U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Manufacturing Process of Premium Quality Titanium Alloy Rotating Engine Components

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Initiated by: ANE-110

Change:

1. PURPOSE. This advisory circular (AC) provides guidance and information for compliance with the provisions under Title 14 under the Code of Federal Regulations, part 33 (14 CFR 33) pertaining to the materials suitability and durability requirements, § 33.15, as applicable to the manufacture of titanium alloy high energy rotating parts of aircraft engines. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. It is issued to provide an acceptable means, but not the only means, of compliance with § 33.15. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

2. RELATED READING MATERIAL.

Title 14 of the Code of Federal Regulations, part 33

AC 33.2B: Aircraft Engine Type Certification Handbook

AC 33.3: Turbine and Compressor Rotor Type Certification Substantiation Procedures

AC 33.4: Design Consideration Concerning the use of Titanium in Aircraft Turbine Engines.

3. DEFINITIONS.

Bar - Converted material having a cross section less than or equal to 16 square inches (103 cm2), and a width less than five times the thickness.

Billet - Converted material having a constant round cross section greater than 16 square inches (103 cm2).

Bottom Charge - The material placed in the VAR crucible to protect the crucible during arc initiation.

CHM - The Cold Hearth Melting process (i.e., EBM or PAM) where the metal is melted and then maintained molten as it traverses a specified hearth distance, allowing inclusion elimination either by dissolution in the molten pool, or by density separation into the skull.

EBM - The Electron Beam cold hearth Melting process that may be used in conjunction with VAR to meet the primary melting recommendations of this document.

Electrode - The consumable feedstock form for VAR or the product of the primary EBM or PAM that becomes the consumable electrode for the final VAR.

Electrode Holder - The material that is joined to the top of the electrode, or the electrode stub, to hold the electrode and to provide the connection between the electrode and the VAR furnace electrical equipment.

Electrode Marker - A titanium rod or other shape affixed to the consumable electrode, electrode stub, or electrode holder for VAR. The purpose of this marker is to provide visual reference for the electrode height position.

Electrode Stub - The material that may be joined to the top of the electrode to provide the connection between the electrode and the electrode holder.

Established Procedure - A procedure that is subject to purchaser approval and is contained in a controlled document. It includes limits, controls, and applicable standards.

Heat/Cast - The ingot and ingot product produced from the final VAR of a single consumable electrode (in the case of the multiple VAR process) or the ingot and ingot product produced from one VAR of a single EBM or PAM consumable electrode.

HAD - High Aluminum Defect. An aluminum-rich alpha stabilized region containing an abnormally large amount of aluminum which may extend across a large number of beta grains (also known as Type II defects).

HDI - High Density Inclusion. A region with a high concentration of refractory elements, usually tungsten, molybdenum, or columbium, having a higher density than the matrix.

HID - High Interstitial Defect. An interstitially stabilized alpha phase region of substantially higher hardness than surrounding material, arising from very high local nitrogen, oxygen, or carbon concentrations which increase the beta transus and produce the high hardness, often brittle, alpha phase. Also commonly called a Type I defect, low-density inclusion (LDI), or a hard alpha. Often associated with voids and cracks.

Hot Topping - Adjustments of process parameters during the latter stages of a melt process to minimize pipe, shrinkage porosity, and segregation.

Inclusions - Particles of impurities or foreign materials that are present or introduced during any stage of alloy processing. Examples include, but are not necessarily limited to HAD's, HDI's, and HID's.

JETQC - The Jet Engine Titanium Quality Committee formed under the auspices of the FAA, with membership including all the US and European Aircraft Engine Producers, for the purpose of rapid dissemination of titanium alloy melt related defect issues and data.

Macroetch - Chemical treatment of a metal surface to accentuate structural details and anomalies for visual observation.

Non-Consumable Arc Melting - A method of consolidating and melting titanium and its alloys using arc energy from an electrode designed to carry the melting current without being consumed. It may be a continuous or batch process and may, or may not, fully melt the input materials. It should not be considered a primary or a complete melt step, therefore the term "consolidation melt" is used.

PAM - The Plasma Arc cold hearth Melting process that may be used in conjunction with VAR to meet the primary melting recommendations of this document.

Plates - Material converted by hot working and delivered into straight lengths of constant rectangular cross section, having a width greater than five times the thickness.

Premium Quality - Material produced under special process and quality control requirements and used primarily for critical rotating parts.

PAH - A Production Approval Holder is the holder of a production certificate (PC), approved production inspection system (APIS), parts manufacturing approval (PMA), or technical standard order authorization (TSOA) who controls the design and quality of a product or part thereof.

