Welding Specification for Weldments used within the Advanced LIGO Vacuum System

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1 Scope

This specification controls the process of welding aluminum and stainless steel for parts (weldments) intended for service inside the Ultra-High Vacuum (UHV) for the Advanced LIGO project. Unless otherwise directed all weldments should be fabricated in compliance with this specification.

This specification does not cover welding elements of the vacuum envelope itself, but rather parts which are placed within the vacuum envelope.

2 Certification and End Item Data Package

The fabricator must provide the following certification or documentation:

1. To approve seamed tubing, if applicable, (see section 3.2) submit an inspection report confirmation on qualification of as received stainless steel seamed tubing, prior to starting production. As noted in section 3.2 this should include 100% inspection of flash removal if required (see section 3.2)
2. To approve welder and weld samples submit a Procedure Qualification Record (PQR) on welder and weld samples (see section 8), prior to starting production.
3. To approve method used for production weldments (see section 7) submit a Certified Welding Procedure Specification (WPS) on production weldments, this can be submitted with the PQR, prior to starting production.
4. To approve production weldments (see section 10) submit prior to final machining:
    a. An inspection report confirming the qualification of the production weldments to Class C, as per section 7.1 and 7.2 should be submitted.
    b. Certification that the requirements of the specification (WPS) have been met
    c. Material certifications for all materials (filler rod and base material) which comprise the weldment.
5. To approve final machining (see section 12) submit dimensional inspection report on final machining, at the time of delivery.

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3 Acceptable Materials

3.1 Base Material

Only the material alloys defined in the associated drawings are acceptable. No substitutions shall be made without prior written consent from the LIGO Contracting Officer. All material should be selected and transported according to our requirements, for example for stainless steel tubing follow section 3.2.5 and 3.2.6 below. A similar specification should be followed and agreed with the LIGO Contractual officer for Aluminum or other materials.

No parts, including seamed tubing, shall be ground or cut off with grinding tools.

3.2 Stainless steel tubing

Stainless steel seamed tubing, although an option, should not be the first choice if seamless tubing is available.

If seamed tubing is utilized, the weld seam and any weld flash must meet the requirements listed below. If the weld flash does not meet the requirements, then it must be removed. Details, including fixtures required to remove this flash and a method for removal should be included in this quote. The flash removal process must be inspected 100% visually and certified by the vendor and approved by LIGO.

With prior approval from a LIGO Contract Officer stainless steel seamed tubing can be used under the following conditions: -

1. Take a cross-sectional sample of the tube weld for every ~20 ft. of every continuous weld run (batch) and verify that the weld is Class B in Table V of Mil-Std-2219. The verification requires
   (a) visual inspection for weld discontinuities, porosity and inclusions,
   (b) x-ray for complete penetration and fusion and
   (c) microstructural examination of weld samples cross-sections (refer to section 8.3 for further details)
2. Supply inspection report for approval to the LIGO contract officer confirming that the as-received seamed welds conform to class B prior to continuing.
3. Prior to welding all seamed tubing (inside and out) should be electropolished to ASTM B-912. (Scotch-Brite(TM) or similar products are prohibited.)
4. As per section 11 of ASTM A554-10 the finished tubes shall be free of injurious defects and have a workmanlike finish. Surface imperfections such as handling marks, shallow pits and scratches shall not be considered as serious defects provided they are within 10% of the specified wall or 0.002 inch (0.05mm), whichever is greater.
5. Each tube should be individually wrapped and protected from scratches, pitting and digs during transport and handling. Each tube should be inspected and handled appropriately.

If stainless steel seamless tubing is available items 3.2.4 and 3.2.5 still apply.

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3.3 Filler Rod

The following Table shows the filler rod that should be used with various alloys:

Table 1: Welding Filler Rod

Material	Alloy	Filler
Stainless Steel	304	308, 308L
	304L	308L
	316	316, 316L
	316L	316L
	321	347
	347	347
Aluminum	6061	4043 (Linde H.Q.)

