Zircadyne® 702 and 705

OVERVIEW

Zircadyne alloys are composed of 95.5% to 99.2% zirconium and hafnium with a maximum hafnium content of 4.5%. Zircadyne mill products are available in two chemical grades each sharing excellent corrosion resistance and also having slightly different physical and mechanical properties. Zircadyne 702 is commercially pure zirconium. Zircadyne 705 zirconium is alloyed with niobium to increase its strength and improve its formability. Table 1 shows the chemical composition of Zircadyne alloys. The presence of hafnium in Zircadyne alloys does not significantly influence the physical, mechanical, or corrosion properties.

Zirconium, a reactive metal, has a high affinity for oxygen that results in the formation of a protective oxide layer in air at room temperature. This protective oxide gives Zircadyne alloys their superior corrosion resistance and this oxide layer can be enhanced through a heat treating process. A properly formed enhanced oxide layer serves as an excellent bearing surface against a variety of materials, imparts impressive erosion resistance in high velocity systems, and can improve the corrosion resistance in certain aggressive environments.

Zircadyne alloys exhibit good ductility even at cryogenic temperatures and good strength comparable with other common engineering alloys. In addition to being integral to the oxide layer, oxygen is an

Table 1. Chemical Compositions of Zircadyne® Alloys

Grade	Zr 702	Zr 705
UNS Designation	R60702	R60705
Element	Weight %	Weight %
Zirconium + Hafnium, min	99.2	95.5
Hafnium, max	4.5	4.5
Iron + Chromium, max	0.20	0.20
Tin	–	–
Hydrogen, max	0.005	0.005
Nitrogen, max	0.025	0.025
Carbon, max	0.05	0.05
Niobium (Columbium)	–	2.0 – 3.0
Oxygen, max	0.16	0.18

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interstitial strengthening element in Zircadyne® alloys. Zircadyne alloys do not exhibit a low temperature ductile to brittle transition.

Table 2 lists the thermal properties for Zircadyne alloys. Zircadyne alloys have a thermal conductivity that is more than 30% higher than those of stainless steel alloys making Zircadyne alloys ideal for heat exchanger applications. The linear coefficient of thermal expansion of Zircadyne alloys is nearly one-third of the value for stainless steel giving Zircadyne alloys superior dimensional stability at elevated temperatures.

Table 2. Thermal Properties of Zircadyne® Alloys		
	Zr 702	Zr 705
Melting Point	1852°C	1840°C
Specific Heat, KJ/kg-K (0-100°C)	0.2847	0.2805
Vapor Pressure (mm Hg)		
2000°C (3632°F)	0.01	–
3600°C (6512°F)	900	–
Thermal Conductivity, w/m-°K (BTU/hr-ft-°F), 300-800K⁻	22 (13)	17.1 (10)
Coefficient of Thermal Expansion x 10^{-6}/°C	5.8 (3.2)	3.6 (2.0)
149°C (300°F)	6.3 (3.5)	4.9 (2.7)
260°C (500°F)	7.0 (3.9)	5.6 (3.1)
371°C (700°F)	7.4 (4.1)	5.9 (3.3)
Latent Heat of Fusion (cal/gm)	60.4	–
Latent Heat of Vaporisation (cal/gm)	1550	–

Zircadyne 702 has a hexagonal close-packed crystal structure (alpha) below approximately 865°C (1590°F) which transforms to a body-centered cubic crystal structure (beta) above this temperature. Zircadyne 705 is a two phase system composed of a hexagonal close-packed crystal structure (alpha) and body-centered cubic crystal structure (beta) below approximately 920°C (1688°F). Above this temperature, Zircadyne 705 transforms to a body-centered cubic crystal structure (beta). Due to the nature of hexagonal close-packed deformation systems which have only one predominant slip system and three predominant twin systems at typical fabrication temperatures, wrought Zircadyne alloys are anisotropic. Table 3 lists the crystallographic characteristics of Zircadyne alloys.

Typical wrought and annealed Zircadyne alloys exhibit a uniform equiaxed grain structure. All Zircadyne alloy mill products are supplied in the annealed condition, unless specified otherwise.

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MECHANICAL PROPERTIES

Table 4 lists physical property data for Zircadyne® alloys. The modulus of elasticity for Zircadyne alloys decreases rapidly at elevated temperatures as shown in Table 4. Zircadyne alloys have a density that is less than 20% of nickel and iron based stainless alloys.

Table 3. Atomic and Crystallographic Properties of Zircadyne® Alloys		
	Zr 702	Zr 705
Atomic Number	40 (pure Zr)	–
Atomic Weight	91.22 (pure Zr)	–
Atomic Radius		
Å (Zero Charge)	1.60–1.62 (pure Zr)	–
Å (+4 Charge)	0.80–0.90 (pure Zr)	–
Crystal Structure		
Alpha Phase	HCP* below 865°C (1590°F)	–
Beta Phase	BCC* above 865°C (1590°F)	BCC* above 920°C (1688°F)
Alpha + Beta Phase	–	HCP*-BCC* below 920°C (1688°F)
*HCP: Hexagonal Close-Packed, BCC: Body Centered Cubic		

