SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

SAE AMS 4335

Issued 2001-10
Reaffirmed 2011-08

Forgings, Aluminum Alloys 2xxx and 7xxx, Heat-Treated, Finished-Part Properties: Short-Transverse Tensile Properties and Fracture Toughness

1. SCOPE:

1.1 Form:

This specification establishes requirements for 2xxx-series and 7xxx-series aluminum alloy forgings of any shape or form from which finished parts are to be made. (See 8.2, 8.3, 8.4, 8.5.4, 8.6 and 8.8.)

1.2 Application:

These forgings are used typically in the manufacture of high-performance parts when control of short-transverse tensile properties and fracture toughness 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 microstructural properties and of mechanical properties in the heat-treat condition and section size of the finished part.

1.2.2 Certain design and processing procedures may cause these products to become susceptible to stress-corrosion cracking after heat treatment. ARP823 recommends practices to minimize such conditions.

1.3 Classification:

Forgings shall be one of the following Types defined below and in Table 1, as specified in the ordering data. (See 8.4.) When no Type is specified, Type 2 shall be supplied.

1.3.1 Type 1: For maximum acceptance testing and product uniformity. All requirements are preproduction tests, all requirements excepting grain flow are acceptance tests, and all of the forgings in a lot must be from the same lot of forging stock. (See 8.5.3.1.)

1.3.2 Type 2: For maximum acceptance testing without maximum product uniformity. All requirements are preproduction tests, all requirements excepting grain flow are acceptance tests, and the forgings in a lot may be from different lots of forging stock. (See 8.5.3.2.)

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TABLE 1 - Classification of Forgings

Paragraph	Requirement	Forging Type 1 (1.3.1)	2 (1.3.2)	3 (1.3.3)
4.2.1	*Acceptance of Production Lots of Forgings*			
3.0	All Technical Requirements with the exception of: 3.3.3 Grain Flow. (Fracture Toughness and Internal Soundness only when specified.)	✔	✔	—
3.0	All Technical Requirements with the exceptions of: 3.3.1.1 Tensile Properties, Capability test. 3.3.1.2 Fracture Toughness, Capability test. 3.3.3 Grain Flow. (Fracture Toughness and Internal Soundness only when specified.)	—	—	✔
1.3	Forging Stock	Same lot of same alloy	Same alloy	Same alloy
4.2.2	*Periodic Inspection of Production Lots of Forgings*			
3.3.1.1	Tensile Properties, Capability test.	—	—	✔
3.3.1.2	Fracture Toughness, Capability test (only when specified).	—	—	✔
4.2.3	*Pre-production Inspection of Forgings*			
3.0	All Technical Requirements (Fracture Toughness and Internal Soundness only when specified.)	✔	✔	✔
1.3	Forging Stock	Same lot of same alloy	Same alloy	Same alloy

1.3.3 Type 3: For economic advantage so long as the forging manufacturer has a firmly-entrenched, fairly sophisticated quality system. All requirements are preproduction tests, tensile and fracture toughness tests are periodic tests (8.7), all other requirements excepting grain flow are acceptance tests, and the forgings in a lot may be from the different lots of forging stock. (See 8.5.3.2.)

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 canceled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications:

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

AMS 2375	Control of Forgings Requiring First Article Approval
AMS 2772	Heat Treatment of Aluminum Alloy Raw Materials
ARP823	Minimizing Stress-Corrosion in Wrought Heat-Treatable Aluminum Alloy Products

2.2 ASTM Publications:

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

ASTM B 666/B 666M	Identification Marking of Aluminum and Magnesium Products
ASTM B 557	Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products
ASTM B 557M	Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products (Metric)
ASTM B 594	Ultrasonic Inspection of Aluminum-Alloy Wrought Products for Aerospace Applications
ASTM B 645	Plane-Strain Fracture Toughness Testing of Aluminum Alloys
ASTM B 646	Fracture Toughness Testing of Aluminum Alloys
ASTM E 10	Brinell Hardness of Metallic Materials
ASTM E 399	Plane-Strain Fracture Toughness of Metallic Materials
ASTM E 407	Microetching Metals and Alloys
ASTM E 561	R-Curve Determination
ASTM E 1304	Plane-Strain (Chevron-Notch) Fracture Toughness of Metallic Materials
ASTM E 1417	Liquid Penetrant Examination

3. TECHNICAL REQUIREMENTS:

3.1 Material:

Forgings shall be produced from forging stock specified by the purchaser. (See 8.4.)

