7. FILLER METAL OF TITANIUM BASED ALLOYS

7.1 Lancaster Alloys Company can offer the following Titanium based alloys weld rods and bare electrodes (1) :

Table 7.1. Stock list of LAC for Titanium based weld wire

LAC STOCK #	AMS SPECIFICATION	ALLOY NAME	AWS SPECIFICATION	AWS CLASS	UNS # (2)
4951	AMS 4951	CP-Ti	(3)	(3)	R50550
4954	AMS 4954	6-4	AWS. A5.16	ERTi-5	R56400
4956	AMS 4956	6-4 ELI	AWS. A5. 16(4)	ERTi-5ELI (4)	R56402

1. Other Titanium alloys are also available upon request.
2. SAE/ASTM Unified Numbering System for metals and alloys.
3. A perfect match for AWS specification does not exist; there are four classes of AWS A5.16-ERTi-1, ERTi-2, ERTi-3 and ERTi-4 available upon request.
4. The only difference between the AWS and AMS requirement for this alloy is a maximum limit on Oxygen; 0.08% for AMS, and 0.10% -AWS.

7.2 Chemical composition requirements for Titanium alloys

Table 7.2 gives the chemical composition requirements for Titanium alloys.

TABLE 7.2 CHEMICAL COMPOSITION REQUIREMENTS FOR TITANIUM ALLOY ELECTRODES AND RODES (1) (2)

STOCK #	CARBON	OXYGEN	HYDROGEN	NITROGEN	ALUMINIUM	VANADIUM	IRON	YTTRIUM
4951	0.08	0.18	0.005	0.05	-	-	0.20	-
4954	0.05	0.18	0.015	0.03	5.5-6.75	3.50-4.50	0.30	0.005
4956	0.03	0.08	0.005	0.012	5.5-6.75	3.50-4.50	0.15	0.005

1. Single values are maximum
2. Residual elements, total, 0.040% maximum with single element- 0.10%; exemption for 4956- total- 0.10% and 0.03%, respectively.

7.3 Filler metal selection

7.3.1 General welding considerations

Titanium is a reactive metal that is sensitive to embrittlement by oxygen, nitrogen and hydrogen, at temperatures above 500° F (260° C). Consequently, the metal must be protected from atmospheric contamination. This can be provided by shielding the metal with high purity inert gas in air or in a chamber, and by a vacuum of at least 10^{-4} torr. That's why titanium and titanium alloys can be welded by the gas-tungsten-arc, gas-metal-arc, plasma-arc and electron beam welding processes. During arc welding, the titanium should be shielded from the atmosphere until it has cooled bellow 800° F (430°C). Adequate protection by auxiliary inert gas shielding can be provided when welding in air, but ventilation and exhaust at the arc should be carried out in such a manner that the protective atmosphere (arc shielding and backing) is not impaired. For critical applications, the welding should be done in a gas tight chamber thoroughly purged of air and filled with high purity gas.

7.3.2 Weld porosity

Porosity in titanium welds has been a persistent problem. The most porosity is caused by gas bubbles formed during solidification of the weld. The welding procedures and techniques, as well as filler wire, can affect the porosity. If the content of gases (as impurities) in solution in the metal stays within established limits for filler wire, it is not likely a cause for porosity in the weldment.

Cleanliness of the joint area as well as filler metal is a major factor in producing porosity-free welds. The number of foreign materials, specifically on the surface of the weld wire, that can cause porosity is endless. For example, grinded particles embedded in the metal, fingerprints, dirty rags, lint-bearing gloves, burrs, surface oxides, rust (iron oxide) will cause not only porosity, but weld embrittlement.

Surface and sub-surface inclusions worked into filler wire during drawing are a major cause of porosity because of lubricants and tiny particles of metal entrapped during drawing. The only way to produce weld wire free from foreign materials on its surface is strict control of the drawing processes, and cleaning the wire after drawing.

7.3.3 Corrosion resistance of welds

In commercially pure titanium, corrosion of properly made weldments has not been found to be essentially different from that of unwelded material. The iron content and, possibly, nickel or chromium exceeding 0.005% in the weld metal, can produce a selective accelerated corrosion of the weld when in highly oxidizing acid solutions. If filler metal composition is controlled to be comparable to base metal of titanium alloys, there is no differential corrosion of weld and base metal.