Table 4. Physical Properties of Zircadyne® Alloys		
	Zr 702	Zr 705
Modulus of Elasticity, GPa (psi x 10^6)		
Room Temperature	99.2 (14.4)	94.7 (13.7)
38°C (100°F)	98.6 (14.3)	93.8 (13.6)
93°C (200°F)	93.1 (13.5)	90.5 (13.1)
149°C (300°F)	86.9 (12.6)	87.3 (12.7)
204°C (400°F)	80.7 (11.7)	84.2 (12.2)
260°C (500°F)	75.2 (10.9)	81.0 (11.7)
316°C (600°F)	69.6 (10.1)	77.8 (11.3)
371°C (700°F)	64.1 (9.3)	74.6 (10.8)
Shear Modulus of Elasticity, GPa (psi x 10^6)		
Room Temperature	36.2 (5.25)	34.5 (5.0)
Poisson's Ratio	0.35	0.33
Density, g/cm³ (lbs/in³)	6.51 (0.235)	6.64 (0.240)

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Table 5 and Figures 1 and 2 show the typical mechanical property data for Zircadyne® alloys in the annealed condition. The data shown are the average of the longitudinal and transverse values at specific temperatures. The yield strength was determined using the 0.2% offset method. Like most non-ferrous metals, Zircadyne alloys exhibit a gradual transition from elastic to plastic behavior. Some of the physical and mechanical properties of Zircadyne zirconium are affected by its anisotropy. These properties include thermal expansion, yield strength, ultimate tensile strength, elongation, notch toughness, and bend ductility whose magnitudes vary anisotropically with the direction of the material.

Table 5. Typical Mechanical Properties of Zircadyne® Alloys (Cold Worked and Annealed)

	ASTM Min Value	Room Temp.	93°C (200°F)	149°C (300°F)	204°C (400°F)	260°C (500°F)	316°C (600°F)	371°C (700°F)
Zircadyne® 702 (R60702)								
Ultimate Tensile Strength, MPa (ksi)	379	468.1	364.0	303.7	229.6	200.6	197.9	156.5
	(55)	(67.9)	(52.8)	(44.2)	(33.3)	(29.1)	(28.7)	(22.7)
Yield Strength, MPa (ksi)	207	321.1	267.5	195.8	139.3	128.9	97.2	82.0
	(30)	(46.6)	(38.8)	(28.4)	(20.2)	(18.7)	(14.1)	(11.9)
Elongation, % (0.2% offset)	16	28.9	31.5	42.5	49.0	49.0	40.1	44.1
Zircadyne® 705 (R60705)								
Ultimate Tensile Strength, MPa (ksi)	552.0	615.0	494.7	388.9	369.3	326.1	299.7	281.0
	(80)	(89.2)	(71.8)	(56.4)	(53.6)	(47.3)	(43.5)	(408)
Yield Strength, MPa (ksi)	379.0	506.1	390.7	272.3	261.8	195.8	190.2	173.0
	(55)	(73.4)	(56.7)	(39.5)	(38)	(28.4)	(27.6)	(25.1)
Elongation, % (0.2% offset)	16.0	18.8	30.5	31.7	33.0	28.9	29.0	27.8

Figure 1. Zircadyne 702®

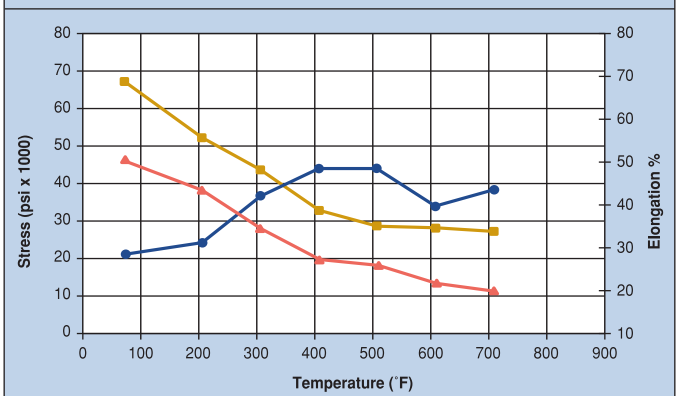
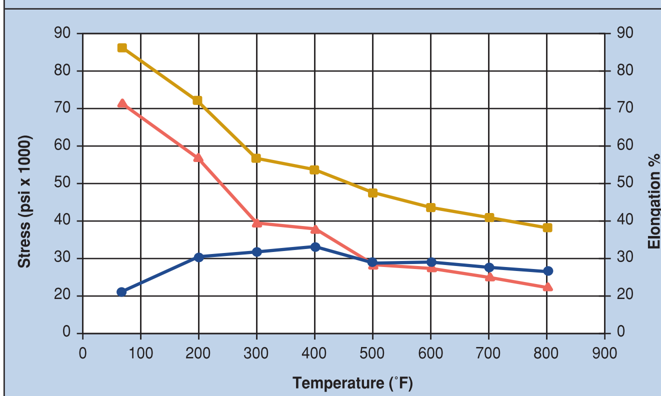


Figure 2. Zircadyne 705®



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The ductility in both Zircadyne® alloys increases significantly with temperature. This improved ductility combined with a lower yield strength at 400°F provides improved conditions for severe forming operations.

Zircadyne alloys work harden rapidly. A stress relief heat treatment at 565°C (1050°F ± 50°F) for 1/2 to 1 hour at temperature can be utilized to relieve residual stresses.

