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Machining of Alloy 709 Creep-fatigue Specimens from G. O. Carlson Heat

December 2023

Ting-Leung Sham

Changing the World's Energy Future

Idaho National Laboratory

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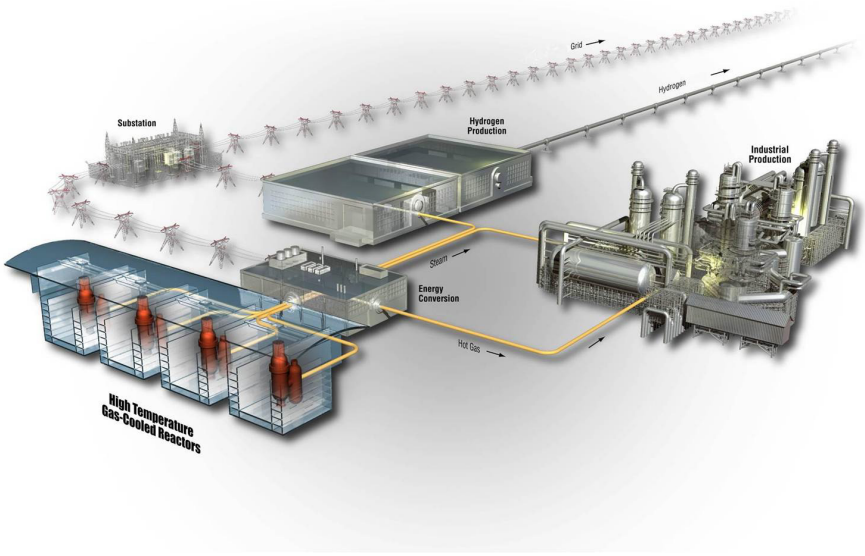
Specification

Project No. 32132

Machining of Alloy 709 Creep-fatigue Specimens from G. O. Carlson Heat



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INL ART Program

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INL/MIS-23-75872

12/18/2023

Prepared by: (Confirmation of mathematical accuracy, and correctness of data and appropriateness of assumptions.)

Ting-Leung Sham — December 14, 2023

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12/18/2023

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12/14/2023

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INL Quality Assurance — Date

CONTENTS

PART 1 GENERAL

Alloy 709 has been selected as the next candidate material for Section III, Division 5 qualification in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) for elevated-temperature nuclear construction. The qualification data package requires an assortment of information and material data including tensile, creep, and creep-fatigue performance at elevated temperatures from different material heats. The goal of the project is to generate a dataset to support qualification of Alloy 709 material for ASME BPVC design code.

Working towards the project goal, Idaho National Laboratory needs to conduct a series of tests on three different heats to support the A709 code case development. At present, there is a gap in the data package for one of the heats: Heat number 58776 manufactured by G.O. Carlson. To address this data gap, Argonne National Laboratory transmitted five plates of A709 heat 58776 manufactured by G.O. Carlson to Idaho National Laboratory. These plates were solution annealed at 1150°C and heat treated at 775°C for 10 hours.

The objective of this specification is to procure a series of creep-fatigue specimens to support the qualification data package. The creep-fatigue specimen design captures the cyclic material performance at elevated temperature. The material performance data generated from specimens machined herein will support the ASME BPVC code case development and establish design limits, and design life curves for Alloy 709 material.

PART 2 WORK INCLUDED

The following contains the work included for the subcontractor to fulfill the requirements of creep-fatigue sample machine from provided material.

A. Subcontractor shall machine the listed test specimens following the identified standards.
   1. Total 41 creep-fatigue specimens per ASTM E606/E606M-21, Standard Test Method for Strain-Controlled Fatigue Testing and INL Drawing No. 771960 Rev. 1 “NGNP materials button head low cycle fatigue specimen (metric)” (See Appendix D) NOTE 4 in Drawing No. 771960 Rev. 1 need not be maintained.

B. Specimens shall be machined from provided material following the Machining Plan in Appendix B which describes specimen orientation, location, design, material block identification number, and specimen quantity.

C. For each material heat and test specimen type, 20% of the specimens shall have a full dimensional analysis documented on a verified, signed report that is delivered to the contractor, Battelle Energy Alliance, LLC (BEA).

D. Diameter in the reduced gauge section of all specimens shall be measured, documented, and reported.

E. Subcontractor shall label and mark machined specimens per Part 5 and Specimen Nomenclature and Marking discussed in Appendix C.

PART 3 WORK NOT INCLUDED

There is no work identified that should not be included.