3.2 Condition:

3.2.1 Physical: Forgings shall not be welded, and shall be supplied etched with all test-material prolongations not consumed in pre-delivery testing, in place. (See 8.5.2.)

3.2.2 As-supplied Heat-treat Condition: Forgings shall be supplied in the “-O1” temper.

3.3 Properties:

3.3.1 Response to Heat Treatment: Tensile and fracture-toughness properties shall conform to the response-to-heat-treatment requirements specified by the purchaser. (See 8.2.) Room-temperature tensile requirements (3.3.1.1) shall be applicable always; fracture toughness requirements (3.3.1.2) shall be applicable only when so specified by the purchaser. (See 8.2.) Test specimens for tensile testing and for fracture-toughness testing shall be manufactured from a test-material source in accordance with 4.3.5.

3.3.1.1 Room-Temperature Tensile: Room-temperature tensile properties shall be determined in accordance with ASTM B 557 (or ASTM B 557M). The short-transverse test direction shall be applicable when $S_{\text{final HT}} \geq$ 1 1/2 inches (38.1 mm); see Figure 1 for definition of $S_{\text{final HT}}$. The longitudinal test direction shall be applicable when $S_{\text{final HT}}$ < 1 1/2 inches (38.1 mm). (See 8.5.1.)

3.3.1.2 Room-Temperature Fracture Toughness: Fracture toughness shall be determined in accordance with ASTM E 399 or ASTM E 1304 as augmented by ASTM B 645, B 646, and E 561. Fracture toughness may 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 8.2.) 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 as specified on the engineering drawing for all other shapes.

3.3.2 Hardness: Hardness, determined in accordance with ASTM E 10, shall be that which is characteristic of the as-supplied heat-treat condition (3.2.2). The hardness values shall conform to the requirements of Table 2 when the forgings are supplied in the “-O1” temper, and shall conform to the requirements in the material specification for the alloy when in a “-TX” temper.

TABLE 2 - Hardness Requirements for the -O1 Temper

Applicable to Aluminum Alloy Type	Maximum Hardness
2xxx	74 HB 10/500
7xxx	80 HB 10/500

