U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Casting Factors

Date: 10/06/14 **AC No:** 25.621-1
Initiated By: ANM-115

This advisory circular describes an acceptable means for showing compliance with the requirements of § 25.621, *Casting factors*, of Title 14, Code of Federal Regulations part 25. Section 25.621 outlines the factors, tests, and inspections that must be applied to castings used in structural applications.

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1 PURPOSE.

This advisory circular (AC) describes an acceptable means for showing compliance with the requirements of § 25.621, *Casting factors*, of Title 14, Code of Federal Regulations (14 CFR) part 25. Section 25.621 outlines the factors, tests, and inspections that must be applied to castings used in structural applications.

2 APPLICABILITY.

2.1 The guidance provided in this document is directed to airplane manufacturers, modifiers, foreign regulatory authorities, and Federal Aviation Administration (FAA) transport airplane type certification engineers and their designees.

2.2 The material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. These means are issued, in the interest of standardization, for guidance purposes and to outline a method that has been found acceptable in showing compliance with the standards set forth in the rule. If, however, we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation or design changes as a basis for finding compliance.

2.3 The material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes in, or permit deviations from, regulatory requirements. The applicant should be aware that § 25.621 is an additional requirement for structural substantiation of cast parts and components. It is used in combination with a number of other sections, and it does not replace or negate compliance with any other paragraph of 14 CFR part 25.

2.4 Except in the explanations of what the regulations require, the term “must” is used in this AC only in the sense of ensuring applicability of this particular method of compliance when the acceptable method of compliance described in this AC is used.

3 RELATED REGULATIONS.

The following 14 CFR regulations are referenced in this AC. The full text of these regulations can be downloaded at the U.S. Government Printing Office e-CFR. You can order a paper copy by sending a request to the U.S. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402-0001; or by calling telephone number (202) 512-1800; or by sending a request by facsimile to (202) 512-2250.

- Section 25.303, *Factor of safety*.
- Section 25.305, *Strength and deformation*.
- Section 25.307, *Proof of structure*.

- Section 25.571, *Damage-tolerance and fatigue evaluation of structure*.
- Section 25.613, *Material strength properties and material design values*.
- Section 25.619, *Special factors*.

4 DEFINITIONS.

For the purposes of this AC, the following definitions apply:

4.1 Casting.

A method of forming an object by pouring molten metal into a mold, allowing the material to solidify inside the mold, and removing it when solidification is complete.

4.2 Critical Casting.

A casting whose failure could preclude continued safe flight and landing of the airplane or could result in serious injury to occupants is considered a critical casting. Examples of castings that may be critical are structural attachment fittings; parts of flight control systems; control surface hinges and balance weight attachments; seat, berth, and safety belt supports and attachments; fuel and oil tank supports and attachments; pressurized doors; and cabin pressure valves.

4.3 Premium Casting Process.

A casting process that produces castings characterized by a high quality and reliability.

4.4 Prolongation.

An integrally cast test bar or test coupon.

4.5 Test Casting.

A casting produced specifically for the purpose of qualifying the casting process.

5 BACKGROUND.

5.1 Regulatory Background.

5.1.1 The airworthiness standards of 14 CFR part 25 relative to transport category airplanes require classification of structural castings as either “critical” or “non-critical.” Depending on classification, the current standards specify the accomplishment of certain inspection and test requirements, and the application of special factors of safety for ultimate strength and deformation.

5.1.2 The original requirements specified in § 25.621, *Casting factors*, stated that critical castings in structural applications must have a minimum casting factor of 1.25, which was to be applied in addition to the limit load factor of safety required by § 25.303, *Factor of safety*. Those requirements were in effect for many years, having been carried forward in 1964 from Part 4b of the Civil Air Regulations (CAR 4b.307). Prior to that, Civil Aeronautics Manual 04 required a minimum additional ultimate strength factor of

2.0 for castings used in primary structure. Under those regulations, the Administrator had the authority to prevent the use of any casting that was not considered acceptable for a given application.