ASME ALLOWABLE STRESS

Both Zircadyne alloys are approved for use in the construction of pressure vessels designed to the ASME Boiler and Pressure Vessel Code. Zircadyne 705 zirconium requires a stress relief heat treatment within 14 days after welding. Tables 6A and 6B list the allowable stress values for Zircadyne alloys per the ASME Boiler and Pressure Vessel Code, Section II, Part D (2008a).

Table 6A. ASME Allowable Stress Values for Zircadyne® 702 and Zircadyne 705 Zirconium for Unfired Pressure Vessels (Customary)

Material Form and Condition	ASME Specification Number	Alloy Grade	Minimum Tensile Strength	Minimum Yield Strength	Maximum Allowable Stress in Tension for Metal Temperatures, °F							
					-20 to 100	150	200	300	400	500	600	700
			ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi	ksi
Plate, Sheet, Strip	SB 551	702	55	30	15.7	15.1	13.7	11.2	9.1	7.4	6.0	5.2
		705	80	55	22.9	–	19.0	16.2	14.3	12.9	11.9	11.3
Seamless Tubing	SB 523	702	55	30	15.7	15.1	13.7	11.2	9.1	7.4	6.0	5.2
		705	80	55	22.9	–	19.0	16.2	14.3	12.9	11.9	11.3
Welded Tubing (a)	SB 523	702	55	30	13.4	12.8	10.8	9.5	7.7	6.3	5.1	4.5
		705	80	55	19.4	–	16.1	13.8	12.2	11.0	10.1	9.9
Forgings	SB 493	702	55	30	15.7	15.1	13.7	11.2	9.1	7.4	6.0	5.2
		705	80	55	22.9	–	19.0	16.2	14.3	12.9	11.9	11.3
Bar	SB 550	702	55	30	15.7	15.1	13.7	11.2	9.1	7.4	6.0	5.2
		705	80	55	22.9	–	19.0	16.2	14.3	12.9	11.9	11.3
Seamless Pipe	SB 658	702	55	30	15.7	15.1	13.7	11.2	9.1	7.4	6.0	5.2
		705	80	55	22.9	–	19.0	16.2	14.3	12.9	11.9	11.3
Welded Pipe (a)	SB 658	702	55	30	13.4	12.8	11.6	9.5	7.7	6.3	5.1	4.5
		705	80	55	19.4	–	16.1	13.8	12.2	11.0	10.1	9.9

(a) 85% joint efficiency has been used in determining the allowable stress value for welded product.

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Table 6B. ASME Allowable Stress Values for Zircadyne® 702 and Zircadyne 705 Zirconium for Unfired Pressure Vessels (Metric)												
Material Form and Condition	ASME Specification Number	Alloy Grade	Minimum Tensile Strength	Minimum Yield Strength	Maximum Allowable Stress in Tension for Metal Temperatures, °C							
					-30 to 40	65	125	175	225	275	325	375
			MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa	MPa
Plate, Sheet, Strip	SB 551	702	380	205	108.0	104.0	84.3	70.1	58.7	47.9	40.3	35.5
		705	550	380	158.0	144.0	119.0	105.0	94.7	86.8	81.2	77.6
Seamless Tubing	SB 523	702	380	205	108.0	104.0	84.3	70.1	58.7	47.9	40.3	35.5
		705	550	380	158.0	144.0	119.0	105.0	94.7	86.8	81.2	77.6
Welded Tubing (a)	SB 523	702	380	205	92.4	88.4	71.4	59.7	49.4	40.7	34.1	30.9
		705	550	380	134.0	122.0	101.0	89.5	80.8	73.9	68.9	66.0
Forgings	SB 493	702	380	205	108.0	104.0	84.3	70.1	58.7	47.9	40.3	35.5
		705	550	380	158.0	144.0	119.0	105.0	94.7	69.4	81.2	77.6
Bar	SB 550	702	380	205	108.0	104.0	84.3	70.1	58.7	47.9	40.3	35.5
		705	550	380	158.0	144.0	119.0	105.0	94.7	86.8	81.2	77.6
Seamless Pipe	SB 658	702	380	205	108.0	104.0	84.3	70.1	58.7	47.9	40.3	35.5
		705	550	380	158.0	144.0	119.0	105.0	94.7	86.8	81.2	77.6
Welded Pipe (a)	SB 658	702	380	205	92.4	88.4	71.4	59.7	49.4	40.7	34.1	30.9
		705	550	380	134.0	122.0	101.0	89.5	80.8	73.9	68.9	66.0

(a) 85% joint efficiency has been used in determining the allowable stress value for welded product.

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ZIRCADYNE® ZIRCONIUM CORROSION DATA

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Acetaldehyde	100	Boiling	<2	–	
Acetic Acid	5-99.5	35-Boiling	<1	<1	
Acetic Acid (anhydride)	99	Room-Boiling	<1	<1	
Acetic Acid (glacial)	99.7	Boiling	<5	–	
Acetic Acid	100	200	<1	<1	
Acetic Acid + 1% Acetyl Chloride	99	Boiling	>50	–	
Acetic Acid (glacial) + 0.5% CH_3OH	99	200	<1	–	
Acetic Acid (glacial) + 200 ppm $FeCl_3$	99	200	<1	–	
Acetic Acid (glacial) + 0.5% CH_3OH + 200 ppm $FeCl_3$ + 1% H_2O	98	200	<1	–	
Acetic Acid + 50 ppm I^-(KI)	100	160, 200	<1	–	
Acetic Acid + 1% I^-(KI) + 100 ppm $Fe^{+3}(Fe_2(So_4)_3)$	99	200	<1	<1	
Acetic Acid + 2% HI	80	100	<1	<1	
Acetic Acid + 2% HI + 1000 ppm Fe (Fe powder)	80	100	<1	–	
Acetic Acid + 2% HI + 1% methanol + 500 ppm formic + 100 ppm Cu	80	150	<1	<1	
Acetic Acid + 2% HI + 1% methanol + 500 ppm formic + 100 ppm Fe	80	150	<1	<1	
Acetic Acid + 2% HI	98	150	<1	<1	
Acetic Acid + 2% HI + 200 ppm $Fe^{+3}(FeCl_3)$	80	100	<1	<1	
Acetic Acid + 2% HI + 200 ppm $Fe^{+3}(Fe_2(So_4)_3)$	80	100	<1	<1	
Acetic Acid + 2% I^-(KI)	98	100	<1	<1	

ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Acetic Acid +2% HI + 1% CH_3OH = 500 ppm HCOOH	80	150	<1	<1	
Acetic Acid + 2% HI +200 ppm Cl^-(NaCl)	80	100	<1	<1	
Acetic Acid + 50% Acetic Anhydride	50	Boiling	<1	<1	
Acetic Acid + 50% 48% HBr	50	115	<1	<1	
Acetic Acid + Saturated gaseous HCl and Cl_2	100	Boiling	>200	>200	
	100	40	<1	–	
Acetic Acid + 0.5% CH_3OH + 200 ppm $FeCl_3$ + 5% H_2O	94	200	<1	–	
Acetic Acid + 10% CH_3OH	90	200	<1	–	
Acetic Acid + 10% CH_3OH + 200 ppm $FeCl_3$ + 5% H_2O	84	200	<1	–	
Acetic Acid + 10% CH_3OH + 200 ppm $FeCl_3$ + 1% H_2O	88	200	<1	–	
Acetyl Chloride	100	25	>200	–	
Aluminum Chlorate	30	100	<2	–	
Aluminum Chloride	5, 10, 25	35-100	<1	–	
	25	Boiling	<1	<1	
	40	100	<2	–	
Aluminum Chloride (aerated)	5, 10	60	<2	–	
Aluminum Chloride	25-50	Boiling	<1	<1	
Aluminum Chloride + Saturated 1% HCl	–	RT	<1	–	
	–	110	10-20	–	
Aluminum Fluoride	20	Room	>50	–	pH = 3.2
Aluminum Fluoride + 0.5% HF + 16% Zr sponge	7.2	90	<1	–	
Aluminum Potassium Sulfate	10	Boiling	nil	nil	pH = 3.2

ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Aluminum Sulfate	25	Boiling	nil	nil	
	60	100	<2	–	
Ammonia (wet)	+ water	38	<5	–	
Ammonium Carbamate	–	193	<1	–	58.4% Urea, 16.8% Ammonia, 14.8% CO_2, 9.9% H_2O at 3,200-3,500 psi
Ammonium Chloride	1, 10, saturated	35-100	<1	–	
Ammonium Hydrogen Phosphate	22.8	204	nil	–	
Ammonium Hydroxide	28	Room-100	<1	–	
Ammonium Fluoride	20	28	>50	–	pH = 8
	20	98	>50	–	pH = 8
Ammonium Oxalate	100	100	<2	–	
Ammonium Sulfate	10	Boiling	nil	–	
Aniline Hydrochloride	5.20	35-100	<1	–	
	5.20	100	<2	–	
Aqua Regia	3.1	Room	>50	–	3 parts HCl, 1 part HNO_3
Barium Chloride	5, 20	35-100	<1	–	
	25	Boiling	5-10	–	
Bromine	100-Liquid	20	<10	20-50	Pitting
	Vapor	20	–	>50	Pitting
Bromochloromethane	100	100	<2	–	
Cadmium Chloride	100	Room	<2	–	
Calcium Bromide	100	100	<2	–	
Calcium Chloride	5, 10, 25	35-100	<1	–	
	70	Boiling	<1	<1	B.P. = 162°C
	75	Boiling	<5	–	
	Mixture	79	<1	–	14% $CaCl_2$, 8% NaCl, 0.2% $Ca(OH)_2$

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Calcium Chloride + 0.1% $MgCl_2$	0.2	80	<1	–	pH = 1
Calcium Chloride + 0.1% $MgCl_2$ + 300 ppm F^-(as CaF_2)	0.2	80	>50	–	pH = 1
Calcium Chloride + 0.1% $MgCl_2$ + 300 ppm F^-(as CaF_2) + 1200 ppm P_2O_2	0.2	80	5-20	–	pH = 1
Calcium Chloride + 1% $MgCl_2$	2	80	<1	–	pH = 1
Calcium Chloride + 1% $MgCl_2$ + 300 ppm F^-(as CaF_2)	2	80	>50	–	pH = 1
Calcium Chloride + 1% $MgCl_2$ + 300 ppm F^-(as CaF_2) + 1200 ppm P_2O_5	2	80	<1	–	pH = 1
Calcium Chloride + 3.3% $MgCl_2$	6.6	80	<1	–	pH = 1
Calcium Chloride + 3.3% $MgCl_2$ + 300 ppm F^-(as CaF_2)	6.6	80	20-25	–	pH = 1
Calcium Chloride + 3.3% $MgCl_2$ + 300 ppm F^-(as CaF_2) + 1200 ppm P_2O_5	6.6	80	<1	–	pH = 1
Calcium Fluoride	Saturated	28	nil	–	pH = 5
	Saturated	90	nil	–	pH = 5
Calcium Hypochlorite	2, 6, 20	100	<5	–	
Carbonic Acid	Saturated	100	<5	–	
Carbon Tetrachloride	0-100	Room-100	<2	–	
Chlorine (water saturated)	–	Room	>50	–	
	–	75	>50	–	
Chlorine Gas (more than 0.13% H_2O)	100	94	>50	–	
Chlorine Gas (dry)	100	Room	<5	–	
Chlorinated Water	–	100	<2	–	

ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Chloroacetic Acid	100	Boiling	<1	–	
Chlorosulfonic Acid	100	R.T.	5-10	–	
	100	0	<2	–	
Chromic Acid	10-50	Boiling	<1	–	
Citric Acid	10-50	35-100	<1	–	
	10, 25, 50	100	<1	–	
	50	Boiling	<5	–	
Chrome Plating Solution	–	66	>50	>50	M + T Chemicals CR-100
Cupric Chloride	5, 10, 20	35-100	>50	>50	
	20, 40, 50	Boiling	>50	>50	
Cupric Cyanide	Saturated	Room	>50	–	
Cupric Nitrate	40	Boiling	nil	nil	B.P. = 115°C
Dichloroacetic Acid	100	Boiling	<20	–	
Ethylene Dichloride	100	Boiling	<5	–	
Ferric Chloride	0-50	Room-100	>50	>50	
	0-50	Boiling	>50	>50	
Ferric Sulfate	10	0-100	<2	–	
Formaldehyde	6-37	Boiling	<1	<1	
	0-70	Room-100	<2	–	
Fluoboric Acid	5-20	Elevated	>50	–	
Fluosilicic Acid	10	Room	>50	–	
Formic Acid	10-90	35-Boiling	<1	–	
Formic Acid (aerated)	10-90	Room-100	<1	–	
Formic Acid	50	Boiling	<1	<1	
	70, 98	Boiling	<1	–	
Formic Acid + 5% H_2SO_4	50, 70, 93	Boiling	<1	–	
Formic Acid + 5% HCl	50, 70, 85	Boiling	<1	–	
Formic Acid + 1% Fe Powder	50, 70, 98	Boiling	<1	–	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Formic Acid + 1% Cu^{+2}	50, 70, 96	Boiling	<1	–	
Formic Acid + 5% HI	50, 70, 90	Boiling	<1	–	
Hydrazine	50	200	nil	nil	
	Mixture	109	<1	–	2% Hydrazine + saturated NaCl + 6% NaOH
	Mixture	130	nil	–	2% Hydrazine + saturated NaCl + 6% NaOH
Hydriodic Acid	47	120	<1	<1	
Hydrobromic Acid	48	Boiling	<5	<5	B.P. + 125°C (shallow pits) 24% HBr + 50% Acetic Acid (glacial)
	Mixture	Boiling	<1	<1	B.P. + 125°C (shallow pits) 24% HBr + 50% Acetic Acid (glacial)
Hydrochloric Acid	2	100	<1	–	
	2	225	<1	<1	
	10	30	<1	–	
	10	100	<1	–	
	20	30	<1	–	
	20	100	<1	–	
	20	150	<2	–	
	32	30	<1	–	
	32	77	<1	–	Weld sensitization
	37	30	<1	–	Weld sensitization
	37	51	<2	–	Weld sensitization
Hydrochloric Acid + Cl_2 gas	20	58	5-10	–	Pitting
	37	58	<5	–	
Hydrochloric Acid + 100 ppm $FeCl_3$	10	30	<1	<1	SCC observed

ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Hydrochloric Acid + 100 ppm $FeCl_3$	20	105	<5	–	
	34	53	5-10	–	SCC observed
Hydrochloric Acid + 50 ppm Fe^{+3}	10	30	<1	–	
	10	60	<1	–	
	10	100	<1	–	Pitting
	20	30	<1	–	
	20	60	<1	–	
	20	100	<1	–	Pitting
	32	30	<1	–	
	32	77	<2	–	Weld sensitization
	37	30	<2	–	Weld sensitization
	37	51	<5	–	Weld sensitization
Hydrochloric Acid + 100 ppm Fe^{+3}	10	30	<1	–	
	10	60	<1	–	
	10	100	<1	–	Pitting
	20	30	<1	–	
	20	60	<1	–	Pitting
	20	100	<1	–	
	32	30	<1	–	
	32	77	<2	–	Weld sensitization
	37	30	<2	–	Weld sensitization
	37	51	<5	–	Weld sensitization
Hydrochloric Acid + 500 ppm Fe^{+3}	10	30	<1	–	Pitting, SCC
	10	60	<1	–	Pitting, SCC
	10	100	<1	–	Pitting, SCC
	20	30	<1	–	Pitting, SCC
	20	60	<1	–	Pitting, SCC
	20	100	<1	–	Pitting, SCC

