SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4938

Issued JAN 1999
Reaffirmed DEC 2004

Forgings, Titanium Alloys
Heat-Treated, Finished-Part Properties: Short-Transverse Tensile, Fracture Toughness, and Longitudinal Time-Dependent-Tension

1. SCOPE:

1.1 Form:

This specification establishes requirements for titanium forgings of any shape or form from which finished parts are to be made. (See 8.2, 8.4.4, 8.6, and 8.7).

1.2 Application:

These forgings are used typically in the manufacture of high-performance parts when control of short-transverse tensile, fracture toughness, tensile creep, or tensile rupture is required, but usage is not limited to such applications.

1.2.1 These forgings are to be manufactured in accordance with a documented process; product approval is based on first-article demonstrations of mechanical and microstructural properties in the heat-treat condition and section size of the finished part.

1.2.2 Certain design and processing procedures may cause some of these products to become susceptible to stress-corrosion cracking after heat treatment; ARP982 recommends practices to minimize such conditions.

1.3 Classification:

Forgings shall be of the following Grades as specified in the ordering data. (See 8.3). When no Grade is specified, Grade A shall apply.

1.3.1 Grade A: Acceptance tests include verification of room-temperature tensile properties and, when applicable, of room-temperature fracture toughness. Preproduction testing includes verification of all applicable requirements.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
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Email: custsvc@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

1.3.2 Grade B: Acceptance tests do not include verification of mechanical properties. Preproduction testing includes verification of all applicable requirements.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2380 Approval and Control of Premium-Quality Titanium Alloys
AMS 2643 Structural Examination of Titanium Alloys
AMS 2801 Heat Treatment, Titanium Alloy Parts
AMS 2808 Identification, Forgings

ARP982 Minimizing Stress-Corrosion Cracking in Wrought Titanium Products

2.2 ASTM Publications:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 8 Tension Testing of Metallic Materials
ASTM E 8M Tension Testing of Metallic Materials (Metric)
ASTM E 21 Elevated Temperature Tension Tests of Metallic Materials
ASTM E 139 Conducting Creep, Creep-rupture, and Stress-rupture Tests of Metallic Materials
ASTM E 292 Conducting Time-for-rupture Notch Tension Tests of Materials
ASTM E 399 Plane-Strain Fracture Toughness of Metallic Materials
ASTM E 1304 Plane-Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
ASTM E 1447 Hydrogen Analysis

2.3 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-H-82100 Heat Treatment of Titanium and Titanium Alloys
MIL-STD-129 Marking for Shipment and Storage

3. TECHNICAL REQUIREMENTS:

3.1 Material:

Forgings shall be produced from forging stock that conforms to the material specification specified by the purchaser. (See 8.3 and Annex A).

3.2 Condition:

3.2.1 Physical: Forgings shall not be welded, shall have acceptance test tabs, and shall be supplied descaled and etched (3.5.1), with all acceptance-test tabs and test-material prolongations not consumed in predelivery testing in place. (See 8.4 and 8.5).

3.2.2 As-Supplied Heat-Treat Condition: Forgings shall be supplied in the heat-treat condition specified by the material specification (3.1) unless otherwise specified on the drawing. (See 8.1 and 8.3).

3.3 Properties:

Test specimens, excepting those for macrostructure (3.3.2.2), shall conform to 4.3.4 and 4.3.5.

3.3.1 Mechanical Properties: Mechanical properties shall conform to the requirements of the forging-stock material specification (3.1); if no such requirement exists, these properties shall be as specified by the purchaser. (See 8.1). Room-temperature tensile requirements (3.3.1.1.1) shall be applicable always; other mechanical properties shall be applicable only when so specified by the purchaser. (See 8.1).

3.3.1.1 Tensile: The short-transverse test direction shall be applicable when $S_{final\ HT} \geq$ 1 1/2 inches (38.1 mm); see Figure 1 for definition of $S_{final\ HT}$. The longitudinal test direction shall be applicable when $S_{final\ HT}$ < 1 1/2 inches (38.1 mm). (See 8.4.1).

3.3.1.1.1 Room-Temperature: Room-temperature tensile properties shall be determined in accordance with ASTM E 8 or ASTM E 8M.

3.3.1.1.2 Elevated-Temperature Tensile: Elevated-temperature tensile properties shall be determined in accordance with ASTM E 21.

3.3.1.2 Room-Temperature Fracture Toughness: Fracture toughness shall be determined either in accordance with ASTM E 399 using compact specimens or in accordance with ASTM E 1304 using short-rod or short-bar specimens provided that the required value of fracture-toughness is for the test method used. (See 8.1). Crack plane orientation, as defined in ASTM E 399, shall be "R-L" for round bars and hollow cylinders, "L-R" for upset discs, and "S-L" for all other shapes.

3.3.1.3 Time-Dependent Tension: The testing direction shall be the longitudinal direction (See 8.4.1).

3.3.1.3.1 Time-for-Rupture, Room-Temperature Tension: Time-for-rupture properties shall be determined in accordance with ASTM E 292. A standard cylindrical notched specimen shall be used.

3.3.1.3.2 Creep, Creep-Rupture, and Stress-Rupture Tension Properties: Creep, creep-rupture, and stress-rupture tension properties at elevated temperatures shall be determined in accordance with ASTM E 139. For creep tests and for stress-rupture tests, either a standard cylindrical combination smooth-and-notched specimen conforming to ASTM E 292 or separate specimens, smooth and notched, machined from adjacent sections of the same specimen blank shall be used.