5.2 **Application of Special Factors of Safety.**

5.2.1 The application of factors of safety to castings is based on the fact that the casting process can be inconsistent. Casting is a method of forming an object by pouring molten metal into a mold, allowing the material to solidify inside the mold, and removing it when solidification is complete. Castings are subject to variability in mechanical properties due to this casting process, which can result in imperfections, such as voids, within the cast part. Using certain inspection techniques, for example radiographic (X-ray), it is possible to detect such imperfections above a minimum detectable size, but accurate detection depends on the dimensions of the part, the inspection equipment used, and the skill of the inspector.

5.2.2 Section 25.619, *Special factors*, includes a requirement to apply a special factor to the factor of safety prescribed in § 25.303 for each part of the airplane structure whose strength is subject to appreciable variability because of uncertainties in the manufacturing processes or inspection methods. Since the mechanical properties of a casting depend on the casting design, the design values established under § 25.613, *Material strength properties and material design values*, for one casting might not be applicable to another casting made to the same specification. Thus, casting factors have been necessary for castings produced by normal techniques and methodologies to ensure the structural integrity of castings in light of these uncertainties.

5.2.3 Another approach is to reduce the uncertainties in the casting manufacturing process by use of a “premium casting process” (discussed below), which enables the applicant to use a casting factor of 1.0. Section 25.621 does permit the use of a casting factor of 1.0 for critical castings, provided that—

5.2.3.1 The manufacturer has established tight controls for the casting process, inspection, and testing; and

5.2.3.2 The material strength properties of the casting have no more variability than equivalent wrought alloys.

6 GENERAL GUIDANCE FOR USE OF CASTING FACTORS.

6.1 **Factors of Safety.**

Section 25.619 requires that the factor of safety specified in § 25.303 be multiplied by the highest pertinent special factor of safety prescribed in §§ 25.621 through 25.625. While castings are subject to the fatigue and damage tolerance requirements of § 25.571, the factors prescribed in §§ 25.621 through 25.625 need not be considered in demonstrating compliance with § 25.571.

6.2 **Inspections.**

Guidance on non-destructive inspection techniques and methods can be obtained from national and international standards. See paragraph 7.2.4.3 of this AC. To determine whether an inspection method is an "equivalent inspection method" to the methods specified in the rule, the applicant should consider the types and sizes of the internal and external defects detectable by the methods; the capability of the methods to inspect the structurally significant areas and areas where defects are likely to occur; and the capability of the methods relative to the configuration, material specification, and types and sizes of defects expected for the casting being inspected.

6.3 **Static Testing.**

The static test specimen(s) should be selected on the basis of the foundry quality control inspections, in conjunction with those inspections prescribed in § 25.621(c) and (d). The test article may consist of the sample casting to be tested and any additional parts (production or test specific) required to ensure that loads and stresses experienced by the sample casting are representative of expected in-service loading conditions. An attempt should be made to select sample casting(s) for testing from the first batch produced to the production standard. It is desirable that the test specimen(s) contain detectable surface and/or internal defects in structurally significant areas that do not otherwise exceed the threshold for rejection of the cast part. Multiple test conditions may be required to provide complete coverage of all structurally significant areas of the cast part.

6.4 **Rework of Castings.**

If applicable, the applicant should address the effects on material properties of processes intended to correct a non-conforming condition in the cast part (e.g., weld rework). Evaluation of effects of rework processes on material properties should include analysis supported by test data. Material properties of reworked areas should have a population coefficient of variation consistent with the type of casting factor selected for the casting. The extent and limitations of such rework processes should be detailed in the manufacturing specifications as well as on the design drawings, either directly or by reference to a qualified rework process.

7 PREMIUM CASTING PROCESS.

This paragraph provides guidance for compliance with § 25.621 for using a casting factor greater than or equal to 1.0, but less than 1.25, for "critical" castings used in structural applications. A premium casting process is capable of producing castings with predictable properties, thus allowing a casting factor of 1.0 to be used for these components. Three major steps, required by § 25.621(c)(1)(i), are essential in characterizing a premium casting process:

- Qualification of the process.
- Proof of the product.
- Monitoring of the process.