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Hydrochloric Acid + 500 ppm Fe^{+3}	32	30	<1	–	SCC
	32	77	<5	–	Weld sensitization, SCC
	37	30	<2	–	Weld sensitization, SCC
	37	51	<5	–	Weld sensitization, SCC
Hydrochloric Acid + 200 ppm HF	10	100	>50	–	
Hydrochloric Acid + 200 ppm HF + 800 ppm Zr sponge	10	100	<1	–	
Hydrochloric Acid	Mixture	Room	Dissolved	–	20% HCl + 20% HNO_3
	Mixture	Room	Dissolved	–	10% HCl + 10% HNO_3
Hydrofluoric Acid	All	Room	>50	–	
Hydrogen Peroxide	30	Boiling	nil	nil	
	50	100	<2	–	
Hydroxyacetic Acid	70	205	<1	<1	
Iodine Vapor	–	100, 180	<1	–	
Iodine Liquid	100	120	5-20	–	
	100	180	>50	–	
Lactic Acid	10-100	148	<1	–	
	10-85	35-Boiling	<1	–	
Lithium Chloride	Saturated	30-80	5-10	–	
Lithium Chloride	Saturated	80	nil	–	pH adjusted to 6.0 with NaOH
Magnesium Chloride	5-40	Room-100	<2	–	
	47	Boiling	nil	nil	
	30	Boiling	<2	<2	
Magnesium Chloride + 1% HCl	30	Boiling	<2	<2	
Magnesium Chloride + 5% HCl	30	Boiling	<2	<2	
Magnesium Chloride + 10% HCl	30	Boiling	<2	<2	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Manganese Chloride	5, 20	Room-100	<1	–	
Mercuric Chloride	Saturated	35-100	<1	–	
	Saturated	Boiling	<1	<1	
Methanol	100	Boiling 200	nil	nil	
Methanol + 0.1% KI + 0.1% HCOOH	99.8	65	nil	nil	
Methanol + 1% KI	99	200	<1	<1	500 ppm Fe^{+3}
Nickel Chloride	5, 20	35-100	<1	–	
	5-20	100	<1	–	
	30	Boiling	nil	nil	
Nitric Acid	20	103	<1	<1	
	70	121	<1	<1	
	10-70	Room-260	<1	–	
	70-98	Room-Boiling	<1*	–	*SCC observed
	80	120, 150	<1	–	
	90	120, 150	<1	–	
Nitric Acid + Saturated Cl_2	30, 50, 70	Boiling	<1	–	Pitting may be observed in the vapor phase
Nitric Acid + 200 ppm HF	90	25	>50	–	
Nitric Acid + 200 ppm HF + 800 ppm Zr sponge	90	25	<1	–	
Nitric Acid + 1% Fe	65	120, 204	<1	–	
Nitric Acid + 1.45% 304 S.S.	65	120, 204	nil	–	
Nitric Acid + 1% Cl^-(as NaCl)	30, 50, 70	120	nil	–	
Nitric Acid + 1% Seawater	70	120	nil	–	
Nitric Acid + 1% $FeCl_3$	70	120	nil	–	
Oxalic Acid	0-100	100	<1	–	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Perchloric Acid	70	100	<2	–	
Phenol	Saturated	Room	<5	–	
Phosphoric Acid	5-30	Room	<5	–	
	5-35	60	<5	–	
	5-50	100	<5	–	
	35-50	Room	<5	–	
	45	Boiling	<5	–	
	50	Boiling	<5	10-15	B.P. = 108°C
	65	100	5-10	<20	
	70	Boiling	>50	>50	B.P. = 123-126°C
	85	38	5-20	–	
	85	80	20-50	20-50	
	85	Boiling	>50	>50	B.P. = 156°C
	Mixture	Room	nil	–	88% H_3PO_4 + 0.5% HNO_3
	Mixture	Room	nil	–	88% H_3PO_4 + 5% HNO_3
	Mixture	89	>50	>50	85% H_3PO_4 + 4% HNO_3
	20	150	<1	–	
Phosphoric Acid + 4.3% Ammonia	18	204	nil	–	
Phosphoric Acid + 2 ppm F^-	30-50	Boiling	20-50	–	
Phosphoric Acid + 4.3% NH_3	18.5	204	<1	–	
Potassium Chloride	Saturated	60	<1	–	
	Saturated	Room	<1	–	
Potassium Fluoride	20	28	nil	–	pH = 8.9
	20	90	>50	–	pH = 8.9
	0.3	Boiling	<1	–	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Potassium Hydroxide	50	27	<1	–	
	10	Boiling	<1	–	
	25	Boiling	<1	–	
	50	Boiling	<1	–	
	50-anhydrous	241-377	>50	–	
	Mixture	29	<1	–	13% KOH, 13% KCl
Potassium Iodide	0-70	Room-100	<2	<2	
Potassium Nitrite	0-100	Room-100	<2	–	
Silver Nitrate	50	Room	<5	–	
Sodium Bisulfate	40	Boiling	<1	<1	B.P. = 107°C
Sodium Carbonate	10	R.T.-Boiling	<1	<1	
Sodium Chlorate	20	Boiling	nil	–	
Sodium Chloride	3-Saturated	35-Boiling	<1	<1	
	29	Boiling	<1	–	
	Saturated	Room	<1	–	
	Saturated	Boiling	<1	<1	Adjusted to pH = 1
	Saturated	107	nil	–	Adjusted to pH = 0
Sodium Chloride + Saturated SO_2	3.5	80	nil	–	
	25	80	nil	–	
	Saturated	80	nil	–	
Sodium Chloride	Mixture	215	nil	nil	25% NaCl + 0.5% Acetic Acid + 1% S + Saturated H_2S
Sodium Chloride + 0.5% CH_3COOH + Saturated H_2S	25	R.T.-Boiling	<1	<1	
Sodium Chloride + 0.5% CH_3COOH + 0.1% S + Saturated (H_2S + CO_2)	25	204, 232	<1	–	
Sodium Chloride + 0.5% CH_3COOH + 0.1% S + Saturated H_2S	25	250	<1	<1	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Sodium Fluoride	Saturated	28	nil	–	
	Saturated	90	>50	–	
Sodium Formate	0-80	100	<2	–	
Sodium Hydrogen Sulfite	40	Boiling	<1	<1	
Sodium Hydroxide	5-10	21	<1	–	
	28	Room	<1	–	
	10-25	Boiling	<1	–	
	40	100	<1	–	
	50	38-57	<1	–	
	50	149	<2	<2	
	50-73	188	20-50	–	
	70	150	<5	–	
	73	110-129	<2	–	
	73 to anhydrous	212-538	20-50	–	
	Mixture	82	<1	–	9-11% NaOH, 15% NaCl
	Mixture	10-32	<1	–	10% NaOH, 10% NaCl & wet $CoCl_2$
	Mixture	129	<1	–	0.6% NaOH, 2% $NaClO_3$ + trace of NH_3
	Mixture	191	<1	–	7% NaOH, 53% NaCl, 7% $NaClO_3$, 80-100 ppm NH_3
	Mixture	138	<5	–	52% NaOH + 16% NH_3
Sodium Hydroxide (Suspended salt-violent boiling)	20	60	10-20	–	
Sodium Hydroxide + 750 ppm Free Cl_2	50	38	<1	–	
	50	38-57	<1	–	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Sodium Hypochlorite	6	100	<5	–	as received super chlor.
	6	50	nil	nil	
Sodium Iodide	0-60	100	<2	–	
Sodium Peroxide	0-100	Room-100	<2	–	
Sodium Oxychloride +15% Sodium Chloride + 5% Sodium Carbonate	15	46	0	<1	
Sodium Silicate	0-100	Room-100	<2	–	
Sodium Sulfate	0-20	Room-100	<2	–	
Sodium Sulfide	10	200	nil	nil	
	33	Boiling	nil	nil	
Stannic Chloride	5	100	<1	–	
	24	Boiling	<1	–	
Succinic Acid	0-50	100	<2	–	
	100	150	<2	–	
Sulfuric Acid	0-75	20	<1	<1	
	80	20	<5	–	
	80	30	20-50	>50	
	77.5	60	10-20	<10	
	75	50	<1	–	
	77	50	5-10	–	
	80	50	>50	>50	
	75	80	<5	<5	
	65	100	–	<5	
	70	100	<2	<5	
	75	100	<5	<5	
	76	100	<10	–	
	77	100	<20	–	
	77.5	100	>50	>50	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Sulfuric Acid	60	130	–	<5	
	65	130	<1	–	
	70	140	<5	<10	
	58	Boiling	–	<5	B.P. = 140°C
	62	Boiling	<5	10-20	B.P. = 146°C
	64	Boiling	<5	20-50	B.P. = 152°C
	68	Boiling	<5	–	B.P. = 165°C
	69	Boiling	<5	–	B.P. = 167°C
	71	Boiling	<5	–	B.P. = 171°C
	72-74	Boiling	5-10	–	
	75	Boiling	10-20	–	B.P. = 189°C
Sulfuric Acid + 1,000 ppm Fe^{3+}	60	Boiling	<1	–	B.P. = 142°C
Sulfuric Acid + 10,000 ppm Fe^{3+}	60	Boiling	<5	–	Added as $Fe_2(SO_4)_3$
Sulfuric Acid + 200-1,000 ppm Fe^{3+}	65	Boiling	<5	–	B.P. = 152-155°C
Sulfuric Acid + 10,000 ppm Fe^{3+}	65	Boiling	5-10	–	Added as $Fe_2(SO_4)_3$
Sulfuric Acid + 14 ppm-141 ppm Fe^{3+}	70	Boiling	5-10	–	B.P. = 167-171°C
Sulfuric Acid + 200 ppm	70	Boiling	10-20	–	Added as $Fe_2(SO_4)_3$
Sulfuric Acid + 1,410 ppm-10,000 ppm Fe^{3+}	70	Boiling	>50	–	
Sulfuric Acid + 1,000 ppm $FeCl_3$	60	Boiling	<5	<20	B.P. = 138-142°C
Sulfuric Acid + 10,000 ppm $FeCl_3$	60	Boiling	<5	20-50	
Sulfuric Acid + 20,000 ppm $FeCl_3$	60	Boiling	20-50	>50	