PART 4 CONTRACTOR-PROVIDED MATERIALS, EQUIPMENT, AND SERVICES

The contractor, Battelle Energy Alliance, LLC (BEA), shall provide Alloy 709 material to the subcontractor as described in Appendix A: Supplied Material, that lists the heat number, block identification (ID), and nominal dimensions of each block. Contractor shall not provide any other equipment and/or services.

PART 5 APPLICABLE CODES, PROCEDURES AND REFERENCES

A. ASTM E606/E606M-21, “Standard Test Method for Strain-Controlled Fatigue Testing”

B. ASTM E2714-13, “Standard Test Method for Creep-Fatigue Testing”

C. PLN-3346, Rev. 9, “Creep Fatigue Testing”

D. Idaho National Laboratory (INL) Drawing 771960 Revision 1, "NGNP materials button head low cycle fatigue specimen (metric)"

E. American Society for Testing and Materials (ASTM) E8/E8M-16a, "Standard Test Methods for Tension Testing of Metallic Materials"

PART 6 DESIGN REQUIREMENTS

A. Specimen machining requirements:

1. Perform all machining work per Appendix B at the subcontractor's facility. Use coolant that is clean and free of contaminants.
2. Machine the provided material per machining plan described in Appendix B.
3. Specimens shall not be taken from 6.35 mm (0.25") of the plate edges parallel to the RD.
4. Use calibrated measurement and test equipment for all dimensional measurements. Ensure calibrations are traceable to the National Institute of Standards and Technology.
5. The machined fatigue specimens shall meet the following requirements:
   a. Conform to ASTM E606/E606M dimensional, machining marks, and surface finish requirements. Specimens shall be machined using the button head design in Figure 1 in ASTM E606/E606M-21.
   b. Conform to Drawing No. 771960 Rev. 1.

NOTE: *Excerpt from ASTM E606 on machining to a suitable surface finish:*
"X3.2 Procedure: X3.2.1 In the final stages of machining to within 0.025 mm [0.001 in.] of the final diameter, remove small amounts of material and reduce the gage diameter 0.125 mm [0.005 in.] by cylindrical grinding at a rate of no more than 0.005 mm [0.0002 in.]/pass.
X3.2.2 Remove the final 0.025 mm [0.001 in.] by polishing (see Note X3.2) longitudinally to impart a maximum of 0.2-µm [8-µin.] surface roughness.
X3.2—Extreme caution should be exercised in polishing to ensure that material is being properly removed rather than merely smeared to produce a smooth surface. This is a particular danger in soft materials wherein material can be smeared over tool marks, thereby creating a potentially undesirable influence on crack initiation during testing.
X3.2.3 After polishing (see Note X3.2), all remaining grinding and polishing marks should be longitudinal. No circumferential machining should be evident when viewed at approximately 20× magnification under a light microscope."

B. Site and operating environment:

All work shall be done at subcontractor's facility. Subcontractor shall implement the following:

1. Implement the company's safety and health requirements as required to complete this work.
2. Implement the company's environmental requirements as required to complete this work.
3. Implement the company's QA requirements applicable to this work.

C. Labeling, marking and nomenclature for traceability:

1. Permanently engrave each specimen with the three-tier unique specimen identification number determined from Appendix C. The specimen identification number shall be located at specimen end per note 4 in the INL drawing 771960 Rev.1 (Appendix D).
2. Each specimen shall be stored in a hard plastic container.

3. Each container shall be labeled identifying the PO number, the material, the INL drawing number, the three-tier unique specimen identification number per Appendix C, and the plate QA number.
4. The label on each container shall be an adhesive backed waterproof paper or metal foil, and the marking on the label shall be waterproof and fade resistant. No adhesive tape shall be attached directly on the specimen.

PART 7 DELIVERABLES

The subcontractor shall provide a document indicating the traceability and conformance to the dimensional and surface finish requirements as described in Part 6. Additionally, the document shall be signed by an appropriate quality assurance engineer or manager.

PART 8 QUALITY ASSURANCE

The specimens shall be machined as quality level 3 (QL3) materials. Calibrated measurement and test equipment shall be used for all dimensional measurements. Calibrations shall be traceable to the National Institute of Standards and Technology. Item identification and receipt inspection is required.