Corrosion rates in the alpha and alpha-beta alloys could be definitely changed by minor compositional substitution of one element for another.

The possibility of elemental loss in the arc, plus the change of microstructure in the heat- affected zone, can create corrosion differentials between unaffected base metal and heat- affected zone and weld metal. The addition of residual stress needs to be taken into stress corrosion cracking considerations. Close control of the filler metal chemistry, in combination with final annealing or stress relief of weldment and properly controlled weld procedure is important to minimize the corrosion related failure in titanium and titanium alloy weldments.

7.3.4 Selection of filler metal

Titanium can be successfully fusion welded not only to titanium based materials, but even to zirconium, tantalum, niobium (columbium), and vanadium, although the weld metal will be stronger and less ductile than the parent metals. Titanium should not be fusion welded to other commonly welded metals such as copper, iron, nickel, and aluminum,as brittle titanium intermetallic alloys are formed which produce extremely brittle welds.

The following are some typical applications for the most widely used filler metals that Lancaster Alloys Company has offer to its customers.

4951

This alloy, (and other classes of AWS) referred to as commercially pure (C.P), is the most widely used titanium alloy for industrial applications because of its good balance of strength, formability and weldability. Typical uses are in sea water and brackish water heat exchangers, chemical process heat exchangers, pressure vessels and piping systems, pulp bleaching systems, air pollution control scrubbers, electrochemical and chemical storage tanks and in the aerospace and aircraft industries.

In welding Commercially Pure titanium, it is customary to use filler metal one or two grades lower than the parent metal. For example, on 80,000 PSI strength of parent metal use 65,000 PSI filler metal. Dilution and a small pickup of interstitial contaminants will strengthen the weld. The soft filler is relatively pure and will tolerate more contaminants before its toughness and ductility are seriously impaired. AMS specification 4951 encompasses all the commercially pure welding wires.

The Ti-6Al-4V alloy usually is welded with 4954 filler. However, commercially pure titanium filler of the 80,000 PSI grade gives a distinct improvement in ductility, but also a loss in strength that will depend on weld dilution for example, a 3/16-in thick V-groove butt joint in an aerospace tank gave 85% efficiency.

4954

This alloy is probably the most widely used titanium alloy. Its high strength, ability to be heat treated, weldability, excellent fatigue strength and hardness make this alloy excellent for industrial fans, pressure vessels, aircraft components, compressor blades, automotive and jet engine parts.

4956

This filler metal is a slightly purer version of 4954 with ELI (extra low interstitial) content, which in practice, refers primarily to the oxygen content. With special processing, this alloy can develop high fracture toughness. The main uses are in airframe components, surgical implants, and cryogenic vessels.

7.3.5 Storage and use of Titanium filler metal

The use of extremely high quality filler metal is vital for producing good titanium welds, especially for aerospace and aircraft repair industries, as well as for other critical applications. The filler metal must be free of metallic and non-metallic impurities, with an extremely clean,smooth surface free of moisture, dirt, lubricants or other contaminants. It takes some additional care during storage and handling of the filler metal to prevent contamination that would cause poor welds.

Lancaster Alloys Company guarantees the highest quality titanium filler metal supplied to its customers including uniformity, freedom from any surface defects and contaminant. Lancaster Alloys company supplies its products in a wide variety of re-sealable packing bags covered by requirements of AMS, AWS and other commercial practices, including vapor barrier envelopes with desiccant, to assure the filler metal containment free as long as it kept in the original packaging.

7.4 Properties and performance of weldments.

Typical all weld-metal tensile and charpy impact properties of some common alloys are shown in table 7.3 and 7.4. Another common method of comparing the ductility of welds in sheet materials of various alloys is the bend test. The minimum bend radius for titanium welds is defined as the minimum radius around which a sample of titanium containing a weld can be bent without developing a crack, divided by the thickness of the material. Normally, the sample is bent until the permanent deformation equals 105° with the weld transverse to the bend axis. The actual bend is often much greater then 105° because of the "springback" encountered in titanium alloys. Typical minimum bend radiuses are given in table 7.5

7.5 Health and safety precautions

The possibility of spontaneous ignition of titanium or its alloys during welding is extremely remote. Like magnesium or aluminum the occurrence of fires is usually encountered where accumulation of grinding dust or machining chips exists. Even in extremely high surface-to-volume ratios, accumulation of clean titanium particles do not ignite at any temperature below incipient fusion temperature in an ambient atmosphere.

