



Test Methods for Tensile and Fatigue Properties in Metallic Components

1 Introduction

Note: Nothing in this standard supercedes applicable laws and regulations.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. Procedures listed herein may be used whenever tensile and fatigue data is needed. This specification provides standard procedures for determination of tensile and fatigue properties in parts, Table 1.

Table 1: Methods Included in GMW16705

Calculation of statistical minimum	Recommended practice for determining Weibull B1C50 and -3Sigma as minimum standards.	Appendix A
Correlation between gage mark and extensometer	Recommended practice for validating gage mark method as a replacement for the extensometer method for elongation measurement.	Appendix B
Tensile study	Basic procedures and data analysis plus additional requirements for determination of yield strength (YS), ultimate tensile strength (UTS), and elongation (EL) as plastic strain at failure.	Appendix C
Staircase fatigue study	Test procedure and data analysis for determination of average and standard deviation fatigue strength. The methodology for the staircase fatigue test is codified solely in this document.	Appendix D
Overstress-probe fatigue study	Test procedure and data analysis for evaluating certainty that fatigue strength is greater than a given specification.	Appendix E
Strain-controlled fatigue study	Test procedures and data analysis for determination of strain-life fatigue constants, plus additional requirements on coordination with staircase fatigue test results and characterization of cyclic stress-strain curve.	Appendix F

1.2 Applicability. This is not a general specification. It must be called out in each use per Section 8. GMW16705 was specifically written to provide test detail for GMW16704. However, methods detailed herein apply wherever rigorous tensile and fatigue testing is needed.

1.3 Remarks.

1.3.1 Tensile and fatigue properties are difficult to measure because testing is destructive so error, reproducibility and bias can only be determined indirectly. International standards governing tensile and fatigue testing tend to provide details on testing a single sample. GMW16705 builds on these existing test standards and details how to organize and test a collection of samples for the purpose of characterizing properties.

1.3.2 The emphasis of GMW16705 is properties of samples excised from parts. However, cast-to-size, co-cast, or otherwise separately manufactured samples may also be tested by procedures herein.

1.3.3 In this document reference is made to **Purchaser**, **Supplier**, and **Lab**, defined in 7.1 Glossary.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

ASTM B557/B557M	ASTM E466	ASTM E8/E8M	ISO 6892
ASTM E21	ASTM E606	DCT-4627 (Delphi)	ISO 17025
ASTM E83	ASTM E1012	IATF 16949	SAE J1099

2.2 GM Standards/Specifications.

GMW16704

2.3 Additional References.

- P.N. Crepeau, Shape Casting: 2nd International Symposium, TMS Annual Meeting, 2007
- W. J. Dixon, A.M. Mood, *J. Am. Statist. Assoc.*, vol. 43, p. 109 (1948)

3 Resources

3.1 Facilities. All testing to generate data against this specification shall be performed in laboratories accredited to either IATF 16949, ISO 17025, or one of their successors. Lab certification shall be provided upon request.

- Choice of test lab shall be approved by **General Motors Materials Engineering**.
- Test Environment: All testing shall be conducted in laboratory air.

3.1.1 Calibration. The test facilities and equipment shall be in good working order and shall have a valid calibration label.

3.1.2 Alternatives. Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

3.2 Equipment. Follow the requirements in ASTM B557/B557M, ASTM E8/E8M, ASTM E21, ASTM E466, ASTM E606, and ISO 6892. Strain shall be measured with an extensometer per ASTM E83, Class B2 or better.

3.2.1 For Fatigue Testing.

- Servo-hydraulic, uniaxial test machine, equipped to control and measure loads to within 1.0% in the range needed for the material tested and the test frequency used, and also to stop the test when the specimen breaks.

Note: It is advantageous if the fractured ends of the specimen are not crushed together after the specimen breaks. An unmarred fracture surface holds information about crack initiation.

- Gripping mechanism to hold specimen, aligned per ASTM E1012. Collet grips are recommended as they align more reliably and require smaller specimen ends.
- Heating device capable of heating entire gage section of specimen to targeted temperature $\pm 3^\circ\text{C}$ with a maximum temperature gradient of 5°C across the specimen. Measures must be taken to overcome the tendency for grips to act as heat sinks.

3.3 Test Vehicle/Test Piece. Parts to be characterized shall contain sufficient volume of material to provide standard test specimens per ASTM B557/B557M, ASTM E8/E8M, ASTM E466, or ASTM E606. Use of sub-size specimens must be approved by **Purchaser**.