PART 9 DELIVERY, STORAGE, AND PROTECTION

A. Each specimen shall be stored in a hard plastic container.
B. Store, handle and package all specimen containers for transportation in a manner to prevent damage to the specimen. Specimen containers shall be covered with cushioning material while returning them to the contractor, i.e., bubble wrap. a plastic container.
C. Return all remaining material supplied by the contractor, excluding machining turnings to the contractor. Ensure the plate ID, the rolling direction, and QA number are marked on any returned material.
D. The deliverables are:
    1. Total 41 Creep-fatigue specimens.
    2. Subcontractor shall submit the final report that includes a completed Certificate of Conformance, including the following as a minimum:
        a. Identified SOW/Specification, along with any approved changes, waivers, or deviations,
        b. Requirements that have not been met, along with an accompanying explanation and the means for resolving the nonconformance,
        c. Signature of the manager or person responsible for the QA function
        d. Any nonconformance reports
        e. Subcontractor-generated redlined drawings (as applicable)
        f. Full dimensional information for a minimum of 20% of the specimens
        g. The reduced section diameter of all specimens.
E. The surface of the specimens shall be clean and free of any material, oil, debris, or contaminants.
F. Partial deliveries are acceptable with concurrence by the contractor.
G. The specimens shall be delivered to Idaho National Laboratory at the address below:
Idaho National Laboratory
Attn: Heramb Mahajan
2370 North Ave.
Idaho Falls, ID 83401

Appendix A

Supplied Material from Contractor

Contractor shall provide total five material plates of G. O. Carlson heat. All plates shall be marked with the block identification number and an arrow to indicate the rolling direction (RD) as listed in Table 1.
Table 1. List of all Alloy 709 plates supplied by the contractor with heat information and nominal dimensions.

Block Identification number	Reference block number	Dimension along RD (mm)	Dimension perpendicular to RD (mm)	Dimension along thickness (mm)
3RB-C2-1-S1	1	172	165	28
3RB-C2-1-S2	2	172	216	28
3RB-C2-1-S3	1	172	165	28
3RB-C2-1-S4	2	172	216	28
3RB-C2-1-S6	2	172	216	28

Appendix B

Machining Plan

This appendix describes a plan to machining different specimen types from provided materials. A list of specimens to be machined from plates are shown in Table 2.

A. Subcontractor shall use INL drawing 771960 Revision 1 (Appendix D).
B. Subcontractor shall not take specimens from 6.35 mm (0.25 inch) of the edges parallel to the RD.
C. Specimens shall be machined across thickness with specimen axis centered at half thickness.
D. Specimens shall be machined with specimen axis parallel to RD.
E. Specimens shall be named following Nomenclature procedure per Appendix C.
F. Spacing between specimens will be determined by contractor based on feasible kerf widths.

Table 2. Number of specimens to be machined from each block.

Block ID number	Number of specimens from block ID	Reference figure
3RB-C2-1-S1	7	Figure 1
3RB-C2-1-S2	9	Figure 2
3RB-C2-1-S3	7	Figure 1
3RB-C2-1-S4	9	Figure 2
3RB-C2-1-S6	9	Figure 2

