AEROSPACE MATERIAL SPECIFICATION

AMS4938™	REV. B

Issued 1999-01
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Revised 2024-11

Superseding AMS4938A

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

RATIONALE

AMS4938B results from a Five-Year Review and update of this specification with changes to relocate Definitions (see 2.4) and update Applicable Documents (see Section 2), Mechanical Properties (see 3.3.1), Surface Contamination (see 3.4), Hydrogen Control (see 3.5.4), presentation of tolerances (see Table 1), and Surface Contamination (see 4.3.1.3).

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 2.4.4, 8.3, and 8.6).

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 8.4); 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.

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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 issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent specified herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2380	Approval and Control of Premium-Quality Titanium Alloys
AMS2643	Structural Examination of Titanium Alloys, Chemical Etch Inspection Procedure
AMS2750	Pyrometry
AMS2801	Heat Treatment of Titanium Alloy Parts
AMS2808	Identification, Forgings
ARP982	Minimizing Stress-Corrosion Cracking in Wrought Titanium Alloy Products
AS7766	Terms Used in Aerospace Metals Specifications

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM E8/E8M	Tension Testing of Metallic Materials
ASTM E21	Elevated Temperature Tension Tests of Metallic Materials
ASTM E139	Conducting Creep, Creep-rupture, and Stress-rupture Tests of Metallic Materials
ASTM E292	Conducting Time-for-Rupture Notch Tension Tests of Materials
ASTM E399	Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
ASTM E1304	Plane-Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
ASTM E1447	Determination of Hydrogen in Reactive Metals and Reactive Metal Alloys by Inert Fusion with Detection by Thermal Conductivity or Infrared Spectrometry

2.3 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.3.1 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-STD-129 Military Marking for Shipment and Storage

2.4 Definitions

Terms used in AMS are defined in AS7766 and as follows:

2.4.1 TEST DIRECTIONS

2.4.1.1 LONGITUDINAL

Direction of maximum extension of the metal during forging.

2.4.1.2 SHORT TRANSVERSE

Direction of maximum contraction of the metal during forging.

2.4.2 TEST MATERIAL

2.4.2.1 ACCEPTANCE-TEST TAB

An extension of the forging to provide material for lot-acceptance testing (surface contamination and hydrogen control; see 3.4 and 3.5.5). The tab may be an extension of a prolongation.

2.4.2.2 PROLONGATION

An extension of the forging to provide test material, in many cases, for a test block (see 2.4.2.5).

2.4.2.3 TEST SPECIMEN

The configuration of test material that testing to determine properties (see 3.3) is performed. Test specimens are extracted, in many cases, from specimen blanks (see 2.4.2.4).

2.4.2.4 SPECIMEN BLANK

Specimen blanks are volumes of material from which test specimens are extracted. A specimen blank is generally encompassed by and heat-treated within a test block. Specimen blanks are dimensioned so as to contain adequately shaped and sized volume(s) for the desired test specimen(s) (see 2.4.2.3 and 2.4.2.5).

2.4.2.5 TEST BLOCK

A volume of test material that encompasses a specimen blank. The size of a test block is based on the dimension of the specimen blank (as specified in Figures 5 and 6). Specimen blanks are encompassed by test blocks to control the cooling rate of the specimen blank during heat treatment of test material (see 2.4.2.4).

2.4.3 LOT

All forgings of the same part number or configuration, opposite hands being considered one configuration, produced in the same forging run from the same lot of forging stock, heated and forged in the same manner, and heat treated in a continuous furnace or in a series of batch-type furnace operations with no change in furnace settings or interruption of power.

2.4.4 FINISHED PART

The part to be manufactured from the forging.

3. TECHNICAL REQUIREMENTS

3.1 Material

Forgings shall be produced from forging stock that conforms to the material specification specified by the purchaser (see 8.4 and Appendix A).

3.2 Condition

3.2.1 Physical

Forgings shall not be welded, shall have acceptance test tabs and/or prolongations, and shall be supplied descaled and etched (see 3.5.1), with all acceptance-test tabs and test-material prolongations not consumed in predelivery testing left in place (see 2.4 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 (see 3.1) unless otherwise specified on the drawing (see 8.2 and 8.4).

