ORNL/SPR-2022/2657

Light Water Reactor Sustainability Program

Complete the weld campaign on Ni-base irradiated materials using stress improved laser welding including the preliminary weld quality inspections

M3LW-22OR0406013

September 2022
U.S. Department of Energy
Office of Nuclear Energy

ORNL/SPR-2022/2657

Materials Science and Technology Division

COMPLETE KEY POST-WELD EVALUATIONS AND PRE- AND POST-IRRADIATION EVALUATIONS OF BASELINE AND IRRADIATED WELD FROM FY18 AND FY19 CAMPAIGNS

M3LW-22OR0406013

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ACRONYMS

ABSI-LW	auxiliary beam stress improved laser welding
appm	atom parts per million
DIC	digital image correlation
DOE	Department of Energy
EDM	electrical discharge machining
EPRI	Electric Power Research Institute
FSW	friction stir welding
HAZ	heat-affected zone
HeIC	helium induced cracking
LTO	Long-Term Operation
LW	laser weld
LWRS	Light Water Reactor Sustainability
NE	Office of Nuclear Energy
ORNL	Oak Ridge National Laboratory
SEM/EDS	scanning electron microscopy/energy-dispersive x-ray spectroscopy
THDS	thermal helium desorption spectroscopy
VAR	vacuum arc melting
VTI	Vacuum Technology Incorporated
wppm	weight parts per million

ACKNOWLEDGMENT

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ABSTRACT

This report summarizes the most recent welding campaign on irradiated Ni-base alloy 182 and the preliminary weld quality inspections at the Radiochemical Engineering Development Center (REDC). Equipment and capabilities were developed jointly by the U.S. Department of Energy, Office of Nuclear Energy, Light Water Reactor Sustainability Program, the Electric Power Research Institute, Long Term Operations Program (and the Welding and Repair Technology Center), and Oak Ridge National Laboratory. Irradiated nickel alloy 182, with target helium contents of 5 atom parts-per million (appm), 10 appm, and 20 appm, were laser welded in the hot cell successfully. 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.

This report fulfills the FY 2023 milestone M3LW-22OR0406013, “Complete the weld campaign on Ni-base irradiated materials using stress improved laser welding including the preliminary weld quality inspections”.

1. INTRODUCTION

Today, welding is widely used for repair, maintenance, and upgrades of nuclear reactor components. As a critical technology to extend the service life of nuclear power plants beyond 60 years, weld technology must be further developed to meet new challenges associated with the aging of the plants, such as control and mitigation of the detrimental effects of weld residual stresses and repair of highly irradiated materials. To meet this goal, a fundamental understanding of welding effects is necessary for the development of new and improved welding technologies.

Welding repair of irradiated nuclear reactor materials (such as austenitic stainless steels used for the reactor internals) is very challenging because the existence of helium in the steel, even at very low levels (*i.e.*, parts per million), can cause cracking during repair welding. Helium is a product of the boron and nickel transmutation process under intense neutron irradiation. Under the influence of high temperatures and high tensile stresses during welding, rapid formation and growth of helium bubbles can occur at grain boundaries, resulting in intergranular cracking in the heat-affected zone (HAZ) – the so-called helium-induced cracking (HeIC) (Kanne Jr. 1988). Over the past decades, a basic understanding has been established for the detrimental effects of weld stresses on HeIC (Feng and Wilkowski 2002) (Feng, Wolfe, *et al*. 2009). However, practical methods for weld repair of irradiated materials are still evolving. Industry's experience is based on current arc-welding–based and laser-welding–based repair technologies that are limited to situations where the helium in the irradiated materials is less than 10 appm. Although no welding restrictions are required for helium levels below 0.1 appm helium, restrictions on welding parameters, such as welding heat input, are necessary when the helium levels are above 0.1appm. Reactor internals with helium levels above 5-10 appm are generally considered to be not weldable (or weld repairable) using today's welding practices common to the industry (EPRI 2015) (JNES 2004).

