in 2 inches)	66	23	3
Hardness	(Rockwell)	F54	B70	B92

Fatigue limits: 13,000 to 23,000 psi @ 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.37v

Types of Corrosion Suffered: uniform, dezincification & SCC

Typical Corrosion Rate Ranges: 2 to 3 MPY

USES: multiple

Forms available: wire, rod, bar, tube, strip & sheet, fasteners

Fabricability: machinability index 30; otherwise excellent

MATERIAL: Muntz Metal CDA 280

NOMINAL COMPOSITION: 60 Cu, 40 Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .303 lb/in^3; in sea water, ρ_{sw} = .266 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 20.8 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 15 x 10^6 psi

b) Shear G = 5.6 x 10^6 psi

Property	Condition →	Annealed	Half Hard	
.2% Yield Strength σ_y	(1000 psi)	17	50	
Tensile Strength σ_u	(1000 psi)	54	70	
Shear Strength γ	(1000 psi)	40	44	
Elongation	(% in 2 inches)	45	15	
Hardness	(Rockwell)	F80	B75	

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening (two phase alloy)

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.32v

Types of Corrosion Suffered: uniform, crevice, dezincification & SCC

Typical Corrosion Rate Ranges: corrodes uniformly at 0.5 to 1.5 MPY below 1,000 m and 2to 3 MPY in surface water. Also a few scattered shallow pits up to 10 mills deep in 200 days.

USES: architectural trim, structural plates, large bolts & valve stems

Forms available: rod, bar, tube, strip & sheet & plate, fasteners, large bolts and nuts.

Fabricability: machinability index 40

MATERIAL: Inhibited Admiralty CDA 443, 444, & 445

NOMINAL COMPOSITION: 71 Cu, 28 Zn, 1 Sn, .6 As, Sb or P

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .308 lb/in^3; in sea water, ρ_{sw} = .271 lb/in^3

Coefficient of Thermal Expansion (-50 to 100^{o}C) = 20.2 x 10^{-6}in/in/^{o}C

Poissons Ratio =

Elastic Modulus in a) Tension E = 16 x 10^6 psi

b) Shear G = 6 x 10^6 psi

Property	Condition →	Annealed	Hard	
.2% Yield Strength σ_y	(1000 psi)	13	72	
Tensile Strength σ_u	(1000 psi)	45	88-97	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	65-69	4	
Hardness	(Rockwell)	F59	F109	

Fatigue limits: 17,000 to 19,000 psi at 10^7 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.30v

Types of Corrosion Suffered: uniform and crevice corrosion

Typical Corrosion Rate Ranges: up to 1 MPY below 1,000 meters for 200 days; 1 to 2.5 MPY in surface water

USES: heat exchanger & condenser tubes & plates

Forms available: wire, tube, sheet & plate

Fabricability: machinability index 30

MATERIAL: Naval Brass CDA 464

NOMINAL COMPOSITION: 60 Cu, 39 Zn, 1 Sn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .304 lb/in^3; in sea water, ρ_{sw} = .267 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 21.2 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 15 x 10^6 psi

b) Shear G = 5.6 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Hard Drawn
.2% Yield Strength σ_y	(1000 psi)	25-30	53-57	66
Tensile Strength σ_u	(1000 psi)	56-62	75-80	88
Shear Strength γ	(1000 psi)	40	45	
Elongation	(% in 2 inches)	45-47	20	18
Hardness	(Rockwell B)	55	82-85	95

Fatigue limits: 15,000 psi @ 3 x 10^8 cycles

Impact Strength: Charpy (Keyhole) 32 ft/lb at 70°F (annealed)

Strengthening Mechanism: work hardening (two phase alloy)

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.32v

Types of Corrosion Suffered: uniform & dezincification

Typical Corrosion Rate Ranges: 1 to 2.5 MPY

USES: condenser plates, marine hardware, propeller shafts

Forms available: rod, bar, strip & plate, fasteners, shapes

Fabricability: machinability index 30

MATERIAL: Phosphor Bronze 10% CDA 524

NOMINAL COMPOSITION: 10 Sn, 0.2P

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .317 lb/in^3; in sea water, ρ_{sw} = .280 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 10.2 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 16 x 10^6 psi

b) Shear G = 6 x 10^6 psi

Property	Condition →	Annealed	Cold Worked	
.2% Yield Strength σ_y	(1000 psi)	26	63	
Tensile Strength σ_u	(1000 psi)	116	147	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)			
Hardness				

Fatigue limits: 25 to 32,000 psi @ 10^8 cycles

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform & some crevice corrosion

Typical Corrosion Rate Ranges: less than .5 MPY after 200 days below 1000 meters

USES: heavy bars & plates for compressive loading

Forms available: wire, rod, strip

Fabricability: machinability index 20

MATERIAL: Aluminum Bronze D CDA 614

NOMINAL COMPOSITION: 91 Cu, 7 Al, 2 Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .281 lb/in^3; in sea water, ρ_{sw} = .244 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 16.4 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 18 x 10^6 psi

b) Shear G = 6.7 x 10^6 psi

Property	Condition →	Annealed	Hard	
.2% Yield Strength σ_y	(1000 psi)	30-42	40-55	
Tensile Strength σ_u	(1000 psi)	70-75	75-85	
Shear Strength γ	(1000 psi)		35-45	
Elongation	(% in 2 inches)	30-42	30-35	
Hardness	(Rockwell B)	69	84	

Fatigue limits: 21,000 to 30,000 psi at 10^8 cycles

Impact Strength: Charpy 74 ft/lb at 68°F

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ~.37v

Types of Corrosion Suffered: uniform & some crevice corrosion; trace of dealuminization.

Typical Corrosion Rate Ranges: less than .5 MPY after 200 days below 1,000 meters. Up to 2 MPY in surface water.

USES: corrosion resist tanks, tubing,nuts & bolts, protective sheathing

Forms available: wire, rod, bar, tube, plate & sheet, fasteners

Fabricability: machinability index 80; good workability but difficult to weld.

MATERIAL: High Silicon Bronze A CDA 655

NOMINAL COMPOSITION: Cu 94.8, 3.3 Si, 1.5 Mn, 1.5 Maximum Fe & Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .308 lb/in^3; in sea water, ρ_{sw} = .271 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 18.0 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 15 x 10^6 psi

b) Shear G = 5.6 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Spring
.2% Yield Strength σ_y	(1000 psi)	21-30	45-57	62-70
Tensile Strength σ_u	(1000 psi)	56-63	78-98	108-145
Shear Strength γ	(1000 psi)	42-45	50-58	63-70
Elongation	(% in 2 inches)	55-63	8-35	3-5
Hardness	(Rockwell B)	40-65	85-87	97

Fatigue limits: 19,000 to 33,600 at 3 x 10^8 cycles

Impact Strength: Charpy (Keyhole) 66 ft/lb at 70°F , better at low temperature

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = 0.27v

Types of Corrosion Suffered: uniform only

Typical Corrosion Rate Ranges: up to 2 MPY after 200 days at 1,000 meters. Similar on surface. Accelerates if velocity is greater than 3 fps.

USES: marine hardware & fasteners, shafting & heat exchanger tubes

Forms available: wire, rod, bar, tube, pipe, strip & sheet & plate, fasteners

Fabricability: machinability index 30; good workability and weldability

MATERIAL: Manganese Bronze A CDA 675

NOMINAL COMPOSITION: 58.5 Cu, 39 Zn, 1.4 Fe, 1 Sn, 0.1 Mn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .302 lb/in^3; in sea water, ρ_{sw} = .265 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 21.2 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 15 x 10^6 psi

b) Shear G = 5.6 x 10^6 psi

Property	Condition →	Annealed	Half Hard	Hard
.2% Yield Strength σ_y	(1000 psi)	30	40	60
Tensile Strength σ_u	(1000 psi)	65	72	82
Shear Strength γ	(1000 psi)	42	44	47
Elongation	(% in 2 inches)	35	35	25
Hardness	(Rockwell B)	65	70	90

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.32v

Types of Corrosion Suffered: uniform and dezincification

Typical Corrosion Rate Ranges: 1 to 3 MPY

USES: shafting, valve stems & bodies, pump rods

Forms available: rod, bar, shapes

Fabricability: machinability index 30; more difficult to work and weld than alloy 655