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Sulfuric Acid + 200 ppm $FeCl_3$	65	Boiling	<5	<20	B.P. = 152-155°C
Sulfuric Acid + 1,000 ppm $FeCl_3$	65	Boiling	<5	<20	
Sulfuric Acid + 10,000 ppm $FeCl_3$	65	Boiling	<5	<20	
Sulfuric Acid + 10 ppm $FeCl_3$	70	Boiling	<20	>50	B.P. = 167-171°C
Sulfuric Acid + 100 ppm $FeCl_3$	70	Boiling	<20	>50	
Sulfuric Acid + 200 ppm $FeCl_3$	70	Boiling	<20	>50	
Sulfuric Acid + 1,000 ppm $FeCl_3$	70	Boiling	<20	>50	
Sulfuric Acid + 10,000 ppm $FeCl_3$	70	Boiling	20-50	>50	
Sulfuric Acid + 200 ppm Cu^{2+}	60	Boiling	<5	–	Added as $CuSO_4$
Sulfuric Acid + 1,000-10,000 ppm Cu^{2+}	60	Boiling	<1	–	
Sulfuric Acid + 200-10,000 ppm Cu^{2+}	65	Boiling	<5	–	Added as $CuSO_4$
Sulfuric Acid + 3 ppm Cu^{2+}	70	Boiling	5-10	–	Added as $CuSO_4$
Sulfuric Acid + 27-266 ppm Cu^{2+}	70	Boiling	>50	–	
Sulfuric Acid + 1,000-10,000 ppm NO^-_3	60	Boiling	<5	–	Added as $NaNO_3$
Sulfuric Acid + 50,000 ppm NO^-_3	60	Boiling	>50	–	