7.1 **General.**

7.1.1 The objective of a premium casting process is to consistently produce castings with high quality and reliability. To this end, the casting process is one that is capable of consistently producing castings that include the following characteristics:

7.1.1.1 Good dimensional tolerance.

7.1.1.2 Minimal distortion.

7.1.1.3 Good surface finish.

7.1.1.4 No cracks.

7.1.1.5 No cold shuts.

7.1.1.6 No laps.

7.1.1.7 Minimal shrinkage cavities.

7.1.1.8 No harmful entrapped oxide films.

7.1.1.9 Minimal porosity.

7.1.1.10 A high level of metallurgical cleanness.

7.1.1.11 Good microstructural characteristics.

7.1.1.12 Minimal residual internal stress.

7.1.1.13 Consistent mechanical properties.

7.1.2 The majority of these characteristics can be detected, evaluated, and quantified by standard non-destructive testing methods, or from destructive methods on prolongation or casting cut-up tests. However, a number of them cannot. Thus, to ensure an acceptable quality of product, the significant and critical process variables must be identified and adequately controlled.

7.2 **One Means of Qualification for Casting Process.**

7.2.1 To demonstrate a premium casting process, the applicant should subject it to a qualification program that is specific to a foundry and material combination. The qualification program should establish the following:

7.2.1.1 The capability of the casting process to produce a consistent quality of product for the specific material grade selected for the intended production component.

7.2.1.2 The mechanical properties for the material produced by the process have population coefficients of variation equivalent to that of wrought products of similar composition (in other words, plate, extrusions, and bar). Using the population coefficient of variation from forged products does not apply. In most cases, the coefficients of variation for tensile ultimate strength less than or equal to 3.5 percent, and tensile yield strength less than or equal to 4.0 percent, is adequate to demonstrate this equivalency of mechanical properties.

7.2.1.3 The casting process is capable of producing a casting with uniform properties throughout the casting or, if not uniform, with a distribution of material properties that can be predicted to an acceptable level of accuracy.

7.2.1.4 The (initial) material design data for the specified material are established.

7.2.1.5 The material and process specifications are clearly defined.

7.2.2 For each material specification, a series of test castings from a number of melts, using the appropriate production procedures of the foundry, should be manufactured. The test casting produced should undergo a standardized inspection or investigation using non-destructive inspection and cut-up testing to determine the consistency of the casting process.

7.2.3 The test casting should be representative of the intended cast product(s) with regard to section thicknesses and complexity, and it should expose any limitations of the casting process. In addition, the standard test casting should be large enough to provide mechanical test specimens from various areas for tensile and, if applicable, compression, shear, bearing, fatigue, fracture toughness, and crack propagation tests. If the production component complies with these requirements, it may be used to qualify the process. The number of melts sampled should be statistically significant. Typically, at least 10 melts are sampled with no more than 10 castings produced from each melt. If the material specification requires the components to be heat-treated, this should be done in no fewer than 10 heat treatment batches consisting of castings from more than one melt. Reduction of qualification tests may be considered if the casting process and the casting alloy is already well known for aerospace applications and the relevant data are available.

7.2.4 Inspection Program for Test Casting.

7.2.4.1 Each test casting should receive a non-destructive inspection program, which should include the following as a minimum:

7.2.4.1.1 Inspection of 100 percent of its surface using visual and liquid penetrant or equivalent inspection methods.

7.2.4.1.2 Inspection of structurally significant internal areas and areas where defects are likely to occur using radiographic methods or equivalent inspection

methods. The specific radiographic reference standard to be employed is to be determined, and the margin by which the test castings exceed the minimum required standard should be recorded.

7.2.4.2 The program of inspection is intended to—

7.2.4.2.1 Confirm that the casting process is capable of producing a consistent quality of product.

7.2.4.2.2 Verify compliance with the stated objectives of a premium casting process with regard to surface finish, cracks, cold shuts, laps, shrinkage cavities, and porosity. (See paragraph 7.1.1 of this AC.)