MATERIAL: 90-10 Copper-Nickel CDA 706

NOMINAL COMPOSITION: 88.7 Cu, 10 Ni, 1.3 Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .323 lb/in^3; in sea water, ρ_{sw} = .286 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 17.1 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 18 x 10^6 psi

b) Shear G = 6.8 x 10^6 psi

Property	Condition →	Annealed	light drawn	
.2% Yield Strength σ_y	(1000 psi)	16	57	
Tensile Strength σ_u	(1000 psi)	44	60	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	42	10	
Hardness	(Rockwell F)	65 (B15)	100 (B72)	

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.28v

Types of Corrosion Suffered: uniform & crystallographic surface attack. Sulfur and H_2S are detrimental

Typical Corrosion Rate Ranges: up to 1.5 MPY below 2000 ft - usually less. Similar on surface. accelerates if velocity is greater than 8 to 10 fps

USES: Excellent resistance to marine fording , salt water tubing & piping, ship hulls

Forms available: wire, rod, bar, tube, plate & strip

Fabricability: machinability index 20; good formability & excellent weldability

MATERIAL: 80-20 Copper-Nickel CDA 710

NOMINAL COMPOSITION: 78 Cu, 21 Ni, .6 Mn, .5 Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .323 lb/in^3; in sea water, ρ_{sw} = .286 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 16.3 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 20 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	light drawn	
.2% Yield Strength σ_y	(1000 psi)		75	
Tensile Strength σ_u	(1000 psi)	45-51	80	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	40	27	
Hardness	(Rockwell)		B81	

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.25v

Types of Corrosion Suffered: uniform & crystallographic surface attack. Sulfur and H_2S are detrimental

Typical Corrosion Rate Ranges: up to 1.25 MPY below 2,000 ft. - usually lower. Similar on surface. Accelerates if velocity is greater than 12 fps.

USES: same as Alloy 706, higher strength

Forms available: wire, rod, bar, tube, plate & sheet & strip

Fabricability: similar to Alloy 706

MATERIAL: 70-30 Copper-Nickel CDA 715

NOMINAL COMPOSITION: 68.9 Cu, 30 Ni, 0.5 Fe, 0.6 Mn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .323 lb/in^3; in sea water, ρ_{sw} = .286 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 16.2 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 22 x 10^6 psi

b) Shear G = 8.3 x 10^6 psi

Property	Condition →	Annealed	Cold Drawn	
.2% Yield Strength σ_y	(1000 psi)	18-20	79	
Tensile Strength σ_u	(1000 psi)	49-55	85	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	36-50	3-15	
Hardness	(Rockwell B)	36-50	81-86	

Fatigue limits: 22,000 to 32,000 psi

Impact Strength: Charpy (Keyhole notch) 79 ft/lb at 70°F, 65 ft/lb at -100°F

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.21v

Types of Corrosion Suffered: uniform & crystallographic surface attack. Sulfur and H_2S are detrimental

Typical Corrosion Rate Ranges: up to 1.2 MPY below 2,000 ft. - usually lower Similar on surface. at 5% Fe rate is ≃ .25 MPY. accelerates if velocity is greater than 15 fps

USES: Slightly less resistant to fouling than Alloy 706. Higher strength. Best material for sea water heat exchangers requiring high velocities.

Forms available: wire, rod, bar, tube, plate

Fabricability: similar to Alloy 706

MATERIAL: Copper-Nickel-Zinc (65-18) CDA 752 (Nickel Silver)

NOMINAL COMPOSITION: 65 Cu, 18 Ni, 17 Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .316 lb/in^3; in sea water, ρ_{sw} = .279 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 9.0 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 18 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Half Hard	Hard
.2% Yield Strength σ_y	(1000 psi)	25-30	60-80	74-90
Tensile Strength σ_u	(1000 psi)	56-60	70-86	85-103
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	32-45	7-20	3
Hardness	(Rockwell)	B 40-55	B 78-83	B 87

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform and stress corrosion cracking

Typical Corrosion Rate Ranges:

USES: marine hardware and trim

Forms available: wire, rod, bar, sheet & strip, shapes

Fabricability: machinability index 20; can be soldered, welded and brazed.

MATERIAL: Cast High Strength Yellow Brass

NOMINAL COMPOSITION: 56-68 Cu, .5 to 4.0 Ea. Pb, Fe, Al, Mn, Balance Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, $\rho = \begin{matrix}.277-\\.301\end{matrix}$ lb/in^3; in sea water, ρ_{sw} = .255 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 11.0 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 14.5-16 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast		
.2% Yield Strength σ_y	(1000 psi)	60-97		
Tensile Strength σ_u	(1000 psi)	20-50		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	15-35		
Hardness	(Brinell)	110-195		

Fatigue limits: 21,500 psi at 10^8 cycles

Impact Strength:

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform and dezincification

Typical Corrosion Rate Ranges: approximately 2 to 3 MPY

USES: marine castings, propeller hubs & blades, valve stems, bearings & gears

Forms available: castings

Fabricability: machinability index 26-60

MATERIAL: Cast Silicon Brass & Bronze

NOMINAL COMPOSITION: 5 to 14 Zn, 4 Si, others, Balance Cu.

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .302 lb/in^3; in sea water, ρ_{sw} = .265 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 10.9 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 15-18 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast		
.2% Yield Strength σ_y	(1000 psi)	22-35		
Tensile Strength σ_u	(1000 psi)	55-70		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	17-55		
Hardness	(Brinell)	85-120		

Fatigue limits: 22,000 psi @ 10^8 cycles

Impact Strength: Izod 15-60 ft/lb

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform only

Typical Corrosion Rate Ranges: 1.5 to 2.5 MPY

USES: bearings, gears, impellers, pump and valve parts, marine fittings, propellers

Forms available:

Fabricability: machinability index approximately 50

MATERIAL: Cast Aluminum Bronzes

NOMINAL COMPOSITION: 81 to 88 Cu, 9 to 12 Al, 1 to 5 Fe & others

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, $\rho = .272\text{-}.281$ lb/in^3; in sea water, $\rho_{sw} = .240$ lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.5 - 9.8 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 14-20 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast	Heat Treated	
.2% Yield Strength σ_y	(1000 psi)	25-50	40-80	
Tensile Strength σ_u	(1000 psi)	70-105	80-124	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	7-40	5-16	
Hardness	(Brinell)	110-210	160-260	

Fatigue limits: 25,000 to 32,00- psi @ 10^8 cycles

Impact Strength: Izod variable 9-50 ft/lb

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform only

Typical Corrosion Rate Ranges: approximately 2 MPY

USES: pump casings & impellers, marine propellers, fittings, bearings, and gears

Forms available: castings

Fabricability: machinability index 20

MATERIAL: Cast G & M Tin Bronzes

NOMINAL COMPOSITION: 87-88 Cu, 8-10 Sn, 2-4 Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, $\rho = \frac{.315-}{.318}$ lb/in^3; in sea water, ρ_{sw} = .280 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 10.0 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 14-15 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast		
.2% Yield Strength σ_y	(1000 psi)	16-24		
Tensile Strength σ_u	(1000 psi)	36-50		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	24-45		
Hardness	(Brinell)	60-85		

Fatigue limits:

Impact Strength: Izod 12-15 ft/lb

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform

Typical Corrosion Rate Ranges: approximately 1 to 3 MPY

USES: bearings, bushings, gears, pump bodies & impellers, valves

Forms available: castings

Fabricability: machinability index 40-50

MATERIAL: Monel 400

NOMINAL COMPOSITION: 31.5 Cu, 1.35 Fe, .9 Mn, Balance Ni

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .319 lb/in^3; in sea water, ρ_{sw} = .282 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 14.0 x 10^{-6} in/in/°C

Poissons Ratio = 0.32

Elastic Modulus in a) Tension E = 26 x 10^6 psi

b) Shear G = 9.5 x 10^6 psi

Property	Condition →	Annealed	Full Hard	
.2% Yield Strength σ_y	(1000 psi)	25-45	90-130	
Tensile Strength σ_u	(1000 psi)	70-85	100-140	
Shear Strength γ	(1000 psi)	49	65	
Elongation	(% in 2 inches)	30-50	2-15	
Hardness	(Rockwell B)	60-75	98-100	

Fatigue limits: 31,000 to 47,000 psi @ 10^8 cycles. corrosion fatigue limit in Brackish H_2O 20 to 22,000 psi @ 10^8 cycles

Impact Strength: Charpy (V-notch) 150 to 220 ft/lb

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.11v

Types of Corrosion Suffered: uniform, general pitting and crevice corrosion; also non-uniform (crystallographic) surface dissolution.

