Zircadyne® 702
Zircadyne® 705

Zirconium Alloys

(UNS R60702 and UNS R60705)

INTRODUCTION

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 Zirconium is commercially pure. 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 interstitial strengthening element in Zircadyne alloys. Zircadyne alloys do not exhibit a low temperature ductile to brittle transition.

Table 1. Typical 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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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 alloy 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 alloy 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 alloy 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.

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		

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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/cm^3 (lbs/in^3)	6.51 (0.235)	6.64 (0.240)

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)								

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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

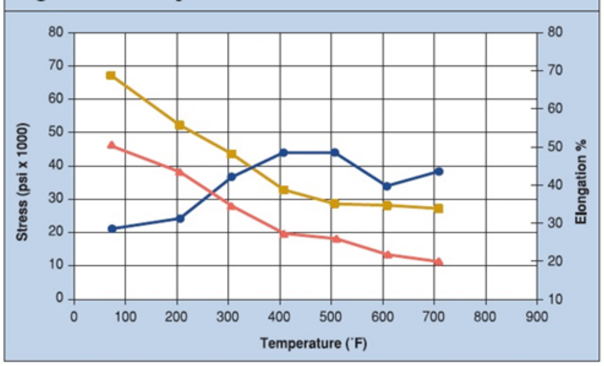
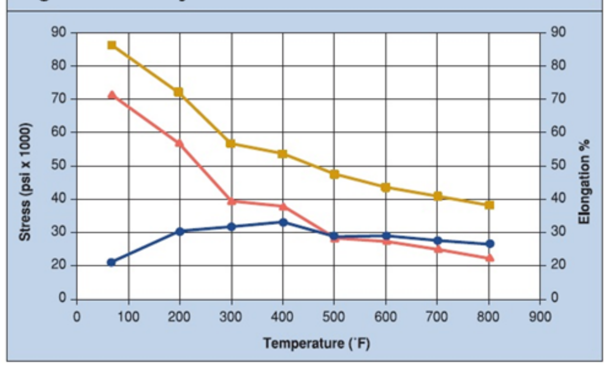


Figure 2. Zircadyne® 705



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

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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	22.9	–	19.0	16.2	14.3	12.9	11.9	11.3
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.

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	SB 658	702	380	205	92.4	88.4	71.4	59.7	49.4	40.7	34.1	30.9

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Pipe (a)		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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