7.2.4.2.3 Ensure that the areas from which the mechanical property test samples were taken were typical of the casting as a whole with respect to porosity and cleanness.

7.2.4.3 Guidance on non-destructive inspection techniques and methods can be obtained from national and international standards. The standard listing below is not a comprehensive list, but is given as an initial reference guide:

- American Society for Testing and Materials (ASTM) A802/A802M, *Standard Practice for Steel Castings, Surface Acceptance Standards, Visual Examination*.
- ASTM A903/A903M, *Standard Specification for Steel Castings, Surface Acceptance Standards, Magnetic Particle and Liquid Penetrant Inspection*.
- ASTM E155, *Standard Reference Radiographs for Inspection of Aluminum and Magnesium Castings*.
- ASTM E192, *Standard Reference Radiographs of Investment Steel Castings for Aerospace Applications*.
- ASTM E433, *Standard Reference Photographs for Liquid Penetrant Inspection*.
- ASTM E1030, *Standard Test Method for Radiographic Examination of Metallic Castings*.
- ASTM E1320, *Standard Reference Radiographs for Titanium Castings*.
- International Organization for Standardization (ISO) 4986, *Steel Castings—Magnetic Particle Inspection*.
- ISO 4987, *Steel Castings—Liquid Penetrant Inspection*.
- ISO 4993, *Steel and Iron Castings—Radiographic Inspection*.
- ISO 9915, *Aluminum Alloy Castings—Radiography Testing*.

- ISO 9916, *Aluminum Alloy and Magnesium Alloy Castings—Liquid Penetrant Inspection*.
- ISO 10049, *Aluminum Alloy Castings—Visual Method for Assessing the Porosity*.
- ISO 11971, *Steel and Iron Castings—Visual Examination of Surface Quality*.

7.2.4.4 The test castings must show that the foundry and process combination is capable of producing a product free of cracks, laps, and cold shuts. Ideally, the test castings should be free of detectable shrinkage cavities and porosity. Guidance for acceptance criteria regarding dimensional tolerance, distortion, and surface finish can be obtained from the standards cited in paragraph 7.2.4.3 of this AC. When these standards are used, it should be taken into account that these standards are for general quality castings.

7.2.5 All test castings should be cut up using a standardized methodology to produce the mechanical test specimens detailed in paragraph 7.2.3 of this AC. Principally, the tests are to establish the variability within the cast component, as well as determine the variability between components from the same melt and from melt to melt. Typically, the evaluation to compare the cast material to wrought material should use the ultimate tensile strength and tensile yield strength. The data gathered also may be used during later phases to identify deviations from the limits established in the process qualification and product proving programs.

7.2.6 All the fracture surfaces generated during the qualification program should be inspected at least visually for detrimental defects. Evidence of inclusions, oxide films, porosity, or shrinkage cavities would indicate inadequate control of the casting process.

7.2.7 As part of the cut-up investigation, it is usually necessary to take metallographic samples for cleanness determination and microstructural characterization.

7.2.8 When the process has been qualified, it should not be altered without completing comparability studies and necessary testing of differences.

7.3 **Proof of Product.**

7.3.1 Subsequent to the qualification of the process, the production castings should be subjected to a production-proving program. Such castings should have at least one prolongation; however, large and/or complex castings may require more than one. If a number of castings are produced from a single mold with a single runner system, they may be treated as one single casting. The production-proving program should establish the following:

7.3.1.1 The design values developed during the process qualification program are valid (for example, same statistical distribution) for the production casting.

7.3.1.2 The production castings have the same or less than the level of internal defects as the test castings produced during qualification.

7.3.1.3 The cast components have a predictable distribution of tensile properties.

7.3.1.4 The prolongation(s) is representative of the critical area(s) of the casting.

7.3.1.5 The prolongation(s) consistently reflects the quality process and material properties of the casting.

7.3.2 At least two (or more) pre-production castings of each part number to be produced should be selected for testing and inspection. All of the selected castings should be non-destructively inspected in accordance with the qualification program.