Typical Corrosion Rate Ranges: corrodes uniformly at about .5 MPY after 200 days below 1,000 meters. Attack is greatly reduced in well aerated, flowing sea water--i.e., less than 1 MPY at velocities greater than 5 fps but may be accelerated under fouling deposits. Pitting attack up to 10 mills deep in 200 days.

USES: valves & pumps, propeller shafting, marine fixtures, fasteners

Forms available: wire, rod, bar, pipe, plate & sheet & strip, fasteners

Fabricability: easily soldered, brazed, and welded.

MATERIAL: Monel K-500

NOMINAL COMPOSITION: 29.5 Cu, 2.8 Al, 1.0 Fe, 0.6 Mn, 0.5 Ti, Balance Ni

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .306 lb/in^3; in sea water, ρ_{sw} = .269 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 14.0 x 10^{-6} in/in/° C

Poissons Ratio = 0.32

Elastic Modulus in a) Tension E = 26 x 10^6 psi

b) Shear G = 9.5 x 10^6 psi

Property	Condition →	Annealed	Full Hard	ppt Hardened & Full Hard
.2% Yield Strength σ_y	(1000 psi)	40-65	105-120	130-195
Tensile Strength σ_u	(1000 psi)	90-110	145-165	170-222
Shear Strength γ	(1000 psi)	65	71	99
Elongation	(% in 2 inches)	30-45	2-10	2-10
Hardness	(Rockwell)	B75 to 90	C25-32	C33-40

Fatigue limits: 38,000 to 53,000 psi @ 10^8 cycles

Impact Strength: Charpy 42 to 170 ft/lb

Strengthening Mechanism: ppt hardening & work hardening. Solution heat treat 1/2 hr @ 1600°F. Quench ppt @ 1100°F, 8 to 16 hrs.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.11v

Types of Corrosion Suffered: mostly similar to Monel 400

Typical Corrosion Rate Ranges:

USES: Applications requiring high strength in large sections with good low temperature ductility

Forms available: wire, rod, bar, tube, pipe, sheet & plate & strip

Fabricability: can be welded, brazed, & soldered

MATERIAL: Inconel 600

NOMINAL COMPOSITION: 76 Ni, 16 Cr, 7.2 Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .304 lb/in^3; in sea water, ρ_{sw} = .267 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 11.5 x 10^{-6} in/in/° C

Poissons Ratio = 0.29

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = 11 x 10^6 psi

Property	Condition →	Annealed	Hot Rolled	Cold Drawn
.2% Yield Strength σ_y	(1000 psi)	25 to 50	35 to 95	150 to 175
Tensile Strength σ_u	(1000 psi)	80 to 110	85 to 140	165 to 185
Shear Strength γ	(1000 psi)	61		66
Elongation	(% in 2 inches)	35 to 50	20 to 45	2 to 10
Hardness	(Rockwell)	B65 to 85	B75 to 100	C27

Fatigue limits: 31,000 to 51,000 psi at 10^8 cycles

Impact Strength: Charpy 151 cold drawn to 230 ft/lb annealed

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.17v (.4 active)

Types of Corrosion Suffered: mild pitting and crevice corrosion; virtually immune to Cl^- SCC

Typical Corrosion Rate Ranges: pitting is < 1 MPY at velocities > 5 fps

USES: evaporator tubes & tube sheets, high temperature engine parts

Forms available: wire, rod, bar, tube, pipe, sheet, strip, plate

Fabricability: machining is similar to type 304 stainless; can be welded & brazed

MATERIAL: Inconel 625

NOMINAL COMPOSITION: 65.3 Ni, 18.6 Cr, 9 Mo, 4 Cb, 3 Fe, .05 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .305 lb/in^3; in sea water, ρ_{sw} = .268 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 7.1 x 10^{-6} in/in/° F

Poissons Ratio = .278

Elastic Modulus in a) Tension E = 29.8 x 10^6 psi

b) Shear G = 11.4 x 10^6 psi

Property	Condition →	Annealed	as rolled	70% C. W.
.2% Yield Strength σ_y	(1000 psi)	60 to 95	110	201
Tensile Strength σ_u	(1000 psi)	120 to 150	160	219
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	30 to 60	30 to 60	5
Hardness	(Brinell)	145 to 220	175 to 240	45 Rc

Fatigue limits: 48 to 55,000 psi at 10^8 cycles in corrosion fatigue in S. W.
70 to 100,000 psi at 10^8 cycles in air

Impact Strength: 46 to 50 ft/lb at 85°F
Charpy 39 to 45 ft/lb at -110°F

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ≃ -.1v

Types of Corrosion Suffered: one of the most resistant to all types of degredation. Comparable to Titanium and Hastelloy "C". Highly resistant to crevice corrosion, pitting and chloride SCC.

Typical Corrosion Rate Ranges:

USES: wire rope, propeller blades, fittings, springs, seals, fasteners, instrument components.

Forms available: rod, tube, pipe, sheet, strip, & plate, wire rope

Fabricability: work hardens rapidly during machining

MATERIAL: Inconel 718

NOMINAL COMPOSITION: 53 Ni, 18.6 Cr, 18.5 Fe, 5 Cb, 3.1 Mo, .04 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .296 lb/in^3; in sea water, ρ_{sw} = .259 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 7.2 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 29 x 10^6 psi

b) Shear G = 11.2 x 10^6 psi

Property	Condition →	Annealed	ppt hard	cold rolled & aged sheet
.2% Yield Strength σ_y	(1000 psi)	47-77	150-175	210
Tensile Strength σ_u	(1000 psi)	99-135	185-210	224
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	26-62	23	10
Hardness	(Rockwell)	85-95b	40-44c	

Fatigue limits: good in sea water corrosion fatugue 40 to 90,000 psi at 10^8 cycles

Impact Strength: Charpy V-notch Room temp - 19 to 23 ft/lb
-320°F - 18 to 20 ft/lb

Strengthening Mechanism: work & ppt hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ≃ -.1v

Types of Corrosion Suffered: crevice corrosion & occasional pitting--especially under marine growth

Typical Corrosion Rate Ranges: pitting nil at velocities > 3 fps
good resistance to hydrofoil velocities

USES: Applications requiring good weldability and good low temperature properties

Forms available: wire, rod, bar, tube, sheet, plate, & strip

Fabricability: machinability index 70 (AISI B1112 Steel = 100) Rough machine before ppt treatment then finish. Very weldable with a high resistance to post weld cracking

MATERIAL: Inconel X-750

NOMINAL COMPOSITION: 73 Ni, 15 Cr, 6.75 Fe, 2.5 Ti, 1 Cb, .04 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .298 lb/in^3; in sea water, ρ_{sw} = .261 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 7.0 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 31 x 10^6 psi

b) Shear G = 11 x 10^6 psi

Property	Condition →	Annealed	ppt hard	
.2% Yield Strength σ_y	(1000 psi)		120-149	
Tensile Strength σ_u	(1000 psi)		180-199	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)		18-25	
Hardness	(Rockwell C)		34-42	

Fatigue limits: 32,000 psi at 10^8 cycles for a notched specimen.

Impact Strength:

Strengthening Mechanism: work and ppt hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ≃ -.1v

Types of Corrosion Suffered: similar generally to Inconel 600; high resistance to Cl^- SCC

Typical Corrosion Rate Ranges: excellent properties at cryogenic temperatures

USES: pressure vessles, fasteners, tow cables, and springs

Forms available: wire, rod, bar, tube, sheet, plate, strip, fasteners, shapes

Fabricability: machinability index 15 (AISI B1112 Steel = 100) should be rough machined before ppt treatment, then finished. difficult to weld

MATERIAL: Incoloy 825

NOMINAL COMPOSITION: 41.8 Ni, 21.5 Cr, 30 Fe, 3 Mo, 1.8 Cu, 1 Ti, .03 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .294 lb/in^3; in sea water, ρ_{sw} = .257 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 7.8 x 10^{-6} in/in/ °F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Cold Drawn	
.2% Yield Strength σ_y	(1000 psi)	25-35	35-45	
Tensile Strength σ_u	(1000 psi)	75-85	85-101	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	30-50	43	
Hardness				

Fatigue limits:

Impact Strength: Charpy - about 80 ft/lb, 47-66 ft/lb in heat effected zone of welds

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ≃ - .1v

Types of Corrosion Suffered: occasional shallow crevice corrosion & pitting, otherwise none visible; good resistance to Cl^- SCC

Typical Corrosion Rate Ranges: pitting nil at velocities > 3 to 5 fps but may be induced under marine growth.

USES: components in desalination plants.