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Sulfuric Acid + 200-1,000 ppm NO^-_3	65	Boiling	<5	–	Added as $NaNO_3$
Sulfuric Acid + 10,000 ppm NO^-_3	65	Boiling	10-20	–	
Sulfuric Acid + 50,000 ppm NO^-_3	65	Boiling	>50	–	
Sulfuric Acid + 200 ppm NO^-_3	70	Boiling	5-10	–	Added as $NaNO_3$
Sulfuric Acid + 6,000 ppm NO^-_3	70	Boiling	20-50	–	
Sulfuric Acid + 1,000 ppm NO^-_3	60	Boiling	<5	–	Added as HNO_3
Sulfuric Acid + 10,000 ppm NO^-_3	60	Boiling	10-20	–	
Sulfuric Acid + 50,000 ppm NO^-_3	60	Boiling	>50	–	
Sulfuric Acid + 1,000 ppm NO^-_3	65	Boiling	<5	–	Added as HNO_3
Sulfuric Acid + 10,000-50,000 ppm NO^-_3	65	Boiling	>50	–	
Sulfuric Acid	Mixture	Room-100	<1	–	1% H_2SO_4, 99% HNO_3
	Mixture	Room-100	nil	–	10% H_2SO_4, 90% HNO_3
	Mixture	Boiling	<1	–	14% H_2SO_4, 14% HNO_3
	Mixture	100	>50	>50	25% H_2SO_4, 75% HNO_3
	Mixture	Room	<1	–	50% H_2SO_4, 50% HNO_3
	Mixture	Boiling	>50	>50	68% H_2SO_4, 5% HNO_3
	Mixture	Boiling-135	10-20	>50	68% H_2SO_4, 1% HNO_3
	Mixture	Room	>50	>50	75% H_2SO_4, 20% HNO_3

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Sulfuric	Mixture	Boiling	<1	–	7.5% H_2SO_4, 19% HCl
	Mixture	Boiling	<1	–	34% H_2SO_4, 17% HCl
	Mixture	Boiling	<1	–	40% H_2SO_4, 14% HCl
	Mixture	Boiling	1-5	–	56% H_2SO_4, 10% HCl
	Mixture	Boiling	<1	–	60% H_2SO_4, 1.5% HCl
	Mixture	Boiling	<5	–	69% H_2SO_4, 1.5% HCl
	Mixture	Boiling	10-20	–	69% H_2SO_4, 4% HCl
	Mixture	Boiling	<20	–	72% H_2SO_4, 1.5% HCl
	Mixture	Boiling	>50	>50	20% H_2SO_4, 7% HCl with 50 ppm F impurities
	2	225	<1	<1	
	5	232	<1	<1	
	10	225	<1	–	
	15	225	<5	–	
Sulfuric Acid + 11% $SnSO_4$	10	103	<1	<1	
Sulfuric Acid + 1% $SnSO_4$	35	103	<1	<1	
Sulfuric Acid + 8% Fe	20	80	<1	–	
Sulfurous Acid	6	Room	<5	–	
	Saturated	192	5-50	–	
Sulfamic Acid	10	Boiling	nil	nil	B.P. = 101°C
Tannic Acid	25	35-100	<1	–	
Tartaric Acid	10-50	35-100	<1		
Trichloroacetic Acid	10-40	Room	<2		
	100	Boiling	>50		
	100	100	>50		B.P. = 195°C
Tetrachloroethane	100	Boiling	<5		B.P. = 146°C symmetrical B.P. = 129°C unsymmetrical
Trichloroethylene	99	Boiling	<5		B.P. = 87°C

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ZIRCADYNE® ZIRCONIUM CORROSION DATA (CONTINUED)

Corrosive Media	Concentration %	Temperature °C	CORROSION RATE, mpy		Remarks
			Zr 702	Zr 705	
Trisodium Phosphate	5-20	100	<5	–	
Urea	50	Boiling	0.1	0.1	
Urea Reactor Mixture	Mixture	193	<1	–	58 Urea, 17 NH_3, 15 CO_2, 10 H_2O
Water - Sea (Pacific)	–	Boiling	nil	nil	
	–	200	nil	–	pH = 7.6
White Liquor	–	121, 177, 227	<1	<1	A mixture of NaOH, Na_2S, Na_2CO_3, etc.
Zinc Chloride	70	Boiling	nil	nil	
	5-20	35-Boiling	<1	–	
	40	Boiling-180	<1	<1	

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