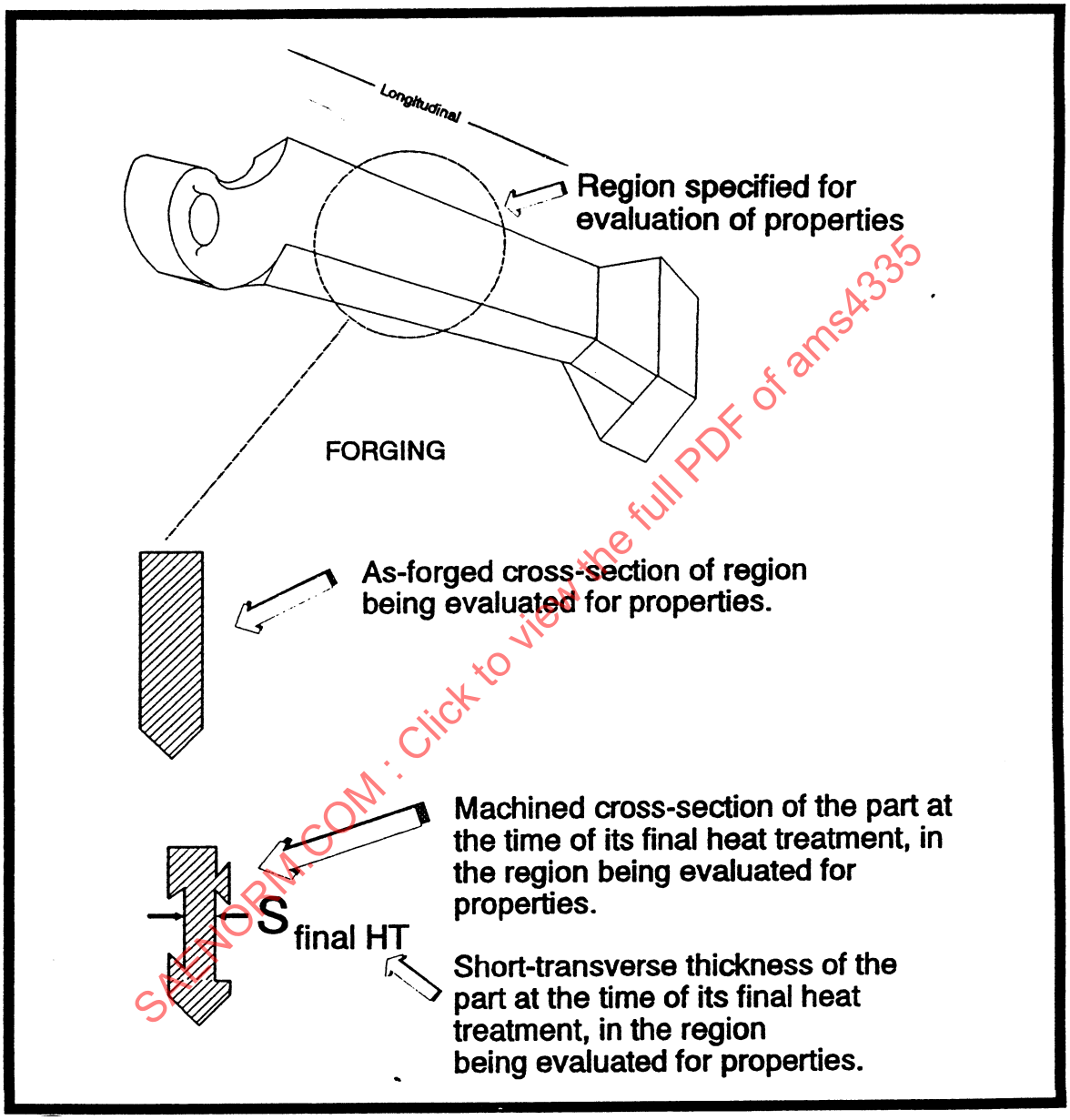

FIGURE 1 - Definition of $S_{\text{final HT}}$

3.3.3 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 prolongation attachment or of flash extrusion ("flash line" or "parting plane"). (See 8.2 and 8.5.) 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 forging characteristics may be used as a test medium when the grain flow pattern of the specified aluminum alloy (3.1) is too faintly revealed to record photographically. Sections shall be finished and etched in accordance with ASTM E 407 to reveal the grain flow pattern, or in accordance with any other procedure which reveals the grain-flow pattern. The grain-flow pattern shall be recorded photographically for reporting purposes (4.5).

3.4 Quality:

3.4.1 Surface Condition: Forgings shall be free of visually-verified tears, cracks, seams, laps, and imbedded foreign material. Surfaces shall be inspected in accordance with ASTM E 1417; the nature of any indication shall be established by visual examination. Imperfections may be removed, in which case surfaces shall be reinspected.

3.4.2 Internal Condition: This requirement is applicable only when so specified by the purchaser. Internal condition shall conform to the requirements specified by the purchaser. (See 8.2.) Evaluation of internal condition shall be performed in accordance with ASTM B 594 and the inspection class specified by the purchaser.

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

3.4.4 Heat Treating Control: Forgings shall be heat treated in accordance with AMS 2772 or, for alloys not listed in AMS 2772, in accordance with instructions from the purchaser. (See 8.2.)

3.5 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 3.

TABLE 3 - 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 0.03 (0 to 0.8)
Over 5 to 25, incl (Over 2.3 to 11.3, incl)	0 to 0.06 (0 to 1.5)
Over 25 to 50, incl (Over 11.3 to 22.7, incl)	0 to 0.09 (0 to 2.3)
Over 50 to 100, incl (Over 22.7 to 45, incl)	0 to 0.13 (0 to 3.3)
Over 100 to 200, incl (Over 45 to 91, incl)	0 to 0.19 (0 to 4.8)
Over 200 to 500, incl (Over 91 to 227, incl)	0 to 0.25 (0 to 6.4)
Over 500 to 1000, incl (Over 227 to 454, incl)	0 to 0.31 (0 to 7.9)
Over 1000 (Over 454)	0 to 0.38 (0 to 9.6)

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 perform any confirmatory testing deemed necessary to ensure that the forgings conform to specified requirements.

4.2 Classification of Tests:

4.2.1 Acceptance Tests: Acceptance test requirements are shown in Table 1. Acceptance tests shall be performed on each lot. See 8.5.3 for the definition of a lot.