Forms available: rod, bar, tube, pipe, strip, sheet, shapes & forgings

Fabricability: easily welded & welds are corrosion resistant in sea water. Machining should be done in the annealed temper.

MATERIAL: Hastelloy C-276

NOMINAL COMPOSITION: 54 Ni, 17 Mo, 15 Cr, 5 Fe, 4 N

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .323 lb/in^3; in sea water, ρ_{sw} = .286 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 11.3 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 29.8 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	(Cast) Annealed	Sheet	
.2% Yield Strength σ_y	(1000 psi)	50 to 52	58	
Tensile Strength σ_u	(1000 psi)	80 to 89	121	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	9 to 11	47.5	
Hardness	(Rockwell)	B91 to 96	B 91 to 96	

Fatigue limits:

Impact Strength: Izod V-notch 5 to 20 ft/lb as cast

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ≃ -0.08v

Types of Corrosion Suffered: virtually inert under all sea water conditions for at least 20 years

Typical Corrosion Rate Ranges:

USES: applications requiring complete innertness in sea water

Forms available: wire, rod, bar, tube, pipe, sheet, plate, & strip, fasteners, electrodes

Fabricability: can be welded without heat treatment in C-276 condition

MATERIAL: Wrought Iron

NOMINAL COMPOSITION: .02C, .06 Mn, .13 each Si & P, 2.5 slag, bal Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .278 lb/in^3; in sea water, ρ_{sw} = .241 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 7.4 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 29.5 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Rolled Longitudinal	Transverse	
Yield Point σ_y	(1000 psi)	27 (min)	27	
Tensile Strength σ_u	(1000 psi)	48 (min)	39	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	14(in 8inches)	2(in 8 inches)	
Hardness	(Brinell)	97-105		

Fatigue limits: 23,000 to 19,000 psi endurance limit

Impact Strength: Charpy 24-28 ft.-lb.

Strengthening Mechanism: Work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.62v

Types of Corrosion Suffered: uniform and slight crevice corrosion.

Typical Corrosion Rate Ranges: corrodes at lower rate than carbon steels in salt water. 0.6 to 2.6 MPY at depths greater than 2000 ft. with lower rate for longer exposure times.

USES: Plate for storage tanks and stacks, exhausts, chain, condensers & heat exchangers, fresh and salt water piping.

Forms available: wire, bar, tube, sheet and plate, structural shapes.

Fabricability: Readily weldable. Machinability index = 50 (AISI B1112 Steel = 100)

MATERIAL: Austenitic Nickel Cast Iron

NOMINAL COMPOSITION: 18-22 Ni, 3.0C, 2.0-3.2 Si, 0-2.5 Cr, .8-1.5 Mn, bal Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = 0.268 lb/in^3; in sea water, ρ_{sw} = .231 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 10.4 x 10^{-6} in/in/° F

Poissons Ratio =

Elastic Modulus in a) Tension E = 18.5 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast		
Yield Point σ_y	(1000 psi)	32-38		
Tensile Strength σ_u	(1000 psi)	58-68		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	7-40		
Hardness	(Brinell)	140-200		

Fatigue limits: 50 to 55% of σ_u in soft versions down to 30% or lower in high strength versions.

Impact Strength: Charpy V-notch 10-28 ft.-lb.

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.50v

Types of Corrosion Suffered: Uniform only. Good resistance to crevice corrosion.

Typical Corrosion Rate Ranges: less than that for plain carbon steels under most conditions. Usually about 2 to 3 MPY. Good resistance (ie <10 MPY) to velocities up to 50 ft. per sec.

USES: Impellers, machine parts, pumps, valves.

Forms available: castings

Fabricability: machinability excellent in both as cast and annealed conditions. Can be welded and brazed.

MATERIAL: High Nickel Cast Iron (Ni-Resist)

NOMINAL COMPOSITION: 14-30 Ni, 1.8-3.0C, 1.0-2.75 Si, .4-1.5 Mn, .5-5.5 Cr, 0-7.0 Cu.

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, $\rho = \begin{matrix}.264 \\ .270\end{matrix}$ lb/in^3; in sea water, $\rho_{sw} = \begin{matrix}.227 \\ .233\end{matrix}$ to lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = $\begin{matrix}4.5 \\ 10.7\end{matrix}$ to x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast		
Yield Point σ_y	(1000 psi)			
Tensile Strength σ_u	(1000 psi)	25-45		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)			
Hardness	(Brinell)	130-250		

Fatigue limits:

Impact Strength: Charpy 60-150 ft.-lb.

Strengthening Mechanism:

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: mostly uniform

Typical Corrosion Rate Ranges: corrodes slower than carbon steels - the rate depending upon alloy content.

USES: Heat and corrosion resistant parts, exhaust manifolds, steam lines, pump casings and impellers, non-magnetic grades are available.

Forms available: castings.

Fabricability:

MATERIAL: AISI 1020 Steel

NOMINAL COMPOSITION: Fe + .2%C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .283 lb/in^3; in sea water, ρ_{sw} = .246 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.4 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
Yield Point σ_y	(1000 psi)	48		
Tensile Strength σ_u	(1000 psi)	75		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	31		
Hardness	(Rockwell)	Case 62 Rc	Core 156R_B	

Fatigue limits: about 50% of σ_u

Impact Strength: Izod 93 ft.-lb.

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.65v

Types of Corrosion Suffered: uniform and sometimes slight crevice corrosion. Hydrogen embrittlement and caustic cracking.

Typical Corrosion Rate Ranges: 1 to 3 MPY below 1000 meters. Lower rate for longer exposures. In quiet surface water 10 to 15 MPY in first year down to 5 MPY after 5 years. 15 MPY in splash zone. Up to 3 MPY crevice attack occasionally.

USES: multiple

Forms available: almost all wrought forms are available.

Fabricability: easily welded and forged but difficult to machine.

MATERIAL: AISI 1040 Steel

NOMINAL COMPOSITION: Fe + .4%C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .283 lb/in^3; in sea water, ρ_{sw} = .246 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.3 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	
Yield Point σ_y	(1000 psi)	62	86	
Tensile Strength σ_u	(1000 psi)	89	113	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	33	19	
Hardness	(Brinell)	183	262	

Fatigue limits: about 50% of σ_u

Impact Strength: Izod 36 - 72 ft.-lb.

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.65v

Types of Corrosion Suffered: Similar to 1020 Steel

Typical Corrosion Rate Ranges:

USES: Multiple where 1020 steel is not strong enough

Forms available: most wrought forms are available

Fabricability: easily forged and more readily machined than 1020 steel but welding requires special procedures

MATERIAL: AISI 1080 Steel

NOMINAL COMPOSITION: Fe + .8%C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .283 lb/in^3; in sea water, ρ_{sw} = .246 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.1 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	
Yield Point σ_y	(1000 psi)	70	142	
Tensile Strength σ_u	(1000 psi)	117	190	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	24	12	
Hardness	(Brinell)	223	388	

Fatigue limits: about 40 to 50% of σ_u

Impact Strength: Izod 10 - 12 ft.-lb.

Strengthening Mechanism: work hardening and martensite reaction.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.65v

Types of Corrosion Suffered: similar to 1020 steel but less resistant to SCC and hydrogen embrittlement.

Typical Corrosion Rate Ranges:

USES: Implements and tools, blades, coil springs.

Forms available: most wrought forms are available

Fabricability: easily forged and machined in the annealed condition. Welding requires special procedures.

MATERIAL: AISI 1095 Steel

NOMINAL COMPOSITION: Fe + .95%C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .283 lb/in^3; in sea water, ρ_{sw} = .246 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.1 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	
Yield Point σ_y	(1000 psi)	74	120	
Tensile Strength σ_u	(1000 psi)	188	190	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	26	10	
Hardness	(Brinell)	229	401	

Fatigue limits: about 40 to 50% of σ_u

Impact Strength: Izod 5 - 6 ft.-lb.

Strengthening Mechanism: work hardening and martensite reaction.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.65v

Types of Corrosion Suffered: similar to 1020 steel but less resistant to SCC and hydrogen embrittlement.

Typical Corrosion Rate Ranges:

USES: springs and various tools.

Forms available:

Fabricability: similar to 1080 steel.

MATERIAL: Low alloy - high strength steels such as ASTM A-242 and A-441.