4 Cleaning and Preparation

1. Pre weld machining must be carefully controlled. All machines & fixtures are to be cleaned to avoid cross contamination before any machining takes place.
2. Weld preps must be machined and under no circumstances should weld preps be ground (due to risk of cross contamination). If machining is impractical use new carbide burrs.
3. Welds are not to be ground (due to risk of cross contamination); If welds need to be cleaned up, they must be cut.
4. Water soluble (not just water miscible) cutting fluid (lubrication) is to be used for all machining operations, such as weld prep, weld clean up or weld repair. The use of cutting fluids or lubricants, which contain sulfur, chlorine or silicone compounds is prohibited.
5. The contractor must define suitable methods for initial cleaning (oxide cleaning, degreasing, and dirt/soil removal), interpass cleaning and post-weld cleaning. An etchant (acid or basic) should be used, similar to the solutions defined in Annex G, "Solutions for Macroetching Aluminum Weldments" of AWS D1.2/D1.2M:2003 Structural Welding Code -- Aluminum. The contractor must define degreasing, deoxidizing, interpass and post-weld cleaning methods in the Weld Process Specification (WPS) and Process Qualification Record (PQR) which must be approved by LIGO before welding.
6. Prior to welding, clean the filler rod using lint- free tissue and analytical Reagent Grade isopropyl alcohol.

5 Handling and Storage

1. Latex gloves are to be worn for handling room temperature cleaned parts – parts to be welded or tools and fixtures.
2. If hot parts must be manipulated, clean tools are preferred rather than gloved hands. If hot parts or tools/fixtures need to be handled, then clean welding gloves should be used. A new pair of gloves should be dedicated to the LIGO work.

3. Tools and fixtures, which may contain cleaned parts in assembly or transport, are to be kept clean from oxides, oils, fingerprints, etc.
4. Parts are to be stored in a clean dry area until welding commences. Parts should not be stored for a long periods after cleaning, welding should commence as soon as possible and definitely within one work shift after parts are chemically cleaned.
5. Store filler metal in bonded storage and in a manner such that it is protected from oil and other contaminates. The package seal must not be broken until just prior to welding. Rod from an opened package must be kept in a cabinet or other area within the clean welding area.
6. Weldments and cleaned parts, tools and fixtures are to be covered between welding operations. The material used for covering can be UHV quality aluminum foil or clean stainless steel covers/boxes. If the parts are at room temperature, then cleanroom grade sheeting materials (low lint, low shedding), such as DuPont™ Tyvek®.
7. Welding should be performed in a clean, particulate and humidity (50% maximum relative) controlled environment.
8. Completed weldments are to be double wrapped and stored in a clean, controlled area prior to shipment. The inner wrap must be UHV quality aluminum foil. The outer wrapping, or bag, should be Ameristat® or similar class 100 cleanroom grade packaging material. No tape (adhesive) should be used to attach or close the inner wrapping. Heat sealing can not be performed with the part in the wrapping/bag.

6 Welding

6.1 General Requirements

1. All welding must take place in a clean, particulate and humidity (50% maximum relative) controlled environment. Welders must adhere to the contamination control practices described in these specifications.
2. Thin (less than 0.010 inch thick) stainless steel or beryllium-copper parts (e.g.: RF shields) may be spot welded using a resistance welding process. All other welding shall be by the tungsten inert gas (TIG) fusion process, unless specifically approved. Welding electrodes shall be 2 percent thoriated tungsten.
3. Prior to welding, all parts must be cleaned according to these specifications. Jigs, fixtures, chill rings (if used), and welding bench which contact the clean parts must also be cleaned according to these specifications.
4. The filler rod and must be kept clean at all times.
5. Leather welders gloves are of course used by the welder during welding. However, Latex gloves must be worn when clean “cold” parts are handled. If the gloves come in contact with anything other than clean surfaces, they must be replaced with new ones.

6. Appropriate brushes and high quality hand scrapers can be used for cleaning oxides off welds. Brushes and scrapers shall be degreased before use and kept free from oxides. Brass brushes and Scotch-Brite pads are prohibited.
7. Preheating is discouraged. If preheating the parts is necessary we would prefer that neither Propane nor Oxy-Acetylene be used as this will cause contamination in the weld. If Oxy-Acetylene is required please get prior written approval from the LIGO contracting officer.
8. All welds must be full penetration and full fusion welds. No trapped volumes are permitted. Weldments with crevices are considered non-cleanable since these crevices act as traps for cleaning solutions. Inspect the root weld before further passes, if remedial action is required only use clean Carbide burrs. Grinding (with abrasive wheels, cloth, or stones), or use of abrasive cloth or paper, is not permitted.
9. It can be difficult to achieve full penetration with a single-sided weld. Double-sided welds are permissible, as long as sectioning of weld samples indicate weld overlap and no voids (refer to section 7).
10. The welder shall protect material adjacent to the welds to prevent damage. In general final machining and machined details (tapped holes, etc.) are added after welding, but not in all cases. Care should be taken not to blemish or damage the part while welding.

