Light Water Reactor Sustainability Program

Report on the Progress of Weld Development of Irradiated Materials at the Oak Ridge National Laboratory

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U.S. Department of Energy

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ORNL/SPR-2018/833

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	April 26, 2018
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ABSTRACT

This report summarizes recent welding activities on irradiated alloys in the advanced welding facility at the Radiochemical Engineering Development Center of Oak Ridge National Laboratory and the development of post-weld characterization capabilities and procedures that will be critical for assessing the ability of the advanced welding processes housed within the facility to make successful repairs on irradiated alloys. This facility and its capabilities were developed jointly by the U.S. Department of Energy, Office of Nuclear Energy, Light Water Reactor Sustainability Program and the Electric Power Research Institute, Long Term Operations Program (and the Welding and Repair Technology Center), with additional support from Oak Ridge National Laboratory. The significant, on-going effort to weld irradiated alloys with high Helium concentrations and comprehensively analyze the results will eventually yield validated repair techniques and guidelines for use by the nuclear industry in extending the operational lifetimes of nuclear power plants.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the program management of Keith Leonard, engineering support of Kurt Smith and Bob Sitterson, hot cell facilities and operations contributions of Mark Delph and Clay Morris, along with the technical support of Doug Kyle.

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Report on the Progress of Weld Development of Irradiated Materials at the Oak Ridge National Laboratory

1. INTRODUCTION

In November 2017, the first welds on irradiated alloys were carried out in the advanced welding facility based at the Radiochemical Engineering Development Center (REDC) at Oak Ridge National Laboratory (ORNL). This facility was developed through a joint effort by the U.S. Department of Energy, Office of Nuclear Energy, Light Water Reactor Sustainability Program and the Electric Power Research Institute, Long Term Operations Program (and the Welding and Repair Technology Center), with additional support from Oak Ridge National Laboratory. Since then, additional welding has been completed and further activities carried out to support post-weld evaluation and the development of validated weld repair techniques and guidelines for use by the nuclear industry.

This report summarizes recent welding activities and outlines the development of post-weld characterization procedures. Included within are details on:

- Further Friction Stir Welding (FSW) of irradiated 304L stainless steel
- Equipment modifications to enable post-weld destructive sectioning of coupons in a hot cell
- Development of detailed procedures for post-weld destructive sectioning and testing

Additional friction stir welding of irradiated 304L stainless steel was carried out to provide a reference point against which to compare the results of previously completed welds. Concurrently, equipment modifications for enabling in-cell, post-weld destructive sectioning of welded coupons was initiated; these equipment modifications were recently completed. Finally, detailed post-weld destructive sectioning and testing procedures have been developed and are highlighted in this report.

2. FRICTION STIR WELDING OF IRRADIATED MATERIALS

Further welding on irradiated material has been carried out at the advanced welding facility at REDC of ORNL. The first welds on irradiated material in this facility were completed in November 2017 (laser beam welding on November 17 – 20 and FSW on November 21) and documented in references [1, 2]. These included laser beam welding (LBW) and FSW on irradiated coupons 304D-1 and 304C-6, which were 304L stainless steel that contained controlled levels of natural Boron at 20 and 10 ppm (weight), respectively, prior to irradiation. Interestingly, the approximate level of transmuted He generated is expected to be near 20 and 10 appm He, respectively, for the afore mentioned coupons. This is due to the conversion efficiency of the isotopes present in natural Boron based on the energy level and flux conditions of the High Flux Isotope Reactor irradiation position at which the coupons were placed. Until confirmation of the He levels is conducted through experimental analysis, the samples will be identified by their Boron content prior to irradiation. Following these initial welding trials in the facility, an additional friction stir weld was completed on coupon 304B-1 (on December 4, 2017), which was 304L stainless steel that contained natural

Boron at 5 ppm (weight) prior to irradiation. The weld on this coupon will provide a lower Helium reference point against which to compare the results of 304C-6. Weld parameters were modified only slightly compared to those utilized on 304C-6 in order to increase the plunge depth of the tool, increasing the tool-workpiece engagement, penetration, and weld width. The FSW parameters used for coupon 304B-1 are shown in Table 1.

Table 1. FSW Parameters for Irradiated Coupon 304B-1

Parameter	*Value*	*Units*
Starting Position	4.500 (x), 0.000 (y), 2.747 (z)	inch
Tool Rotation Rate	+400 (counter clockwise)	rev/min
Tool Tilt Angle	0	degrees
Welding Speed	0.033	inch/sec
Weld Path Z Travel	0.347	inch
Plunge Speed	0.004	inch/sec
Weld Length	4.0	inch

Conventional FSW involves only a single weld pass per coupon. Unirradiated run-on and run-off tabs, of the same alloy, are placed on the ends of the irradiated coupon to serve as locations for the tool plunge and retraction. This technique increases the overall weld length and increases the amount of welded, irradiated material that is available for post-weld analysis. A photo taken from the overview camera in the hot cell shows the welding of coupon 304B-1 in progress.

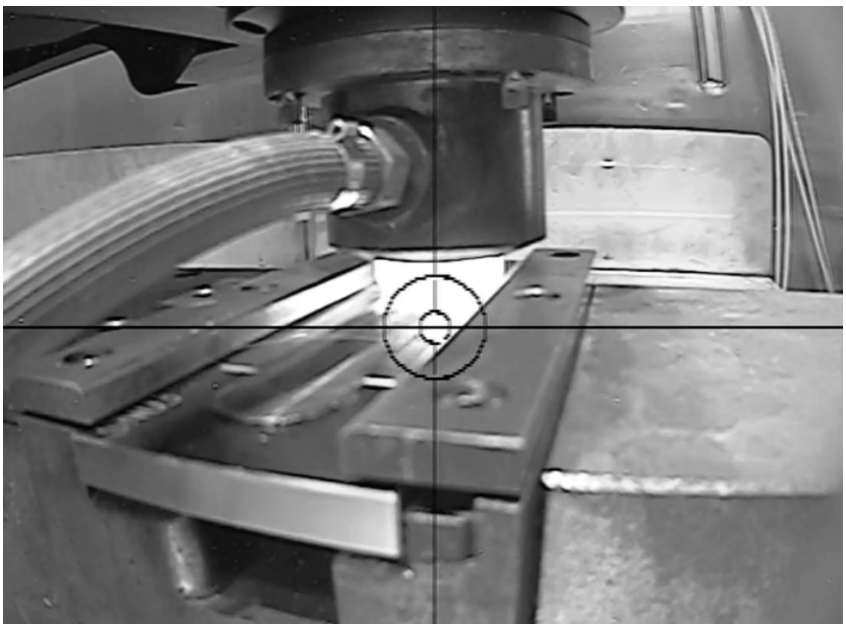

Figure 1: Friction Stir Welding of Irradiated Coupon 304B-1 in Progress

Figure 2 displays an overview image of the completed friction stir weld on irradiated coupon 304B-1. The majority of the weld has a desirable surface finish with an overall weld width that is slightly greater than that of the friction stir weld on coupon 304C-6. A small surface defect was observed near the end of the weld, likely related to improper tool-workpiece positioning, or inadequate plunge depth when the FSW tool traveled onto the unirradiated end tab. No other flaws or obvious defects that would be related to Helium induced cracking were apparent in post-weld visual inspection.

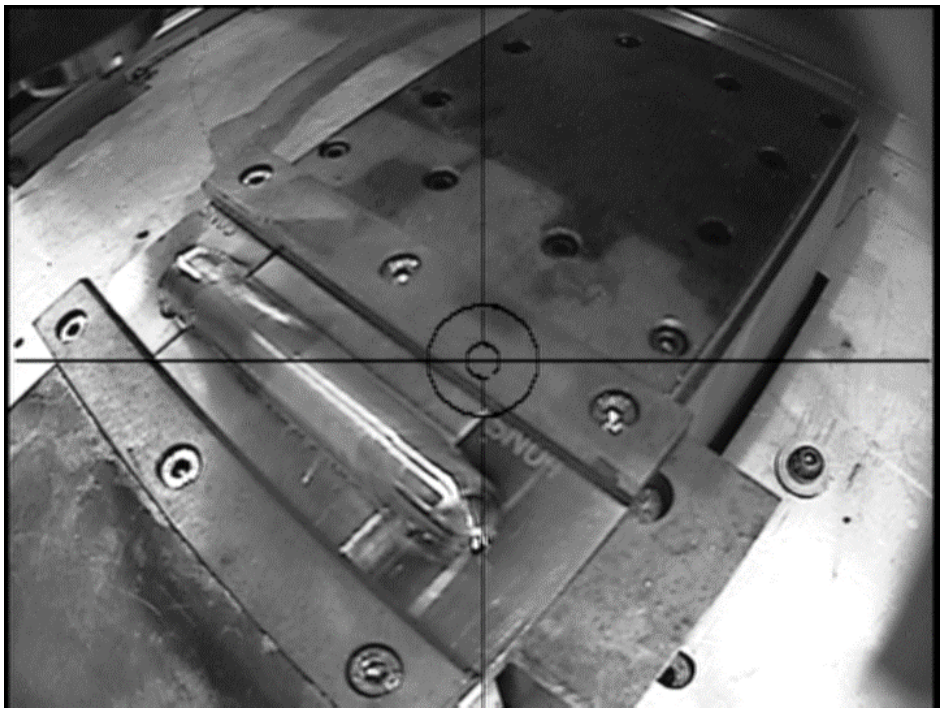

Figure 2: Completed Friction Stir Weld on Irradiated Coupon 304B-1 (the Bright Contrast in the Weld is Caused by Light Reflecting off the Surface)

Coupon 304B-1 will be cut to produce cross-sections, along with previously welded coupons 304D-1 and 304C-6, in Hot Cell 6 at Building 3025E at ORNL. Equipment modifications for enabling capabilities for post-weld destructive sectioning of irradiated coupons is the subject of Section 3 of this report.

3. HOT CELL EQUIPMENT MODIFICATIONS FOR POST-WELD SECTIONING OF WELDED COUPONS

Cutting of welded, irradiated coupons to produce metallographic cross-sections and samples for additional testing will be carried out in Hot Cell 6 at Building 3025E at ORNL with both a band saw and a slow-speed saw. The procedure for cutting weld cross-sections includes the following general steps:

- Clamp welded coupons and sections of welded coupons with band saw or slow-speed saw vise in various orientations (depending on the specified cut). A guide pin will be used to aid the operator in positioning welding sections in prescribed positions relative to the band saw blade.

- Complete cuts, using weights to remotely apply the proper pressure to the blade during cutting.
- Use a vacuum cleaner while cutting to collect materials that are removed to reduce contamination levels within the cell (these materials will be waste).
- Mark and track specimen IDs and store them in labeled cans or tubes for transfer to additional ORNL facilities for post-weld evaluation or for long-term storage.