NOMINAL COMPOSITION: .18 to .22%C .5 to 1.5% each Mn, Ni and Cr usually about .25% each of P, Si, S and Cu

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .283 lb/in^3; in sea water, ρ_{sw} = .246 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
.2% Yield Strength σ_y	(1000 psi)	40 - 60		
Tensile Strength σ_u	(1000 psi)	60 - 80		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	22 - 24		
Hardness				

Fatigue limits:

Impact Strength: NDT range A-242 -20 to +40°F
A-441 0 to +70°F

Strengthening Mechanism: alloying

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.6v

Types of Corrosion Suffered: uniform and slight crevice corrosion. The general corrosion rate is halved by 2.5% or more Cr.

Typical Corrosion Rate Ranges: 10 to 15 MPY first year down to 5 MPY after 5 years in quiet surface sea water. .5 to 5.0 MPY below 1000 meters with the higher rate at shorter exposure times (ie <200 days). Up to 5 MPY occasionally in crevices.

USES: Structural sections where weight savings are important.

Forms available: bar, sheet, plate and strip, structural shapes

Fabricability: about the same as the carbon steels.

MATERIAL: HY-80

NOMINAL COMPOSITION: 2.0-3.25 Ni, 1-1.8 Cr, .2-.6 Mo, .15-.35 Si, .25 max P & S, .1-.4 Mn, .18C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .284 lb/in^3; in sea water, ρ_{sw} = .247 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Quenched and Tempered		in Compression
.2% Yield Strength σ_y	(1000 psi)	80 - 100		98
Tensile Strength σ_u	(1000 psi)	103		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	19 - 22		
Hardness				

Fatigue limits:

Impact Strength: charpy V-notch 60 to 100 ft.-lb. at -120°F.
NDT temp. -130°F or lower

Strengthening Mechanism: heat treating

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ∿ -.62v.

Types of Corrosion Suffered: mostly uniform

Typical Corrosion Rate Ranges: about 2 to 3 MPY in surface water, higher in splash zone and on short exposure.

USES: hull plate for ships and submersibles

Forms available: rod, bar, sheet, plate, structural shapes, forgings, extrusions.

Fabricability: readily welded, forgable.

MATERIAL: HY-100

NOMINAL COMPOSITION: 2.25-3.5 Ni, 1-1.8 Cr, .2-.6 Mo, .15-.35 Si
.25 Max P & S, .1-.4 Mn, .2C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .284 lb/in^3; in sea water, ρ_{sw} = .247 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6}in/in/°

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 30 x 10^6 psi
b) Shear G = x 10^6 psi

Property	Condition →	Quenched and Tempered		in Compression
.2% Yield Strength σ_y	(1000 psi)	100 - 105		115
Tensile Strength σ_u	(1000 psi)	110 - 118		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	18 - 22		
Hardness				

Fatigue limits:

Impact Strength: NDT -100°F or lower

Strengthening Mechanism: Quench and tempered

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: uniform and slight tendency toward SCC and hydrogen embrittlement

Typical Corrosion Rate Ranges: 2 to 3 MPY in surface water higher in splash zone and for short exposure

USES: hull plate for surface ships and submersibles.

Forms available: sheet and plate

Fabricability: weldable.

MATERIAL: HY-140

NOMINAL COMPOSITION: approximately 5 Ni, .8Mn, .5 Cr, .5 Mo

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .284 lb/in^3; in sea water, ρ_{sw} = .247 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Guaranteed Minimum	
.2% Yield Strength σ_y	(1000 psi)		140	
Tensile Strength σ_u	(1000 psi)		150	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)			
Hardness				

Fatigue limits:

Impact Strength: nill ductility temp. -20°F or lower

Strengthening Mechanism: Quench and tempered

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: Similar to HY 100 but greater resistance to Cl^- SCC and to hydrogen embrittlement.

Typical Corrosion Rate Ranges:

USES: primarily military

Forms available: sheet and plate

Fabricability: weldable

MATERIAL: HY-180

NOMINAL COMPOSITION: approximately 9 Ni, 4 Co, 1 Mo, .8 Cr, .3 Mn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .284 lb/in^3; in sea water, ρ_{sw} = .247 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio = .33

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Guaranteed Minimum		
.2% Yield Strength σ_y	(1000 psi)	180		
Tensile Strength σ_u	(1000 psi)	190		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)			
Hardness				

Fatigue limits:

Impact Strength: NDT temp. about 0°F

Strengthening Mechanism: Quench and tempered

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: See HY-140

Typical Corrosion Rate Ranges:

USES: Primarily military

Forms available: sheet and plate

Fabricability: weldable

MATERIAL: Maraging 180 Steel

NOMINAL COMPOSITION: 17-19 Ni, 8-9 Co, 3-3.5 Mo, .15-.25 Ti
.05-.15 Al, .03C max

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio = .32

Elastic Modulus in a) Tension E = 29 x 10^6 psi
b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	in Compression
.2% Yield Strength σ_y	(1000 psi)	110	190-210	220
Tensile Strength σ_u	(1000 psi)	140	200-220	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	17	14-16	
Hardness		28-32 Rc		

Fatigue limits: Endurance limit 95,000 psi

Impact Strength: Charpy V-notch 60-110 ft.-lb. at 70°F

Strengthening Mechanism: Martensite and precipitation hardening (Ni_3Mo ppt)

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = ∿-.5v

Types of Corrosion Suffered: Uniform, SCC and hydrogen embrittlement. The susceptibility to SCC and hydrogen embrittlement increases sharply with strength level in MA steels.

Typical Corrosion Rate Ranges: 1 to 3 MPY

USES: Pressure hulls for submersibles

Forms available: sheet and plate

Fabricability: weldable but entire structure must be heat treated after welding.

MATERIAL: Maraging 250 Steel

NOMINAL COMPOSITION: 17-19 Ni, 7-8.5 Co, 4.6-5.1 Mo, .3-.5 Ti, .05-.15 Al, .03C Max.

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio = .32

Elastic Modulus in a) Tension E = 29 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	in Compression
.2% Yield Strength σ_y	(1000 psi)	110	240-268	280
Tensile Strength σ_u	(1000 psi)	140	250-275	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	17	10-12	
Hardness		28-32 Rc		

Fatigue limits: Endurance limit 95-100,000 psi

Impact Strength: Charpy V-notch 18-26 ft.-lb. at 70°F

Strengthening Mechanism: Martensite and precipitation hardening.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: See MA 180 Steel

Typical Corrosion Rate Ranges:

USES: Weldments requiring high strength

Forms available: sheet and plate

Fabricability: weldable (see MA 180 steel)

MATERIAL: Maraging 300 Steel

NOMINAL COMPOSITION: 18-19 Ni, 8.5-9.5 Co, 4.7-5.2 Mo, .5-.7 Ti, .05-.15 Al, .03C max.

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio = .32

Elastic Modulus in a) Tension E = 29 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	in Compression
.2% Yield Strength σ_y	(1000 psi)	110	295-303	340
Tensile Strength σ_u	(1000 psi)	140	297-306	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	17	12	
Hardness		28-32 Rc		

Fatigue limits:

Impact Strength:

Strengthening Mechanism: Martensite and precipitation hardening.

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: See MA 180 steel.

Typical Corrosion Rate Ranges:

USES: Weldments requiring exceptionally high strength

Forms available: plate and sheet

Fabricability: weldable (see MA 180 steel)

MATERIAL: 4130 and 4140 Alloy Steels

NOMINAL COMPOSITION: 4130: .3C, .5 Mn
4140: .4C, .9 Mn
.2-.35 Si, .75-1.20 Cr, .15-.25 Mo

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .283 lb/in^3; in sea water, ρ_{sw} = .246 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = x 10^{-6} in/in/°

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi
b) Shear G = x 10^6 psi

Property	Condition →	Range		
.2% Yield Strength σ_y	(1000 psi)	90 to 250		
Tensile Strength σ_u	(1000 psi)	100 to 290		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	11 to 28		
Hardness	(Brinell)	200 to 575		

Fatigue limits: 78,000 to 97,000 psi at hardness of 35 Rc
83,000 to 125,000 psi at hardness of 50 Rc

Impact Strength: Izod 11 to 108 ft.-lb.

Strengthening Mechanism: Alloying and heat treatment

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered:

Typical Corrosion Rate Ranges:

USES: gears, shafts, axles, bolts, clutch and machine tool parts.