Segregation - Volumes in the alloy product containing an abnormal content of alloying elements, which may also appear as zones of abnormal quantities of either the alpha or beta phases of titanium.

Skull - The solidified metal in the hearth of the CHM process. During CHM, the skull is the solidified metal adjacent to the hearth, not including the molten pool.

Sonic Shape - The sonic shape is the intermediate machined rectilinear or curvilinear forging shape at which the forging may be ultrasonically inspected. Shape and envelope relative to the finished component should be controlled.

Sponge/Granules - The titanium or zirconium metal which is extracted or produced from the natural minerals containing TiO_2 or ZrO_2, respectively.

Sponge Batch - The metal product of a single titanium or zirconium sponge reactor process.

Sponge Lot - The mixed or blended sponge product containing portions of one or more sponge batches.

Supplier - Any person who furnishes materials, parts or related services (at any tier) to the manufacturer of a product or part.

Swarf/Turnings - Material produced as a result of machining titanium alloy disc or billet material.

VAR - The Vacuum Arc Remelting process used to produce ingots meeting the recommendations of this document, either as a final melt subsequent to CHM, or as multiple VAR product.

Void (Clean) - A cavity constituting a structural discontinuity related to solidification and/or conversion conditions of the ingot.

NOTE: Other definitions are consistent with those found in Terminology for Titanium Microstructures-AEROSPACE STANDARDS (AS) 1814.

4. BACKGROUND.

a. The manufacture of titanium alloy forged rotating components can introduce component life limiting anomalies at all stages of material processing, from sponge processing, through melting, billet conversion, component forging, and inspection of the finished component. Since optimum capability to detect these anomalies may vary according to their type and source in the manufacturing process, the manufacturing process should be established so that, at each stage, appropriate controls and inspections are in place to minimize the occurrence of and to maximize detection of, such anomalies based on the best available technologies.

b. The conventional melting process for titanium alloys has been the VAR process. Triple VAR has been recommended as the current standard for critical rotating component use. Improvements in VAR technology have resulted in a significant reduction in the occurrence of melt related defects since the mid 1980's. The newer CHM technology virtually eliminates the risk of having HDI's survive through the melting cycle. Current cold hearth melting technology involves a CHM cycle either PAM or EBM followed by a final VAR cycle.

c. Advisory Circulars 21-1B, 21-6A, 21-9A, 21-27, and 21.303-1A, provide a means to obtain and maintain production approvals; however, these documents do not fully cover the manufacturing processes used in the manufacture of premium quality titanium alloy forged rotating components for type certificated turbine engines. This AC, therefore, provides supplemental guidance for the establishment of manufacturing processes, in-process material and component inspections, and finished component inspections, for manufacture of premium quality titanium alloy forged rotating components, such as disks, spacers, hubs, shafts, spools and impellers, but not blades.

5. GENERAL.

a. Part 21 of the Federal Aviation Regulations requires that PAH’s must establish and maintain, as appropriate, manufacturing and process control and inspection systems which ensure that products used in type certificated engines conform to FAA-approved design data.

b. PAH’s should also assure, through appropriate agreements with their suppliers, that effective process control documents are developed, identifying significant process control points, parameters and control limits. Measurement of these process control parameters should be made at the control points; consideration should be given to use of statistical process control.

c. A method of approval of changes to the process control documents, as well as the means of handling exceedences of any defined control limits, should be established between the PAH and the suppliers. Process phases where inclusions could be formed or entrapped, or segregation generated, or porosity induced should be particularly detailed for methods of control, monitoring and detection.

d. Records of material and component inspection and disposition results, property test results, traceability of forged components to billet location, material heat, and to raw material ingredient lots making up the heat, as well as other records indicated in this AC, should be maintained for the appropriate period of time and be available for review as needed.

e. New melters and raw material suppliers and their processes should be adequately qualified.

f. A system of handling deviations and non-conformances with respect to product or part limits should be established between the PAH and the suppliers.

6. RAW MATERIALS & STORAGE.

a. Raw Material Requirements.

(1) Raw Material Controls. Melt suppliers should maintain effective specifications and procedures for procurement, storage, and processing of charge materials for VAR, PAM, or EBM. For procured raw materials, the raw material supplier should inspect its raw material on a sampling plan sufficient to assure compliance with the melt supplier raw material procurement specifications. The melt supplier should inspect raw material sufficient to verify conformance to its procurement specifications.

(a) Charge Composition. The charge materials should be composed of only approved raw materials, such as sponge, master alloys, elemental additions, titanium oxide, and recycle material (where permitted). The weight percent, chemical composition, and batch or lot number of each type of raw material used in the charge materials should be recorded and maintained for each heat of material.