As the service life of nuclear reactors in the United States is extended, the amount of helium in the structural materials in certain highly irradiated areas will continue to increase, reaching levels much higher than 10 appm, as shown in **Figure 1** (EPRI 2015). Therefore, innovations in repair welding technology are essential to addressing this critical industry need.

This research, a joint effort of the US Department of Energy Office of Nuclear Energy (DOE NE) Light Water Reactor Sustainability (LWRS) Program and the Electric Power Research Institute (EPRI) Long-Term Operations (LTO) Program, is aimed at developing advanced welding technology for reactor repair and upgrades. It focuses on welding repair of irradiated materials that are extremely challenging and require long-term R&D. Multiple weld campaigns have been completed on irradiated 304 and 316 stainless steels with the targeted helium concentration up to 30 appm between FY2018 and FY2021. Microstructural characterizations demonstrated the feasibility to use advanced auxiliary beam stress improved laser welding (ABSI-LW) and friction stir welding (FSW) to mitigate the formation of HeIC. In this most recent weld campaign, irradiated nickel alloy 182 samples with targeted helium concentrations up to 20 appm were selected for ABSI-LW studies. This milestone report summarizes the results of this welding campaign on irradiated Ni-base irradiated materials and the preliminary weld quality inspections performed at the Radiochemical Engineering Development Center (REDC).