6.2 Stainless Steel

1. Careful control of the parts shall be imposed so that carbon steel contamination is prohibited. In the event of carbon steel contamination, skim with a carbide tool to remove any residual contaminant
2. Back purge stainless steel welds in all cases. Maintain gas flow until the metal cools to prevent oxidation. Use Argon or Nitrogen Commercial Grade 99.98 percent or mixture of these for cover and purge gas.
3. Stainless steel parts should be welded within 24 hours after they are chemically cleaned.

6.3 Aluminum

1. For welding thick parts, the suggested procedure is to use D.C. straight polarity with Atomic Grade Helium as the cover gas. This method does not require pre-heating of the parts.
2. For parts of 1/8 inch thickness or less, use A.C. polarity with Argon cover gas.
3. Aluminum parts should be welded within 24 hours after they are chemically cleaned.

7 Weld Quality Requirements and Inspection

1. All welds on production weldments must meet requirements for Class C in table V of Mil-Std-2219 verified by visual inspection. Note that dye penetrant may only be used on a practice weld configuration and never on a final weldment.
2. All Class C welds shall be 100% visually inspected for cracks and weld discontinuities, porosity and inclusions. This should be aided by a magnifying lens of [5X] or [10X] power

wherever required to discern indications or defects otherwise not clear. Measure size and contour of welds with suitable gages. Clean welds per section 6.1.6 for inspection.

3. Submit a copy of certified Welding Procedure Specification (WPS) for approval, describing how the welding will be carried out on the production weldments. This should be submitted for approval with the LIGO Contracting Officer's Technical Representative along with the Procedure Qualification Record (PQR) referenced below in section 8. Once all of this is approved work can start on the production weldments.

8 Weld & Welder Qualification

1. All welders should be certified to American Welding Society (AWS).
2. Qualify the weld preparation, cleaning process, welders and welds by creating sample welds representative of each type of weld in the final weldment. It is important to design the samples to mimic the weld access and heat path that will be present in the weldment.
3. The sample weldments must meet requirements for Class B in Table V of Mil-Std-2219 as verified by: -

   (a) visual inspection for weld discontinuities, porosity and inclusions,

   (b) x-ray for complete penetration and fusion and

   (c) Cross-sections of weld samples, for microstructural examination, should be prepared by cutting in an orientation perpendicular to the direction of the weld bead so that the size and shape of the weld and the heat-affected zone (HAZ) can be observed. Each weld sample should be sectioned and polished by standard metallographic procedures (for example, mounted in an epoxy, polished with a 5 micron diamond paste and then be etched with Keller's reagent). The section samples should be examined and photo-micrographed at approximately 15x. Any weld discontinuities should be further examined and photographed at 50x to 200x magnification.
4. Submit a Procedure Qualification Record (PQR) and the sample welds to LIGO. The PQR should include all evidence of compliance with the Class B qualification including photographic evidence of samples and documentation on the weld preparation, parts cleaning process, welding process, and preparation and qualification of the welder(s). All welds, and associated photographs and micrographs, must be labeled and presented in the form of a test or inspection report.
5. Prior to a new welder producing a LIGO weldment. They must be qualified for the welding process(es) and weld joints used on the LIGO weldment. Copies of the welder's certification for the LIGO weldment, in the form of a Performance Qualification Record on the weld samples outlined above, must be kept on file and available for LIGO inspection.

6. Vendors should qualify the welding procedures, welders and welder operators in accordance with Section 3 of AWS D1.2/D1.2M:2003 and Section 4 of AWS D1.1/D1.1M:2008.

9 Weld Repair

1. If a weld has surface blemishes, high porosity, hairline cracks or incomplete penetration then the weld should be re-flowed and then re-inspected.

10 Weld approval

Once the production weldments have been satisfactorily completed and prior to completing the remaining steps in this specification the contractor must have the welds accepted and approved by the LIGO Contracting Officer's Technical Representative. The approval step should include a visit by the LIGO Contracting Officer's Technical Representative. At the time of the visit the following items should be delivered to the LIGO Contracting Officer's Technical Representative: -

1. An inspection report confirming the qualification of the production weldments to Class C, as per section 7 (points one and two) should be submitted.
2. Certification that the requirements of the specification (WPS) have been met
3. Material certifications for all materials (filler rod and base material) which comprise the weldment.

The approval step can also be done without a visit and via e-mail, if approved by the LIGO Contracting Officer's Technical Representative and only if photographs of all of the welds are added to the report.