However, spontaneous ignition of fine grinding dust or lathe chips, saturated with oil under hot humid conditions have been reported. Water or water-based coolants should be used for all machining operations. Carbon dioxide is also a satisfactory agent. Large accumulations of chips, turnings, or other metal powders should be removed and stored in enclosed metal containers. Dry grinding should be done in a manner that will allow proper heat dissipation, with the powder similarly stored in enclosed containers.

Dry compounds extinguishing agents or dry sand are effective fire extinguishing agents. Ordinary extinguishing agents such as water, carbon tetrachloride, and carbon dioxide foam are ineffective in extinguishing titanium fires.

Use of titanium in aqueous systems at elevated temperatures over pressurized with oxygen can result a localized combustion where fresh titanium surfaces are exposed to the media by localized scoring of fractures. The temperature attained, oxygen overpressure, oxygen content of atmosphere, are major variables in producing spontaneous combustion. Bulk, shape, surface-to-volume ratio, surface conditions of fresh metal exposed to media (smooth, rough, or jagged) are variables less amenable to a direct evaluation.

Titanium can react in a pyrophoric manner with red-fuming nitric acid if a proper balance is not maintained between the water and nitrogen dioxide content. Titanium will react pyrophorically with anhydrous chlorine, but as little as 0.015% water by weight completely inhibits this reaction. Similar pyrophoric reactiong have been reported with other anhydrous halides.

As with any welding operation, before starting to weld be thoroughly familiar with the contents of *Safety in Welding and Cutting, U.S.A. Standard Z49.1* (latest edition).

TABLE 7.3 TYPICAL ROOM TEMPERATURE MECHANICAL PROPERTIES OF TITANIUM PLATE WELDS

ALLOY	TENSILE STRENGTH 1000 PSI	YIELD STRENGTH 0.2% OFFSET 1000 PSI	ELONGATION %	REDUCTION OF AREA %	IMPACT STRENGTH CHARPY V NOTCH, FT./LB
4951	83	69	24	44	17
4954	148	139	5	10	18
4956	136	124	12	21	30

TABLE 7.4 MECHANICAL PROPERTIES OF TITANIUM AND TITANIUM ALLOY WELD METAL

LAC STOCK #	AWS FILLER METAL CLASSIFICATION	ALL-WELD METAL TENSILE TEST				WELD METAL CHARPY V-NOTCH IMPACT TEST Ft.-Lbs			ROCKWELL HARDNESS			WELD METAL COMPOSITION (1)		
		UTS ksi	0.2% YS ksi	El in 1" %	RA %	R.T.	32F	-80F	BM	HAZ	WELD	H ppm	O %	Fe %
									(Rockwell A)					
4951	ERTi-1 (2)	60.0	47.0	41.3	76.6	162.0	159.0	164.8	46.3	46.9	46.3	20	0.09	< 0.06
4951	ERTi -2(2)	57.5	43.0	41.8	76.2	40.0	42.0	35.0	42.9	44.9	44.3	60	0.07	< 0.006
4951	ERTi-3	81.5	64.0	23.8	47.8	15.5	14.0	12.5	53.4	54.8	55.7	50	0.16	0.13
4951	ERTI-4	88.0	69.0	21.5	46.2	27.0	22.0	24.5	54.9	56.5	57.3	40	0.20	0.28
									(Rockwell C)					
4954	ERTi-6Al-4V	146.0	121.5	12.0	38.7	17.0	18.0	11.3	32.2	35.6	35.6	35	0.13	0.18
4956	ERTi-6Al-4V-1	139.0	120.0	10.0	24.6	18.0	15.5	13.3	29.8	34.3	33.8	45	0.10	< 0.6

1. The composition for all the weld metals includes carbon in the range of 0.02 to 0.04% and nitrogen in the range of 0.005 to 0.012%. The nominal alloy contentin percent are shown in the AWS classification designation.

2. Difference in toughness between ERTi-1 and ERTi-2 is due to hydrogen content. Other titanium alloys are not sensitive to hydrogen within normal specification limits.

TABLE 7.5
Typical minimum bend radius of welds in various alloys as welded

ALLOY	MINIMUM BEND RADIUS (XT)
4951	3-5
4954	8-12
4956	8-10