4.2.2 Periodic Tests: Periodic test requirements are applicable only to Type 3 and are shown in Table 1. Periodic tests shall be performed at a frequency selected by the supplier unless frequency of testing is specified by purchaser. (See 8.7.)

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 paragraphs 4.3.1, 4.3.2, and 4.3.3 the term “forging” shall denote either the forged shape or an associated prolongation or separately-forged coupon, as is applicable.

4.3.1 Acceptance:

Each of the following inspections shall be performed on each lot of forgings. See 8.5.3 for the definition of a lot.

4.3.1.1 Room-Temperature Tensile: For Types 1 and 2 only, one or more forgings shall be tested for room-temperature tensile properties.

4.3.1.2 Fracture Toughness: For Types 1 and 2 only (when specified), one or more forgings shall be tested for room-temperature fracture toughness properties.

4.3.1.3 Hardness: For forgings supplied in the “-O1” temper, each forging of the sample required by Table 4 shall be tested for hardness. Each forging supplied in a “-TX” temper shall be tested for hardness.

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

4.3.1.5 Internal Condition: Each forging shall be inspected for internal condition, when applicable.

4.3.1.6 Monitoring of Processes and Materials and Inspection of Tolerances: The supplier’s quality assurance function shall determine the frequency for monitoring processes and materials, and for inspection of tolerances.

TABLE 4 - Acceptance Sampling Plan for Hardness of -O1 Temper

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

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

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

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

4.3.3.4 Internal Condition: Each forging shall be inspected for internal condition, when applicable.

4.3.3.5 Monitoring of Processes and Materials and Inspection of Tolerances: All of the forgings subjected to preproduction tests shall be monitored for compliance with process and material requirements, and shall be inspected for compliance with tolerance requirements.

4.3.4 Sources of Test Material for Tensile and Fracture Toughness (3.3.1.1 and 3.3.1.2): 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 region in the forging specified on the engineering drawing for evaluation of properties. When the engineering drawing does not specify location the thickest section in the forging shall be selected. (See 8.2.)

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.

4.3.4.3 A separately-forged coupon which simulates a prolongation. The approved, documented process (to the maximum practical extent) and forging stock from the same heat (preferably from the same lot for Type 1), shall be used to produce a separately-forged coupon.

4.3.5 Preparation of Test Specimens for Tensile and Fracture Toughness (3.3.1.1 and 3.3.1.2):

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 are to be made shall be heat treated in accordance with AMS 2772 or, for alloys not listed in AMS 2772, in accordance with instructions from the purchaser. (See 8.2.)