3.4 Test Time. After **Lab** receives test material the following times can be expected for each test procedure, including specimen preparation:

- Extensometer correlation: 1 day (assumes tensile bars are already available)
- Tensile test, 16 specimens: 3 days for room temperature, 5 days for elevated temperature
- Staircase fatigue study, 30 specimens + 5 specimens: 2 months to 3 months
- Overstress-probe fatigue study, 16 samples: 2 weeks to 4 weeks
- Strain-controlled fatigue study, 20 samples to 25 samples: 4 weeks to 6 weeks

3.5 Test Required Information. Material tested shall be fully identified: part name and number, primary forming manufacturer and location, alloy, heat treatment, location in part, part production or pre-production phase and, if applicable, manufacturing line.

3.6 Personnel/Skills. Test personnel shall be fully trained in the execution of required test procedures in applicable test methods cited in Section 2.

4 Procedure

4.1 Preparation. A detailed test matrix and sectioning plan shall be prepared prior to test. Target locations in parts shall be identified and sufficient parts shall be provided to **Lab** in order to obtain the number of specimens necessary.

4.1.1 Sample Location in Part. One or more sample locations are generally identified in part specifications. In other usages of this specification **Purchaser** shall approve sample location.

4.1.2 Geometrically Similar Locations. When multiple samples taken from the same part are to be grouped together for statistical calculations, special requirements apply:

- Locations must be geometrically similar with the expectation that they exhibit similar properties
- For staircase fatigue testing, samples must be tested in subgroups per D2.1
- Statistics on properties shall be calculated separately prior merging subgroups per 5.1.1

4.1.3 Sampling Plan. When different test types (e.g., tensile, fatigue) are included in the same test study, a systematically randomized sampling plan shall be developed by **Supplier** and approved by **Purchaser**.

4.1.3.1 Lab shall document exact locations where samples have been extracted from part.

4.1.3.2 General Motors Materials Engineering can provide example test plans.

4.2 Conditions.

4.2.1 Environmental Conditions. Specimen temperature shall be allowed to stabilize 30 minutes prior to test.

4.2.2 Test Conditions. Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.3 Instructions. See appendices for specific test instructions.

5 Data

5.1 Calculations.

5.1.1 Treatment of Subgroups. When a test study contains subgroups, calculate separate averages of each subgroup to determine if significant differences exist. Due to large uncertainty in averages of small sample counts, the final judgment on combining subgroups shall be made by **Purchaser**.

5.1.2 Test Specific Requirements. See appendices.

5.1.3 Statistical Analysis. See Appendix A.

5.2 Interpretation of Results.

5.2.1 Comparison of Test Data with Specifications. (Does not apply when no specification is applicable.)

5.2.1.1 Minimum (Min) Specifications. Individual test results that do not meet specified minimum (Min) shall be reported to **Purchaser**. Test results that fail to meet specified minimum (Min) may qualify for retest per 5.4.

- In the case where cases where minimum (Min) permits retesting, this statistic is not the true minimum. (Reference: P.N. Crepeau, Shape Casting: 2nd International Symposium, TMS Annual Meeting, 2007.)

5.2.1.2 Group Statistics. Statistical measures of average, -3σ , and Weibull B1C50 from tensile and fatigue tests that do not meet the specification shall be flagged and reported to **Purchaser**.

5.3 Test Documentation. (Report) Test reports shall disclose data per applicable standards ASTM B557/B557M, ASTM E8/E8M, ASTM E466, ASTM E606, and/or ISO 6892, plus:

- Sample identification including alloy, heat treatment condition, environmental exposure, etc.
- Sectioning plans, including sample counts and where samples have been excised from parts, etc.
- Strategy for selecting subgroups
- Individually calculated statistics for each subgroup
- Disclosure and explanation of any retests and replacement tests
- Upon request by **Purchaser**: Engineering stress-strain data in tabular and graphical x-y format (e.g., full tensile curves with extensometer readings through fracture, strain-controlled fatigue hysteresis loops, etc.)

5.4 Retests and Replacement Tests.

5.4.1 When a test result fails to meet a specified minimum, retesting may be permitted. If a discrepancy occurs with a test, a replacement test may be permitted. Samples must be provided to **Lab** for this purpose.

Note: Requirements herein for retests and replacement tests are based on ASTM B557/B557M.

5.4.1.1 If material is unavailable for retest or replacement, **Purchaser** shall be queried for subsequent instructions.