Large cuts (such as bulk material removal and cutting of metallographic cross-sections) will be made with the band saw, and cuts of finer detail (for producing Thermal Desorption Spectroscopy specimens for Helium measurement) will be made with the slow-speed saw. Significant modifications to the band saw, purchased specifically for this program, were required to make it suitable for use in a hot cell and remote manipulator friendly. The modifications included:

- Modification of the clamping vise, including accommodation of the guide pin housing
- Design and fabrication of two guide pins for completing necessary cuts on FSW and LBW coupons
- Addition of a vacuum fitting, handle, weights, and other items for ease of remote operation
- Modification of the saw to allow for remote blade changes by swapping the entire head assembly

Figure 3 displays images containing the custom hardware that was developed for use on the band saw.

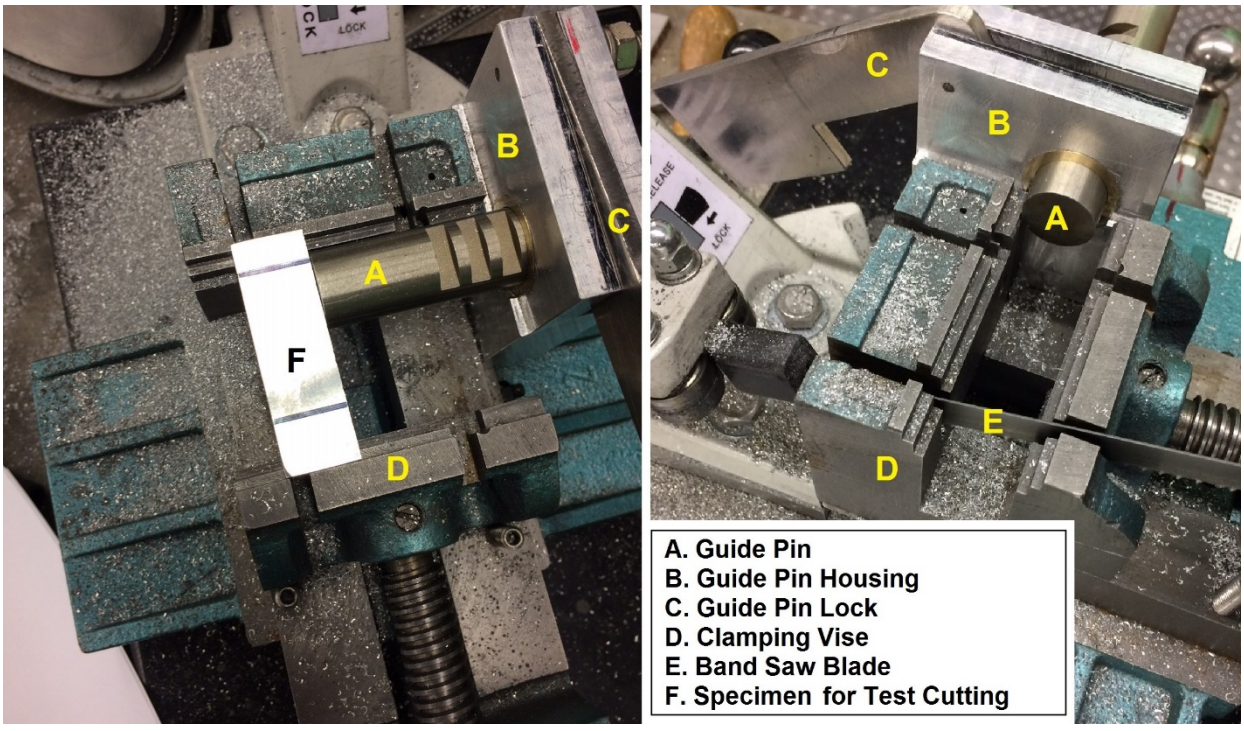

Figure 3: Images of Custom Hot Cell Band Saw Hardware; Blade Raised and Sample Clamped (Left), Blade Lowered and Sample Removed (Right)

The guide pins allow hot cell operators to precisely position welded sections in the band saw clamping vise relative to the blade. Guide pins were produced based on the required positions of the cuts, as specified by researchers, and include positioning notches as well as laser-etched position indicators to aid the operator in following the correct order of the cuts. Figure 4 shows the detail of guide pin A.

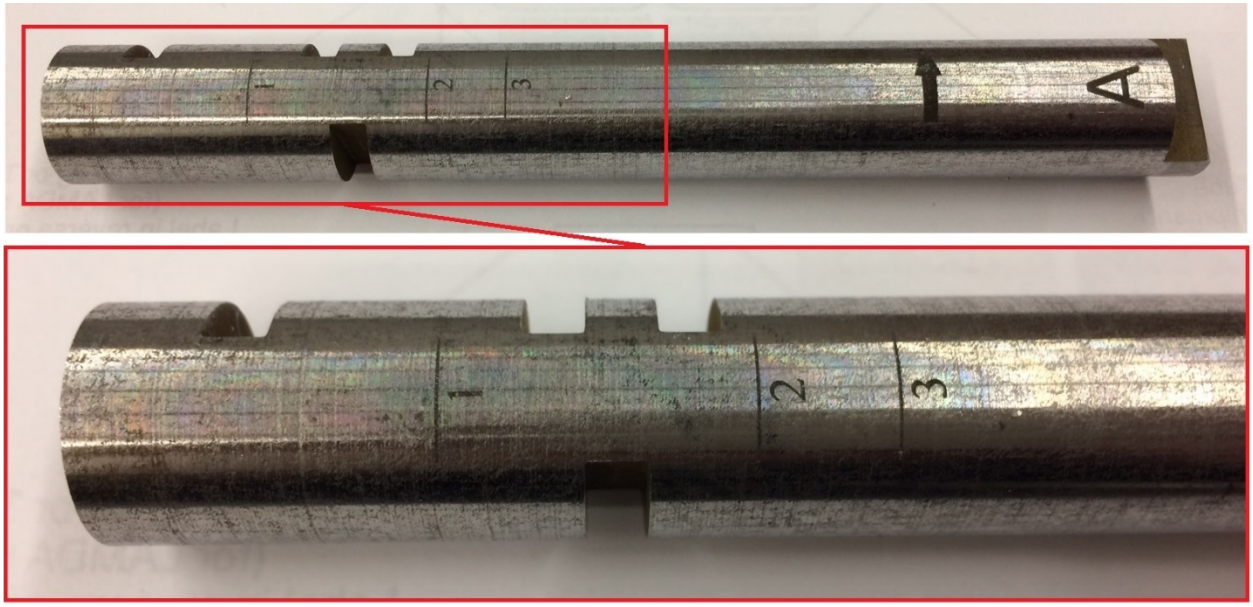

Figure 4: Detail of Guide Pin A

4. PROCEDURE DEVELOPMENT FOR POST-WELD SECTIONING OF WELDED COUPONS

Detailed procedures have been developed for the use of the modified band saw and a slow-speed saw that will be located in Hot Cell 6 at ORNL Building 3025E for carrying-out post-weld sectioning of welded, irradiated coupons. Procedures outline the purpose and scope of the work, environmental, safety, and health (ES&H) concerns, responsibilities, procedural steps, quality assurance, and record keeping. The activities described in the procedures are planned, conducted, and documented in accordance with Document #QAP-ORNL-NR&D-01, Revision 0 entitled *Quality Assurance Plan for Nuclear Research and Development Conducted at the Oak Ridge National Laboratory*. Procedures for sectioning of laser welded coupons and friction stir welded coupons are attached in Appendices **A** and **B**, respectively, of this report. Procedures are currently being routed for review, approval, and final signatures prior to initiating the effort to cut cross-sections from welded coupons.

5. DETAILED POST-WELD CHARACTERIZATION AND MECHANICAL TESTING PLANS FOR WELDS

After welded coupons are sectioned at Building 3025E, cross-sections will be transferred to the LAMDA (Low Activation Materials Development and Analysis) Laboratory at Building 4508 for extensive post-weld analysis. Weld characterization activities in LAMDA may include, but not be limited to, further trimming or sectioning of specimens if necessary, sample mounting, grinding, polishing, optical microscopy to examine weld structure and identify cracking or other defects, focused ion beam extraction of foils or atom probe tomography needles, transmission electron microscopy, thermal desorption spectroscopy of base material to measure helium concentration, electron backscatter diffraction analysis, tensile bar machining and testing, and microhardness evaluation. Together these analyses will yield a comprehensive picture of the post-irradiation material properties, the impact of subsequent welding on microstructure and mechanical properties, and an assessment of the ability of the advanced welding processes to make crack-free repairs on highly irradiated, helium containing materials. Of recent interest, particularly due its interaction with specimen size and the potential for limitations, has been the layout of mini-tensile bar specimens in weld cross-sections that are cut with the band saw. Effort has been made to plan the layout of specimen removal to ensure that the desired number of specimens can be extracted from the available materials. Mini-tensile bars will be extracted from the base metal, weld zone, and heat affected zone (HAZ) of both friction stir and laser beam welds. Specific locations of specimen extraction were determined using the cross-sections of welds on unirradiated material. Figure 5 displays a cross-section of FSW on helium-containing 304 stainless steel produced through a powder metallurgy (PM) technique. The approximate bounds of the weld geometry are indicated by lines that were subsequently used to determine the layout for mini-tensile bar extraction.

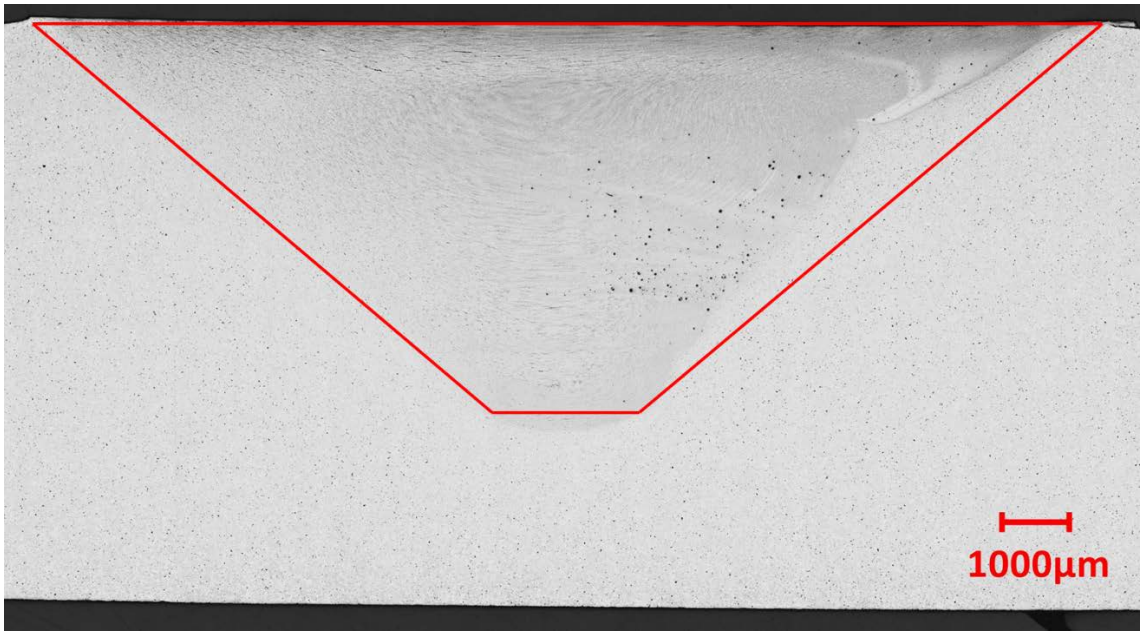

Figure 5: Cross-Section of FSW on Unirradiated, PM-Based, Helium Containing 304 Stainless Steel; Lines Approximate the Weld Geometry for Planning the Extraction of Mini-Tensile Bars

Using the approximate weld geometry shown in Figure 5, Figure 6 displays the anticipated layout of the "dog-bone" mini-tensile bars for FSW sections.