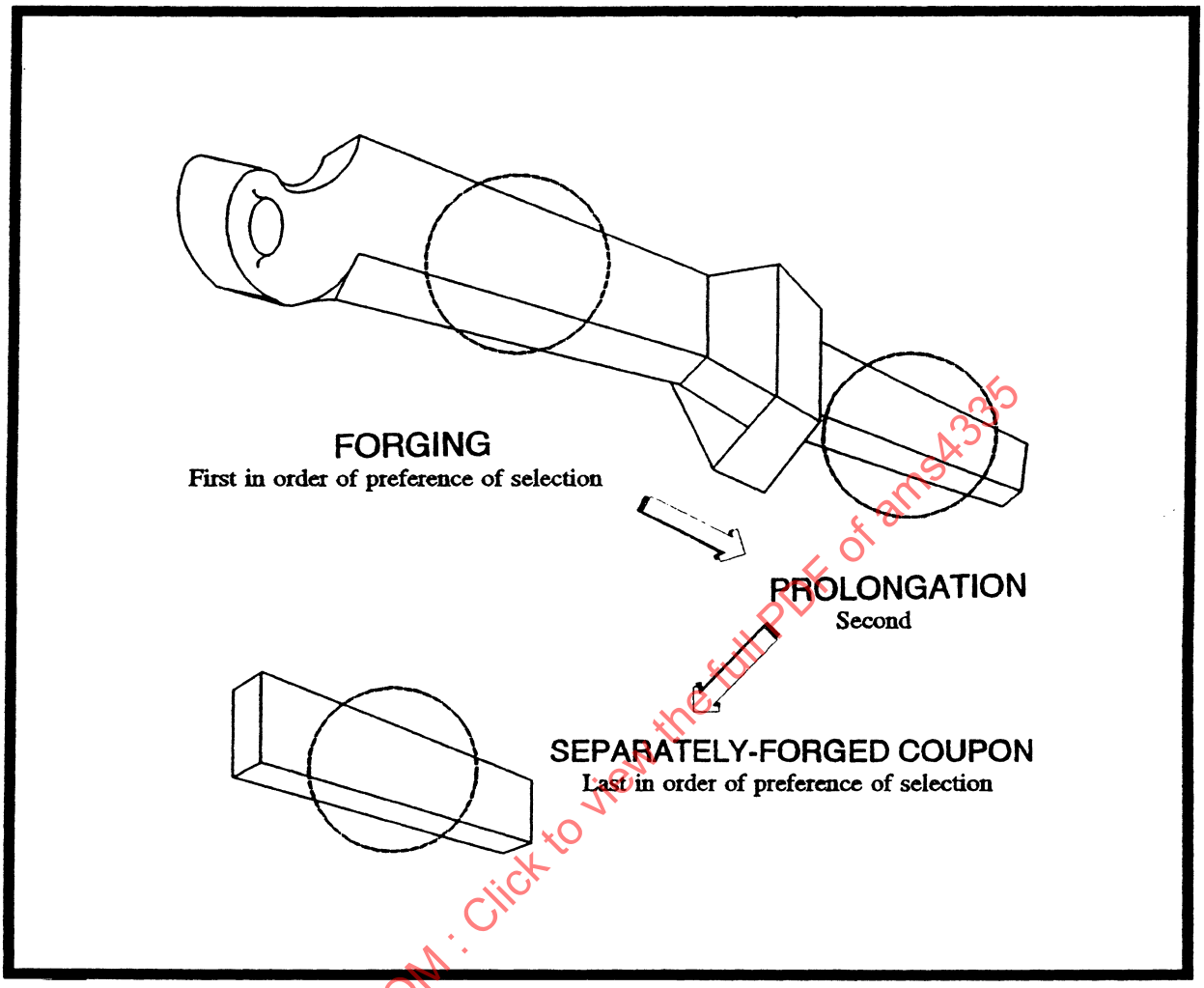

FIGURE 2 - Sources of Test Material

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 8.5.2.)

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).

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), or 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 $1/8S_{\text{final HT}}$, 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, $S_{\text{final HT}}$; and