5.4.2 Retests. If a tensile test result fails to conform to a specified minimum (Min), retesting is permitted under the following conditions:

- For each test result that fails to exceed specified minimum (Min), retest at least two additional specimens from the same designated control location in either the original part (if sufficient material remains), or from other parts from the same lot. **Purchaser** may specify an alternate location for this purpose

5.4.3 Failure at Acceptable Defects. If a test specimen fails at a defect explicitly accepted by the part specification, **Purchaser** may permit the test result to be disregarded. In this case, retest per 5.4.2.

5.4.4 Replacement Tests. A test specimen may be discarded and a replacement specimen selected from the same lot of material in any of the following situations:

- The specimen was poorly machined
- The test procedure was incorrect or the test equipment malfunctioned.
- Either fracture or necking occurred outside the gage length, and elongation was below the specified minimum (Min)
- If the specimen failed at a discontinuity that would not be present in parts that pass quality control procedures in the process control plan

5.4.4.1 For separately manufactured test specimens, pre-existing cracks exhibited in the fracture are grounds for selecting replacement test specimens.

5.4.4.2 For test specimens excised from parts, however, discontinuities revealed in the fracture that are indicative of inferior material, such as cracks, ruptures, flakes, and excessive porosity, are not grounds for a replacement test.

Note: This specification is intended to measure material properties in parts (not material *per se*) as affected by part design and casting parameters.

5.5 Data Quality. See test-specific requirements in appendices.

6 Safety

This Engineering Standard may involve safety requirements for hazardous materials, the method of operations and equipment. This standard does not propose to address all the safety issues associated with its use. It is the responsibility of the user of this standard to ensure compliance with all appropriate safety and health practices. This would include any specific training that may be required. The safety and health standards include site specific rules and procedures, company rules and procedures, and Government Standards. Contact shall be made with the appropriate site Safety and Health personnel for further direction and guidance in these matters.

7 Notes

7.1 Glossary.

Elongation: A measure of ductility (as plastic strain in GMW16705) at the failure point in a tensile test.

Failure: Attainment of damage criteria where testing is stopped. In tensile tests, complete separation of a specimen at a crack induced by the test method. In fatigue, failure can occur at complete separation or at a measure of crack size.

First turnaround: In the set-up phase of a staircase fatigue test, there will be an initial sequence of failures or runouts. The first turnaround is the first occurrence of a different outcome (runout after initial failures, etc.)

Purchaser: Entity purchasing parts subject to this specification.

GM: General Motors Company and all fully owned subsidiaries.

Lab: The facility where testing is performed. **Lab** can be internal to **Purchaser** or **Supplier**, or it can be a 3rd party.

Minimum Standard: A measure of the lower value of a distribution of properties such as Min, -3σ and Weibull B1C50.

Runout: Where a fatigue sample has attained a predetermined number of cycles without failure and the test is stopped.

Sampling Plan: A document detailing the test matrix, part sectioning, exact sample locations and special instructions.

Staircase Fatigue Test: A procedure whereby successive samples are tested to a predetermined number of cycles, each at a stress amplitude dependent on the outcome of the previous test, either "fail" or "runout". Staircase test data can be analyzed to provide estimates of population average and standard deviation.

Stress Increment: In the staircase fatigue test, the predetermined increment of stress amplitude imposed on successive samples. In the overstress-probe fatigue test, 10% of the specified fatigue strength.

Strain-Controlled Fatigue: A test protocol whereby samples are repetitively loaded between two predetermined total strain levels until failure or runout.

Stress Time Percent: A statistic unique to the overstress-probe fatigue test measuring the degree a specimen surpasses a specified fatigue strength at a specified number of cycles.

Supplier: The provider of parts subject to **Purchaser** specifications. **Supplier** may be a subsidiary of **Purchaser**.

Tensile Test: A procedure for determining response to uniaxial loading, including definition of plastic deformation, and ductility.

7.2 Acronyms, Abbreviations, and Symbols.

7.2.1 Statistical.

-3σ Shorthand for [mean $- 3s$]

B1C50 Probability-based Weibull statistic meaning, at 50% confidence, that at least 99% of results exceed a specified value. (i.e., a 1% maximum failure rate)

Max Maximum

Min Minimum

s Standard deviation (also referred to as sigma)

7.2.2 Test-Specific.

E Elastic Modulus

EL Elongation

G:d Gage Length to Diameter Ratio

ID Identification

LCF Low Cycle Fatigue

STP Stress Time Percent

UTS Ultimate Tensile Strength

YS Yield Strength

7.2.3 Other.

GM General Motors Company

GSSLT Global Subsystem Leadership Team

PPAP Production Part Approval Process

8 Coding System

This standard shall be referenced in other documents, drawings, etc., as follows:

Use the format suggested in the examples shown in Table 2. Procedures and data operations apply when GMW16705 is specified.