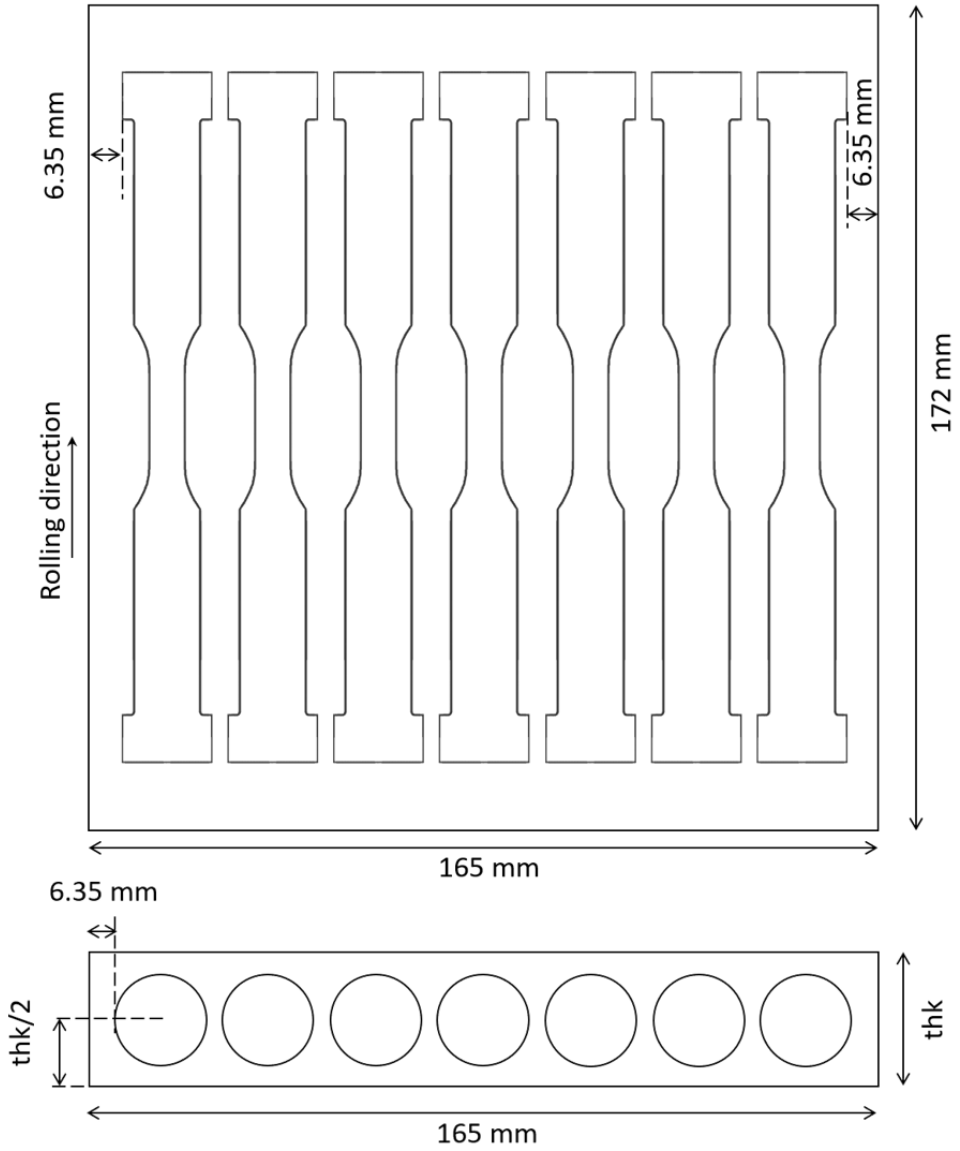

Figure 1. Specimen location and machining plan applicable to block number 1. (Total 7 number of specimens for each block.)