3.3 Properties

Test specimens, excepting those for macrostructure (see 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 (see 3.1) or to requirements specified by the purchaser (see 8.2). Room-temperature tensile requirements (see 3.3.1.1.1) shall be applicable always; other mechanical properties shall be applicable only when so specified by the purchaser (see 8.2).

3.3.1.1 Tensile

Tensile testing shall be in the short-transverse direction when $S_{final\ HT} \geq$ 1-1/2 inches (38.1 mm) and in the longitudinal direction when $S_{final\ HT}$ < 1-1/2 inches (38.1 mm) (see 2.4.1 and Figure 1).

3.3.1.1.1 Room Temperature

Room-temperature tensile properties shall be determined in accordance with ASTM E8/E8M with the rate of strain set at 0.005 in/in/min (0.005 mm/mm/min) and maintained within a tolerance of ±0.002 in/in/min (±0.002 mm/mm/min) through the 0.2% offset strain.

3.3.1.1.2 Elevated-Temperature Tensile

Elevated-temperature tensile properties shall be determined in accordance with ASTM E21.

3.3.1.2 Room-Temperature Fracture Toughness

Fracture toughness shall be determined either in accordance with ASTM E399 using compact specimens or in accordance with ASTM E1304 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 E399, 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 2.4.1).

3.3.1.3.1 Time-for-Rupture, Room-Temperature Tension

Time-for-rupture properties shall be determined in accordance with ASTM E292. 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 E139. For creep tests and for stress-rupture tests, either a standard cylindrical combination smooth-and-notched specimen conforming to ASTM E292 or separate specimens, smooth and notched, machined from adjacent sections of the same specimen blank shall be used.