Forms available: all standard mill forms

Fabricability: easily weldable, machinability index = 60
(AISI B1112 Steel = 100)

MATERIAL: 302 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 17-19 Cr, 8-10 Ni, 0.15 C, Balance Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = 0.290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 9.6 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28.0 x 10^6 psi

b) Shear G = 12.5 x 10^6 psi

Property	Condition →	Annealed	1/4 hard	Maximum
.2% Yield Strength σ_y	(1000 psi)	35 to 40	75	165
Tensile Strength σ_u	(1000 psi)	85 to 90	125	190 to 350*
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	50 to 60	12 to 35	8
Hardness		80 to 85 R_B	25 R_C	40 R_C

* after severe cold drawing

Fatigue limits: 34,000 psi annealed endurance limit

Impact Strength: Izod 110 ft/lb annealed

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09 v(-0.5v active)

Types of Corrosion Suffered: crevice, edge, tunnel & pitting. Especially subject to attack in shielded areas such as fouling deposits. Velocity of 5 fps will prevent local attack

Typical Corrosion Rate Ranges: In surface H_2O pits up to 0.060" deep form in 1645 days. In deep water, crevice attack up to 0.020" deep in 200 days. Pits, if occuring, will be few, random, and deep.

USES: General purpose but avoid crevices

Forms available: wire, rod, bar, tube, sheet, strip, & plate

Fabricability: machinability index = 55 (AISI B1112 Steel = 100) weldable

MATERIAL: 304 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 18-20 Cr, 9-12 Ni, 0.08 C, Balance Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 9.6 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = 12.5 x 10^6 psi

Property	Condition →	Annealed	Cold Worked	Maximum
.2% Yield Strength σ_y	(1000 psi)	35 to 42	75	160
Tensile Strength σ_u	(1000 psi)	82 to 85	110	185
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	50 to 60	60	4
Hardness	(Brinell)	149 (80 R_B)	240	(40 R_c)

Fatigue limits: 35,000 psi annealed endurance limit

Impact Strength: Izod 110 ft/lb annealed, 90 ft/lb cold worked

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09v(-0.5v active)

Types of Corrosion Suffered: crevice, tunnel, edge & pitting attack. Susceptible to local attack in shielded areas such as fouling deposits. Local attack prevented by velocity of 5 fps.

Typical Corrosion Rate Ranges: Pitting up to 50 mills deep in six months in surface water. In deep water it is better than type 302 on short exposure but up to 75 mills deep crevice attack in 1000 days. Pits, if occuring, will be scattered and deep.

USES: general purpose but avoid crevices. Topside wire rope.

Forms available: wire, bar, tube, sheet, strip, & plate, forgings, fasteners

Fabricability: machinability index = 50 (AISI B1112 Steel = 100)
weldable

MATERIAL: 304 L Stainless Steel

NOMINAL COMPOSITION: 18 to 20 Cr, 8 to 12 Ni, 0.03C Bal Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 9.6 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = 12.5 x 10^6 psi

Property	Condition →	Annealed	Cold Worked	
.2% Yield Strength σ_y	(1000 psi)	28-35	65	
Tensile Strength σ_u	(1000 psi)	75-85	110	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	55-60		
Hardness		70-79 R_B		

Fatigue limits: Similar to 304

Impact Strength: Similar to 304

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09v (-0.5v active)

Types of Corrosion Suffered: Similar to type 304 but less liable to be sensitized in welded areas.

Typical Corrosion Rate Ranges:

USES: weldments that cannot be subsequently annealed

Forms available: bar, sheet, strip & plate

Fabricability: same as type 304

MATERIAL: 310 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 24 to 26 Cr, 19 to 22 Ni, 0.25 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.8 x 10^{-6} in/in/°

Poissons Ratio =

Elastic Modulus in a) Tension E = 30 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
.2% Yield Strength σ_y	(1000 psi)	40 to 45		
Tensile Strength σ_u	(1000 psi)	95		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	45		
Hardness		85 to 89 R_B		

Fatigue limits:

Impact Strength: Izod 90 ft/lb annealed

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09v(-0.5v active)

Types of Corrosion Suffered: Pitting and crevice corrosion especially under fouling deposits

Typical Corrosion Rate Ranges: after 320 days in surface H_2O: pitting .006" deep; crevice corrosion .024" deep.

USES: heat exchanger tubing, processing equipment, gas turbines

Forms available: wire, bar, tube, sheet, strip, & plate

Fabricability: machinability index = 50 (AISI B1112 Steel = 100) weldable

MATERIAL: 316 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 16-18 Cr, 10-14 Ni, 2 -3 Mo, 0.08 C, Balance Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.9 x 10^{-6} in/in/ °F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28.0 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
.2% Yield Strength σ_y	(1000 psi)	30 to 42		
Tensile Strength σ_u	(1000 psi)	80 to 90*		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	50 to 60		
Hardness		79 to 85 R_B		

* can be cold drawn to 300,000 psi

Fatigue limits: 38,000 lb annealed endurance limit; 40,000 psi cold drawn

Impact Strength: Izod annealed 110 ft/lb

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09 v(-0.5v active)

Types of Corrosion Suffered: Best of all 300 series stainless steels. Slight tunnel, edge, crevice, & pitting attack expecially under fouling deposits.

Typical Corrosion Rate Ranges: after 1645 days in surface sea water: pitting up to 50 mills deep; crevice 50 to 60 mills deep. In deep water: crevice corrosion up to 25 mills deep in 1,000 days.

USES: general marine useage where good resistance to pitting and crevice corrosion are required.

Forms available: wire, bar, tube, sheet, strip, plate, fasteners

Fabricability: machinability index = 50 (AISI B1112 Steel = 100) weldable

MATERIAL: 316 L Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 16-18 Cr, 10-14 Ni, 2-3 Mo, 0.03 C, Balance Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.9 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
.2% Yield Strength σ_y	(1000 psi)	32-42		
Tensile Strength σ_u	(1000 psi)	75-81		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	50-55		
Hardness		72-79 R_B		

Fatigue limits: Probably similar to 316

Impact Strength: Probably similar to 316

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09v(-0.5v active)

Types of Corrosion Suffered: Similar to type 316 but less apt to be sensitized in welded areas

Typical Corrosion Rate Ranges:

USES: weldments that cannot be subsequently annealed

Forms available: sheet, strip, & plate

Fabricability: similar to type 316

MATERIAL: 317 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 18-20 Cr, 11-15 Ni, 3-4 Mo, 0.08 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 8.9 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28.0 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
.2% Yield Strength σ_y	(1000 psi)	35-40		
Tensile Strength σ_u	(1000 psi)	80-90		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	45-50		
Hardness		85 R_B		

Fatigue limits:

Impact Strength: Izod annealed 110 ft/lb

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09v(-0.5v active)

Types of Corrosion Suffered: pitting, crevice & edge attack

Typical Corrosion Rate Ranges: after 1,000 days in surface sea water: pitting up to 23 mills deep; crevice up to 50 mills deep.

USES:

Forms available: bar, sheet, strip, & plate

Fabricability: weldable

MATERIAL: Armco 22-13-5 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 20.5-23.5 Cr, 11.5-13.5 Ni, 2-3 Mo, 4-6 Mn, 0.06 C,

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .285 lb/in^3; in sea water, ρ_{sw} = .248 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 9.0 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = 10.1 x 10^6 psi

Property	Condition →	Annealed		Maximum
.2% Yield Strength σ_y	(1000 psi)	60-86		234
Tensile Strength σ_u	(1000 psi)	120-128		246
Shear Strength γ	(1000 psi)	109		
Elongation	(% in 2 inches)	50-30		8
Hardness		21-30 R_c		43 R_c

Fatigue limits: 42,000 psi in air, 22,000 psi in sea water at 10^8 cycles

Impact Strength: Izod 170 ft/lb annealed

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: Better than 316; some crevice and pitting under extreme conditions

Typical Corrosion Rate Ranges:

USES: Parts requiring higher strength and better corrosion resistance than type 316.

Forms available: wire, rod, bar, sheet, strip

Fabricability: about the same as type 316

MATERIAL: Allegheny-Ludlam 6X Stainless Steel

NOMINAL COMPOSITION: 24 Ni, 20 Cr, 6.5 Mo, 1.5 Mn, .5 Si, .03 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = ≃ 8.0* x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 29 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	20% CW	50% CW
.2% Yield Strength σ_y	(1000 psi)	44	114	151
Tensile Strength σ_u	(1000 psi)	94	126	162
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	45	15	5
Hardness			25 R_c	32 R_c

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: Little if any attack. Highly resistant to pitting and crevice corrosion.

Typical Corrosion Rate Ranges:

USES:

Forms available: wire, welded tube, strip

Fabricability: Alloy is still experimental so not much is known yet.

*not known accurately yet.