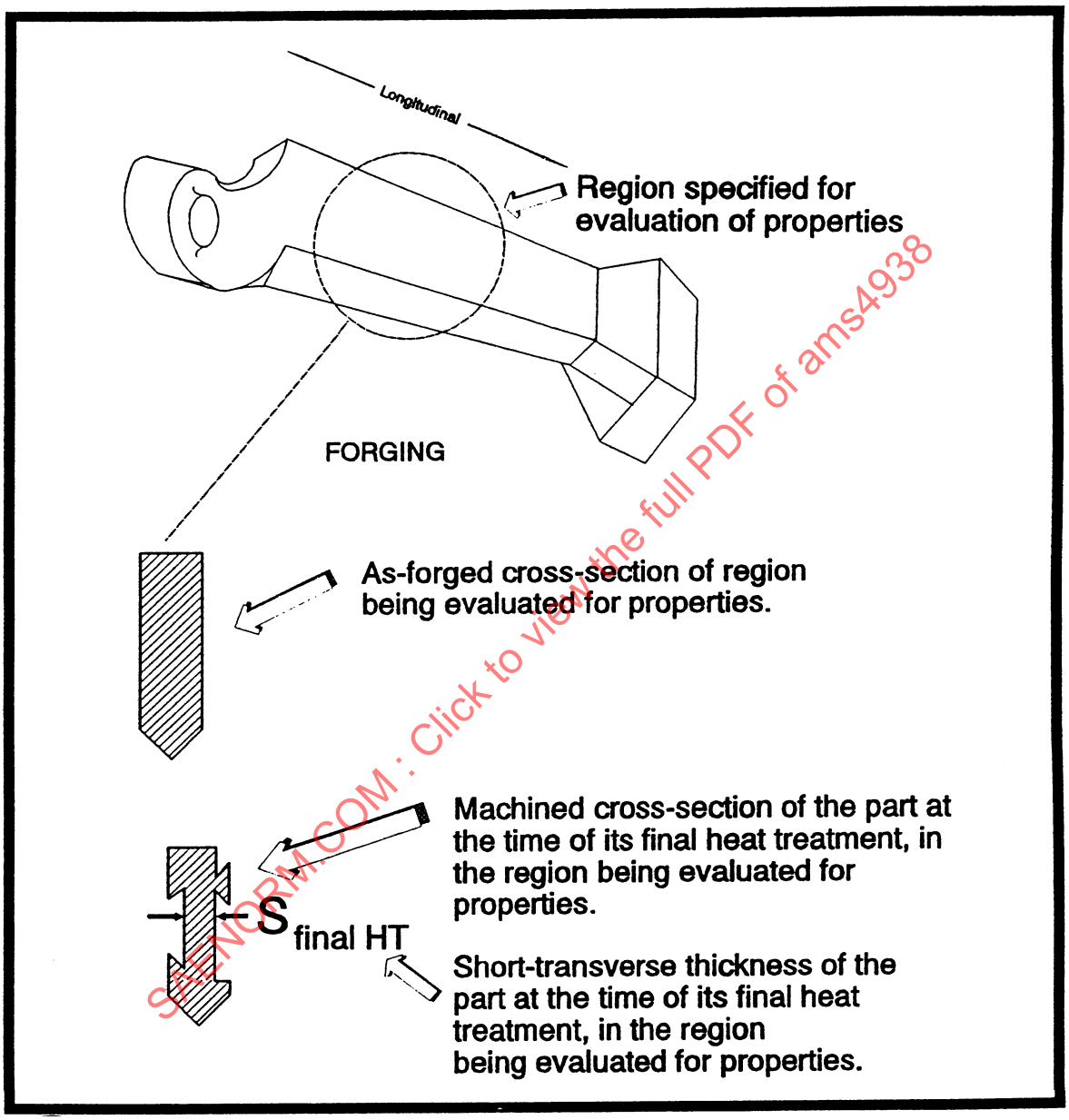

FIGURE 1 - Definition of $S_{final\ HT}$

3.3.2 Metallurgical Structure:

3.3.2.1 Microstructure: Microstructure shall conform to the requirements of AMS 2380 for forgings; the product specification shall be the specification which controls the forging stock (3.1).

3.3.2.2 Macrostructure: Macrostructure shall also conform to the requirements of AMS 2380 for forgings; macrostructural evaluations shall be performed on sections transverse to the grain flow at the locations of grain-flow sections (3.3.2.3).

3.3.2.3 Grain Flow: The internal grain-flow pattern shall conform to the requirements of the forging drawing. When not specified by the drawing, grain flow of die forgings in regions within 0.25 inch (6.4 mm) or 25 percent of the section thickness, whichever is smaller, of the forged surface shall follow the general contour of the forging; this requirement shall not apply to areas of acceptance-test-tab attachment, of prolongation attachment, or of flash extrusion ("flash line" or "parting plane"). (See 8.1 and 8.4). Unless locations are specified by the purchaser, the forging manufacturer shall select suitable locations for sectioning sufficient to fully document compliance with these requirements; as a minimum, cross-sections shall be taken normal to all die-closures. (See 8.1). A different alloy with similar hot-working characteristics may be used as a test medium when the grain flow pattern of the specified titanium alloy (3.1) is too faintly revealed to record photographically. Sections shall be finished and etched in accordance with AMS 2643 to reveal the grain flow. The grain-flow pattern shall be recorded photographically for reporting purposes (4.5).