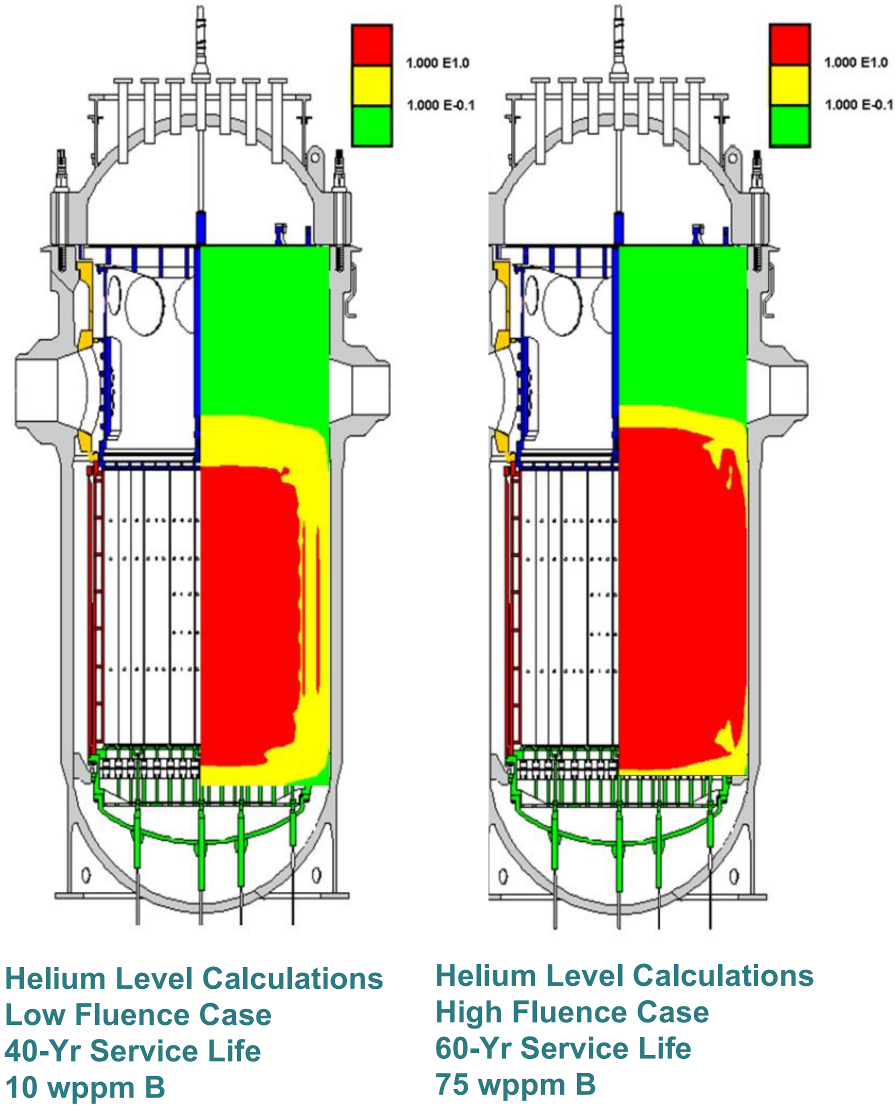


Figure 1 Forecast of helium generation of a typical Combustion Engineering (CE) pressurized water reactor. Red zone: helium generation greater than 10 appm (not weldable with current welding processes). Yellow zone: helium generation greater than 0.1 appm and less than 10 appm (weldable with heat input control). Green zone: helium generation less than 0.1 appm (no special process control is needed). From (EPRI 2015).

2. EXPERIMENTS

2.1 Materials

Five heats of Alloy 182 having five boron concentration levels (nominally 0, 5, 10, 20, and 30 ppm by weight) were produced by Sophisticated Alloys, Inc, following the specifications established by ORNL to cover the anticipated range of helium levels in materials exposed up to 80 years of reactor operation (M3LW-14OR0406014, 2014). Table **1** shows the complete chemistry analysis of the Alloys 182 heats used in this project. As shown in the Table 1 not all the target boron concentrations were achieved but a wide range of boron levels were produced ranging from 0.3 to 23 ppm. All other elements met the chemistry requirements for Alloy 182. Bar stock sections were machined to final dimensions (76x56x8.9mm nominal) to yield 7 pieces at each boron level for subsequent irradiation. Alloy 182, being weld filler metal, typically has a coarser weld microstructure in reactor structures. An additional fifteen specimens from heats 182D and 182E respectively were fusion welded on one side to half of the specimen depth to produce a representative weld microstructure.

The custom alloy 182 blocks were irradiated at the ORNL High Flux Isotope Reactor with a total fluence ranging from 5.08×10^{20} to 1.31×10^{21} depending on the location of the blocks inside the irradiation bores. The irradiated blocks were aged for more than 2 years to allow decay of short half-life isotopes before welding experiments began. Details of the irradiation of the coupons can be found in the previous milestone report M3LW-17OR0406013 (Feng, Miller, *et al*. 2017).

Table 1 Chemistry Analysis Results of Alloy 182

		Alloy 182 Heat Identification				
Element	Unit	182A	182B	182C	182D	182E
B	ppm	0.3	5	15	14	23
Co	ppm	2	2	2	2	2
Al	ppm	81	34	32	54	56
Mo	ppm	1	1	8	1	1
Cu	ppm	2	1	2	1	1
C	wt%	0.03	0.08	0.03	0.04	0.04
Mn	wt%	7.03	7.00	6.76	7.17	7.08
Si	wt%	0.50	0.50	0.51	0.50	0.49
Cr	wt%	15.99	16.00	16.00	16.16	16.10
Fe	wt%	7.36	7.92	7.31	7.14	7.12
Nb	wt%	2.07	2.06	1.83	1.82	1.84
Ti	wt%	0.44	0.43	0.43	0.43	0.46
P	wt%	0.00013	0.00011	0.00018	0.00015	0.00016
S	wt%	0.00207	0.00199	0.00280	0.00200	0.00220
Ni		Balance	Balance	Balance	Balance	Balance