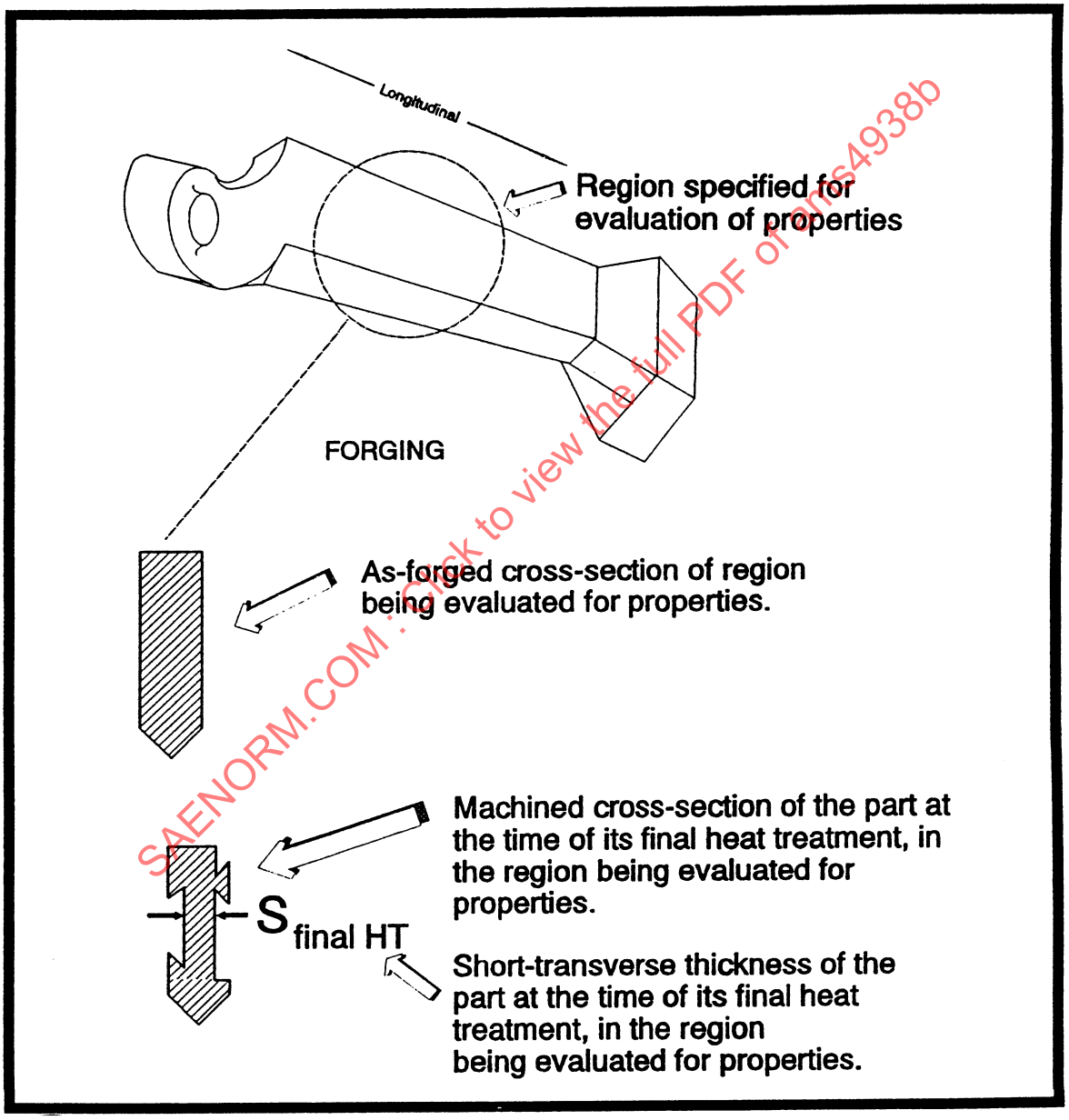

Figure 1 - Definition of $S_{final\ HT}$

3.3.2 Metallurgical Structure

3.3.2.1 Microstructure

Microstructure shall conform to the requirements of the material specification (see 3.1).

3.3.2.2 Macrostructure

Macrostructure shall also conform to the requirements of AMS2380 for forgings. Macrostructural evaluations shall be performed on sections transverse to the grain flow at the locations of grain-flow sections (see 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% 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 2.4 and 8.2). 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 8.2). 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 (see 3.1) is too faintly revealed to record photographically. Sections shall be finished and etched in accordance with AMS2643 to reveal the grain flow. The grain-flow pattern shall be recorded photographically for reporting purposes (see 4.5).

3.4 Surface Contamination

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

3.5 Quality

3.5.1 Surface Condition

Forgings shall conform to the etch inspection requirements for forgings in AMS2380. 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 that has met approval requirements (see 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 Heat-Treat Condition (See 3.2.2)

Forgings shall be heat treated in accordance with the material specification or, for alloys not having heat-treating parameters in the material specification, in accordance with instructions from the purchaser (see 8.2). Pyrometry shall be in accordance with AMS2750.

3.5.4 Hydrogen Control

The maximum concentration of hydrogen in the forged material shall be as specified in the material specification that controls the forging stock (see 3.1); if this material specification does not specify hydrogen content, it shall not exceed 0.015% by weight (150 ppm). Hydrogen analysis shall be performed on acceptance-test tabs from the completely processed forgings in accordance with ASTM E1447. The hydrogen sample shall be excised no more than 1/4 inch (6.35 mm) below the surface of the as-chem-milled or as-machined surface.

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 1A - Flash extension tolerances, inch/pound Units (see 8.8)

Weight of Forging after Trimming Pounds	Flash Extension Limits Inches
5 and under	0 to 0.06
Over 5 to 25, incl	0 to 0.09
Over 25 to 50, incl	0 to 0.13
Over 50 to 100, incl	0 to 0.19
Over 100 to 200, incl	0 to 0.25
Over 200 to 500, incl	0 to 0.31
Over 500 to 1000, incl	0 to 0.38
Over 1000	0 to 0.50

Table 1B - Flash extension tolerances, SI units (see 8.8)

Weight of Forging after Trimming Kilograms	Flash Extension Limits Millimeters
2.3 and under	0 to 1.5
Over 2.3 to 11.3, incl	0 to 2.3
Over 11.3 to 22.7, incl	0 to 3.3
Over 22.7 to 45, incl	0 to 4.8
Over 45 to 91, incl	0 to 6.4
Over 91 to 227, incl	0 to 7.9
Over 227 to 454, incl	0 to 9.6
Over 454	0 to 12.7