MATERIAL: 347 Stainless Steel (austenitic, non-magnetic)

NOMINAL COMPOSITION: 17-19 Cr, 9-13 Ni, 0.08 C,

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 9.3 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed		
.2% Yield Strength σ_y	(1000 psi)	35-40		
Tensile Strength σ_u	(1000 psi)	90-95		
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	45-50		
Hardness		85 R_B		

Fatigue limits: 39,000 psi endurance limit annealed

Impact Strength: 110 ft/lb Izod annealed

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -0.09v(-0.5v active)

Types of Corrosion Suffered: pitting, crevice, & heavy edge attack especially under fouling deposits. Local attack prevented by belocity > 5 fps

Typical Corrosion Rate Ranges: after 755 days in surface sea water, pitting: up to .150" deep; crevice corrosion: up to .060" deep.

USES: stabilized weldments for extreme corrosive service

Forms available: bar, sheet, strip, & plate

Fabricability: weldable

MATERIAL: Alloy 20 & 20 Cb-3

NOMINAL COMPOSITION: 29-34 Ni, 20 Cr, 2.5 Mo, 3.5 Cu

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .290 lb/in^3; in sea water, ρ_{sw} = .253 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = $\frac{7.86 \text{ to}}{8.31}$ x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28 x 10^6 psi

b) Shear G = 11 x 10^6 psi

Property	Condition →	Annealed	Cold Drawn	
.2% Yield Strength σ_y	(1000 psi)	35-55		
Tensile Strength σ_u	(1000 psi)	85-95	up to 280	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	50		
Hardness	(Brinell)	160		

Fatigue limits:

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: slight crevice corrosion only

Typical Corrosion Rate Ranges:

USES:

Forms available: rod, bar, tube, sheet, plate

Fabricability:

MATERIAL: 17-4 PH Stainless Steel

NOMINAL COMPOSITION: 16.5 Cr, 4 Ni, 4 Cu, .07 C, Cb & Ta 0.3

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .280-.282 lb/in^3; in sea water, ρ_{sw} = .243 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 6.0 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 28.5 x 10^6 psi

b) Shear G = 12.7 x 10^6 psi

Property	Condition →	Solution Annealed	Hardened	
.2% Yield Strength σ_y	(1000 psi)	110	178-185	
Tensile Strength σ_u	(1000 psi)	150	200	
Shear Strength γ	(1000 psi)	130	130	
Elongation	(% in 2 inches)	12	14	
Hardness		32 R_c	44 R_c	

Fatigue limits: 80 to 90,000 psi at 10^8 cycles

Impact Strength: 19 to 50 ft/lb Charpy

Strengthening Mechanism: precipitation hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: tunnel and weld bead attack, hydrogen embrittlement and SCC.

Typical Corrosion Rate Ranges:

USES: Parts requiring high specific strength & good corrosion resistance

Forms available: wire, rod, bar, tube, sheet, plate, strip, forgings

Fabricability: readily arc welded

MATERIAL: 410 Stainless Steel Martensitic

NOMINAL COMPOSITION: 11.5-13.5 Cr, 1 Mn, 0.15 C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .280 lb/in^3; in sea water, ρ_{sw} = .243 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 6.1 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 29 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Heat Treated	
.2% Yield Strength σ_y	(1000 psi)	35-45	140-145	
Tensile Strength σ_u	(1000 psi)	65-75	180-190	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	25-35	15	
Hardness		80 R_B	39 R_c	

Fatigue limits: 40,000 psi endurance limit annealed, ≃ 55,000 psi tempered

Impact Strength: Izod 90 ft/lb (Ann) 35 to 75 (heat treated)

Strengthening Mechanism: martensite reaction

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: tunnel, edge, pitting, and crevice attack

Typical Corrosion Rate Ranges: up to 15 mills deep crevice attack in 200 days in deep water

USES: general purpose, applications requiring high strength where a non-magnetic alloy is not important

Forms available: wire, rod, bar, tube, sheet, plate, strip, structural shapes

Fabricability: weldability is fair

MATERIAL: 431 Stainless Steel Martensitic

NOMINAL COMPOSITION: 15-17 Cr, 1.25=2.50 Ni, .2C

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .280 lb/in^3; in sea water, ρ_{sw} = .243 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 6.5 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 29 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Annealed	Tempered	Full Hard
.2% Yield Strength σ_y	(1000 psi)	95	95 up to →	155
Tensile Strength σ_u	(1000 psi)	125	125 up to →	205
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	20 to 25		15
Hardness	(Brinell)	260 (R_c24)		415 (R_c43)

Fatigue limits: 45,000 psi annealed endurance limit

Impact Strength: 50 ft/lb Izod annealed down to 30 ft/lb full hard

Strengthening Mechanism: Martensite reaction

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode =

Types of Corrosion Suffered: edge, tunnel, crevice, and pitting attack especially under fouling deposits.

Typical Corrosion Rate Ranges: after 550 days in surface sea water, pitting up to .135" deep; crevice up to .072" deep. In deep water, up to 100 mills penetration by any method in 1000 days.

USES: Similar to type 410. pumps and valves

Forms available: wire, rod, bar, sheet, tube, plate, strip, structural shapes

Fabricability: machinability index = 45 (AlSl B1112 Steel = 100) weldability is fair

MATERIAL: Unalloyed Titanium (Ti-35A to Ti-100A)

NOMINAL COMPOSITION: 98.9 - 99.5 % Ti

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .163 lb/in^3; in sea water, ρ_{sw} = .126 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 5.1 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 15 x 10^6 psi

b) Shear G = 6.5 x 10^6 psi

Property	Condition →	Annealed	Cold Worked	
.2% Yield Strength σ_y	(1000 psi)	25	up to 90	
Tensile Strength σ_u	(1000 psi)	35	up to 100	
Shear Strength γ	(1000 psi)		50 - 60	
Elongation	(% in 2 inches)	17 - 30		
Hardness	R_B	70	100	

Fatigue limits: 63,000 psi at 10^7 cycles and 90,000 psi tensile str.

Impact Strength: Charpy V-notch 11 - 40 ft.-lb.

Strengthening Mechanism: Work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.10v

Types of Corrosion Suffered: nill except for slight possibility of pitting and SCC in hot Cl^- salt solutions.

Typical Corrosion Rate Ranges:

USES: Aircraft skins, webs and stiffeners; marine parts

Forms available: wire, bar, tube, sheet, strip, plate, fasteners, extrusions

Fabricability: Machine at slow speed and high feed. Fully weldable. High formability especially in lower strengths versions.

MATERIAL: Unalloyed Titanium (Ti-35A to Ti-100A)

NOMINAL COMPOSITION: 98.9 - 99.5 % Ti

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .163 lb/in^3; in sea water, ρ_{sw} = .126 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 5.1 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 15 x 10^6 psi

b) Shear G = 6.5 x 10^6 psi

Property	Condition →	Annealed	Cold Worked	
.2% Yield Strength σ_y	(1000 psi)	25	up to 90	
Tensile Strength σ_u	(1000 psi)	35	up to 100	
Shear Strength γ	(1000 psi)		50 - 60	
Elongation	(% in 2 inches)	17 - 30		
Hardness	R_B	70	100	

Fatigue limits: 63,000 psi at 10^7 cycles and 90,000 psi tensile str.

Impact Strength: Charpy V-notch 11 - 40 ft.-lb.

Strengthening Mechanism: Work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.10±

Types of Corrosion Suffered: nill except for slight possibility of pitting and SCC in hot Cl^- salt solutions.

Typical Corrosion Rate Ranges:

USES: Aircraft skins, webs and stiffeners; marine parts

Forms available: wire, bar, tube, sheet, strip, plate, fasteners, extrusions

Fabricability: Machine at slow speed and high feed. Fully weldable. High formability especially in lower strengths versions.

MATERIAL: 6 - 4 Titanium

NOMINAL COMPOSITION: 5.5-6.5 al 3.5-4.5 V .25 max Fe

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .160 lb/in^3; in sea water, ρ_{sw} = .123 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 5.3 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = 16.5 x 10^6 psi

b) Shear G = 6.1 x 10^6 psi

Property	Condition →	Annealed	Aged	
.2% Yield Strength σ_y	(1000 psi)	120 - 128	155	
Tensile Strength σ_u	(1000 psi)	130 - 138	165	
Shear Strength γ	(1000 psi)	100	110	
Elongation	(% in 2 inches)	10	8	
Hardness		30 R_c		

Fatigue limits: @ 10^7 cycles 75,000 psi annealed, 92,000 psi aged.