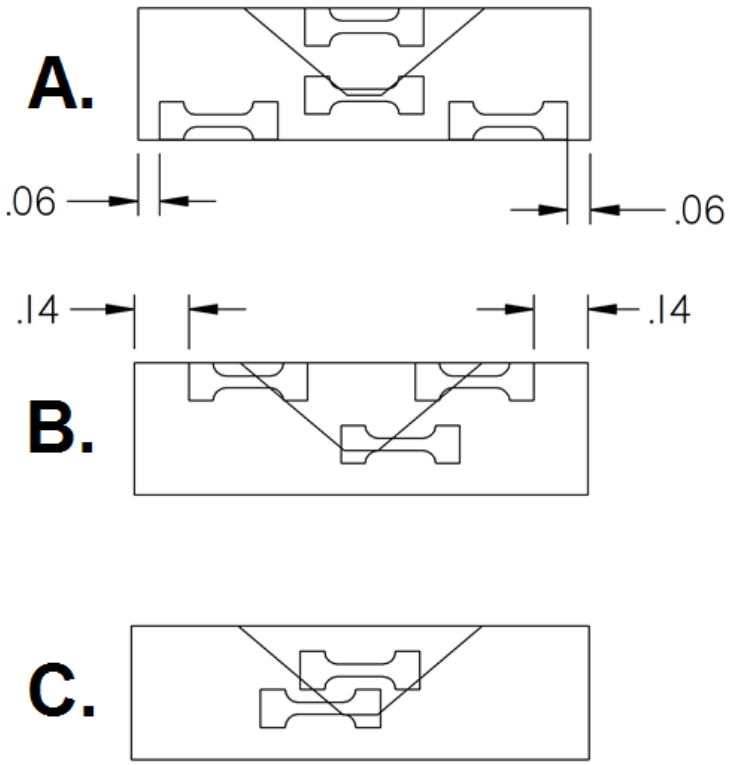

Figure 6: A. Base Metal (bottom left and right), Weld Specimen (top middle), HAZ Specimen (bottom middle); B. Three HAZ Specimens; C. Weld Specimen (top middle), HAZ Specimen (bottom left); Dimensions are in inches.

Figure 7 displays cross-sections from unirradiated laser beam welds. On each irradiated coupon that is welded with the LBW system, multiple welds are made in order to test varying heat inputs and the use of the Auxiliary Beam Stress-Improved (ABSI) capabilities in comparison to conventional LBW. Each weld is comprised of multiple layers of multiple passes. The cross-sections shown in Figure 7 were extracted from welds that have different heat inputs, induced primarily by varying the welding speed in addition to the wire feed speed, that manifest as different overall weld pad widths and heights.

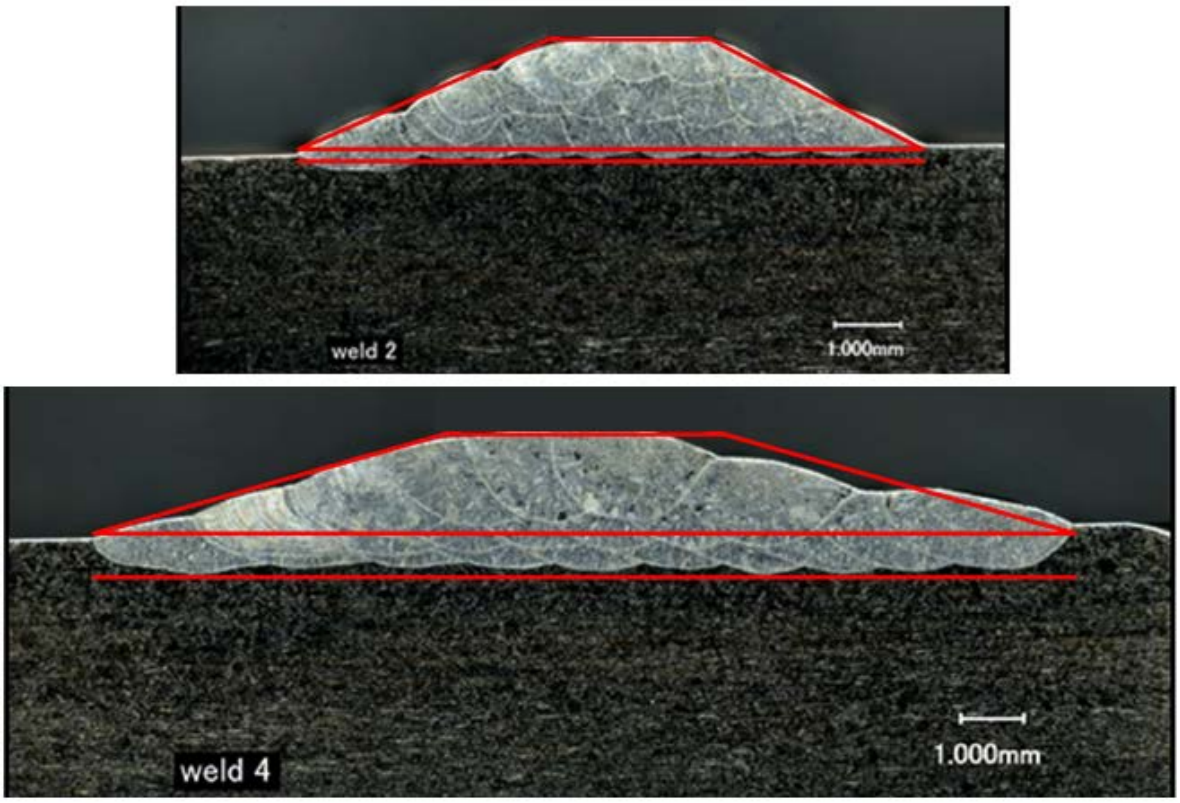

Figure 7: Cross-Sections of LBW on Unirradiated 304 Stainless Steel; Low Heat Input (top), High Heat Input (bottom)

In practice, the low heat input and high heat input welds shown in Figure 7 will typically be on opposite sides of the irradiated coupon; accordingly, Figure 8 displays the anticipated layout of mini-tensile bars that will be extracted from LBW sections, with the low heat input case on top and the high heat input case on the bottom (inverted). Again, the lines of approximation from Figure 7 are used in the diagrams of Figure 8 to appropriately position the mini-tensile bar specimens.

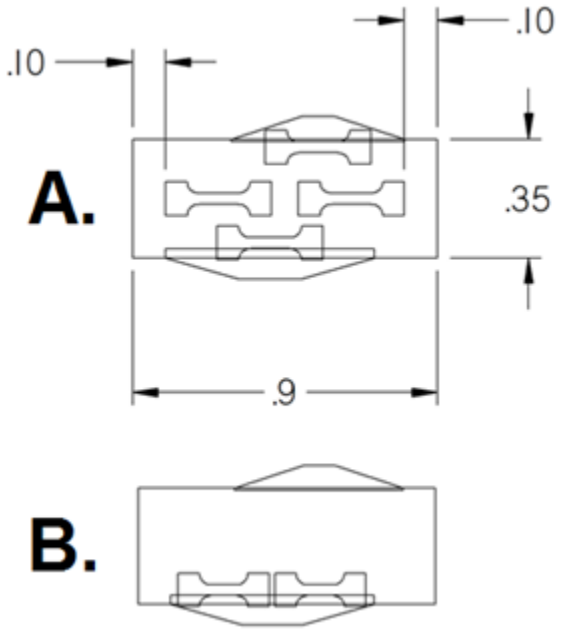

Figure 8: A. HAZ Specimens (top and bottom), Base Metal (middle two); B. HAZ Specimens (if gauge length is reduced); Dimensions are in inches.

It is anticipated that adequate materials will be available for extraction of the desired number of tensile specimens, although the small size of the laser welds makes positioning of the mini-tensile bars within the regions of interest difficult. Tensile bars will be extracted from cross-sections using wire electrical discharge machining (EDM). Tensile testing standards will be followed in both specimen design and testing procedures except when deviations are required due to sample size limitations or other factors.

6. SUMMARY

After the initial welds were carried out on irradiated alloys in the advanced welding facility at REDC of ORNL in November of 2017, further friction stir welding was conducted to provide additional data for 304L stainless steel with a different initial natural Boron concentration prior to irradiation. At the same time, equipment modifications were underway to provide capabilities for destructively sectioning welded coupons in a hot cell environment. These modifications, which were centered around improved capabilities for remote operation of a band saw, are now completed. Detailed procedures for both destructive weld sectioning and post-weld characterization activities are being finalized, and it is anticipated that comprehensive post-weld characterization results will be generated in the near-term, following section of welded coupons.

REFERENCES

[1] Z. Feng, R.G. Miller, J. Chen, W. Tang, et al., Complete report on the development of welding parameters for irradiated materials, U.S. Department of Energy, Office of Nuclear Energy, Light Water Reactor Sustainability Program, Milestone Report, ORNL/SPR-2017/568, November 2017.

[2] W. Tang, J. Chen, B.T. Gibson, R.G. Miller, et al., Advanced welding technology development for nuclear reactor repair, *2018 International Congress on Advances in Nuclear Power Plants*, Charlotte, NC, April 8 - 11, 2018.

Appendix A

Laser Welded Coupon Cutting Procedure

STANDARD OPERATING PROCEDURE

Title: Laser Welded Coupon Cutting at Building 3025E

Prepared by: Wei Tang Date 04/23/2018
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QA Approval: MCVance Date 4/23/18
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DSO Approval: Tracy Strader Date 4/24/18
Tracy W. Strader, Research Support Group Leader
Materials Science and Technology Division

3025E Approvals: Mark Delph Date 4/30/18
Mark Matthews Delph, 3025E Hot Cell Operations Supervisor
Non-reactor Nuclear Facilities Division

1 Purpose

Cut specimens from laser welded irradiated coupons using a band saw and a slow speed saw in a hot cell for post weld characterization.

2 Scope

The activities described in this procedure are to be conducted in a hot cell in Building 3025E and includes the following activities.

- Setup weld coupon on the band saw clamping vise and a slow speed saw.
- Cut specimens in different sizes with the band saw and a slow speed saw.

- Use the vacuum which hose is attached to the band saw to collect materials that are removed (waste) during the cutting process. The vacuum has the grounded power supply and is currently used in building 3025E hot cell.
- Apply water during slow speed saw cutting only. Don't apply water or any other lubricant during band saw cutting.
- Mark and store specimens in cans and tubes.

3 Environmental, Safety and Health (ES&H) Concerns

- Irradiated materials are involved.
- Cutting fines are produced and cutting fines will go into a waste can following non-reactor nuclear facilities division policy.
- Cleaning wipes will be dried and go into a waste can following non-reactor nuclear facilities division policy.