(b) Titanium Sponge. Titanium sponge suppliers should have established procedures and limits for the production of high purity premium quality titanium sponge. A representative sample of each sponge lot should be visually inspected to established standards to ensure its freedom from burned particles capable of causing HID's, and from other contaminants. Sponge particles removed during this inspection should be
evaluated to determine if the entire sponge lot should be subject to disqualification. Specific acceptance standards, including chemical analysis of suspect sponge particles, should be established by the titanium sponge supplier. Sponge batches and/or lots which have been

involved in a fire at any stage of their processing should not be considered for premium quality rotor application.

(c) Zirconium Sponge. Zirconium sponge suppliers should have established procedures and limits for the production of high purity zirconium sponge. Each zirconium sponge lot should have a representative sample visually inspected to established standards to identify and remove particles suspected of containing either burned sponge or other contaminants considered to cause HID's. Suspect particles from this inspection should be removed and evaluated to determine if the entire sponge lot should be subject to disqualification. Specific acceptance standards, including chemical analysis of suspect sponge particles, should be established by the zirconium sponge supplier. Any zirconium sponge batch and/or lot which has been involved in a fire after inspection should not be considered for premium quality rotor application.

(d) Master Alloys. Master alloy suppliers should have established procedures and limits for the production of high purity master alloy. Master alloys should be inspected to established standards to identify and remove detrimental foreign material, oxides, nitrides, and other contaminants considered to cause HID's or other deleterious inclusions.

(e) Elemental Additions. Elemental additions should be processed to preclude contaminants considered to cause HID's or other deleterious inclusions.

(f) Titanium Oxide. Oxides of titanium used as raw material charge should be in powder form and be processed to preclude the presence of detrimental foreign material.

(g) Recycle Material. All recycle materials should be cleaned and be free from contamination. The following limitations should be considered when recycling previously melted alloy:

1. Multiple VAR Processed Material. In general, only turnings should be permitted to be directly recycled in multiple VAR processed premium quality titanium alloy. When used as recycle material, turnings should be segregated as to alloy, crushed and cleaned, and should be 100 percent radiographically inspected for particles considered to cause HDI's and the particles removed. Bulk weldables should be prohibited for use in Multiple VAR processed material, except when previously melted (consolidated) by an approved CHM process. The restrictions on use of bulk weldables in such a CHM consolidation melt should follow the limitations set forth in the following paragraph which applies to material which has been PAM or EBM melted as the primary melting operation.

2. CHM Plus VAR. Previously melted materials may be recycled through the primary CHM process provided the material is clean, free of scale and slag. Recycle material should be of the same alloy. Preparation and cleaning procedures should be established for each form of recycle material. Each form of recycle material should be cleaned and inspected to established standards. Radiographic inspection may be considered unnecessary for turnings. Material forms with surface connected internal cavities,
enfoliations, and other features which prevent complete visual inspection, should not be recycled. Recycling of grinding products, dust, and sludge should be prohibited. Recycle of material that has been involved in a fire at any stage of hearth melt charge material preparation should be prohibited.

b. Bottom Charge Materials. If a bottom charge is used for VAR, the composition, form and preparation procedures should be established; sponge should not be used as bottom charge.

c. Raw Material Storage. All virgin raw material, turnings and bottom charges should be stored in covered containers, in a secure area, immediately after inspection to preclude the extraneous addition of foreign or uninspected material.

7. CONSOLIDATION AND MELTING.

a. This section details some of the more significant process parameters, controls and procedures recommended in the areas of input material consolidation and ingot melting for the production of premium quality titanium. These items should be viewed as guidelines which, when incorporated into the suppliers specific method of manufacture, will result in minimizing HDI and HID occurrence, and produce sound ingot with acceptable homogeneity.

b. Consolidation. Fixed blending and consolidation practices should be established by the supplier and approved by the PAH. Proper preparation, blending, and consolidation practices not only minimize HID and HDI introduction sources, but can also assist in the elimination of HID's from sponge type input materials.

(1) Multiple VAR Process. Double or triple VAR processes typically use blended input materials consolidated either by compaction and welding or by consolidation melting.

(a) Blending. Procedures should be established by the supplier for selecting and preparing the input materials with respect to size and shape. Blending practices should be demonstrated that achieve acceptable chemical homogeneity in the final ingot product. Procedures should also be established to preclude excessive deblending during handling and compaction prior to the first melt. Caution and inspection, as required, should be applied to preclude fires from material crushing, handling and blending, and to exclude any material exposed to such a fire.