Impact Strength: Charpy V-notch 10 to 20 ft.-lb.

Strengthening Mechanism: Age hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -.10v

Types of Corrosion Suffered: None. Comparable to Hastelloy C-276. Slight possibility of SCC in hot Cl^- salt solutions.

Typical Corrosion Rate Ranges:

USES: Most versatile Titanium alloy. Aircraft and jet engine parts and marine hardware.

Forms available: wire, bar, sheet, strip, plate and extrusions.

Fabricability: Machine at slow speed heavy feed. Weldable.

Table 2

ASTM-ASME Titanium Specifications

	ASTM	ASME
Titanium and Titanium Alloy Strip, Sheet and Plate	B-265-72	SB-265
Seamless and Welded Titanium Pipe	B-337-73	SB-337
Seamless and Welded Titanium Tube for Condensers and Heat Exchangers	B-338-73	SB-338
Titanium and Titanium Alloy Bars and Billets	B-348-72	SB-348
Seamless and Welded Unalloyed Titanium Welded Fittings	B-363-71	None
Titanium and Titanium Alloy Forgings	B-381-69	SB-381

Table 3

Mechanical and Chemical Requirements of ASTM-ASME Titanium Grades

Element	Composition, Percent			
	Grade			
	1	2	3	7
Nitrogen, max	0.03	0.03	0.05	0.03
Carbon, max	0.10	0.10	0.10	0.10
Hydrogen, αmax	0.015	0.015	0.015	0.015
Iron, max	0.20	0.30	0.30	0.30
Oxygen, max	0.18	0.25	0.35	0.25
Palladium	...	...	...	0.15 to 0.25
Other Elements β(each)	0.05	0.05	0.05	0.05
Other Elements (total	0.30	0.30	0.30	0.30
Titanium [c]	remainder	remainder	remainder.	remainder

α Lower hydrogen may be obtained by negotiation with the manufacturer.
β Need not be reported.
c The percentage of titanium is determined by difference.

Grade	Tensile Strength, [a] min		Yield Strength, [a] (0.2 percent Offset) min		max		Elongation in 2 in.min. percent	Bend Test [b] Under 0.070 in. in Thickness	Bend Test [b] 0.070 in. to 0.187 in. in Thickness
	ksi	kgf/mm²	ksi	kgf/mm²	ksi	kgf/mm²			
1	35	24.5	25	17.5	45	31.5	24	3T	4T
2	50	35.0	40	28.0	65	45.5	20	4T	5T
3	65	45.5	55	38.5	80	56.0	18	4T	5T
7	50	35.0	40	28.0	65	45.5	20	4T	5T

a. Minimum and maximum limits apply to tests taken both longitudinal and transverse to the direction of rolling. Mechanical properties for conditions other than annealed or plate thickness over 1 in. (25 mm) may be established by agreement between the manufacturer and the purchaser.
b. T equals the thickness of the bend test specimen. Bend tests are not applicable to material over 0.187 in. (4.75 mm) in thickness.

MATERIAL: Commercially Pure Magnesium (Primary Mg)

NOMINAL COMPOSITION: 99.98% Mg

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .063 lb/in^3; in sea water, ρ_{sw} = .026 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 25.2 x 10^{-6} in/in/°C

Poissons Ratio =

Elastic Modulus in a) Tension E = 5.7 to 6.5 x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	As Cast	Cold Rolled Sheet	
.2% Yield Strength σ_y	(1000 psi)	3	17-20	
Tensile Strength σ_u	(1000 psi)	13	26-32	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	2-6	2-10	
Hardness	(Brinell)	30 (16 R_E)	47 (50 R_E)	

Fatigue limits:

Impact Strength:

Strengthening Mechanism: Work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -1.6v

Types of Corrosion Suffered: rapid uniform corrosion in sea water. Mg is anodic to all other common metals thus severe galvanic effects can be expected when coupled to dissimilar metals.

Typical Corrosion Rate Ranges: In tidal water, alloy AZ31A (3 Al, 1Zn) corrodes at 145 MPY uncoupled, 222 MPY coupled to 1/6 its own area of titanium and over 800 MPY coupled to 6 times its own area of titanium.

USES: sacrificial anodes and corrosive links.

Forms available: most mill forms are available.

Fabricability: machinability index = 500 (free cutting brass = 100) can be welded satisfactorily by helium or argon arc methods.

MATERIAL: Zinc

NOMINAL COMPOSITION: .08 Pb, bal. Zn

PHYSICAL AND MECHANICAL PROPERTIES:

Density: in air, ρ = .258 lb/in^3; in sea water, ρ_{sw} = .221 lb/in^3

Coefficient of Thermal Expansion (-50 to 100°C) = 18 x 10^{-6} in/in/°F

Poissons Ratio =

Elastic Modulus in a) Tension E = x 10^6 psi

b) Shear G = x 10^6 psi

Property	Condition →	Not Rolled	Cold Rolled	
.2% Yield Strength σ_y	(1000 psi)			
Tensile Strength σ_u	(1000 psi)	19-23	21-27	
Shear Strength γ	(1000 psi)			
Elongation	(% in 2 inches)	50-65	40-50	
Hardness	(Brinell)	38		

Fatigue limits: 2,500 psi endurance limit (hot rolled)

Impact Strength:

Strengthening Mechanism: work hardening

BEHAVIOR IN NATURAL SEA WATER:

Electrode potential vs. Saturated Calomel Electrode = -1.0v

Types of Corrosion Suffered: mostly uniform corrosion in aerated sea water, but pitting may develop under anearobic conditions. Zinc is anodic to all common metals and alloys except magnesium.

Typical Corrosion Rate Ranges: As a rough "Rule of Thumb", zinc as a galvanized coating protects steel at the rate of 1 year for each one-thousandth of an inch of coating thickness.

USES: galvanizing, corrosive links and sacrificial anodes (composition specified by MIL-A-1800IE: .006 Pb, .0014 Fe, .06 Cd, .005 Cu, .1-.3 Al)

Forms available: wire, rod, sheet, strip, plate, extruded shapes, castings.

Fabricability: good machinability and formability, can be joined by torch and resistance welding and soldering.

Index of Materials Listed in Part B

Aluminum Alloys
- 1100 14
- 3003 15
- 5005 16
- 5050 17
- 5052 18
- 5083 19
- 5086 20
- 5456 21
- 6061 22
- 7039 23
- 7075 24
- 7079 25
- 7178 26

Copper Alloys, Wrought
- CDA 110 Electrolytic Tough Pitch Copper 27
- CDA 172 Beryllium Copper 28
- CDA 230 Red Brass 29
- CDA 260 Cartridge Brass 30
- CDA 280 Muntz Metal 31
- CDA 443-5 Inhibited Admiralty 32
- CDA 464 Naval Brass 33
- CDA 524 Phosphor Bronze 10% 34
- CDA 614 Aluminum Bronze D 35
- CDA 655 High Silicon Bronze A 36
- CDA 675 Manganese Bronze A 37
- CDA 706 90-10 Copper - Nickel 38
- CDA 710 80-20 Copper - Nickel 39
- CDA 715 70-30 Copper - Nickel 40
- CDA 752 Nickel Silver 41

Copper Alloys, Cast
- Cast High Strength Yellow Brass 42
- Cast Silicon Brass and Bronze 43
- Cast Aluminum Bronze 44
- Cast G and M Tin Bronzes 45

Hastelloy C-276 53
Incoloy 825 52
Inconel 600 48
Inconel 625 49
Inconel 718 50
Inconel X-750 51
Iron, Austenitic Nickel Cast 55
- High Nickel Cast (Ni-Resist) 56
- Wrought 54

Magnesium (Commercially Pure) 86
Monel 400 46
Monel K-500 47

Stainless Steels
- Allegheny - Ludlam 6X 78
- Alloy 20 and 20 cb-3 80
- Armco 22-13-5 77
- 302 70
- 304 71
- 304L 72
- 310 73
- 316 74
- 316L 75
- 317 76
- 347 79
- 410 82
- 431 83
- 17-4 PH 81

Steels
- AISI 1020 57
- AISI 1040 58
- AISI 1080 59
- AISI 1095 60
- AISI 4130 and 4140 69
- Low Alloy - High Strength steels 61
- Maraging 180 66
- Maraging 250 67
- Maraging 300 68
- Quenched and Tempered Steels
  - HY-80 62
  - HY-100 63
  - HY-140 64
  - HY-180 65

Titanium, unalloyed 84
Titanium, 6Al - 4V 85
Zinc 87