# Federal Aviation Administration

# Memorandum

Date: March 26, 2008

To: SEE DISTRIBUTION

From: Manager, Engine and Propeller Directorate, Aircraft Certification Service

Prepared by: Mark Rumizen, ANE-111, 781-238-7113 or Mark.Rumizen@faa.gov

Subject: **ACTION**: Policy for microstructure examination of reciprocating engine forged steel alloy crankshafts in support of §33.15 compliance [ANE-2006-33.15-1]

**1. Purpose.** This memorandum establishes FAA policy concerning microstructure inspection of reciprocating engine forged steel alloy crankshafts using Charpy impact testing specimens, and how the test may be used to determine the suitability and durability of these crankshafts. This method is one way, but not the only way that may substantiate compliance with § 33.15(a) and (b).

**2. Related Documents.**

a. ASTM Active Standard (or latest version), "E23-06 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials", ASTM International.

b. ASM Handbook Series, "Volume 12: Fractography", published 1987, ASM International.

**3. Background.**

Recent service experience indicates that reciprocating engine forged steel alloy crankshafts can develop subsurface micro-cracks when honeycomb, a low toughness dimpled feature, develops during manufacture. These micro-cracks led to failure of the part during operation, and engine failure. Examination of the failed crankshafts revealed that they contained these honeycomb features, and metallurgical analysis indicated that these honeycomb features adversely affected the material's fatigue strength.

Honeycomb features result from the segregation of alloying elements, and contamination of the grain boundaries, when a steel alloy part is forged at excessively high temperatures (when the grain boundary begins to melt). The presence of high levels of some alloying elements in the steel alloy, possibly including vanadium, may also facilitate the formation of honeycomb features.

In extreme cases, the honeycomb feature can progress to a micro-crack on the grain boundary. When this happens, it is an indication of excessive overheating, tensile strain, or both, during forging.

The presence of micro-cracks reduces a finished part's fatigue life, and if the operating stresses applied to the part are greater then the material endurance limit, the part may fail during operation. This problem has manifested itself by recent engine crankshaft failures. Therefore, inspections during the crankshaft forging process should incorporate inspection for microstructure anomalies, such as honeycomb features, to ensure the material meets its intended fatigue strength. In addition, other forged steel alloy parts that are subjected to significant levels of working strain during the forging process may also be at risk of honeycomb features and should also incorporate inspections as described in this memo.

The most effective inspection for microstructural anomalies is a fracture surface inspection using Charpy impact test specimens. In this type of test, a specimen from the part, often a test coupon, is subjected to impact loading to evaluate the response of the material. A Charpy test apparatus puts the specimen in the path of a pendulum that fractures or deforms the specimen and measures the energy required to do so.

While the primary purpose of a Charpy impact test is comparative evaluation of the fracture toughness and ductility of various materials, in this case the test is being used primarily to expose the grain boundaries for microscopic inspection. If the type of grain boundary segregation discussed above is present, the test specimen will fracture along a grain boundary without any mechanical damage to the exposed grain boundary. Subsequent fractographic inspection of the fracture surface using a scanning electron microscope will conclusively determine if honeycomb features are present.

If manufacturers use the Charpy test results and specimens when complying with this policy, they must keep in mind that the test is principally used to detect anomalies that occur due to forging overheat. Other types of detrimental anomalies occasionally occur that the microstructure examination of Charpy test specimens will not detect. Some examples are excessive inclusion content, the presence of harmful alloying elements, and forging laps.

Some manufacturers have also developed a micro Charpy test that utilizes a small specimen. Micro Charpy test specimens have been useful in examining crankshafts in service because samples can be removed without destroying the part or removing the crankshaft from the engine. This test removes a small cylinder of steel from the propeller flange using a hollow drill. This extracted steel cylinder is then notched and broken in a controlled impact.

The micro Charpy test is not the preferred method for microstructural anomaly detection since it does not examine a sufficient volume of material. However, it can be useful in reducing risk for problems that have been discovered after the parts enter service.