3.4 Surface Contamination:

This requirement shall apply to forgings in the as-supplied heat-treat condition (3.2.2). Surface contamination (e.g., alpha case) shall conform to the material specification which controls the forging stock (3.1).

3.5 Quality:

3.5.1 Surface Condition: Forgings shall conform to the etch inspection requirements for forgings in AMS 2380. Forging surfaces shall be cleaned so as to be free of foreign material prior to such inspection. Imperfections may be removed, in which case, surfaces shall be reinspected in accordance with this paragraph.

3.5.2 Forging Control: The forging process shall be in accordance with a documented process which has met approval requirements (4.4).

3.5.3 Heat Treating Control: Heat treatment of forgings shall conform to the following requirements.

3.5.3.1 Delivered in the As-Supplied Heat-Treat Condition (3.2.2): Forgings shall be heat treated in accordance with MIL-H-82100 or, for alloys not listed in MIL-H-82100, in accordance with instructions from the purchaser. (See 8.1).

3.5.3.2 Delivered in the Finished-Part Heat-Treat Condition: Forgings shall be heat treated in accordance with AMS 2801 or, for alloys not listed in AMS 2801, in accordance with instructions from the purchaser. (See 8.1).

3.5.4 Hydrogen Control: The maximum concentration of hydrogen in the forged material shall be as specified in the material specification which controls the forging stock (3.1); if this material specification does not specify hydrogen content, it shall not exceed 0.015 percent by weight (150 ppm). Hydrogen analysis shall be performed on acceptance-test tabs from the completely processed forgings, in accordance with ASTM E 1447.

3.6 Tolerances:

Flash extension, measured from the body of the forging to the trimmed edge of the flash, shall not exceed the dimensional limits in Table 1.

TABLE 1 - Flash Extension Tolerances

Weight of Forging after Trimming in pounds (kilograms)	Flash Extension Limits in inches (millimeters)
5 and under (2.3 and under)	0 to 0.06 (0 to 1.5)
Over 5 to 25, incl (Over 2.3 to 11.3, incl.)	0 to 0.09 (0 to 2.3)
Over 25 to 50, incl (Over 11.3 to 22.7, incl.)	0 to 0.13 (0 to 3.3)
Over 50 to 100, incl (Over 22.7 to 45, incl.)	0 to 0.19 (0 to 4.8)
Over 100 to 200, incl (Over 45 to 91, incl.)	0 to 0.25 (0 to 6.4)
Over 200 to 500, incl (Over 91 to 227, incl.)	0 to 0.31 (0 to 7.9)
Over 500 to 1000, incl (Over 227 to 454, incl.)	0 to 0.38 (0 to 9.6)
Over 1000 (Over 454)	0 to 0.50 (0 to 12.7)

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection:

The supplier shall be responsible for the performance of all tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the forgings conform to the specified requirements.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: The requirements shown in Table 2 are acceptance tests and shall be performed on each lot. See 8.4.3 for the definition of a lot.

TABLE 2 - Acceptance Tests

Requirement	Paragraph Reference
Material	3.1
Condition	3.2
Room-Temperature Tensile Properties (Grade A)	3.3.1.1.1
Fracture Toughness (Grade A, when specified)	3.3.1.2
Surface Contamination	3.4
Surface Condition	3.5.1
Hydrogen Control	3.5.4

4.2.2 Periodic Tests: The requirements shown in Table 3 are periodic tests and shall be performed at a frequency selected by the supplier unless frequency of testing is specified by purchaser. When Grade B is specified, the requirements for Grade B in this specification supersede those in the material specification (3.1) when a conflict exists. For Grade A, the requirements of the material specification take precedence over those in this specification when a conflict exists. (See 8.2 and 8.7).

TABLE 3 - Periodic Tests

Requirement	Paragraph Reference
Room-Temperature Tensile Properties (Grade B)	3.3.1.1.1
Fracture Toughness (Grade B, when specified)	3.3.1.2
Elevated-Temp., Tensile Properties (when specified)	3.3.1.1.2
Time-for-Rupture, Room-Temp. (when specified)	3.3.1.3.1
Creep, creep-rupture, & stress-rupture (when specified)	3.3.1.3.2
Metallurgical structure	3.3.2

4.2.3 Preproduction Tests: All technical requirements are preproduction tests and shall be performed for first article approval and after any significant changes in the method of manufacture of the product.

4.3 Sampling and Testing:

NOTE: In 4.3.1, 4.3.2, and 4.3.3 the term “forging” shall denote either the forged shape, its acceptance test tab, or an associated prolongation or separately-forged coupon, as is applicable.

4.3.1 Acceptance: The following inspections shall be performed on each lot of forgings. See 8.4.3 for the definition of a lot.

4.3.1.1 Room-Temperature Tensile: For Grade A only, one or more forgings shall be tested for room-temperature tensile properties.

4.3.1.2 Fracture Toughness: For Grade A only (when specified), one or more forgings shall be tested for room-temperature fracture toughness properties.