(b) Compaction. Procedures should be established for compacting the input materials in a form that facilitates the supplier’s consolidation practice. Compact size and shape, and compaction pressure, should be a fixed practice. Caution and inspection, as required, should be applied to assure no local fires are created during compaction, and to exclude any material exposed to such a fire.

(c) Primary Electrode Fabrication.

1. Welding. When a primary electrode is fabricated by welding, all welding should be conducted in an inert gas filled or a vacuum chamber. Tungsten Inert Gas (TIG) or graphite electrode weld processes should not be used for the electrode construction. Welds should be visually inspected at a minimum for atmospheric contamination; contaminated welds should be removed and replaced prior to primary melting. When appropriate, limits and procedures for the chamber weld should be established for the following:

(i) chamber leak-up rate,

(ii) chamber pressure,

(iii) plasma torch gas, and purge,

(iv) metal-inert gas (MIG) weld wire,

(v) electrode cooling prior to venting chamber.

2. Consolidation Melt Fabrication. Some or all of the charge material may be prepared using an established consolidation melt procedure before the primary VAR step. Effective controls and limits for the consolidation process should be maintained for producing material free from contamination known to cause HID's and HDI's. The consolidation melt should be performed in an inert gas filled or a vacuum chamber. For the non-consumable electrode processes, the electrode should be constructed to avoid the introduction of HDI's or other deleterious materials into the melt. Tungsten or graphite electrodes should not be used. When a CHM refining process is used as the consolidation melt, additional practices, procedures and limits should be established as identified in 7.c.(2) (Cold Hearth Melting). The consolidated ingot should be inspected prior to VAR for surface contamination caused by coolant or air leaks. Limits and procedures should be established for the consolidation melt chamber with respect to the following:

(i) chamber leak-up rate,

(ii) chamber pressure, and

(iii) input material feed system.

(d) Electrode Mechanical/Electrical Attachment. When the possibility exists that the electrode attachment material may be consumed during melting, the attachment material should have the same nominal composition and quality level as the electrode; and should be prepared and inspected using established procedures. The attachment should be joined to the electrode using established inert gas in-chamber welding procedures or plunge-arc welding in a vacuum chamber. Limits and procedures for weld chamber leak detection should be established. When appropriate, limits and procedures for the chamber welds should be established for the following:

1. leak-up rate,

2. chamber pressure,

3. plasma torch gas and purge,

4. metal inert gas (MIG) weld wire, and

5. weld cooling prior to venting chamber.

When plunge welding is used, procedures should be established for the following:

1. depth of plunge,

2. voltage and amperage,

3. rundown, and

4. leak-up rate.

When feasible, all welds should be visually inspected to established standards.

(2) CHM Plus VAR Process. EBM or PAM CHM processes typically use blended input materials that are either compacted as small briquettes for particulate feed, or consolidated using either VAR or one of the non-consumable electrode melt processes. Input material requirements for CHM are the same as the multiple VAR process, with the exception that turnings may not require X-ray inspection because the CHM process effectively removes HDI's.

(a) Blending. Procedures should be established by the supplier for selecting and preparing the input materials with respect to size and shape. Blending practices should be demonstrated that achieve acceptable chemical homogeneity in the final ingot product. Procedures should also be established to preclude excessive deblending during handling and compaction prior to the first melt. Caution and inspections, as required, should be applied to preclude fires from material crushing, handling and blending and to exclude any material exposed to such a fire.

(b) Compaction. Procedures should be established for compacting the input materials into a form that facilitates the suppliers consolidation melt or CHM practice. Compact size and shape, and compaction pressure, should be a fixed practice. As a minimum, the sponge, master alloy, elemental additions, titanium dioxide and turnings should be compacted. Caution and inspections, as required, should be applied to assure no local fires are created during compaction, and to exclude any material exposed to such a fire.

(c) Consolidation Melt Prior to CHM. Some or all of the charge material may be prepared using an established consolidation melt procedure before charging the CHM furnace. Effective controls and limits for the consolidation process should be maintained for producing material free from contamination known to cause HID's and HDI's. The consolidation melt should be performed in an inert gas filled or a vacuum chamber. For the non-consumable electrode processes, the electrode should be constructed to avoid the introduction of high density or other deleterious materials into the melt. Tungsten or graphite electrodes should not be used. For the VAR consolidation process, procedures identified in 7.b.(1) (Multiple VAR Process) for input material consolidation and in 7.c.(1) (Multiple VAR Process) for melting should be followed. The consolidated ingot should be visually inspected prior to CHM for surface contamination caused by water or air leaks.