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The supplier shall be responsible for the performance of all tests. The 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 2.4.3 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 the purchaser. When Grade B is specified, the requirements for Grade B in this specification supersede those in the material specification (see 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 8.3 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-Temperature, Tensile Properties (when specified)	3.3.1.1.2
Time-for-Rupture, Room Temperature (when specified)	3.3.1.3.1
Creep, Creep-Rupture, and 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 2.4.3 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

For forgings where material removal (chemical or mechanical) on all surfaces is at least 0.015 inch (0.381 mm), one forging per lot is required and shall be evaluated for surface contamination. When thickness of material removal is unknown or less than 0.015 inch (0.381mm), sampling shall be per Table 4. If chemical milling is used, evaluation of one or more forgings from each load shall take place after chemical milling.

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 that compliance with all acceptance requirements (see 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 (See 3.3)

The source of test material shall be either a forging, a prolongation of a forging, or a separately forged coupon (see 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 8.2).

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

4.3.4.3 A separately forged coupon that 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 (See 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 (see 4.3.4) in accordance with either option in Figure 3.

4.3.5.1.1.2 Material that test specimens for mechanical and microstructural properties are to be made shall be heat treated in accordance with the material specification (see 3.1 and 8.4).

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 (see Figure 1). Specimen blanks are the aggregate of one or more single-test specimen blanks (see Figures 5 and 6). Section 4.3.5.1.2 covers the design of test blocks; 4.3.5.1.3 covers the design of specimen blanks (see 2.4.2).