4.3.1.3 Surface Contamination: Each forging of the sample required by Table 4, and one or more forgings from each load when chemical milling is used, shall be tested for surface contamination.

TABLE 4 - Acceptance Sampling Plan for Surface Contamination

Lot Size (Number of forgings)	Sample Size, Number of Forgings from Lot (Minimum)
1 to 4	All
5 to 25	5
26 to 100	6
101 and over	7

4.3.1.4 Surface Condition: Each forging shall be inspected for surface condition.

4.3.1.5 Hydrogen Content: One forging per lot, and one forging from each load where chemical milling is used, shall be tested for hydrogen content.

4.3.2 Periodic: Forgings for periodic tests shall be selected randomly from a forging lot for which compliance with all acceptance requirements (Table 2), has been verified. The number of forgings in the sample shall be sufficient to provide the material needed for verification of the applicable properties in Table 3 and number of determinations required.

4.3.3 Preproduction: The following inspections shall be performed. The number of forgings shall be sufficient to provide the material needed for verification of applicable properties and the number of determinations required below.

4.3.3.1 Mechanical Properties: There shall be three or more determinations of each applicable mechanical property.

4.3.3.2 Microstructure: Microstructure shall be determined on one or more mechanical-test specimens and there shall be two or more determinations.

4.3.3.3 Surface Contamination: Each forging shall be tested for surface contamination.

4.3.3.4 Macrostructure and Grain Flow: One or more forgings shall be sectioned for determination of grain flow and macrostructure.

4.3.3.5 Surface Condition: Each forging shall be inspected for surface condition.

4.3.3.6 Hydrogen Content: Each forging shall be tested for hydrogen content. There shall be three or more determinations.

4.3.4 Sources of Test Material for Properties (3.3): The source of test material shall be either a forging, a prolongation of a forging, or a separately-forged coupon (illustrated in Figure 2). The order of preference of selection is:

4.3.4.1 The forging in the region specified on the drawing or, when not specified, in the thickest section (See 8.1);

4.3.4.2 A prolongation which has reductions in the principal directions which are approximately the same as those in the location in the forging which encompasses the region of the finished part to be evaluated (See 4.3.4.1);

4.3.4.3 A separately-forged coupon which simulates a prolongation. The purchaser-approved, documented process (to the maximum practical extent) and forging stock from the same heat (preferably from the same lot), shall be used to produce a separately-forged coupon.

4.3.5 Preparation of Test Specimens for Properties (3.3):

4.3.5.1 Material Size at Time of Heat Treatment:

4.3.5.1.1 Processing:

4.3.5.1.1.1 Test specimens shall be manufactured from a test-material source (4.3.4) in accordance with either option in Figure 3.

4.3.5.1.1.2 Material from which test specimens for mechanical and microstructural properties are to be made shall be heat treated in accordance with AMS 2801 or, for alloys not listed in AMS 2801, in accordance with instructions from the purchaser. (See 8.1).

4.3.5.1.1.3 Test blocks are volumes of test material, such as are illustrated in Figure 4, within which specimen blanks are embedded to control their quench rate; the short-transverse thickness of a test block is the same as that of the part at the time of its final heat treatment (Figure 1). Specimen blanks are the aggregate of one or more single-test specimen blanks (illustrated in Figures 5 and 6). 4.3.5.1.2 covers the design of test blocks; 4.3.5.1.3 covers the design of specimen blanks. (See 8.4.2).