1. Mechanical Attachment. When the possibility exists that the push rod mechanical attachment may be consumed during melting, the push rod should have the same nominal

composition and quality level as the charge material; and should be prepared and inspected using established procedures. If welding is used, the push rod should be joined to the consolidation melt using established inert gas in-chamber welding
procedures or plunge arc welding in a vacuum chamber. Limits and procedures for weld chamber leak
detection should be established. When appropriate, limits and procedures for the mechanical attachment
chamber welds should be established for the following:

(i) leak-up rate,

(ii) chamber pressure,

(iii) plasma torch gas and purge,

(iv) metal-inert-gas (MIG) weld wire, and

(v) procedures for venting chamber.

When plunge welding is used, procedures should be established for the following:

(i) depth of plunge,

(ii) voltage and amperage,

(iii) rundown, and

(iv) leak-up rate.

The weld should be visually inspected to established standards. Since electrical contact of the push rod is not required, mechanical methods of joining the push rod may be employed.

c. Primary Melting. Primary melting may be accomplished by either the VAR of an electrode which has been consolidated as described in 7.b.(1) (Multiple VAR Process), or by the CHM of input materials which have been processed as described in 7.b.(2) (CHM Plus VAR Process).

(1) Multiple VAR Process. The first melt for the multiple VAR process should be conducted using a fixed melt practice established by the supplier and approved by the PAH. A consumable electrode process should be used, which incorporates effective controls and limits shown to minimize the occurrence of HID's and HDI's. Care should be taken to terminate melting before any non-premium material is melted.

(a) Critical Parameters. When using the VAR process to produce primary melt ingot, limits and procedures should be established by the supplier to control the following:

1. bottom charge (initial charge),

2. pressure/leak rate,

3. power levels,

4. melt rate/gap control,

5. arc focusing controls,

6. end of melt control/indicators,

7. crucible cooling,

8. annulus control,

9. interruptions (power, pressure),

10. coolant leaks, and

11. electrode orientation practice.

(b) Multiple Stick Melting - Precautions. Multiple stick melting is an acceptable, but not preferred, practice. When multiple stick melting is used to produce a primary ingot of sufficient size for subsequent melts, care should be taken to assure cooling to appropriate temperatures prior to any furnace opening. Piggy back melting of a second electrode on top of the first ingot should not be allowed. The primary ingots should be removed from the VAR furnace, cleaned, and chamber-weld joined prior to the second VAR step. Multiple stick melting should not be used beyond manufacture of the primary ingot.

(2) Cold Hearth Melting. When the CHM practice is used to produce a primary melt ingot, a fixed melt process should be established at the CHM supplier and approved by the PAH. The heat source used during the CHM melting process should be designed to preclude its being the source of high density or other deleterious materials entering the melt.

(a) Critical Parameters for EBM and PAM. When using either the EBM or PAM CHM method to produce primary melt ingot, limits and procedures should be established by the CHM source to control the following:

1. hearth design and assembly and set up of the associated equipment,

2. method of removing the skull from the hearth, storage of the skull to prevent contamination, provisions for retiring the skull and traceability of the skull back to previous melts,

3. molten pool dimensions during steady state melting,

4. molten pool temperature during steady state melting,

5. chamber leak-up rate,

6. chamber pressure,

7. melting (ingot casting) rate,

8. cooling cycle and atmosphere,

9. melt interruptions,

10. chamber and raw material feed cleaning, and

11. input material feed practice.

(b) Additional Electron Beam Melt Parameter Controls. In addition to the controls listed in 7.c.(2)(a) (Critical Parameters for EBM and PAM), the EBM CHM source should also establish procedures to control the following:

1. electron beam power, deflection pattern, beam diffusion and scanning frequency,

2. duration of beam interruption, and the restart procedure, and

3. condensate control and fall-in.

(c) Additional Plasma Arc Melt Parameter Controls. In addition to the controls listed in 7.c.(2)(a) (Critical Parameters for EBM and PAM), the PAM CHM source should also establish procedures to control the following:

1. torch gas type and flow rate,

2. torch voltage, current, motion pattern, velocity and position,

3. hydrogen, oxygen and moisture control in the chamber and torch gas, and

4. duration of arc interruption, and the restart procedure.

d. Intermediate And Final Melts. The final melt should be by the VAR process following either a primary melt by the VAR or CHM process, or an intermediate VAR melt in the case of a three VAR process.

(1) Multiple VAR or CHM Plus VAR Process. Controls should be applied to the melting process to ensure consistency in the melting parameters and, hence, in the ingot product. It is advisable to restrict furnaces and crucibles used for primary melt from being used for the second and third melt. Cleaning and inspection of crucibles is particularly important for second and final melts, and should be performed to established procedures (reference 7.f.(4), VAR Furnaces).