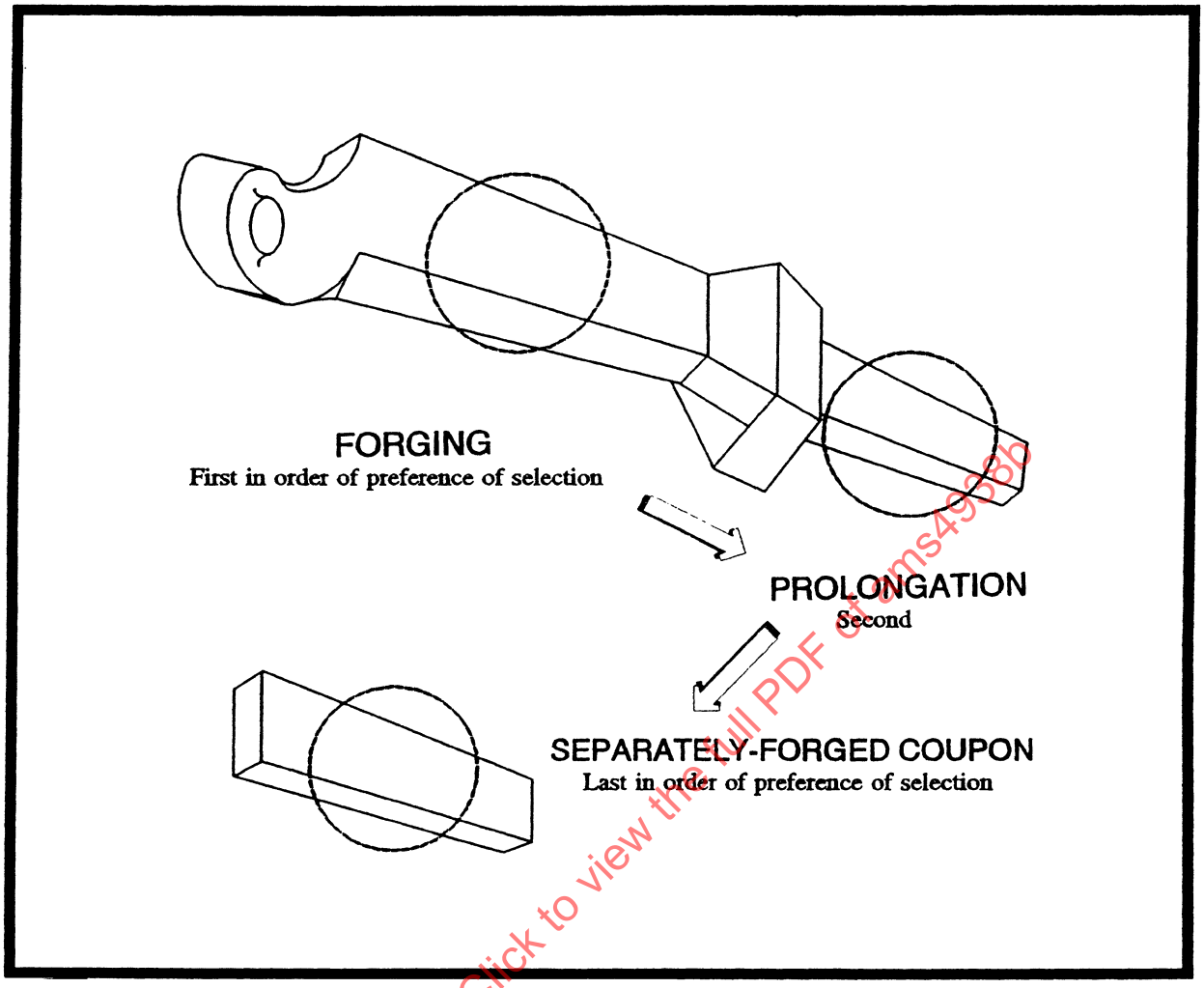

Figure 2 - Sources of test material

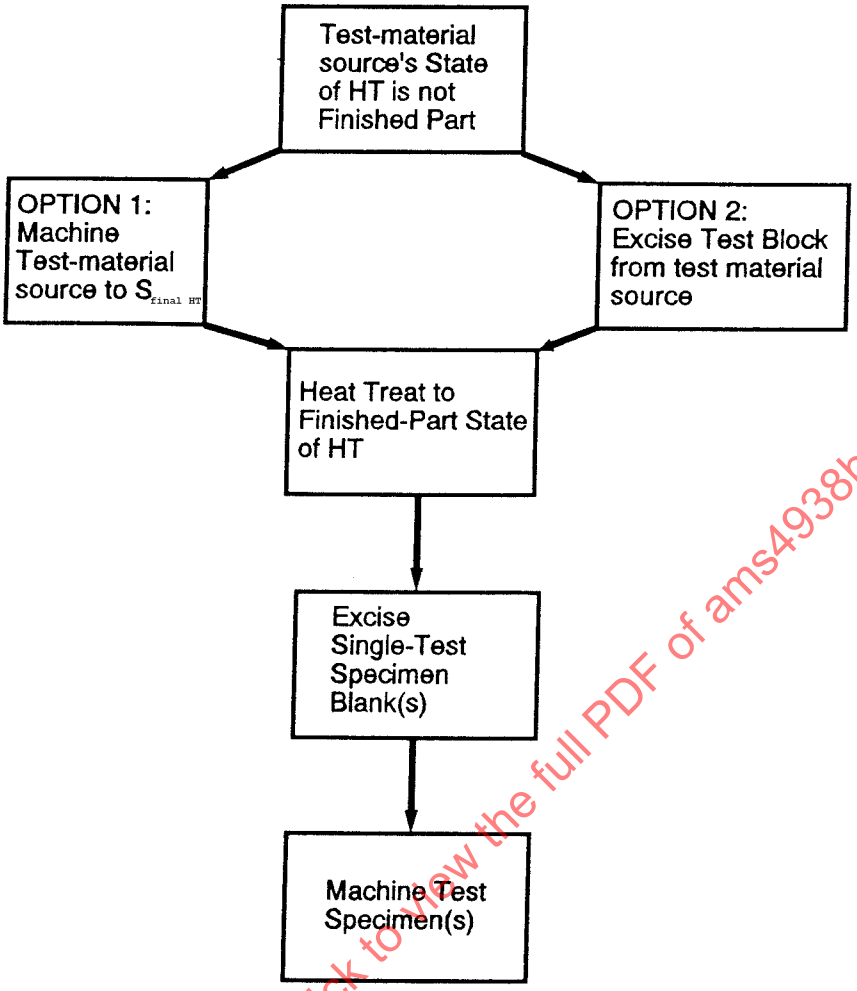

Figure 3 - Heat-treatment (HT) sequence

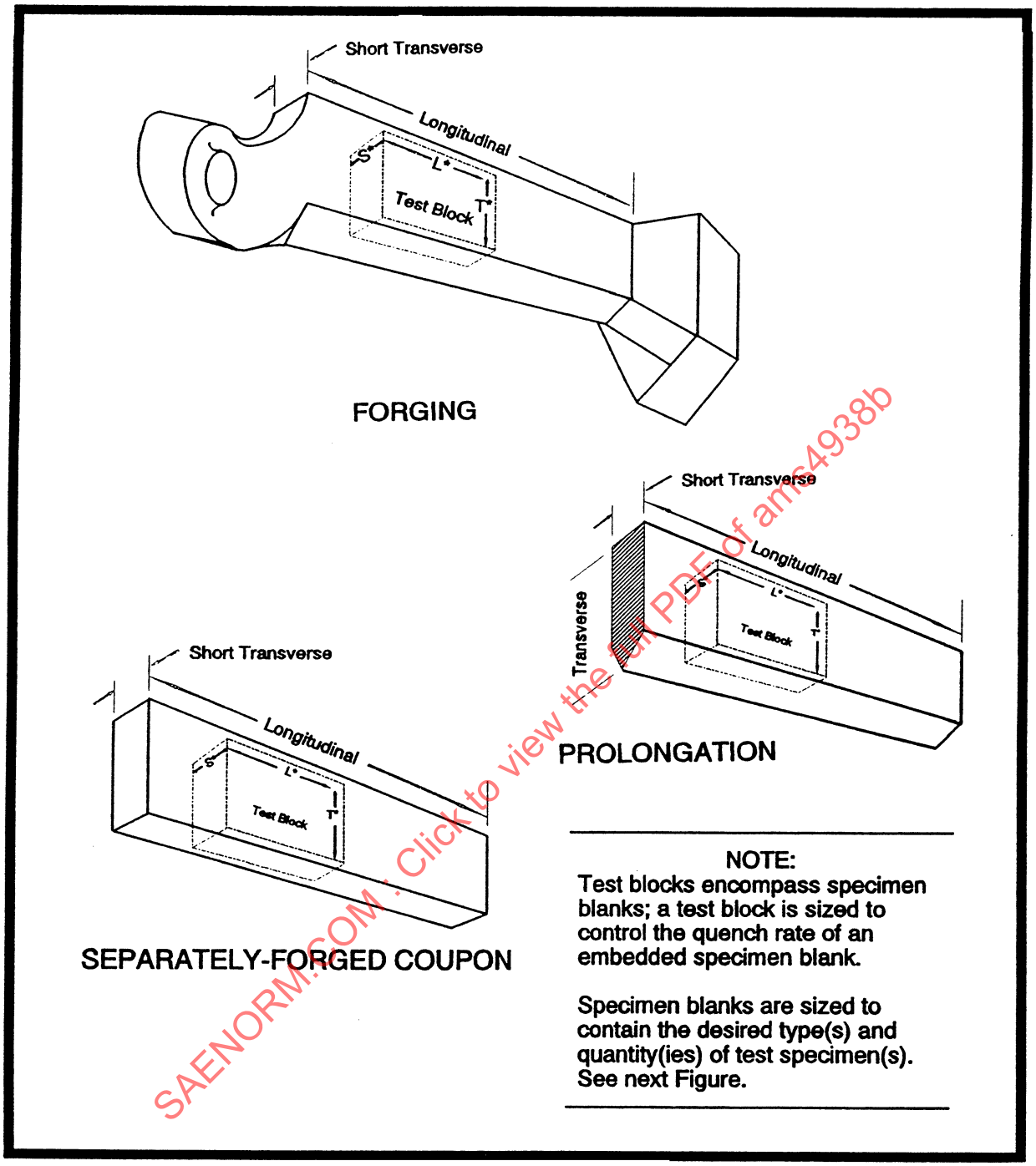

Figure 4 - Test block sources and orientations