2.2 Welding

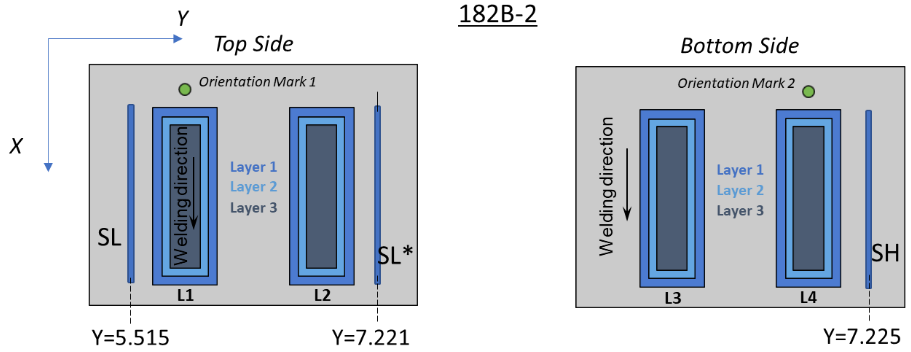
In this weld campaign, laser welding experiments were conducted on three alloy 182 coupons with three nominal boron concentrations (5, 10 and 20 appm). The weld coupon ID, boron concentrations, welding process, and weld campaign identification are given in **Table 2.** For weld coupon 182D-W-1, the letter "W" in the ID indicates that this coupon has been fusion welded to produce a representative weld microstructure before irradiation. Both ABSI-LWs and FSWs were conducted at the dedicated welding hot cell at the ORNL REDC. Details of the equipment and experimental procedures have been reported in the previous milestone report (M2LW-17OR0406014) (Feng, Miller, *et al*. 2017).

Table 2 Weld Coupon ID

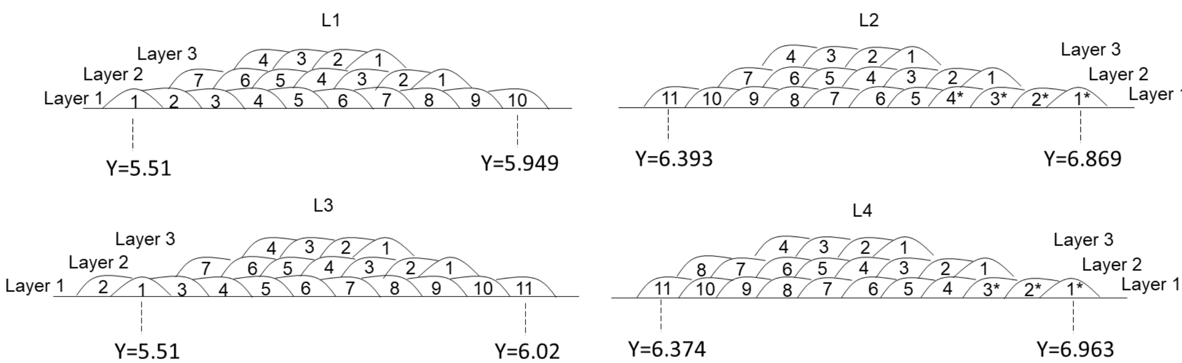
Weld Coupon ID.	Microstructural condition	Target Boron, wppm	Measured boron, wppm
182B-2	Wrought	5	5
182C-1	Wrought	10	15
182D-W-1	Weld	20	14

Laser weld cladding has been performed on irradiated alloy 182 base material with 82 as filler material. Four laser-welded clads (weld IDs L1, L2, L3 and L4) were made using different welding conditions on each coupon. The arrangement of the four laser clads on each coupon is illustrated in Figure 2. In this figure, the two three-layer claddings on the top side of the steel coupon plate are labeled as L1 and L2, and two claddings on the bottom side are labeled as L3 and L4. Weld claddings L2 and L4 in the figure were made with the ABSI-LW and weld claddings L1 and L3 were made with LW without ABSI for comparison. Each weld clad consisted of three layers (Layer 1, layer 2 and Layer 3 from the bottom to the top of each clad). Layer 1 consisted of ten or eleven weld passes. Layer 2 consisted of seven or eight weld passes. Layer 3 consisted of four weld passes. The welding sequence of each layer is denoted using the numerical numbers as shown in **Figure 2.** In addition, single-pass welding (labeled as SL or SH) was also conducted. The purpose is to validate the effective heat input after the weld samples are cut. The relative locations of the single-pass welds are indicated in **Figure 2**. The welding direction of all weld passes was consistently towards the positive direction of the X axis. The Y-coordinates of the first and the last weld passes in Layer 1, as well as the Y- coordinates of the single pass welds, were also shown in **Figure** 2. Note, a new wire feeder was installed before this weld campaign and the new wire feeder was not perfectly aligned with X-axis as it should be **(Figure 3**). To compensate this change, the sequence of weld passes was adjusted as "from right to left" (towards the negative direction of Y-axis) except for the first layer of L1 and L3 on 182B-2. In the previous campaign, the sequence of laser welding passes was always "from left to right" (towards the positive direction of Y-axis).