**4. Policy.** Manufacturers of reciprocating engine forged steel alloy crankshafts should develop a process specification that insures their crankshafts are inspected for microstructural anomalies. The process specification should be used to ensure that forged steel alloy crankshafts have the strength and other properties assumed in the design data as required by §33.15(b). The specification should be submitted to the FAA for approval in accordance with Order 8110.4C titled, "Type Certification", section 5-6. The specification should include the following elements:

a. A drawing or sketch of the Charpy specimen showing dimension and location of the specimen on the actual part.

- The specimen should be approximately one inch long and maintain a minimum 0.5 inch thickness when removed from the part.

b. A process for obtaining a specimen from the part, including:

(1) When a specimen is to be removed (for example, which step in the manufacturing process; after forging, or after first temper).

(2) Where a specimen is to be removed from. The part design may include an extra prolongation of material expressly for this purpose. This extra prolongation should be located in an area of the forging that was subjected to tensile stresses of similar magnitude to the critical section of the part during forging process.

(3) A method that identifies which part a specimen came from.

c. A sampling plan with substantiation for the statistical basis for that plan is required if 100 percent inspection is not implemented.

d. A process for fabricating Charpy test bars from the specimen. Two standard type A test bars should be fabricated and notched in accordance with ASTM E23.

e. A description of the test apparatus and impact test procedure. The test procedure should include recordings of other material data, such as impact energy, percent lateral expansion, percent brittle and ductile fracture area, or any other relevant material data available from the test. See ASTM standard E23 for additional guidance on the type of data that can be obtained from the Charpy test.

f. Instructions for fractographic inspection of the specimen. One fracture surface from each specimen should be examined with a scanning electron microscope. The process should specify an initial low magnification scan (50X to 200X) of the entire surface area to identify any suspect areas, followed by a higher magnification (500X to 2000X) examination of any suspect areas. The processes specification should include:

(1) Qualification criteria for the facility that performs the fractographic inspection.

(2) Qualification and training criteria for the technician that exams the fracture surface.

g. Pass/ Fail Criteria. If any evidence of honeycomb features are found during the examination, the sample should be considered failed, and the manufacturer should initiate an investigation to determine the cause of the failure.

h. Records and Specimen Retention. Requirements for reporting of test results, marking of parts that pass the test, and preservation of specimens should be established. Specimen marking should be traceable to the part from which the specimen was taken.

**5. Effect of Policy.**

a. The general policy stated in this document does not constitute a new regulation or create a "binding norm". Offices that implement this policy should follow it when it is applicable to a specific project. Whenever an applicant's proposed method of compliance differs from this policy, the applicant must coordinate their proposed method with the policy issuing office (for example, through the issue paper process or equivalent).

b. Applicants should expect that the personnel reviewing their applications will consider the information within this policy when determining compliance relevant to new certificate actions. Also, as with all advisory material, this policy statement identifies one means, but not the only means, of compliance.

**6. Conclusion.**

Aircraft Certification Offices (ACOs) should communicate the intent of this policy to applicants seeking approval of reciprocating engine highly-stressed forged steel alloy crankshafts, or approval of engines containing those crankshafts. The microstructure inspection process specification should be submitted as compliance data for § 33.15, and the ACO should review the process specification for compliance with this policy.

Francis A. Favara

Distribution:
Manager, Aircraft Engineering Division, AIR-100
Manager, Brussels Aircraft Certification Staff, AEU-100
Manager, Small Airplane Directorate, ACE-100
Manager, Rotorcraft Directorate, ASW-100
Manager, Transport Airplane Directorate, ANM-100
Manager, Boston Aircraft Certification Office, ANE-150
Manager, New York Aircraft Certification Office, ANE-170
Manager, Ft. Worth Airplane Certification Office, ASW-150
Manager, Special Certification Office, ASW-190
Manager, Atlanta Aircraft Certification Office, ACE-115A
Manager, Chicago Aircraft Certification Office, ACE-115C
Manager, Wichita Aircraft Certification Office, ACE-115W
Manager, Anchorage Aircraft Certification Office, ACE-115N
Manager, Seattle Aircraft Certification Office, ANM-100S
Manager, Denver Aircraft Certification Office, ANM-100D
Manager, Los Angeles Aircraft Certification Office, ANM-100L