Note: Identification and mitigation of risks associated with the described activities are under the purview of subject matter experts affiliated with the Non-reactor Nuclear Facilities Division (NNFD) responsible for work control activities in Building 3025E. All activities shall comply with mandated requirements invoked for the facility.

4 Responsibilities

Research personnel from the Materials Science and Technology Division are responsible for oversight of the cutting and operations described in this procedure; a researcher will be present to observe operations. Personnel from NNFD are responsible for ensuring compliance with imposed operational, environmental, safety, health, radiological control and other mandates necessary to comply with facility baseline requirements.

5 Procedural Steps – **Specimen cutting in hot cell**

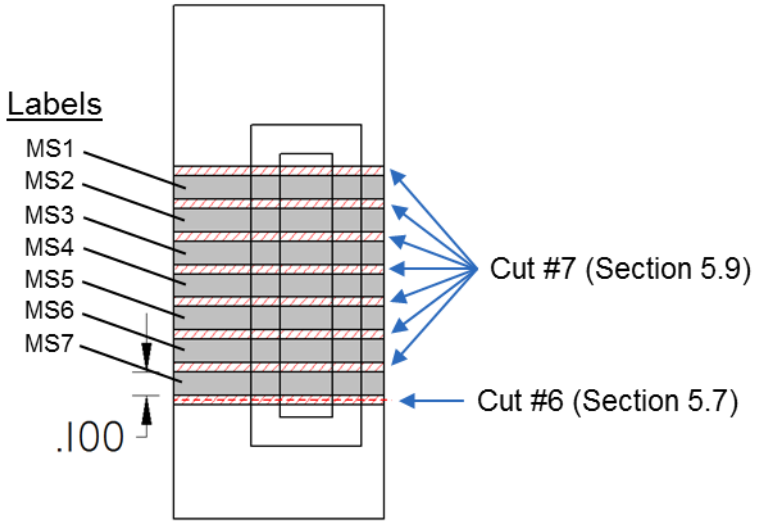
Before coupon cutting, prepare cans for large parts and fiber tubes for small specimens that are cut from the coupons. Mark containers for each part that will be cut prior to introducing the containers to the hot cell. For example: EPRI 304D-1 L1/L4 MS7, for the 7th metallographic specimen cut from coupon 304D-1 that contains welds L1 and L4, or EPRI 304D-1 He, for helium measurement specimens. Excess welded material will be labeled with the coupon ID and L1/L4 or L2/L3 to identify the welds and stored separately. Excess trimmed, un-welded material

may be stored in either welded section container.

The complete list of labeled containers required for coupon EPRI 304D-1, as an example, would be anticipated as:

EPRI 304D-1 L1/L4	Can	Excess L1/L4 weld sections (may also include trimmed, un-welded material)
EPRI 304D-1 L2/L3	Can	Excess L2/L3 weld sections (may also include trimmed, un-welded material)
EPRI 304D-1 He	Tube	Helium measurement specimens
EPRI 304D-1 L1/L4 MS7	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L1/L4 MS6	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L1/L4 MS5	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L1/L4 MS4	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L1/L4 MS3	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L1/L4 MS2	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L1/L4 MS1	Tube	Weld L1 and L4 cross-section
EPRI 304D-1 L2/L3 MS7	Tube	Weld L2 and L3 cross-section
EPRI 304D-1 L2/L3 MS6	Tube	Weld L2 and L3 cross-section
EPRI 304D-1 L2/L3 MS5	Tube	Weld L2 and L3 cross-section
EPRI 304D-1 L2/L3 MS4	Tube	Weld L2 and L3 cross-section
EPRI 304D-1 L2/L3 MS3	Tube	Weld L2 and L3 cross-section
EPRI 304D-1 L2/L3 MS2	Tube	Weld L2 and L3 cross-section
EPRI 304D-1 L2/L3 MS1	Tube	Weld L2 and L3 cross-section

Metallographic specimens (MS) will be labeled in reverse order of cutting, with MS7 produced first, MS6 produced next, and so on. A labeling diagram for MS specimens cut from a welded section is shown here:

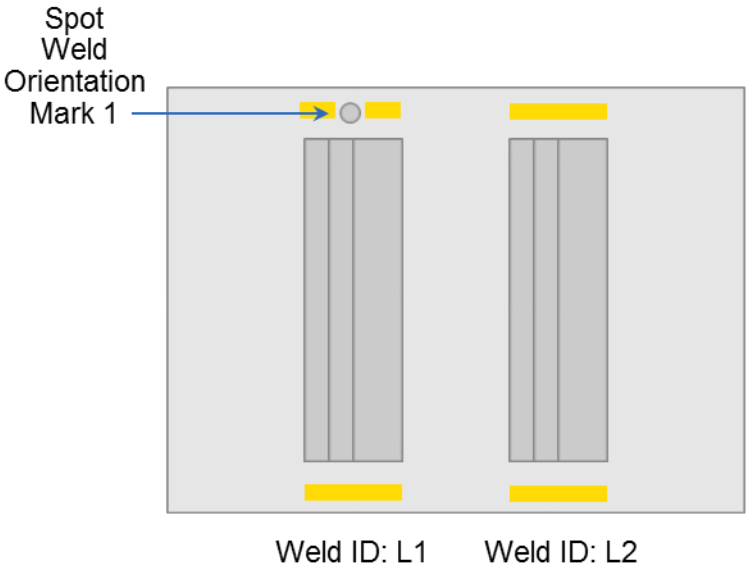


Cutting may proceed if operators are confident that the band saw clamp is properly positioned, relative to the saw blade. If there has been activity that would disturb the positioning since last use of the saw, such as a blade change or movement of the positioning dial on the clamp, the positioning must be reset.

The method of setting the clamp position relative to the saw blade is to indicate the face of the clamp (opposite side from the adjustment dial) against the saw blade, and then turn the dial 0.600 inch, or 6 full rotations, to move the clamp into the proper position such that the saw blade passes through the cut-out in the clamp.

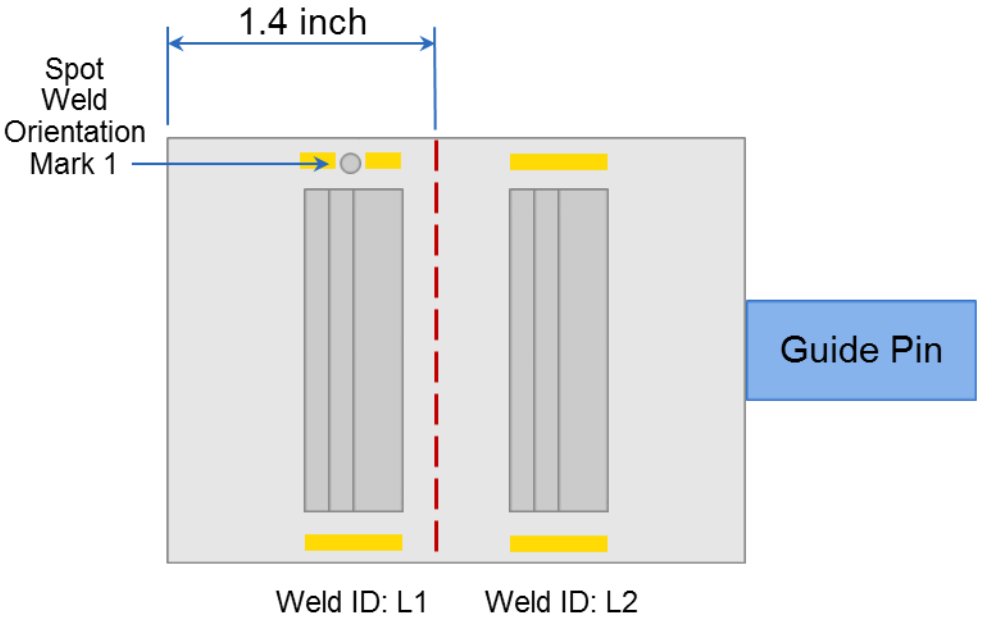
5.1 Verify and Mark Coupon

1. Verify the coupon identity by checking the ID stamped on the short ends.
2. Mark the top side of the coupon with a paint marker as specified in the following figure in yellow. The top side of the coupon is the side on which the spot weld orientation mark can be oriented at top-left, as shown in the figure.



5.2 Cut 1 – Cuts the coupon into two pieces.

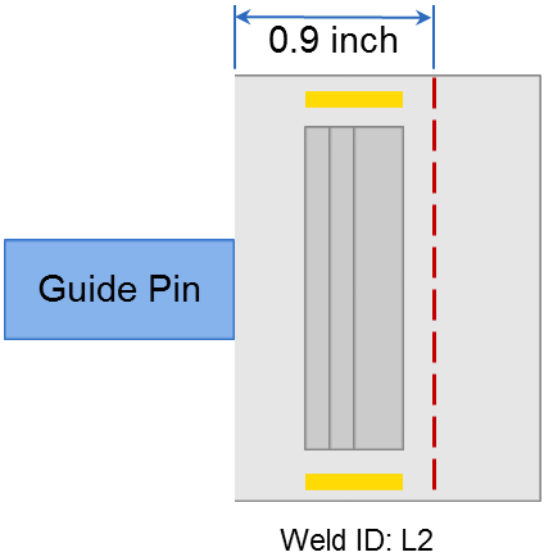
1. Set guide pin **A** to mark **2**.
2. Clamp the laser welded coupon with the edge adjacent to weld L2 firmly in contact with the guide pin such that Cut 1 is located as specified in the following figure. The coupon should be seated in the upper portion of the clamp.
3. Turn on the band saw power and the vacuum power.
4. Unlock and lower the band saw head and start the cut.
5. When the cut is completed, turn off the band saw power, the vacuum power and raise and lock the band saw head.
6. Release the clamp, take out the coupon, deburr the cut edges on both pieces, and clean with alcohol. Coarse silicon carbide papers and/or a file will be used for the deburring for all cut parts in this procedure.



5.3 Cut 2 – Trims excess material from the L2/L3 welded section.

1. Set guide pin **B** to mark **7**.
2. Clamp the laser welded coupon section containing the L2/L3 welds with the cut end firmly in contact with the guide pin such that Cut 2 is located as specified in the following figure. The welded section should be seated in the upper portion of the clamp.
3. Turn on the band saw power and the vacuum power.
4. Unlock and lower the band saw head and start the cut.
5. When the cut is completed, turn off the band saw power, the vacuum power, and raise and lock the band saw head.
6. Release the clamp, take out the coupon section, deburr the cut edges on the welded section, and clean with alcohol.