Once approval is obtained the contractor should continue with the following steps.

11 Post-Weld Stress Relief

After welding and approval all weldments must go through a stress relief heat treatment prior to any final machining.

12 Final Machining

Any features on the weldment which are dimensionally critical are machined after welding and post-welding stress relief. These features will be called out in the associated drawing package. Any dimensional inspection required will be called out in the associated RFQ / RFP / SOW.

13 Post-weld Cleaning

The weldment must be cleaned as per the following specification. (Scotch-Brite(TM) or similar products are prohibited.)

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13.1 Aluminum

1. First the parts or assemblies are de-burred, and cleaned, removing all possible machining and weld process residue. Use only clean Carbide burrs. Grinding (with abrasive wheels, cloth, or stones), or use of abrasive cloth or paper, is not permitted.
2. The part(s) are then washed with Alkaline Soak Cleaner and inspected for cleanliness using the water break test.
3. The weldment is then to be chemically cleaned / etched by acid and / or caustic process. At this step in the process Scotch-Brite ™ or similar mildly abrasive pads can be used. This is the only step where Scotch-Brite ™ is permitted.
4. The acid formulation, time and temperature should be chosen to achieve slight chemical etching (<0.0005 inch).
5. Under no circumstances should the weldments be anodized.
6. The weldment is then thoroughly rinsed with clean water. After rinsing, a full visual inspection is performed, to assure a satisfactory surface finish has been achieved uniformly, over the entire weldment
7. The parts are then dried, re-inspected and un-racked.
8. In order to remove any weld stain, left behind after this process, use acetone and fine Stainless Steel wire brushing, the brush bristles should be .004”/.006” in diameter.
9. No LIGO weldments intended for use within the vacuum system shall be anodized.

13.2 Stainless Steel

1. First the parts or assemblies are de-burred, and cleaned, removing all possible machining and weld process residue. Use only clean Carbide burrs. Grinding (with abrasive wheels, cloth, or stones), or use of abrasive cloth or paper, is not permitted.
2. The part(s) are then cleaned and inspected for cleanliness using the water break test. The water-break test is performed by withdrawing the surface to be tested, in a vertical position, from a container overflowing with water, refer to ASTM A380-06 and in particular ASTM F22 for further information on this step.
3. Stainless steel parts are to be pickled and passivated at room temperature, with special attention paid to sufficiently agitate the solution or flush the inside of the box section used in the particular design. The pickling and passivation process formulation, time and temperature should be chosen to achieve slight chemical etching (<0.0005 inch).
4. The weldment is then thoroughly rinsed with clean water. After rinsing, a full visual inspection is performed, to assure a satisfactory surface finish has been achieved uniformly, over the entire weldment
5. The parts are then dried, re-inspected and if appropriotte un-racked.

14 Delivery and receipt

After post-weld cleaning (section 13) re-inspect all welds. Refer to RFQ / RFP / SOW for information on acceptance and deliver criteria.

15 Subsequent Processing Steps

Any subsequent processing steps are not performed by the manufacturing/welding contractor, but listed here for completeness.

15.1 Ultra-High Vacuum (UHV) Cleaning & Baking

LIGO will inspect, clean and bake in preparation for Ultra-High Vacuum (UHV) service in accordance with E960022.

16 References

1. Mil-Std-2219 — Fusion Welding for Aerospace Applications
2. AWS D1.2/D1.2M:2003 — Structural Welding Code - Aluminum
3. AWS D1.1/D1.1M:2008 — Structural Welding Code - Steel
4. ASTM E-165 — Standard Test Method for Liquid Penetrant Examination
5. ASTM B-912 — Standard Specification for Passivation of Stainless Steels Using Electropolishing
6. LIGO-E960022-v2 — LIGO Vacuum Compatibility, Cleaning Methods and Qualification Procedures
7. ASTM A380 - 06 — Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
8. ASTM F22 — Test Method for Hydrophobic Surface Films by the Water-Break Test

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17 Supply Sources

Item	Description	Supplier
Ameristat®	Clean room sheeting Class 100 stratogrey, single wound, rollstock	Bay Stat 3575 Haven Avenue Menlo Park, CA 94025-1009 (650)364-3205 Voice (650)363-8079 Fax
UHV Aluminum Foil	Part # ASTM B 479 0.015” x 24” x 500’ and 0.015” x 48” x 500’ UHV Certified Aluminum Foil	All Foil 4597 Van Epps Road Brooklyn Heights, Ohio 44131 (216)661-0211 Voice (216)398-4161 Fax