(a) Weld Joining of Electrodes. Melting through a weld should not be permitted in final melting. Therefore, if two ingots are welded together to form a longer electrode, that material shall be melted twice. Controls on welding should be per paragraph 7.b.(1)(c)1. (Welding).

(b) Electrode Cleaning/Descale/Crown. Prior to remelting, all electrodes should be visually inspected and cleaned. The cleaning method used should thoroughly remove all loose material, foreign material, or any evidence of burnt titanium. In addition, any crown or splatter at the top of the ingot should be removed. Identification and recording of electrode orientation for each melt should be maintained.

(c) Electrode Mechanical/Electrical Attachment. Should be in accordance with 7.b.(1)(d) (Electrode Mechanical/Electrical Attachment).

(d) Critical Melt Parameters. The melt supplier should establish a melting sequence to minimize chemical segregation of the ingot. Once a sequence has been adopted, it should be consistently applied.

1. All parameters listed in 7.c.(1)(a) (Critical Parameters) are applicable to the intermediate and final melts. In addition, for final melting, a hot topping procedure should be established. Input power should be reduced in a controlled fashion over a period of time, and the hot top sequence should be recorded. Hot topping should be consistently applied from heat to heat.

2. A system should be established to identify the start of the hot topping sequence. If markers are attached to the electrode, or in any manner introduced into the furnace, they should be manufactured using premium quality titanium of a similar composition and melting point to the alloy being melted. Attachment should prevent markers falling into the melt. Welding of markers for final melt should be prohibited. If machined grooves are used, the tools should be selected to avoid HDI's.

3. The hot topping sequence for the final melt should be arranged to terminate before introduction of any non-premium material into the melt and/or consumption of any welds. This could be done by ensuring that a 'wafer' or 'platter' of electrode is always left unmelted. The furnace should be opened in a controlled manner to avoid surface contamination.

e. Inspection. Ingot inspection procedures should be established by the supplier and approved by the PAH. Inspection procedures relevant to the possible introduction of HID's during the melt procedure are discussed below. It should be noted that at ingot stage, inspection methods are relatively limited and simple, therefore, primary emphasis should be placed on melt process control. Detailed billet inspection procedures are covered in Section 8, Billet Conversion, Disk Forging, and NDT.

(1) Wafer/Platter Inspection. The residual electrode 'wafer'/'platter' should be inspected for thickness and color after each VAR melt, and compared to physical or photographic standards. Melting through a weld during final melt should not be permitted. Any indication of abnormal color due to oxidation should be investigated, and sources of furnace leaks identified and repaired prior to processing additional material in the affected furnace. The heat of material from the abnormally discolored wafer should not be used for premium grade applications.

(2) Ingot Inspection. All electrodes and final ingots should be inspected for color and surface condition and processed as detailed in 7.d(1)(b) (Electrode Cleaning/Descale/Crown). Ingots exhibiting abnormal surface condition (excessive oxidation) indicative of furnace coolant or air

leaks, should not be released for premium grade applications, and additional material should not be processed in the affected furnace until the leak source has been identified and repaired.

(a) Exposed pipe should not be permitted on final ingots. The location of internal pipe should be determined by an inspection technique or by process history to allow appropriate inspection and disposition of the pipe-affected material during or following the subsequent conversion/cropping process.

f. Equipment Maintenance And Cleaning. TIG welds, original or repair, are considered undesirable on equipment surfaces in contact with sponge, raw materials, or other inprocess material.

(1) Blending. Equipment used for blending should be maintained in areas isolated from potential sources of contamination likely to cause HDI's or HID's (e.g., carbide tools, welding operations, etc.). All processing equipment should be regularly cleaned and inspected to written procedures. Procedures should specify methods of cleaning and frequency.

(2) Compaction. Compaction equipment (i.e., tooling, handling, etc.) should be maintained in a clean contamination-free environment. Tools should be regularly cleaned and inspected to established written procedures.

(3) Electrode Fabrication. Procedures should be established for thoroughly cleaning and inspecting the interior of the welding chamber, fixtures, welding equipment, etc., to assure all surfaces are free of all contaminants known to cause HDI's and HID's. Procedures should be specific to what is cleaned, how, at what frequency, and how it is inspected. At a minimum, chambers should be visually inspected before electrode is welded.

(4) VAR Furnaces

(a) Furnace Cleaning. Procedures should be established for thoroughly cleaning and inspecting the interiors of all melt furnaces. Base plates, stubs, covers and seals should be free of all contaminants known to cause HID's and HDI's. Procedures should specify cleaning frequency, method of cleaning, and methods of inspection.