7.3.2.1 One of these castings should be used as a dimensional tolerance test article. The other selected casting(s) should be cut up for mechanical property testing and metallographic inspection.

7.3.2.2 The casting(s) selected for cut-up should be cut in a standardized manner to yield a number of tensile test specimens and metallographic samples. There should be sufficient cut-up tensile specimens to cover all critical ("critical" with respect to both the casting process and service loading) areas of the casting.

7.3.2.3 All prolongations should be machined to give tensile specimens and subsequently tested.

7.3.2.4 The production castings should be produced under production procedures identical to those used for these pre-production castings.

7.3.3 On initial production, a number of castings should undergo a cut-up for mechanical property testing and metallographic inspection similar to that performed for the pre-production casting(s). The cut-up procedure used should be standardized, although it may differ from that used for the pre-production casting(s). Tensile specimens should be obtained from the most critical areas.

7.3.3.1 For the first 30 castings produced, at least 1 casting in 10 should undergo this testing program.

7.3.3.2 The results from the mechanical property tests should be compared with the results obtained from the prolongations to further substantiate the correlation between prolongation(s) and the critical area(s) of the casting.

7.3.3.3 In addition, if the distribution of mechanical properties derived from these tests is acceptable, when compared to the property values determined in the qualification program, the frequency of testing may be reduced. However, if the comparison is found unacceptable, the test program may require extension.

7.3.4 At no point in the production should the castings contain shrinkage cavities, cracks, cold shuts, laps, porosity, or entrapped oxide film, or have a poor surface finish exceeding the acceptance level defined in the technical specifications.

7.4 **Monitoring the Process.**

7.4.1 The applicant should employ quality techniques to establish the significant/critical foundry process variables that have an impact on the quality of the product. The applicant should show that these variables are controlled with corrective action throughout production.

7.4.2 During production, every casting should be non-destructively inspected using the techniques and the acceptance standards employed during the qualification program.

7.4.2.1 Rejections should be investigated and process corrections made as necessary.

7.4.2.2 Alternative techniques may be employed if the equivalence in the acceptance levels can be demonstrated.

7.4.2.3 In addition, tensile tests should be taken from the prolongations on every component produced, and the results should comply with limits developed in the process qualification and product proving programs.

7.4.2.4 Additionally, as mentioned in paragraph 7.3 of this AC, a periodic casting cut-up inspection should be undertaken with the inspection schedule as agreed upon during the proof of product program.

7.4.2.5 Deviations from the limits established in the process qualification and production-proving programs should be investigated and corrective action taken.

7.5 **Modifications to the Casting Design, Material, and Process.**

Additional testing may be required when alterations are made to the casting geometry, material, significant/critical process variables, process, or production foundry to verify that the alterations have not significantly changed the casting's properties. The recommended verification testing is detailed in table 1 of this AC.

Table 1. Recommended Verification Testing

	Modifications				Verification Testing		
Case	**Geometry**	**Material**	**Process**	**Foundry**	**Qualification of Process**	**Proof of Product**	**Tests per § 25.621(c)(1)**
1	Yes	None	None	None	Not necessary	Yes	Yes[2]
2	None	Yes	None	None	Yes[1]	Yes	Yes[2]
3	Yes	Yes	None	None	Yes	Yes	Yes
4	None	None	Yes	None	Yes[1]	Yes	Yes[2]
5	None	None	None	Yes	Yes[1]	Yes	Yes[2]

[1]The program described in paragraph 7 of this AC to qualify a new material, process, and foundry combination may not be necessary if the following three conditions exist for the new combination:

1. Sufficient data from relevant castings to show that the process is capable of producing a consistent quality of product, and that the quality is comparable to, or better than, the old combination.
2. Sufficient data from relevant castings to establish that the mechanical properties of the castings produced from the new combination have a similar or better statistical distribution than the old combination.
3. Clearly defined material and process specifications.

[2]The casting may be re-qualified by testing partial static test samples. With larger castings, re-qualification could be undertaken by a static test of the casting's critical region only.

Advisory Circular Feedback

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