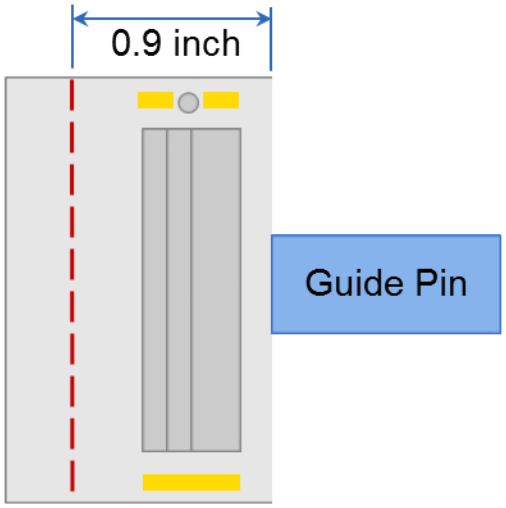
7. Store cut off piece with excess welded sections when all cutting is complete.



Weld ID: L2

5.4 Cut 3 – Trims excess material from the L1/L4 welded section.

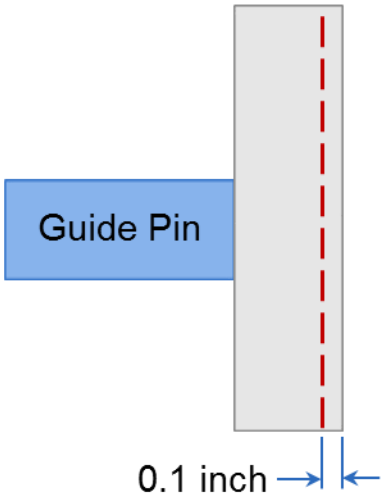
1. Set guide pin **B** to mark **7**.
2. Clamp the laser welded coupon section containing the L1/L4 welds with the cut end firmly in contact with the guide pin such that Cut 3 is located as specified in the following figure. The welded section should be seated in the upper portion of the clamp.
3. Turn on the band saw power and vacuum power.
4. Unlock and lower the band saw head and start the cut.
5. When the cut is completed, turn off the band saw power, vacuum power and raise and lock the band saw head.
6. Release the clamp, take out the coupon section, deburr the cut edges on the welded section, and clean with alcohol.
7. Store cut off piece with excess welded sections when all cutting is complete.



Weld ID: L1

5.5 Cut 4 – Creates a sliver from the larger trimmed excess section.

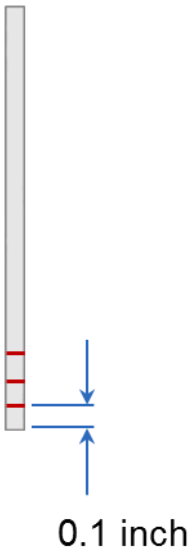
1. Set guide pin **B** to mark **9**.
2. Clamp the larger of the two excess coupon sections (produced with Cut 2) with the cut end firmly in contact with the guide pin such that Cut 4 is located as specified in the following figure. The section should be seated in the upper portion of the clamp
3. Turn on the band saw power and the vacuum power.
4. Unlock and lower the band saw head and start the cut.
5. When the cut is completed, turn off the band saw power, the vacuum power and raise and lock the band saw head.
6. Release the clamp, take out the coupon section, deburr the cut edges of the sliver, and clean with alcohol.
7. Store the larger section with excess welded sections when all cutting is complete. The sliver that was cut in this step will be used in the next step.



5.6 Cut 5 – Cuts small specimens from sliver. To be repeated three times with a slow speed saw. This step may be delayed until the end, following all band saw cuts, or performed simultaneously with the remaining band saw cuts.

1. Clamp the sliver that was produced with Cut 4 such that a 0.1 inch section will be cut, as specified in the following figure.
2. Turn on the slow speed saw power.
3. Start the cut.
4. When the cut is completed, turn off the slow speed saw power.
5. Release the clamp, take out the sliver section, deburr the cut edges of the (0.1 x 0.1 x 0.35 inch) small specimen, and clean with alcohol.
6. If this is not the third cut of Section 5.6, return to the top of Section 5.6 and repeat.
7. Store the sliver section with excess welded sections when all cutting is complete.

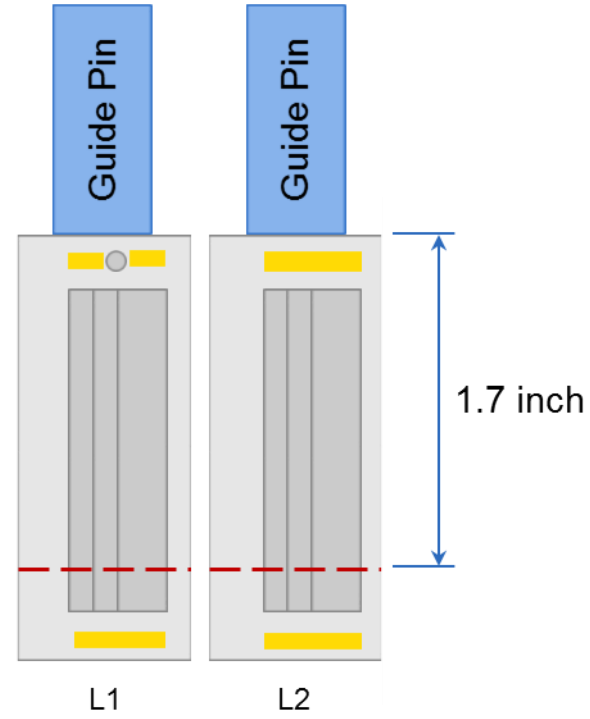
8. Tube the three small specimens together (same container) for shipment to LAMDA with the labeling convention specified at the beginning of Section 5**,** which is EPRI Alloy-Boron-Serial# He.



5.7 Cut 6 – To be repeated twice. Cut open both welded sections.

1. Set guide pin **B** to mark **2**.
2. Clamp the welded section with the spot weld mark end firmly in contact with the guide pin such that the cut is located as specified in the following figure. The section should be seated in the lower portion of the clamp.
3. Turn on the band saw power and the vacuum power.
4. Unlock and lower the band saw head and start the cut.
5. When the cut is completed, turn off the band saw power, the vacuum power and raise and lock the band saw head.
6. Release the clamp, take out the welded section, deburr the cut edges on both pieces, and clean with alcohol.
7. If this is not the second cut of Section 5.7, return to the top of Section 5.7 and repeat.

8. Excess welded sections will be stored as specified at the beginning of Section 5.



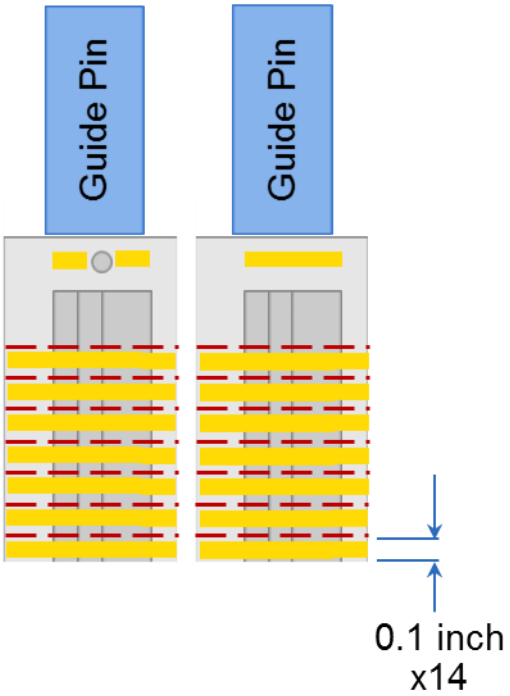
5.8 Apply additional markings.

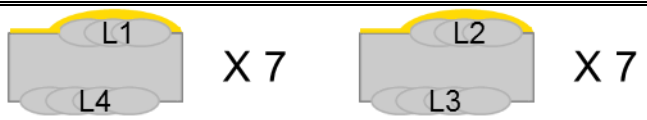
1. Apply additional marks with a paint marker to the top side of welded sections prior to cutting weld cross-sections as depicted in yellow in the following figure in Section 5.9.

5.9 Cut 7 – To be repeated 14 times. Cut weld cross-sections.

1. Set guide pin **B** to marks **3**, **4**, **5**, **6**, **7**, **8**, and **9** sequentially, as needed, starting with mark **3**.

2. Clamp the welded section with the uncut end firmly in contact with the guide pin such that the cut is located as specified in the following figure. The section should be seated in the lower portion of the clamp.
3. Turn on the band saw power and the vacuum power.
4. Unlock and lower the band saw head and start the cut.
5. When the cut is completed, turn off the band saw power, the vacuum power and raise and lock the band saw head.
6. Release the clamp, take out the welded section, deburr the cut edges on the (0.9 x 0.35 x 0.1 inch) cross-section, and clean with alcohol.
7. Bag or tube the (0.9 x 0.35 x 0.1 inch) cross-section for LAMDA shipment. Label in reverse order of cutting as specified in the beginning of Section 5, i.e. the first cross-section cut from the L1/L4 welded section will be EPRI Alloy-Boron-Serial# L1/L4 MS7, the next cross-section will be MS6, and so forth.
8. If this is not the 14th cut of Section 5.9, return to the top of Section 5.9 and repeat. A total of seven cuts will be made on each of two welded sections.
9. Excess welded sections should be stored and labeled as specified at the beginning of Section 5.





6 Quality Assurance

The activities described in this procedure are planned, conducted, and documented in accordance with Document #QAP-ORNL-NR&D-01, Revision 0 entitled *Quality Assurance Plan for Nuclear Research and Development Conducted at the Oak Ridge National Laboratory*

7 Records

A welding traveler form shall be completed for the cutting of each set of coupons.

STANDARD OPERATING PROCEDURE

Review Record

- Required once every 5 years as a minimum
- Signatures indicate adequacy of this document for activity

1st Re-Review

MP&J Group Leader _____ Date _____

MST Division Safety Officer _____ Date _____

2nd Re-Review

MP&J Group Leader _____ Date _____

MST Division Safety Officer _____ Date _____

Appendix B

Friction Stir Welded Coupon Cutting Procedure

STANDARD OPERATING PROCEDURE

Title: Friction Stir Weld Specimen Band Saw and Slow Speed Saw Cutting in Hot Cell

Prepared by: Wei Tang Date 04/23/2018
Wei Tang, Staff Member
Materials Processing and Joining Group

Approved by: James A Haynes Date 04/27/18
Allen Haynes, Group Leader
Materials Processing and Joining

QA Approval: MCVance Date 4/23/18
Mark C. Vance, Quality Representative
Performance Analysis and Quality

DSO Approval: Tracy Strader Date 4/24/18
Tracy W. Strader, Research Support Group Leader
Materials Science and Technology Division

Mark Delph Date 4/30/18
Mark Matthews Delph, 3025E Hot Cell Operations Supervisor
Non-reactor Nuclear Facilities Division

STANDARD OPERATING PROCEDURE

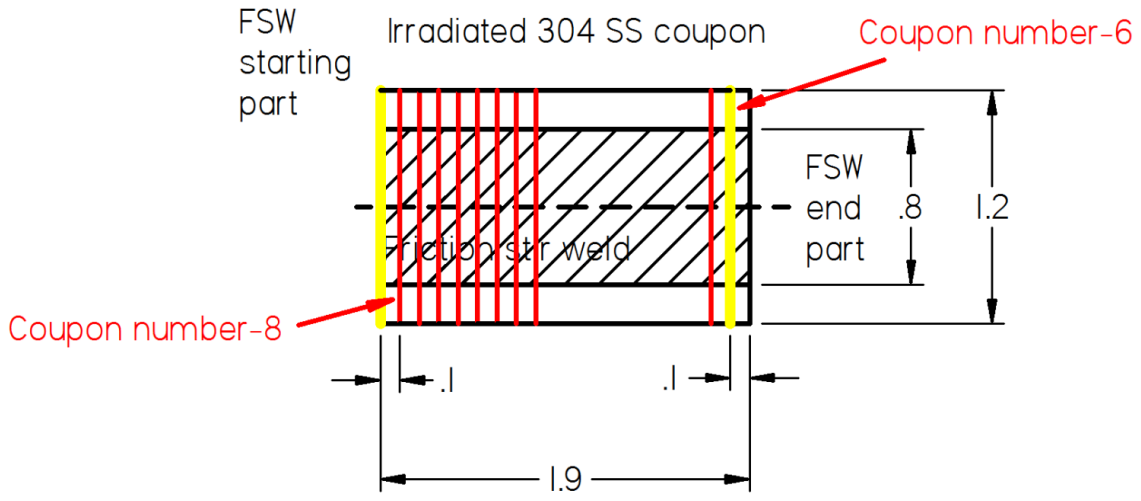
1 Purpose

Cut specimens from irradiated material friction stir welds using a band saw and a slow speed saw in a hot cell for post weld characterization.