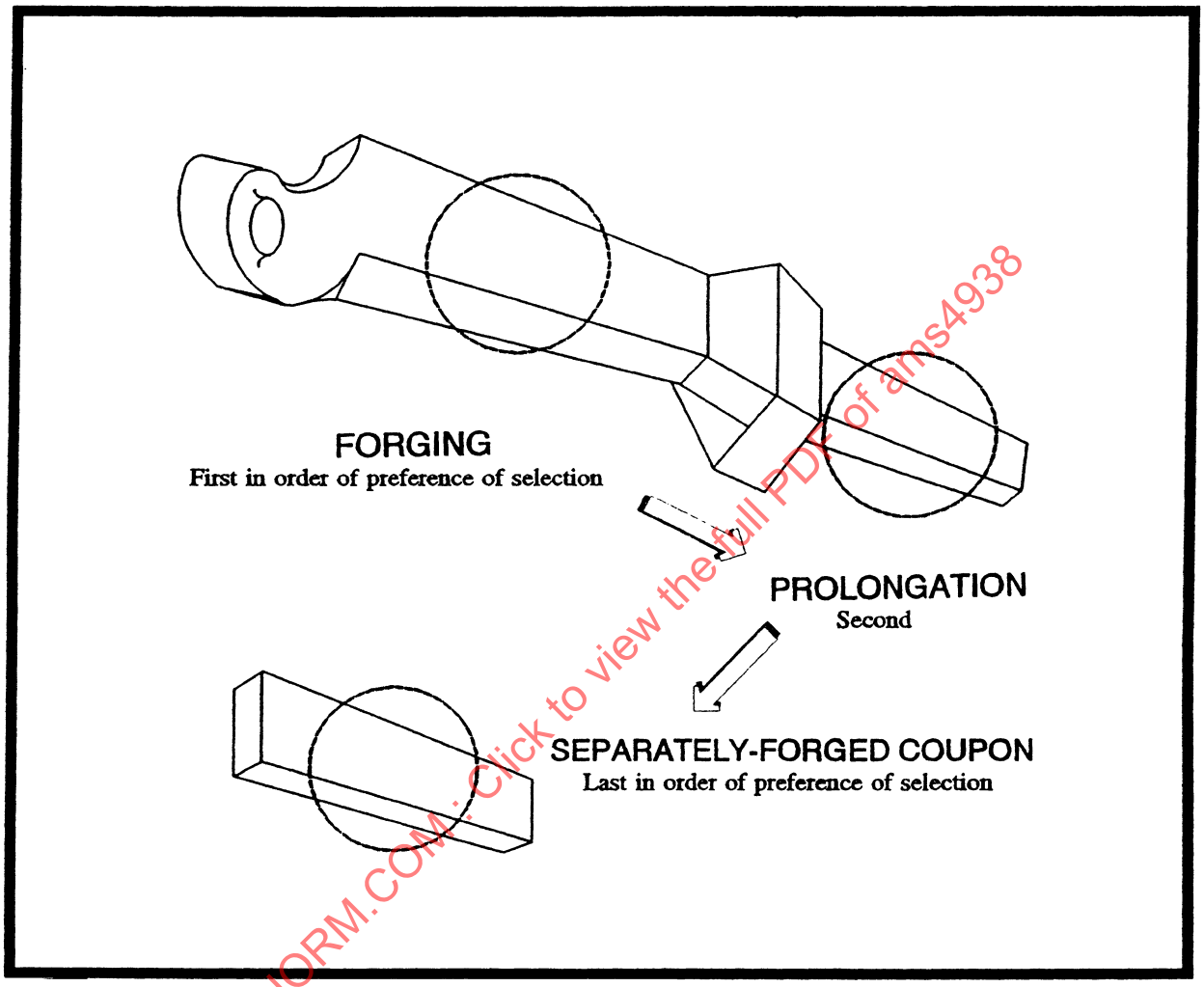

FIGURE 2 - Sources of Test Material

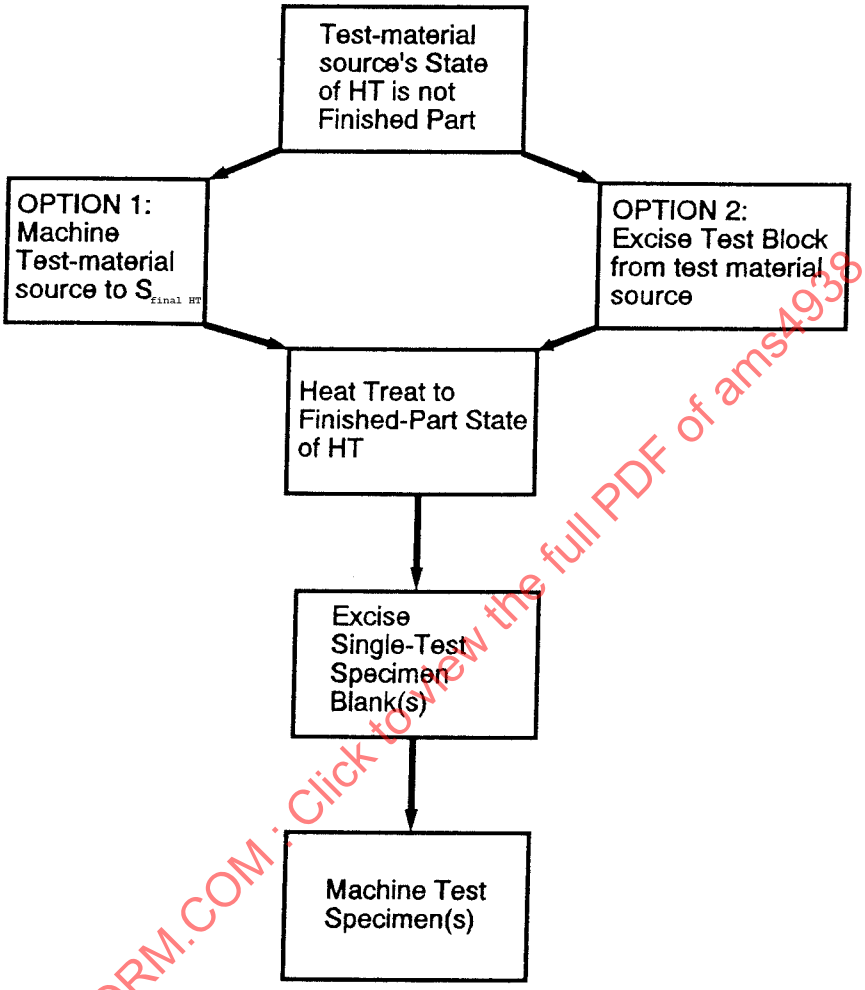

FIGURE 3 - Heat Treatment (HT) Sequence

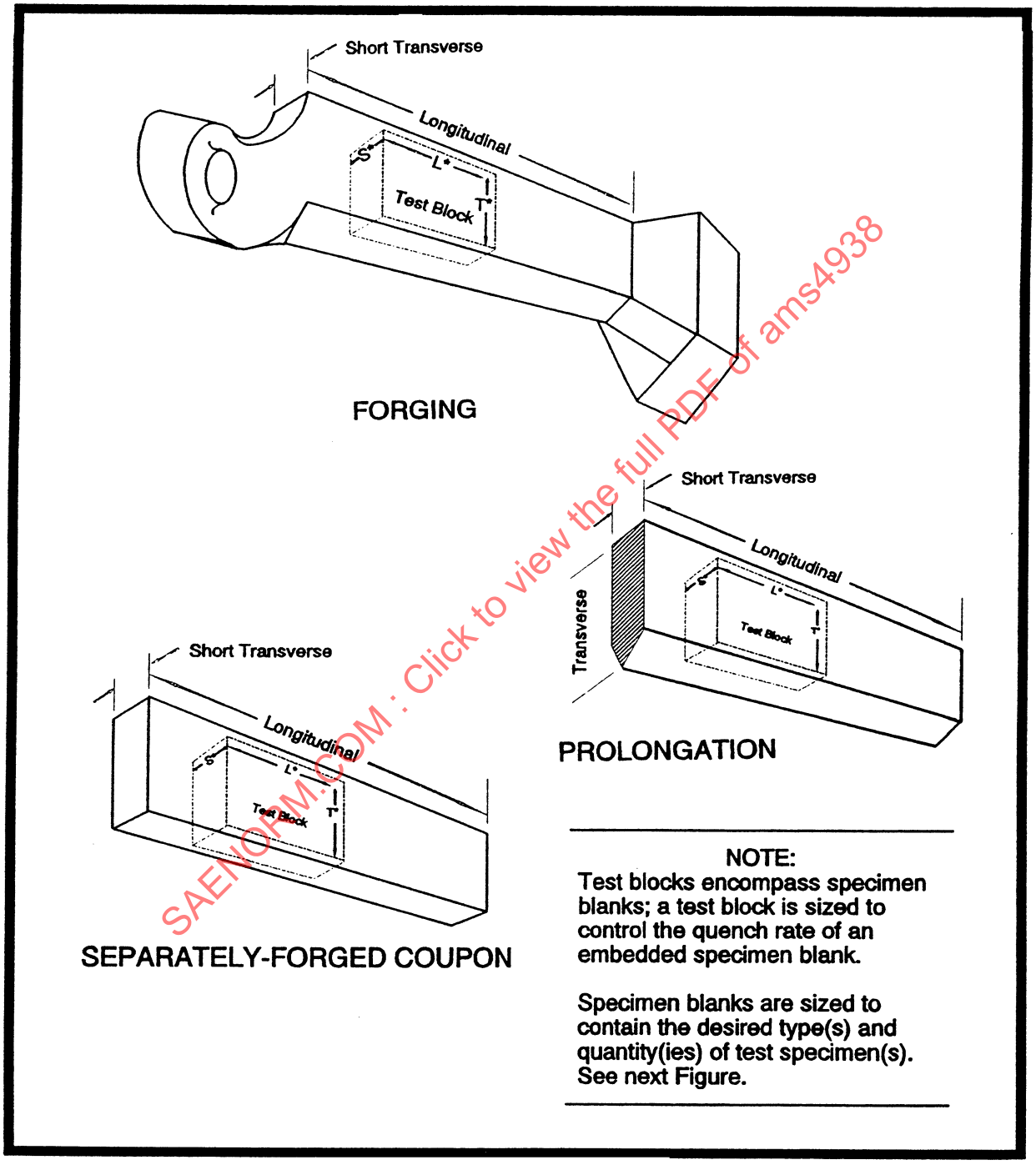

FIGURE 4 - Test Block Sources and Orientations

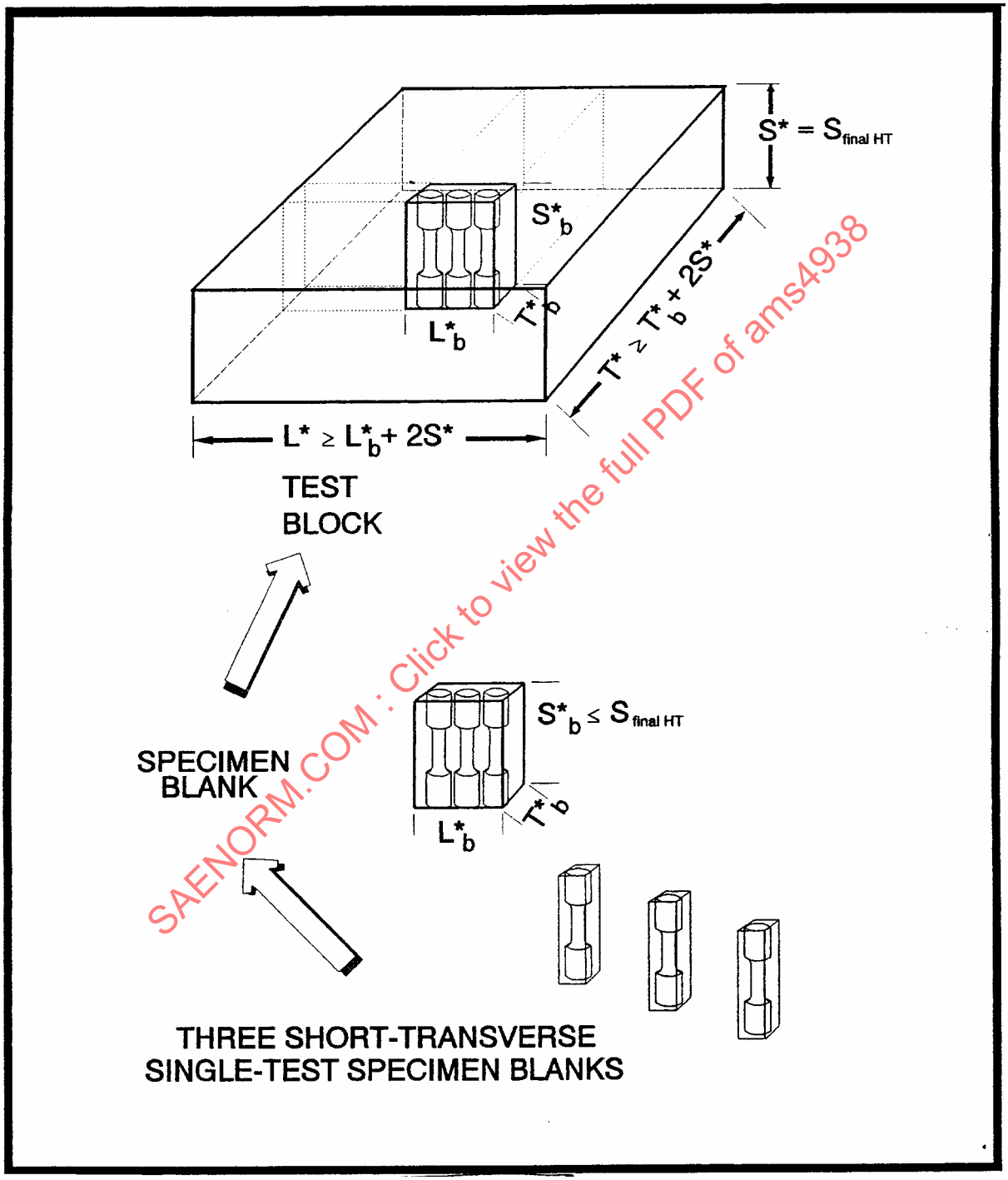

FIGURE 5 - Short-Transverse Specimen Blank Design and Test Block Design

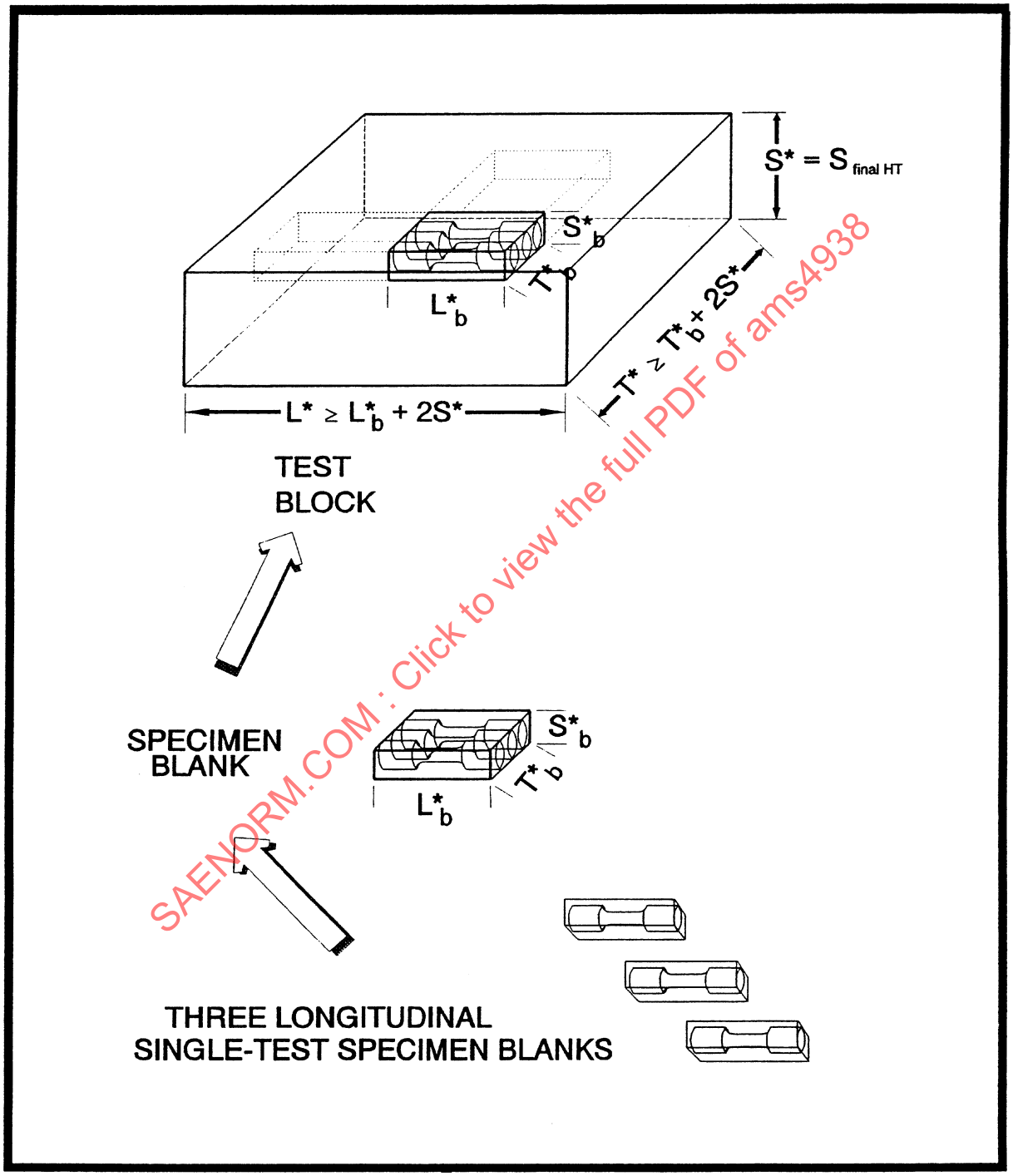

FIGURE 6 - Longitudinal Specimen Blank Design and Test Block Design

4.3.5.1.2 Design of Test Blocks:

4.3.5.1.2.1 Orientation: The dimensions of a test block, L*, T*, and S*, shall be aligned with respect to the metallurgical directions of the forging in accordance with Figure 4.

4.3.5.1.2.2 Size: The dimensions of a test block, L*, T*, and S*, shall be based on the dimensions of the encompassed specimen blank, L^*_b, T^*_b, and S^*_b (4.3.5.1.3), in accordance with Figures 5 and 6.

4.3.5.1.3 Design of Specimen Blanks: Specimen-blank dimensions shall be denoted as L^*_b, T^*_b, and S^*_b; these dimensions shall be sufficient to encompass the desired number(s) and type(s) of single-test-specimen blanks as depicted in Figures 5 and 6. Note that while the figures illustrate a case for three smooth tensile specimens, the concept is applicable to any number of specimens and to other types of test specimens (e.g., fracture toughness or notched stress-rupture).