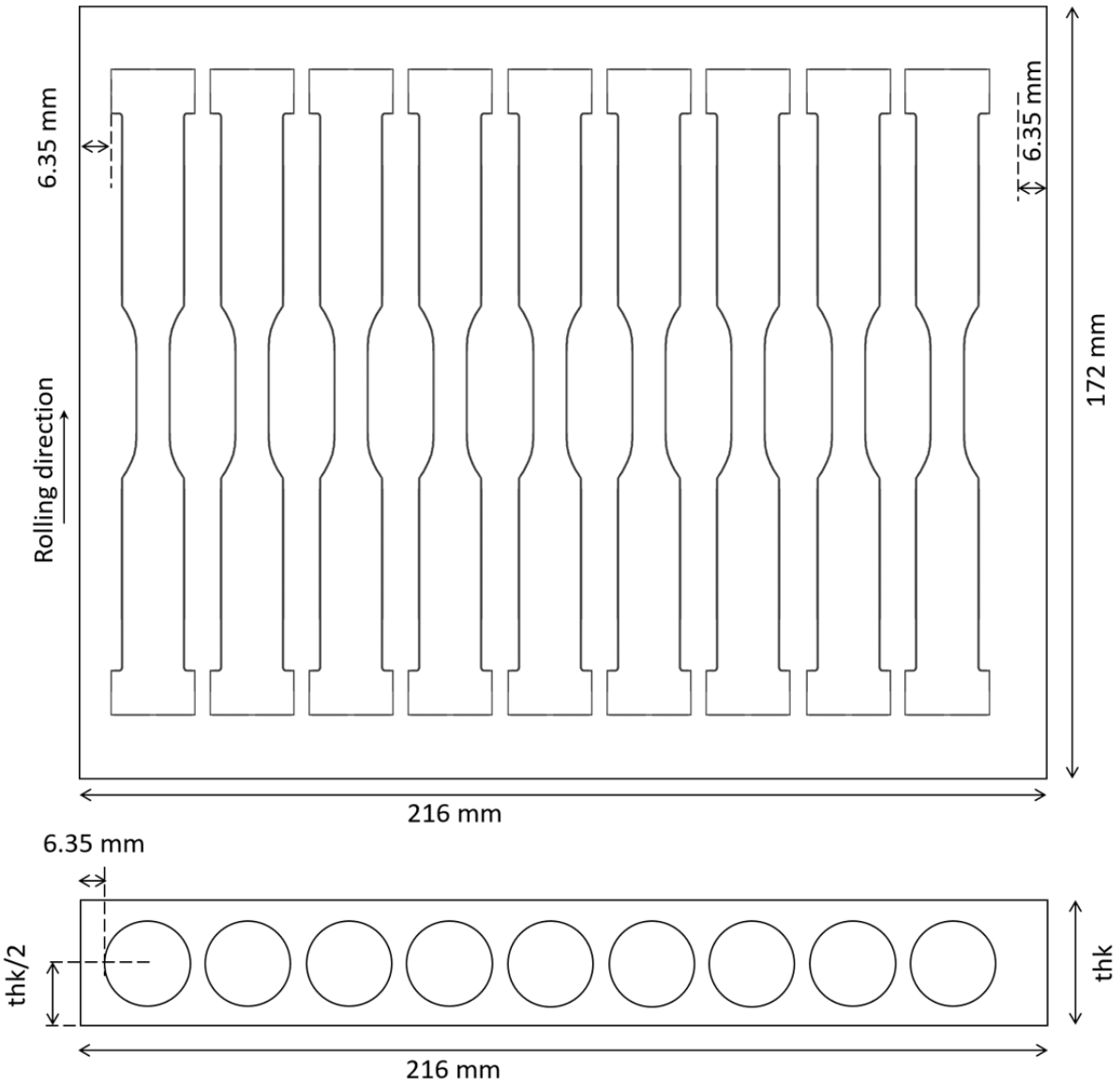

Figure 2. Specimen location and machining plan applicable to block number 2. (Total 9 number of specimens for each block.)

Appendix C

Specimen Nomenclature and Marking Methods

This Appendix describes the nomenclature format to generate unique specimen Identification Number for trackability. Subcontractor shall use this appendix to generate specimen specific unique Identification Number.

A. The specimen's name shall be recorded in the three-tier format – "####-##-##".

NOTE: *First tier represents the heat number and plate reference ID. Second tier represent block number from which specimen is being machined. Third tier represents the unique specimen count from the given block.*

B. Specimen Identification numbers –

1. Subcontractor shall use the first and second tier information per Table 3.

Table 3. Specimen Nomenclature details showing first and second tier of each block.

Block Identification number	First tier	Second tier
3RB-C2-1-S1	11	1
3RB-C2-1-S2	11	2
3RB-C2-1-S3	11	3
3RB-C2-1-S4	11	4
3RB-C2-1-S6	11	6

2. Subcontractor shall generate third tier information following procedure described in Figure 3.
   a. For third tier information, specimens count should start at left of a given block when seen along the specimen axis.
   b. The next specimen count should be the adjacent specimen on the right side as shown in Figure 3.
   c. This specimen counting should continue until end of plate or until planned specimen count is reached.

NOTE: *Specimen originating from a given block will have same first and second tier information. The third-tier information shall follow the specimen naming per Figure 3.*

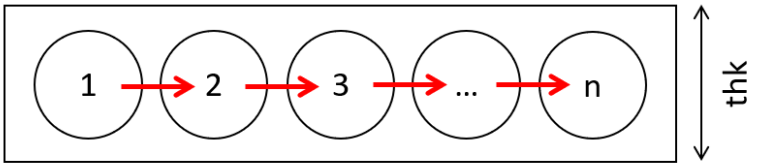

Figure 3. Specimen ID nomenclature technique used in the third tier of the specimen name when seen along the direction of the specimen axis

C. The three-tier specimen identification number shall be engraved on the flat area of the button head in 3mm high characters. The specimen identification number should be clear and legible, and not degrade the function or service life of the specimen.

NOTE: *One example of three tier marking: Creep-fatigue specimens originating from block 3RB-C2-1-S1 shall have specimen IDs from 11-1-1 to 11-1-7 arranged in the following manner when seen from the direction of the specimen axis. The location of these seven specimens in the plate shall be as shown in Table 4.*

Table 4. Examples showing specimen names machined from 3RB-C2-1-S1.

11-1-1	11-1-2	11-1-3	11-1-4	11-1-5	11-1-6	11-1-7

Names of all creep-fatigue specimens are listed in Table 5. Subcontractor shall provide these 41 creep-fatigue specimens.