2 Scope

The activities described in this procedure are to be conducted in a hot cell in Building 3025E and include the following activities.

- Setup weld coupon on the band saw clamping vise and a slow speed saw clamping fixture.
- Cut specimens in different sizes with the band saw and a slow speed saw.
- Use a vacuum to capture cutting fines/shavings and treat them as waste. The vacuum has the grounded power supply and is currently used in building 3025E hot cell.
- Apply water during slow speed saw cutting only. Don't apply water or any other lubricant during band saw cutting.
- Mark specimens. For each specimen, the mark is always placed on the beginning side of the friction stir weld, as it is shown with yellow color bar in the following schematic.



3 Environmental, Safety and Health (ES&H) Concerns

- Irradiated materials are involved.
- Liquid and cutting fines are produced and cutting fines will go into a waste can following non-reactor nuclear facilities division policy.
- Cleaning wipes will be dried and go into a waste can following non-reactor nuclear facilities division policy.

Note: Identification and mitigation of risks associated with the described activities are under the purview of subject matter experts affiliated with the Non-reactor Nuclear Facilities Division (NNFD) responsible for work control activities in Building 3025E. All activities shall comply with mandated requirements invoked for the facility.

4 Responsibilities

Project personnel from the Materials Science and Technology Division are responsible for oversight of the cutting and operations described in this procedure. Personnel from NNFD are responsible for ensuring compliance with imposed operational, environmental, safety, health, radiological control and other mandates necessary to comply with facility baseline requirements.

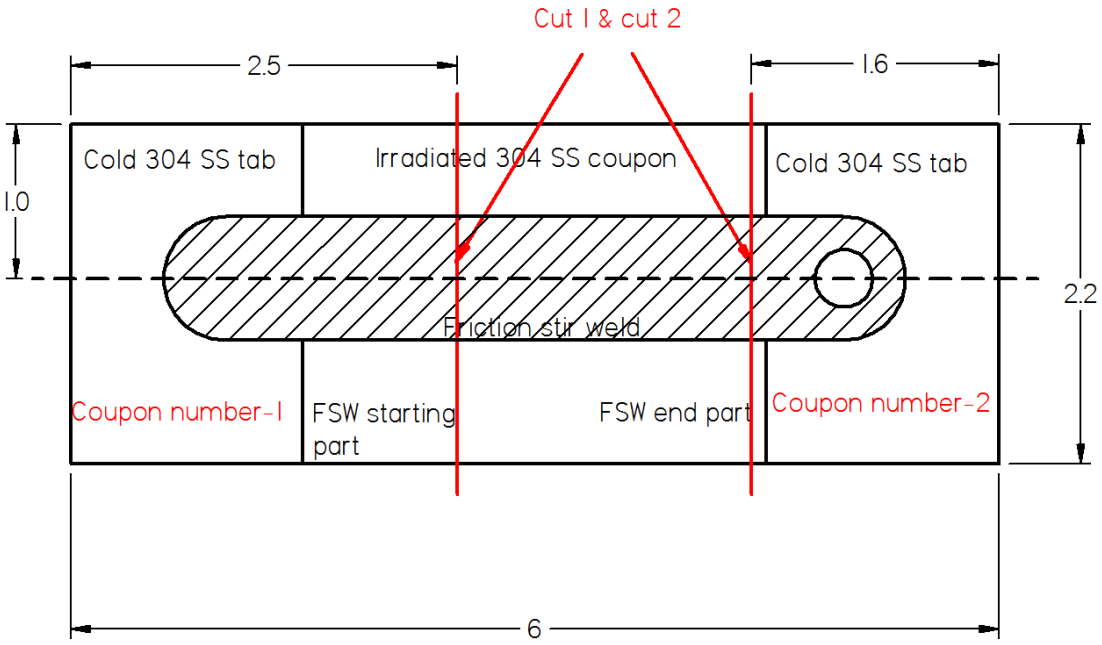
5 Procedural Steps – Specimen cutting in hot cell

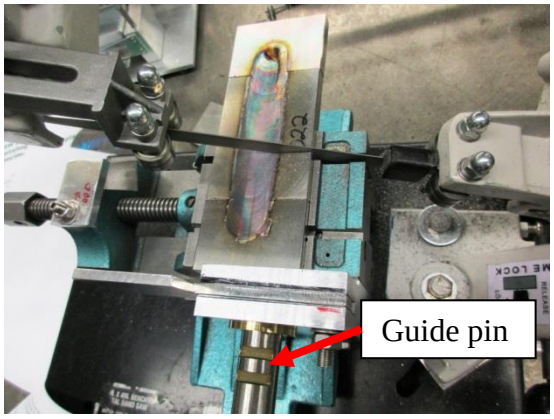
Before the specimen cutting, prepare various aluminum cans for cut off large parts and fiber tubes for cut off small specimens. Following the description in the procedure, mark those aluminum cans and fiber tubes prior to sending them into the hot cell, with Coupon number-x, such as 304C-6-2, where 304C-6 is the Coupon number and -2 is the part from the 2nd cut.

5.1 The 1st cut

1. Set the guide pin A to the mark 1.
2. Clamp the friction stir welded coupon with the run-on tab end firmly in contact with the guide pin shown in the following figure.
3. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
4. When the cutting is completed, turn off the band saw power, raise and lock the band saw head.

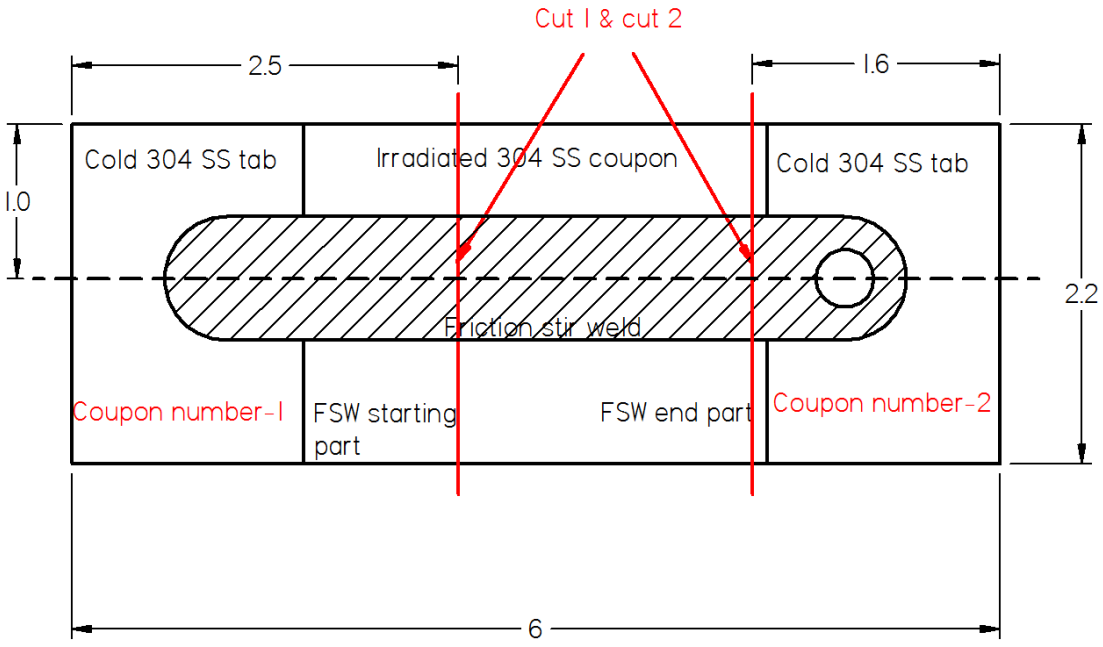
5. Use brush to clean the saw blade and use vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
6. Release the clamp, take out the clamped coupon, deburr cut edges on both pieces, clean with alcohol and dry, and mark cut sides. Coarse silicon carbide papers and/or a file will be used for the deburring for all cut parts in this procedure.
7. Pack the cut off FSW coupon beginning part (~2.5" X 2.2" X 0.35") into the aluminum can marked as Coupon number-1.
8. The Coupon number-1 will be stored.

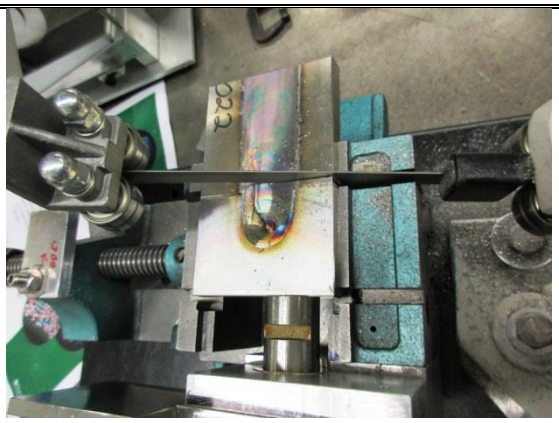




5.2 The 2nd cut

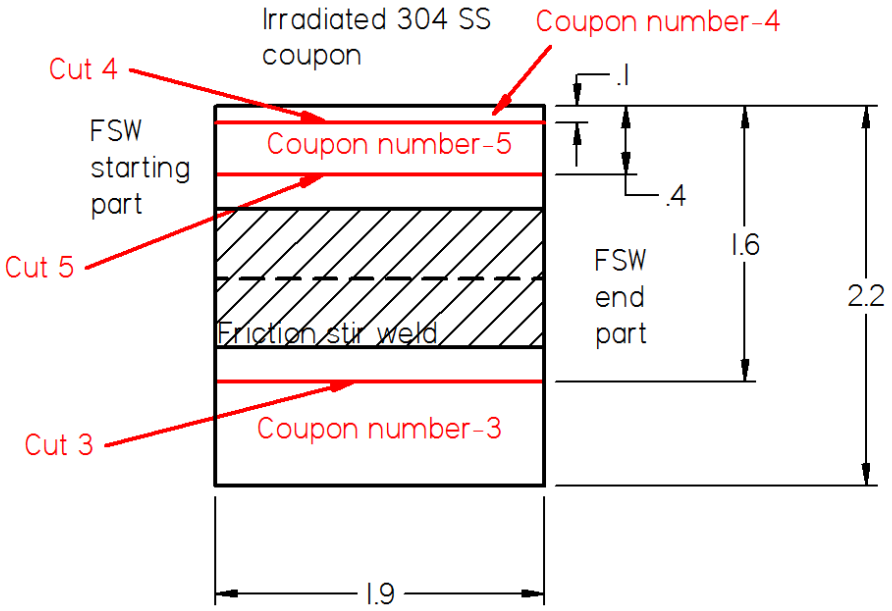
1. Set the guide pin A to the mark 2.
2. Clamp the friction stir welded coupon with the run-off tab end firmly in contact with the guide pin shown in the following figure.
3. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
4. When the cutting is completed, turn off the band saw power, raise and lock the band saw head.
5. Use brush to clean the saw blade and vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
6. Release the clamp, take out the clamped coupon, deburr cut edges on both pieces, and clean with alcohol and dry.
7. Pack the cut off FSW coupon end part (~1.6” X 2.2” X 0.35”) into the aluminum can marked as coupon number-2.
8. The Coupon number-2 will be stored