182B-2

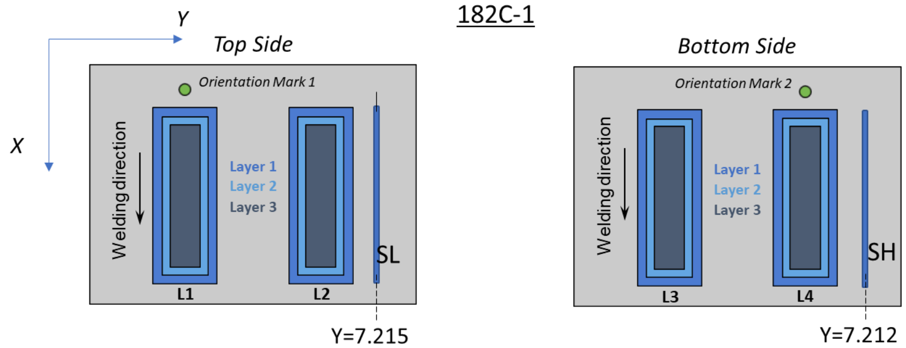


Y
X
Top Side
Orientation Mark 1
Welding direction
Layer 1
Layer 2
Layer 3
SL
SL*
L1
L2
Y=5.515
Y=7.221
Bottom Side
Orientation Mark 2
Welding direction
Layer 1
Layer 2
Layer 3
SH
L3
L4
Y=7.225

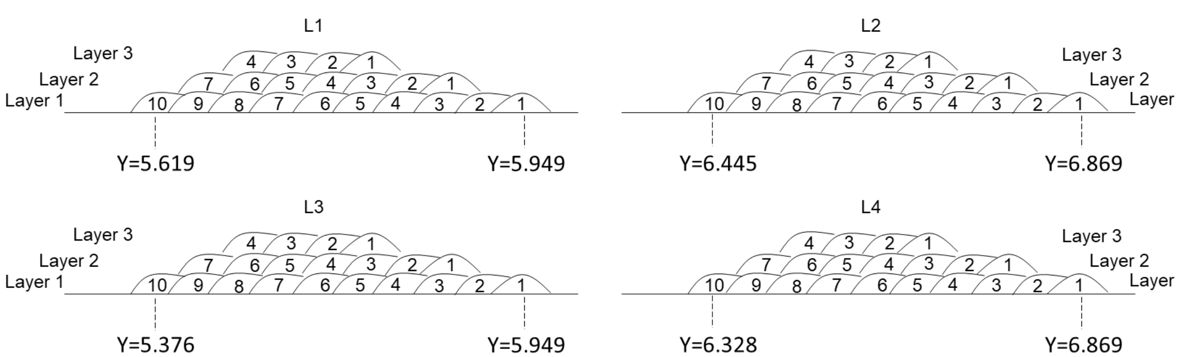


L1
Layer 3
Layer 2
Layer 1
Y=5.51
Y=5.949
L2
Layer 3
Layer 2
Layer 1
Y=6.393
Y=6.869
L3
Layer 3
Layer 2
Layer 1
Y=5.51
Y=6.02
L4
Layer 3
Layer 2
Layer 1
Y=6.374
Y=6.963

182C-1



Y
X
Top Side
Orientation Mark 1
Welding direction
Layer 1
Layer 2
Layer 3
SL
L1
L2
Y=7.215
Bottom Side
Orientation Mark 2
Welding direction
Layer 1
Layer 2
Layer 3
SH
L3
L4
Y=7.212



L1
Layer 3
Layer 2
Layer 1
Y=5.619
Y=5.949
L2
Layer 3
Layer 2
Layer 1
Y=6.445
Y=6.869
L3
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Layer 2
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Y=6.328
Y=6.869