4.3.5.1.3.1 Layout and Sizing: Specimen blanks shall be sized to encompass the single-test specimen blank(s) for the desired number and type(s) of test specimen(s); Figures 5 and 6 illustrate the concept. The length of S^*_b shall be in accordance with Figure 5 for short-transverse specimen blanks. The positioning of single-test-specimen blank(s) within a specimen blank shall conform to the following constraints:

4.3.5.1.3.1.1 The preferred positioning shall be single file and lined up parallel to L^*_b for the short-transverse test direction (Figure 5), parallel to T^*_b for the longitudinal test direction (Figure 6).

4.3.5.1.3.1.2 Short rod/short bar-fracture-toughness-specimen (ASTM E 1304) blanks may be stacked end-to-end parallel to the test direction and treated as though they were a single, single-test specimen blank.

4.3.5.2 Extraction of Specimen Blanks and Manufacture of Specimens:

4.3.5.2.1 Test Material Source (Figure 2) in Finished-Part Heat-Treat Condition: A specimen blank shall be considered to be embedded in the test material source, centered in the source within $1/8S_{final\ HT}$, and with its edges parallel to those of the source within 10 degrees. Single-test specimen blank(s) shall be excised from the specimen blank; test specimen(s) shall be machined from the single-test specimen blank(s). The following constraints shall be conformed to:

4.3.5.2.1.1 The short-transverse thickness of the region of the forging, prolongation, or separately-forged coupon to be evaluated for properties shall be the same as that of the part at the time of its final heat treatment, $S_{final\ HT}$; and

4.3.5.2.1.2 The forging, prolongation, or separately-forged coupon shall have been heat treated to the heat-treat condition of the finished part. (See 8.1)

4.3.5.2.2 Test Block in Finished-Part Heat-Treat Condition: The specimen blank shall be considered as centered in the test block within $1/8S_{final\ HT}$, with its edges parallel to those of the test block within 10 degrees. Single-test specimen blank(s) shall be excised from the specimen blank; test specimen(s) shall be machined from the single-test specimen blank(s).

4.4 Approval:

Approval shall be in accordance with the requirements of AMS 2380 for forgings.

4.5 Reports:

The supplier of forgings shall furnish with each production lot shipped, a report which includes AMS 4938 and the following:

a. Purchase order number
b. Material specification number, revision letter if any, and Grade
c. Supplier's identification number
d. Forging stock identification and acceptance-inspection data (test results)
e. Forging lot number and, if they exist, serial number of forgings
f. Part number
g. Quantity
h. Quantitative test results from acceptance inspection of the lot
i. Statement of conformance with all specification requirements

4.6 Resampling and Retesting:

If the results from a valid test fail to meet the specified requirements, acceptance of the product may be based on the results of retesting three additional specimens for each nonconforming specimen. Failure of the results of a valid retest to meet the specified requirements shall prohibit acceptance. A test may be declared invalid only if the specimen is dimensionally discrepant, exhibits behavior which the test method deems disqualifying, or the test equipment malfunctions. The results of all tests and retests shall be reported. Specimens for retest, or for replacement of invalid tests, shall be taken from a location adjacent to the original specimen(s). If there is no adjacent material available, material shall be taken from other locations in the same lot.

4.7 Acceptance:

Only lots which meet all of the requirements for the inspection of interest, as specified in 4.2, shall be accepted. In acceptance tests, the failure of individual forgings to meet requirements for surface condition shall not be cause for rejection of the entire lot, but only of the individual nonconforming forgings. Rejected lots, or rejected individual forgings, shall not be resubmitted for inspection without a statement showing how the non-conformity was resolved. "Lot" is defined in 8.4.3.