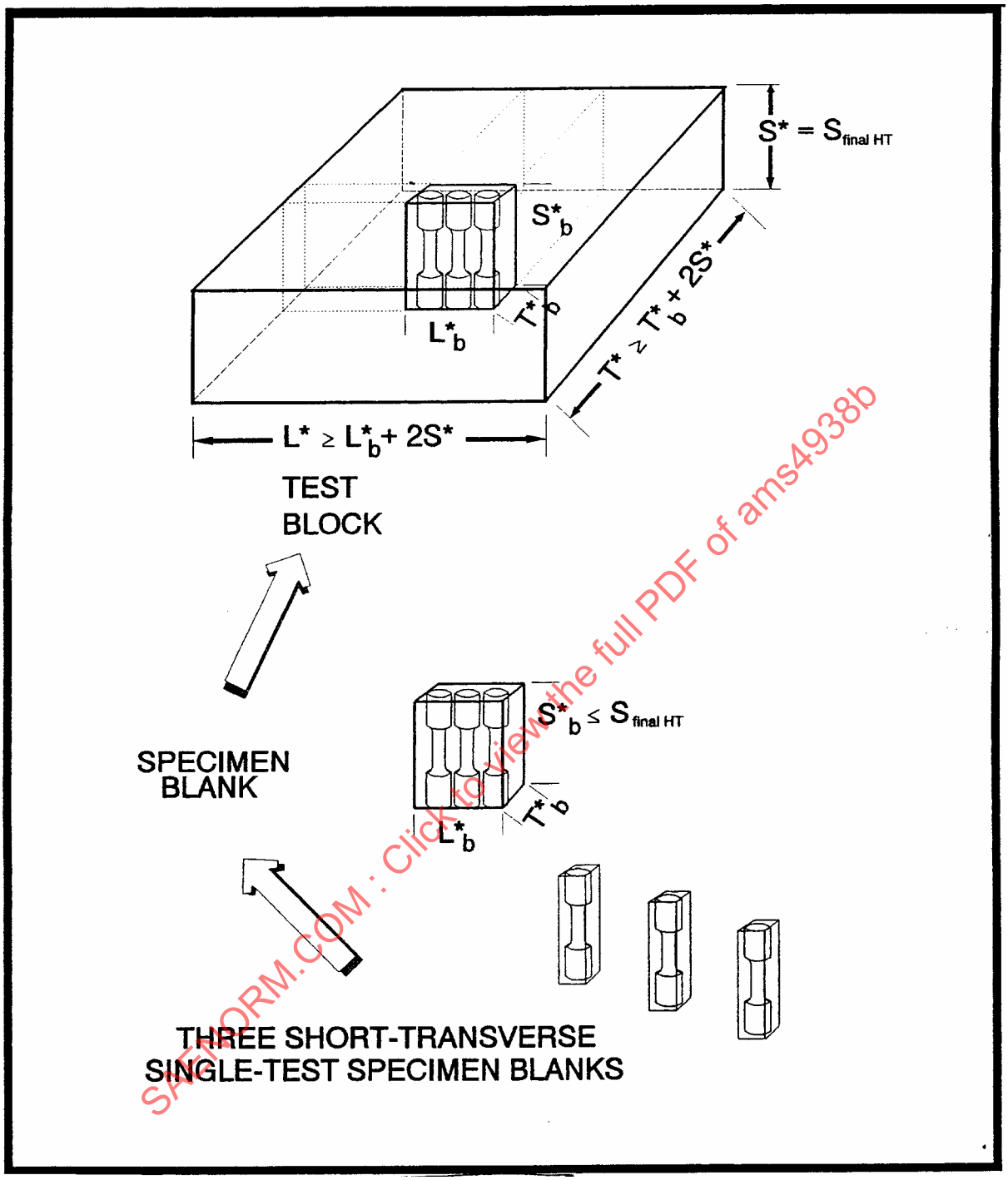

Figure 5 - Short-transverse specimen blank design and test block design

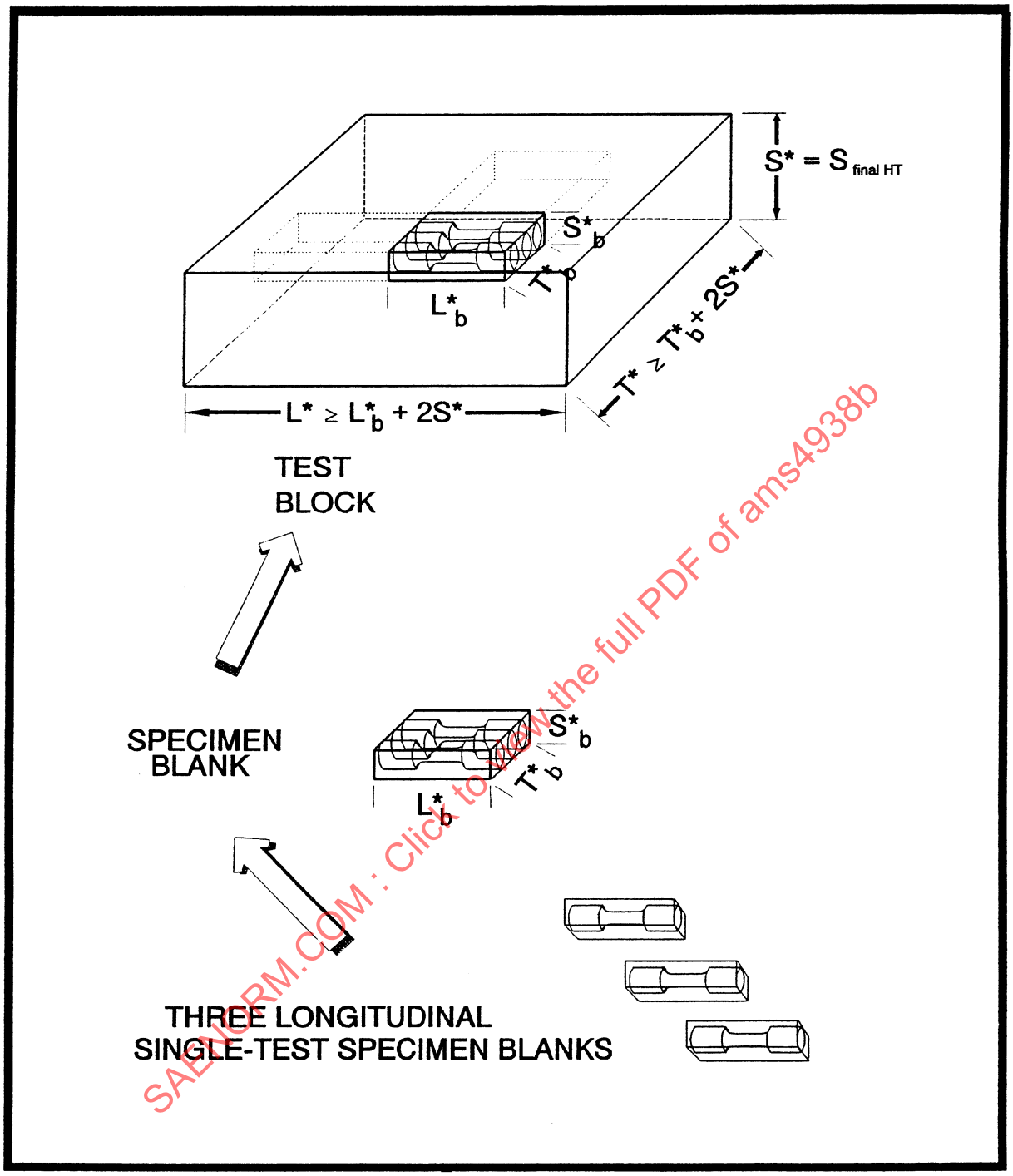

Figure 6 - Longitudinal specimen blank design and test block design

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 (see 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 (see Figure 5) and parallel to T^*_b for the longitudinal test direction (see Figure 6).

4.3.5.1.3.1.2 Short rod/short bar fracture-toughness specimen blanks (refer to ASTM E1304) 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 (See 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, $S_{final\ HT}$.

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 8.2).

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 AMS2380 for forgings.