Table 2: Example Callouts of GMW16705

Callout	Applicable Sections in GMW16705
Conduct tensile tests per GMW16705	Body + Appendix C
Extensometer correlation study per GMW16705	Appendix B
Conduct tensile and staircase fatigue testing per GMW16705	Body + Appendices C and D
Conduct staircase fatigue tests per GMW16705	Body + Appendix D
Strain-controlled fatigue study per GMW16705	Body + Appendix F
Report Weibull B1C50 per GMW16705, Appendix A	Appendix A

9 Release and Revisions

This standard was originated in October 2011. It was first approved by the Non-ferrous Metals and Castings GSSLT in March 2012. It was first published in April 2012.

Issue	Publication Date	Description (Organization)
1	APR 2012	Initial publication.
2	NOV 2017	E1.2-E1.4, E3.4, and E3.5 revised to allow for Min in Fatigue/OP. "Purchaser" replaces "GM" throughout. (Materials – Non-ferrous and Castings Global Subsystem Leadership Team (GSSLT))

Appendix A: Calculation of Statistical Minimum

A1 Scope

A1.1 Utilization. This section describes recommended practice for determination of statistical minimum (i) by Weibull analysis and (ii) by use of average and standard deviation. This methodology is applicable in GMW16705 to tensile YS and UTS, and overstress-probe STP.

A1.2 Limitation. Detailed theory on Weibull analysis is omitted.

A1.3 Description. Test data results are to be inputted into commercial or in-house software.

A2 Procedure

A2.1 Weibull Statistical Minimum. Purchaser may specify use of the Weibull statistical minimum B1C50, defined as stress or STP level for 1% failure rate at 50% confidence.

A2.1.1 Weibull Analysis Options. The analyst shall select the following settings:

- 2-constant fit (β , η) by linear regression minimizing X-errors (e.g., YS, UTS, or cycles-to-failure)
- 50% confidence (unless otherwise specified by Purchaser)
- 2-sided limits, median ranking

A2.1.2 Weibull Example and Validation. Weibull analysis for B1C50 must agree with results in the example of an overstress probe fatigue test shown in Figure A1.

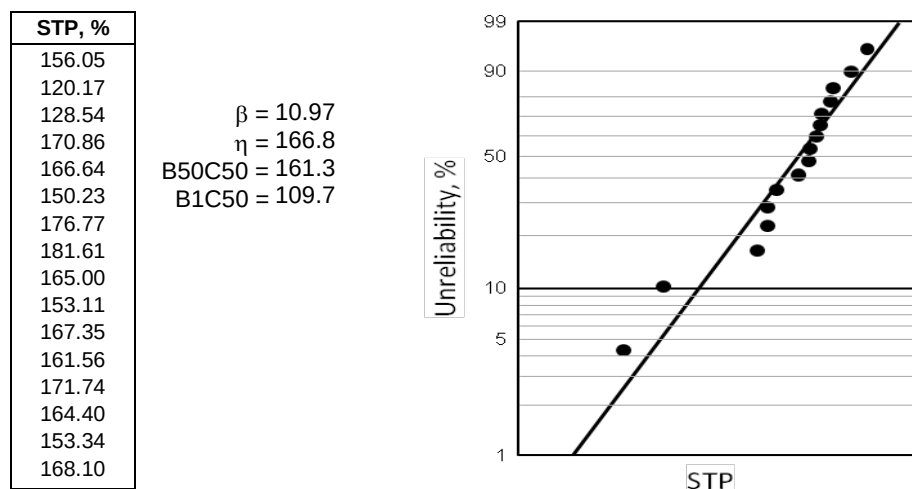


Figure A1: Weibull Analysis Result for B1C50 Showing Least Squares Results for β and η

A2.2 Statistical Minimum -3Sigma. Purchaser may specify use of the statistical minimum -3Sigma, calculated by the following equations. (These equations are average and standard deviation provided by common statistical software.)

Note: The -3Sigma statistic is independent of assumptions on property distribution. All distributions exhibit average and standard deviation.

$$\bar{X} = \frac{\sum X_i}{n} \quad s = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n-1}} \quad -3\text{Sigma} = \bar{X} - 3s$$

Where:

$\bar{X}$ = Average

X_i = Individual test result

n = Number of test results

s = Standard deviation (Sigma)

-3Sigma = Statistical minimum

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