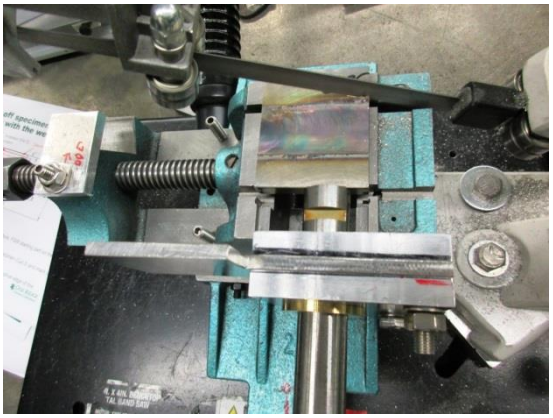


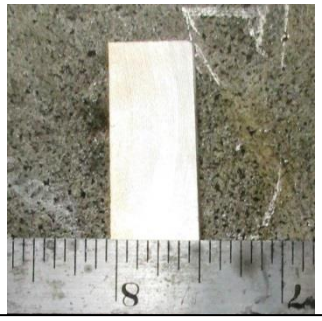


5.3 The 3rd cut

1. Set the guide pin A to the mark 2.
2. Turn the remaining coupon 90 degrees perpendicular with the 1st and 2nd cut orientation, let the arc top (Or bottom of "U") shown on the top of the weld, or weld beginning of the remaining part, or the marked side in step 5.1, point to the band saw motor side. Clamp the friction stir welded coupon with the side firmly in contact with the guide pin shown in the following figure.
3. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
4. When the cutting is completed, turn off the band saw power, raise and lock the band saw head.
5. Use brush to clean the saw blade and vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
6. Release the clamp, take out the clamped coupon, deburr cut edges on both pieces, clean with alcohol and dry, and mark cut sides of both pieces.
7. Pack the cut off small part (~1.8" X 0.55" X 0.35") into the aluminum can marked as coupon number-3.
8. The Coupon number-3 will be stored.







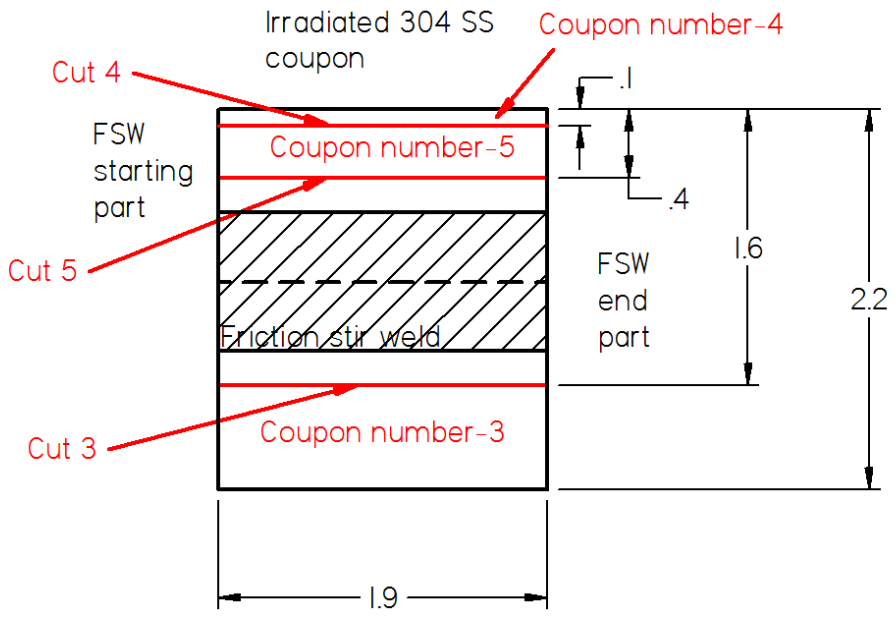
Pack with the Coupon number-3 aluminum can.

5.4 The 4th cut

1. Set the guide pin A to the mark 4.
2. Turn the remaining coupon 180 degrees from the setup of the 3rd cut orientation, let the arc top (Or bottom of “U”) shown on the top of the weld, or weld beginning of the remaining part, or the marked side in step 5.1, point away from the band saw motor side, and the marked cross section in step 5.3 on the longitudinal direction is placed

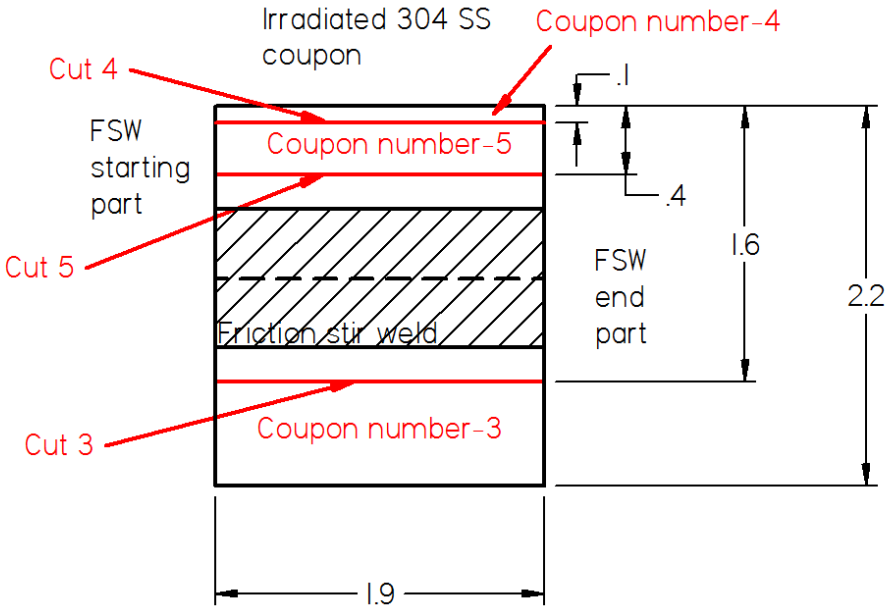
against the guide pin. Clamp the friction stir welded coupon with the side firmly in contact with the guide pin shown in the following figure.

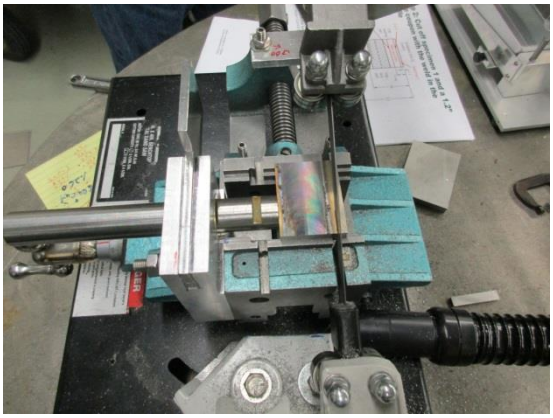
3. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
4. When the cutting is completed, turn off the band saw power, raise and lock the band saw head.
5. Use brush to clean the saw blade and vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
6. Release the clamp, take out clamped coupon, deburr cut edges on both pieces, clean with alcohol and dry, and mark cut sides.
7. If later cuts of Coupon number-4 are required a slow speed saw will be used and carried out at Low Activation Materials Development and Analysis (LAMDA), pack the cut off part (~1.8” X 0.35” X 0.1”) into the aluminum can marked as coupon number-4.
8. If later cuts of Coupon number-4 using a slow speed saw will be carried out at 3025E, leave it aside for the later slow speed saw cutting.

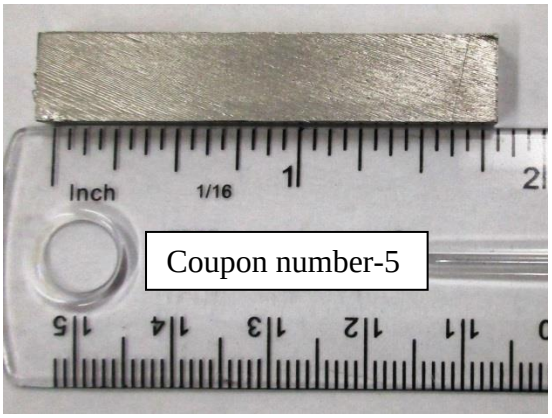


5.5 The 5th Cut

1. Set the guide pin A to the mark 3.
2. Keep remaining coupon the same orientation with the 4th cut, let the arc top (Or bottom of “U”) shown on the top of the weld, or weld beginning of the remaining part, or the marked side in step 5.1, point away from the band saw motor side. Clamp the friction stir welded coupon with the side firmly in contact with the guide pin shown in the following figure.
3. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
4. When the cutting is completed, turn off the band saw power, raise and lock the band saw head.
5. Use brush to clean the saw blade and vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
6. Release the clamp, take out the clamped coupon, deburr cut edges on both pieces, and clean with alcohol and dry.
7. Pack the cut off part (~1.8” X 0.35” X 0.2”) into the aluminum can marked as coupon number-5.
8. The Coupon number-5 will be stored.