(b) Crucible Cleaning. Procedures should be established to clean and inspect the inside surfaces of crucibles before each melt. Examples include tumbling with some hard medium, wire brushing, water jets, etc. The system chosen should be capable of removing any surface contaminant which could cause an HID or HDI. Each crucible should be inspected to a written procedure prior to release for assembly into a furnace melt sequence. After cleaning and inspection, crucibles should be stored in a manner to minimize possible contamination, and a final visual inspection is prudent prior to sealing the furnace for melting.

(c) Leak-Up Rate Checks. After the furnace assembly is sealed, but prior to melting, the system should be checked to written procedures to ensure that requirements for leak-up rate can be met. Results should be recorded.

(5) CHM Furnaces.

(a) Furnace Cleaning. Procedures should be established by the CHM source for thoroughly cleaning and inspecting the interior of the melt furnace, the hearth, barriers, spray shields and all associated equipment used on the interior of the furnace prior to use, to assure that they are free of all contaminants known to cause HDI's and HID's. Procedures should be specific as to what is cleaned, how it is cleaned and the frequency of cleaning. At a minimum, cleaning should be done when the melt chamber is exposed to air, between alloy type or alloy quality changes, and after a contaminated melt.

(b) Ingot Mold Cleaning. Procedures should be established to assure that the mold and base/puller assembly are thoroughly cleaned and inspected prior to each melt.

(c) Feed Mechanism. Procedures should be established to assure that all raw material feed mechanisms are cleaned and inspected to preclude contamination prior to melting.

(d) Skull Maintenance. Care should be used and procedures should be established to assure that skulls that are going to be reused are cleaned and not contaminated during removal, storage or reassembly. Only skulls of like alloy and quality from a non-contaminated melt should be reused. Skulls should have traceability to previous melts and should be inspected prior to reuse to assure that no loose contaminants are present.

8. BILLET CONVERSION, DISK FORGING, AND NDT.

a. Control Of Billet Manufacture.

(1) Conversion Process. Specific detailed procedures should exist for the conversion of ingot to billet and bar products. These include but are not necessarily limited to:

(a) Billet Conversion. Ingot to billet conversion should be performed using controlled, consistent, and detailed procedures.

1. Forge Parameter Control. Documented procedures to control ingot and billet products should be developed and used. These procedures include, but are not limited to:

(i) forge furnace temperatures/atmospheres

(ii) soak times

(iii) amount of draft

(iv) reduction schedules/sequences

(v) quench time, media, and methods

(vi) die type

(vii) single or double end procedures

(viii) off-die procedures

2. Forge Practice. Forge practices should be developed which preclude formation of strain induced porosity (SIP) or clean voids.

3. Records. Reduction sizes, sequences, and temperature records should be maintained.

(b) Traceability. Traceability of billet to exact ingot location should be maintained.

(2) Cropping. Any ingot conversion should incorporate a crop of the ingot extremities. Limits for crop lengths should be established to account for the bottom charge and hot topping procedures used for the final melting.

b. Control Of Disk/Component Manufacture.

(1) Forging/Heat Treatment Process. Specific detailed procedures should exist for the production of finished rotating components from billet product. These should include but not necessarily be limited to:

(a) Forging Controls. Controlled, consistent, and detailed procedures should be established for the control of the forging press/hammer processing.

(b) Thermal Controls. Documented procedures for control of forge/soaking furnace temperature and times should be established.

(c) Heat Treatment Controls. Documented procedures should be established for the control of heat treatment furnaces, atmospheres, times and temperatures.

(d) Quenching. Quench practice and cooling rates should be controlled to ensure freedom from quench related cracking.

(e) Traceability. Traceability of forgings to exact billet location should be maintained.

(2) Records. Reduction sizes, sequences, and temperature records should be maintained.

c. Nondestructive Testing (NDT) And Criteria.

(1) NDT. In order to obtain further confidence that titanium rotating parts are free from potentially detrimental anomalies, NDT should be performed at appropriate stages throughout billet/bar and component manufacture. NDT requirements will typically include but not necessarily be limited to the following:

(a) Billet/Bar.

1. Ultrasonic. Immersion ultrasonic testing of billet/bar should be performed.

2. Macroetch. Macroetch inspection of billet/bar ends adjacent to ultrasonic crops should be done to assure freedom of the remaining material from segregation or other anomalies.

(b) Forging.

1. Ultrasonic. Immersion ultrasonic testing of forgings should be performed.

2. Macroetch. Sonic or intermediate machined forgings may be macroetched for examination for the presence of segregation or other anomalies.