Table 5. Names of all 41 creep-fatigue specimens

Specimens from G. O. Carlson heat				
11-1-1	11-2-1	11-3-1	11-4-1	11-6-1
11-1-2	11-2-2	11-3-2	11-4-2	11-6-2
11-1-3	11-2-3	11-3-3	11-4-3	11-6-3
11-1-4	11-2-4	11-3-4	11-4-4	11-6-4
11-1-5	11-2-5	11-3-5	11-4-5	11-6-5
11-1-6	11-2-6	11-3-6	11-4-6	11-6-6
11-1-7	11-2-7	11-3-7	11-4-7	11-6-7
—	11-2-8	—	11-4-8	11-6-8
—	11-2-9	—	11-4-9	11-6-9

Appendix D

Specimen Drawings

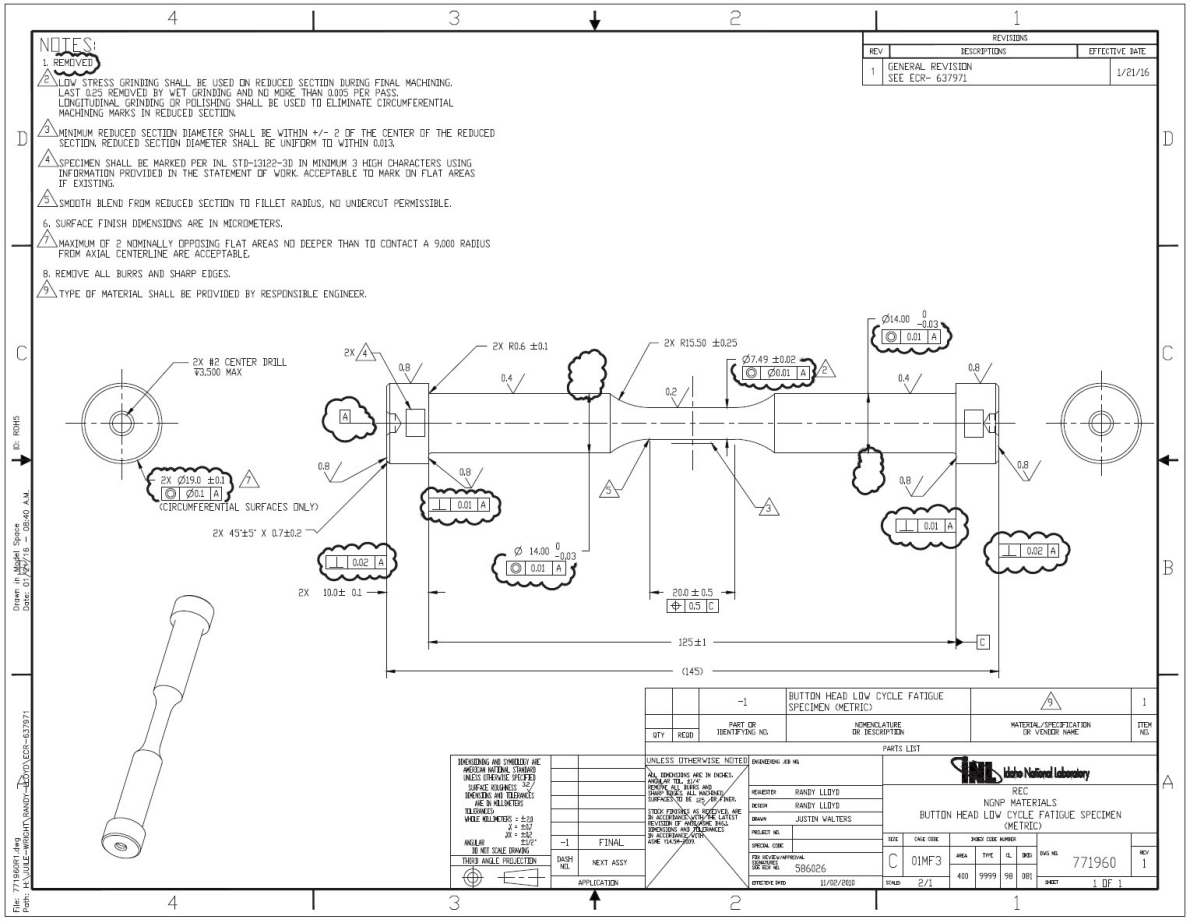

Figure 4. Creep-fatigue specimen INL drawing number 771960 Revision 1. Note 4 shall not apply to this specification. Specimen marking instructions in Part 6 C of this specification should be used.