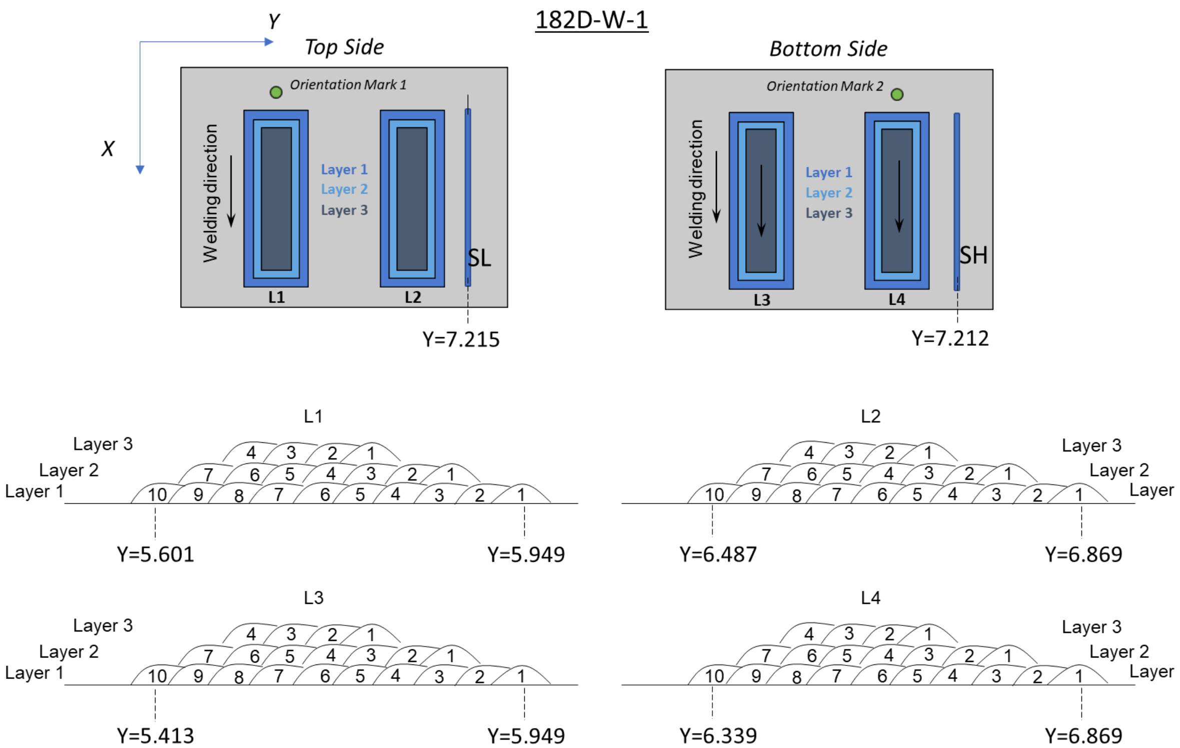


Figure 2 Weld Layout for LW of Irradiated Coupons.