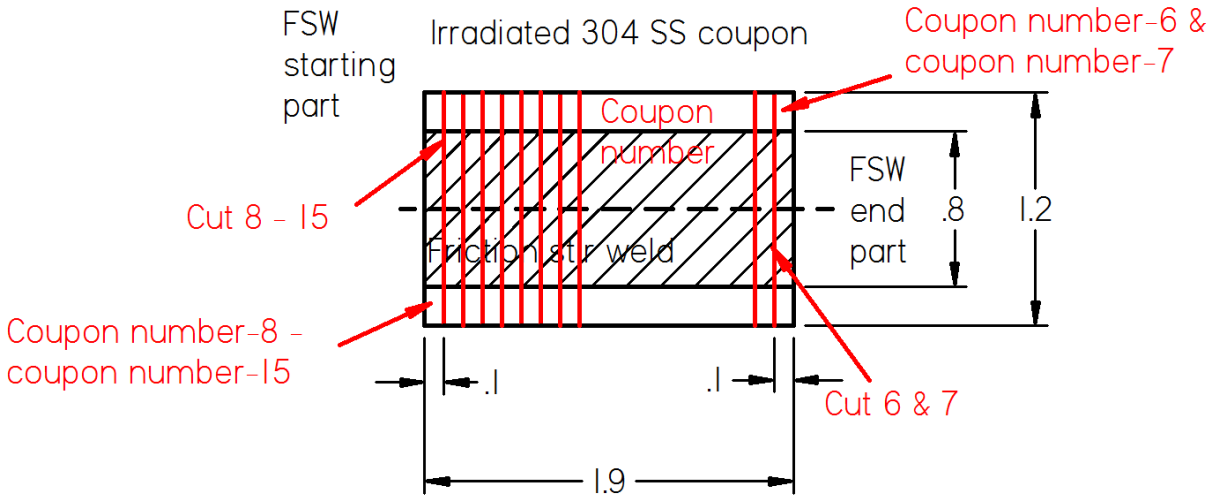


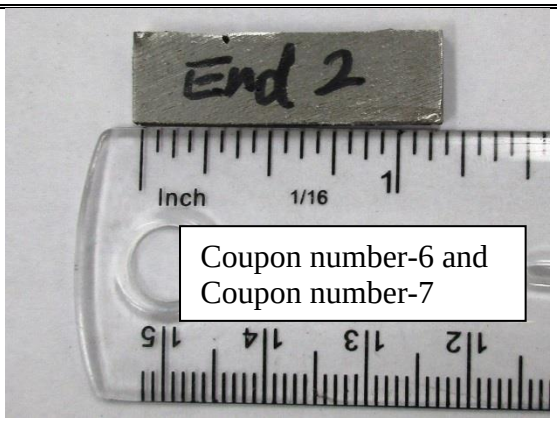


5.6 The 6th and 7th cuts

1. Set the guide pin B to the mark 1.
2. Turn the remaining coupon 90 degrees from the setup of the 5th cut, let the arc top (Or bottom of "U") shown on the top of the weld, or weld beginning of the remaining part, or the marked edge in step 5.1, point to the guide pin. Clamp the friction stir welded coupon with the side firmly in contact with the guide pin.

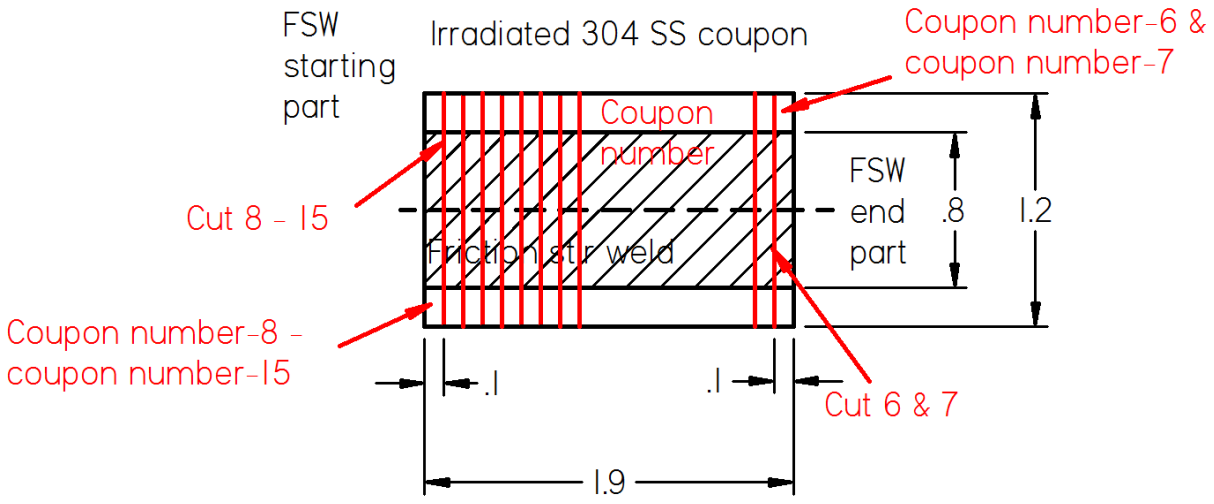
3. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
4. When the cutting is completed, turn off the band saw power, raise and lock the band saw head.
5. Use brush to clean the saw blade and vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
6. Release the clamp, take out clamped coupon, deburr cut edges on both pieces, clean with alcohol and dry, and mark the cut surface of the cut off specimen only.
7. Pack the cut off small specimen (~1.2” X 0.35” X 0.1”) into the fiber tube marked as coupon number-6.
8. Set the guide pin B to the mark 2.
9. Repeat step 2 to step 6 without changing the weld coupon orientation, cut another specimen off, pack the cut off small part (~1.2” X 0.35” X 0.1”) into the fiber tube marked as coupon number-7.
10. Coupon number-6 and Coupon number-7 will be transported to LAMDA.

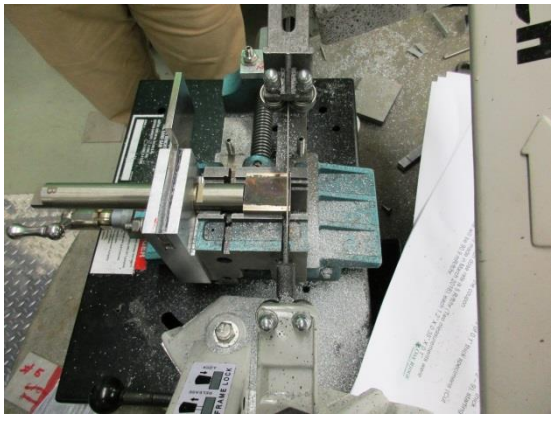


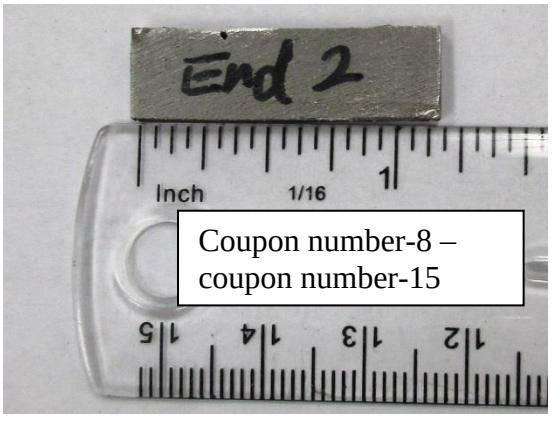


5.7 The 8th – 15th cut

1. Set the guide pin B to the mark 3.
2. Mark the side with arc top (Or bottom of "U") shown on the top of the weld, or the side close to weld beginning of the remaining part, or the side close to the marked side in step 5.1, if it is not marked.
3. Turn the remaining coupon 180 degrees from the setup of the 6th and 7th cuts, let the arc top (Or bottom of "U") shown on the top of the weld, or the side close to the weld beginning of the remaining part, or the marked side in step 5.1, point away the guide pin. Clamp the friction stir welded coupon with the side firmly in contact with the guide pin shown in the following figure.
4. Unlock the band saw head, and make sure the band saw power and vacuum power are on before the saw blade contacts the coupon.
5. When the cutting is completed, raise and lock the band saw head, and turn off the band saw power.
6. Use brush to clean the saw blade and vacuum to collect loose cutting fines if it is necessary then turn off the vacuum.
7. Release the clamp, take out clamped coupon, deburr cut edges on both pieces, and clean with alcohol and dry.
8. Reset the guide pin to the proper mark (Pin B, the mark 4 – the mark 10).
9. Pack the cut off small specimen (~1.2" X 0.35" X 0.1") into the fiber tube marked as coupon number-8.
10. Repeat step 2 to step 8 seven times without change the weld coupon orientation, cut seven more specimens off, pack the cut off small specimens (~1.2" X 0.35" X 0.1") into the fiber tube marked as Coupon number-9 – Coupon number-15.
11. Coupon number-9 – Coupon number-15 will be transported to LAMDA.



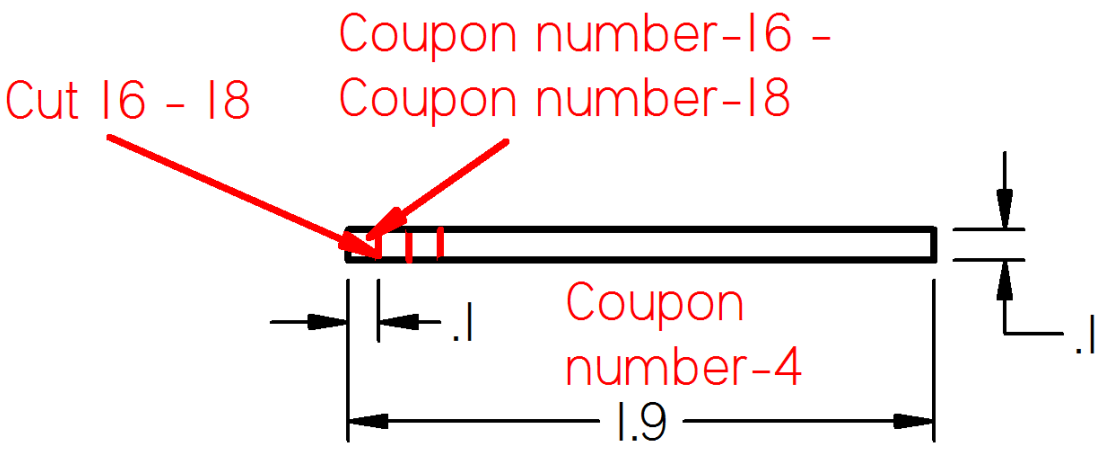




5.8 The 16th – 18th cut

1. Clamp the Coupon number-4 (~1.8” X 0.35” X 0.1”) on a slow speed saw with the orientation cutting through the 0.35” X 0.1” cross section.
2. Adjust the Coupon number-4 stick out position to cut a specimen with about 0.1” long.
3. Cut the specimen.
4. Deburr cut edges on both pieces and clean with alcohol.
5. Pack the cut specimen (~0.35” X 0.1” X 0.1”) with a fiber tube marked as Coupon number-16.
6. Repeat step 1 to step 5 to cut two more specimens, pack them into fiber tubes marked as Coupon number-17 and Coupon number-18, respectively, and pack the remaining specimen into the aluminum can marked as coupon number-4.

7. Coupon number-16 – Coupon number-18 will be transported to LAMDA. Coupon number-4 will be stored.



6 Quality Assurance

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7 Records

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STANDARD OPERATING PROCEDURE

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- Required once every 5 years as a minimum
- Signatures indicate adequacy of this document for activity

1st Re-Review

MP&J Group Leader _____ Date _____

MST Division Safety Officer _____ Date _____

2nd Re-Review

MP&J Group Leader _____ Date _____

MST Division Safety Officer _____ Date _____