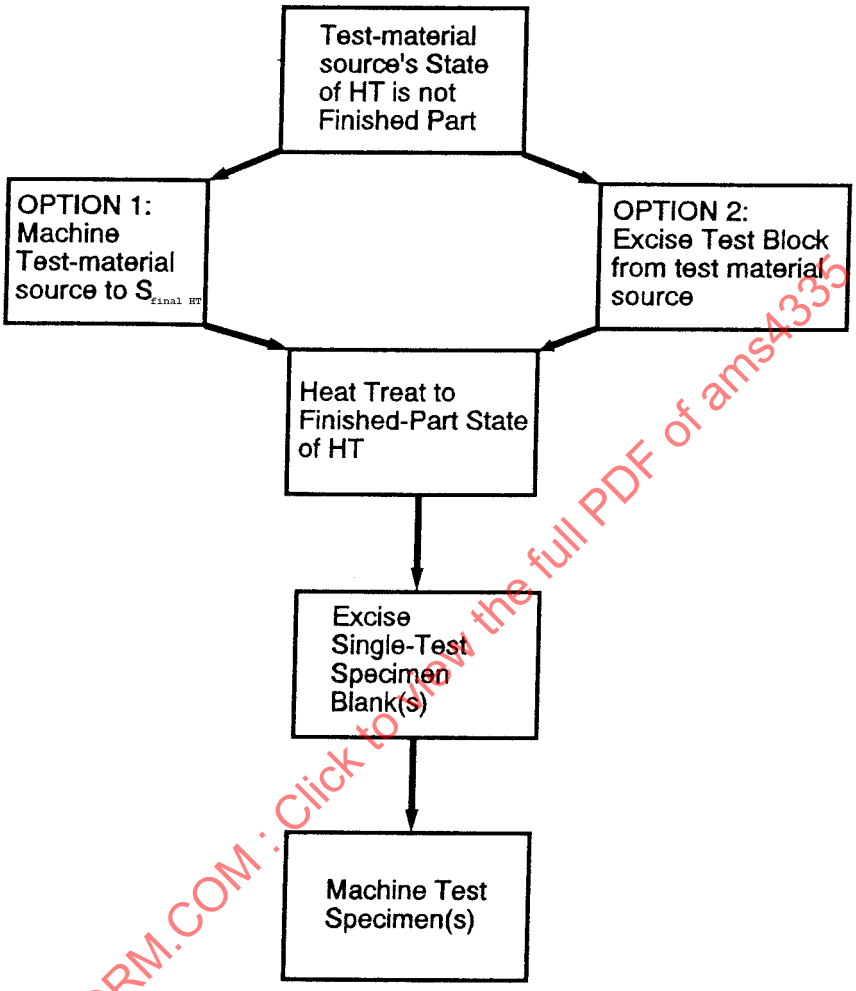

FIGURE 3 - Preparation of Specimens for Properties

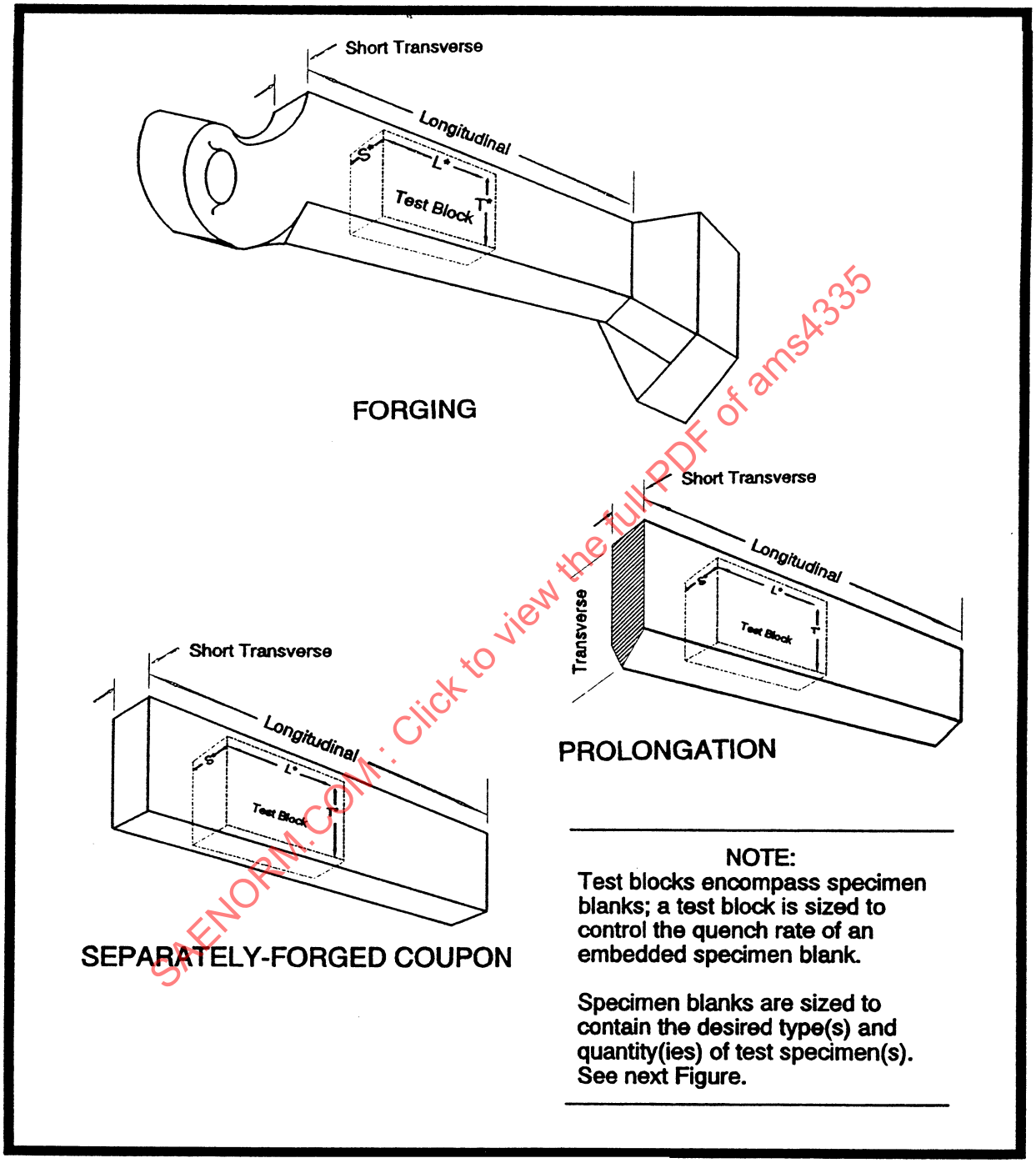

FIGURE 4 - Test Block Sources and Orientation

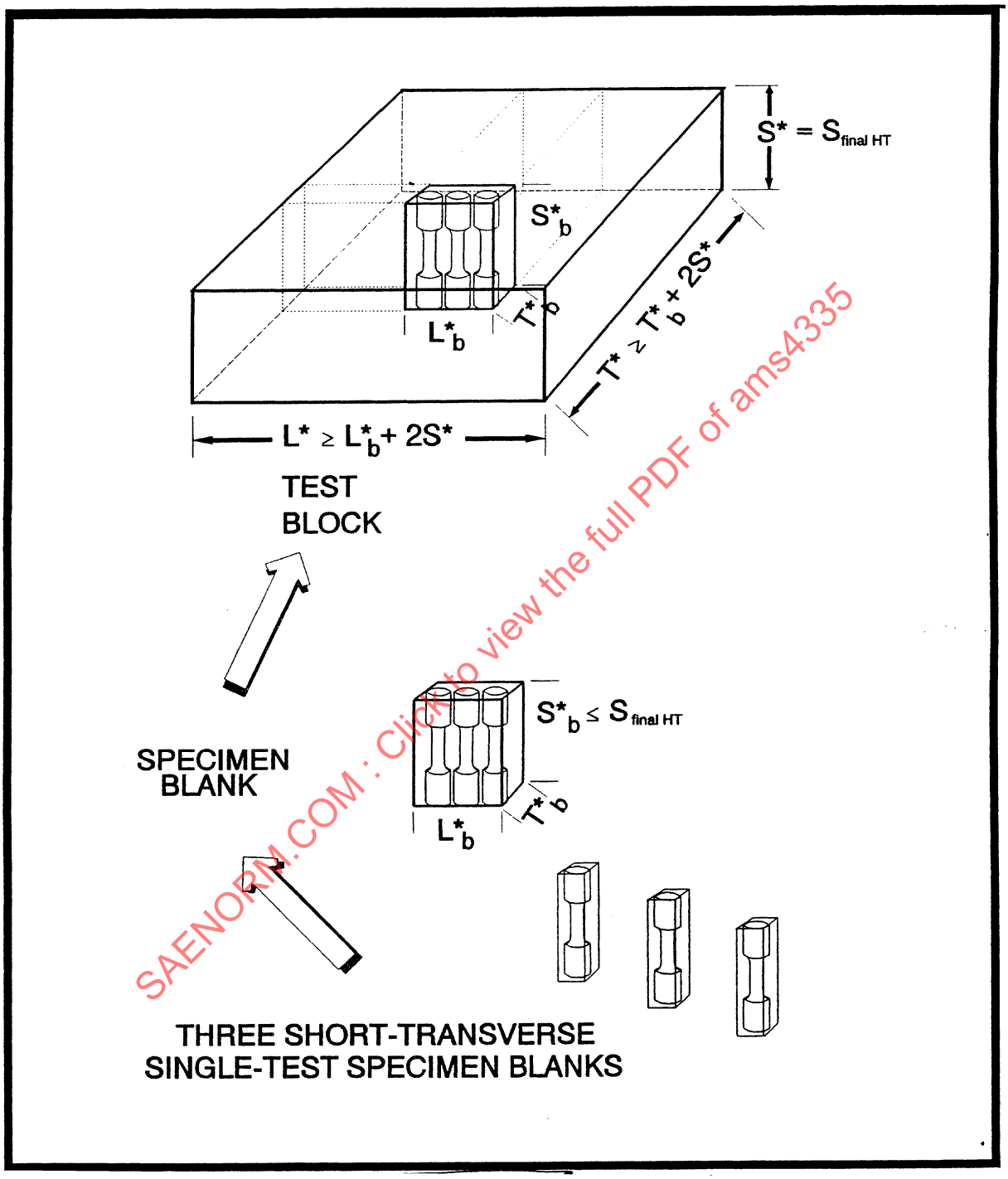

FIGURE 5 - Short-Transverse Specimen Blank Design and Test Block Design

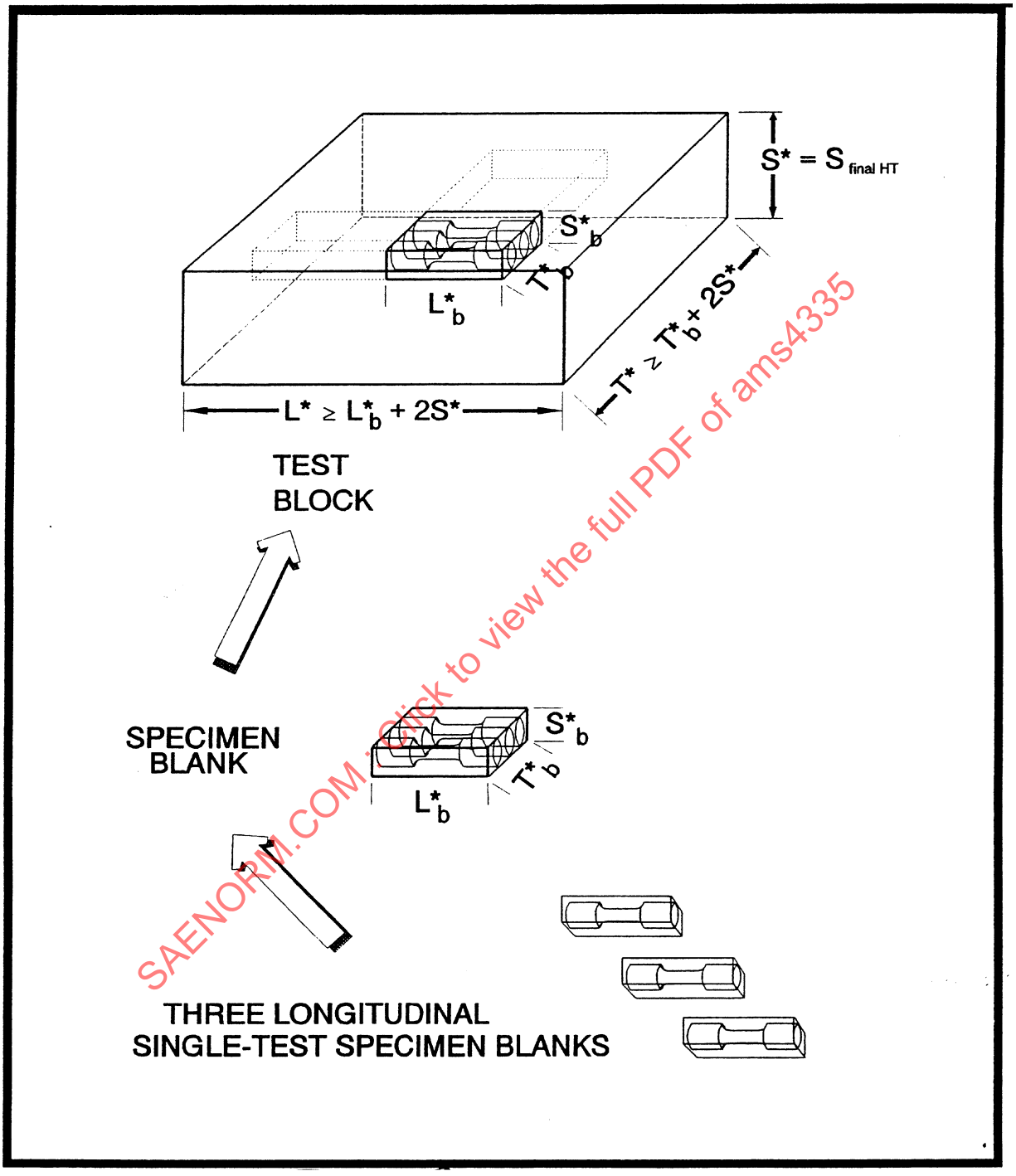

FIGURE 6 - Longitudinal Specimen Blank Design and Test Block Design

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 1/8$S_{final\ HT}$, 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 2375.

4.5 Reports:

The supplier of forgings shall furnish with each production lot shipped, a report which includes:

a. Purchase order number.
b. AMS [AMEC99AB], revision letter if any, and Type.
c. Supplier's identification number.
d. Part number of the forgings.
e. Forging lot number and, if they exist, serial numbers of forgings.
f. Forging stock certification. For chemical composition, a statement that the composition is within the limits specified by the purchaser is acceptable.
g. Lot quantity.
h. 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 hardness or 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 8.5.3.