(c) Finish Machined Component.

1. Etch. Finish machined components should have their surfaces blue etch anodized and inspected to assure freedom from segregates. Alternate suitable macroetch procedures, although not preferred, may be utilized.

2. Fluorescent Penetrant Inspection. Finish machined components should be fluorescent penetrant inspected.

(2) Ultrasonic Testing (UT) Criteria. The criteria for UT of billet/bar and forgings should consider the operational and control requirements that materials/ultrasonic inspection systems must achieve. The criteria should include but not necessarily be limited to the following:

(a) System Variability. Materials systems from billet/bar through forging, heat treatment, and machining should be engineered such that materials-generated ultrasonic noise or boundary (surface finish) ultrasound transmission characteristics do not interfere with detectability of potentially detrimental anomalies. Periodic system reliability/repeatability studies should be conducted to assure instrumentation and standards are functioning properly and within calibration.

(b) Test Blocks. Test blocks used to verify operation of the ultrasonic inspection system should be representative of the part being inspected and should contain appropriate ultrasonic reference standards (flat bottom holes or side drilled holes). The ultrasonic reference standards should be correlated with potentially detrimental anomalies.

(3) Statistical Assessment. Statistical assessment of factors responsible for material/ultrasonic system variability should be conducted.

(4) Acceptance Limit. When using automated scanning systems, the acceptance limit should be set appropriately above the noise level to minimize false calls while maintaining detection sensitivity consistent with design requirements.

(5) Records. Strip charts or equivalent electronic data should be required and retained according to the engine-manufacturer's FAA-approved records retention schedule.

d. Actions Following Indication Detection.

(1) Indication Characterization. Characterization of unacceptable indications should be conducted on billet/bar, forgings or finished parts, as appropriate, and reported to JETQC in accordance to JETQC practices. This characterization, as appropriate and as a minimum, shall provide the following information

(The recommended procedure for 3D inclusion characterization is outlined in Appendix 1.):

(a) Defect type

(b) 3D defect size

(c) 3D void/crack size if any

(d) Microhardness

(e) Scanning Electron Microscope (SEM) evaluation: nature of constituents, fractography of void/crack

(f) Microprobe analysis: Chemical composition of defect, nature of inclusions

(g) Photomicrographs of the defect in two perpendicular directions

(2) Indications Detected In Billet/Bar.

(a) HDI or HID. Any heat which is shown, by billet/bar inspection and indication characterization, to contain an HDI or HID inclusion should be rejected for critical rotating part application.

(b) Other. HAD's and clean voids are considered potentially detrimental; usage of heats shown to contain any of these anomalies should be evaluated on an individual basis.

(3) Indications Detected in Forgings And Finished Parts. The PAH should take appropriate action upon finding and characterizing unacceptable indications in forgings and finished parts. Action regarding suspect material should be based on historic experience with the process and may include, but not necessarily be limited to, overinspections of parts from heats, lots, batches, etc., which contain the forging or part with the anomaly.

(4) Associated Heats. Associated heats shall be identified and investigated for potential similar defects.

Original signed by:

Jay J. Pardee,

Manager, Engine and Propeller Directorate

Aircraft Certification Service

APPENDIX 1: Minimum Recommended Procedure for 3D Inclusion Characterization.

Step 1: Characterize the ultrasonic indication in the product:

- Angulation

- Two different frequencies

- Exact location (marking)

Step 2: Cut a sample (approximately 40 X 40 mm) out of the product containing the indication (mark each face to maintain orientation).

Step 3: NDT Inspection.

Step 4: Relocate indication ultrasonically and remark (to maintain orientation).

Step 5: Cut a cube whose side is approximately 25mm (1 inch). If necessary relocate the indication ultrasonically.

Step 6: Metallurgical characterization

6-1: Approach:

* Approach the defect by the face of the cube perpendicular

to face exhibiting the maximum ultrasonic response.

* Precut at 2 mm from identified position

6-2: Macrographic examination:

* Any segregation

* Orientation of grain structure

6-3: Micrographic examination:

* Polish in steps from 50 to 500 microns

* Determine defect type, 3D defect size, 3D void/crack size,

microhardness.

* Take photomicrographs of the defect at its maximum dimensions in

two perpendicular directions.

6-4: Microprobe analysis (in case of inclusion):

* Chemical composition of the defect.

6-5: Scanning Electron Microscope (SEM) examination (if necessary):

* Nature of constituents

* Fractography of void/crack

NOTE: This is the minimum procedure recommended for any characterization of inclusion (HID, HDI) on
billet/bar, forging, or finished part. Additional Requirements may be established by the PAH.