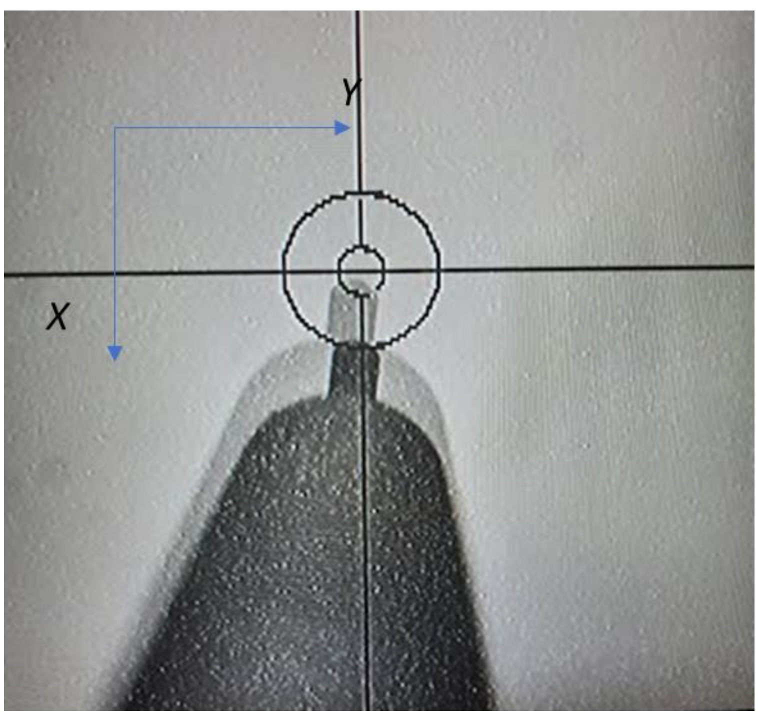


Figure 3 Image of the new wire feeder showing a tilted angle with respect to the welding direction (positive direction along X-axis)

The essential laser weld cladding parameters are given in **Table 3.** Typically, within each completed cladding, identical welding parameters were applied. Weld clads L1 and L2 had a higher laser cladding speed and low heat input than weld clads L3 and L4 in these experiments. Therefore, each weld coupon had four weld claddings (L1 through L4) performed with four different welding conditions. Additional single-pass LW passes without ABSI, labeled as SL and SH in **Figure 2,** were performed to evaluate the effect of heat input and weld bead profile of a single LW pass on HeIC. The letter "S" in the label stands for single-pass weld. "L" or "H" stands for low-heat or high-heat parameter set. This provides the ability to isolate the effect of multi-thermal cycles in the multi-pass, multi-layer clads. Single pass welds also allow for the determination of the base metal percentage dilution of the first weld layer by for each LW parameter set. The percentage Base Metal Dilution = 100 X (Area of Base Metal Melted /Area of Deposited Weld). Furthermore, the weld dilution may also be used to estimate what the maximum helium content of the first layer or individual weld pass could be assuming the helium does not escape the weld pool. It is expected that only a portion of the helium remains in the first weld layer or individual weld pass and successively lower amounts as more layers are applied. Removing specimens for helium measurement to determine the percentage helium remaining also provides an estimate of how many layers are required before conventional welding methods may be used to complete the reactor repair or modification. The welding condition for SL was identical to that in L1; The welding condition for SH was identical to that of L3. The basic laser welding parameters are summarized in **Table 3.** The different welding speeds and corresponding wire feed rates resulted in different individual weld and clad layer thicknesses.

Note, abnormal welding parameters or conditions were accidentally used in some of the passes. They mostly occurred when welding coupon 182B-2. These abnormal conditions include:

(a) The first attempt of single pass (labeled as SL* at the top side of Y-coordinate 7.221) on 182B-2 was conducted using an incorrect wire feed speed of 13.1inch/min. It should be 50 inch/min. Therefore, another single pass was conducted using the right wire feed speed (labeled as SL at the top side of Y-coordinate 5.515).

(b) For weld passes 1-4 in Layer 1 of clad L2 on 182B-2, the welds were not sufficiently protected by the shielding gas due to improper position of the nozzle. This may result in excessive surface oxidization, increased heat absorption, and hence slightly deeper weld penetration.

(c) For weld passes 1-3 in Layer 1 of clad L4 on 182B-2, incorrect raster scanning power (2000W) was used. The correct scanning power should be 368W. It resulted in excessive melting.

Table 3 Laser Weld Cladding Parameters

Parameter	Multi-pass Weld Clads				Single-Pass Weld	
	L1	**L2**	**L3**	**L4**	**SL**	**SH**
Travel speed (in./s)	0.45 (high-speed)	0.45 (high-speed)	0.083 (low-speed)	0.083 (low-speed)	0.45 (high-speed)	0.45 (high-speed)
Expected effective heat input from welding beam (kJ/in)	0.39 (low-heat)	0.39 (low-heat)	1.20 (high-heat)	1.20 (high-heat)	0.39 (low-heat)	1.20 (high-heat)
Wire feed speed (in./min)	50	50	13.1	13.1	50	13.1
Welding laser power (W)	1,000	1,000	1,000	1,000	1,000	1,000
Welding laser diameter (mm)	2	2	2	2	2	2

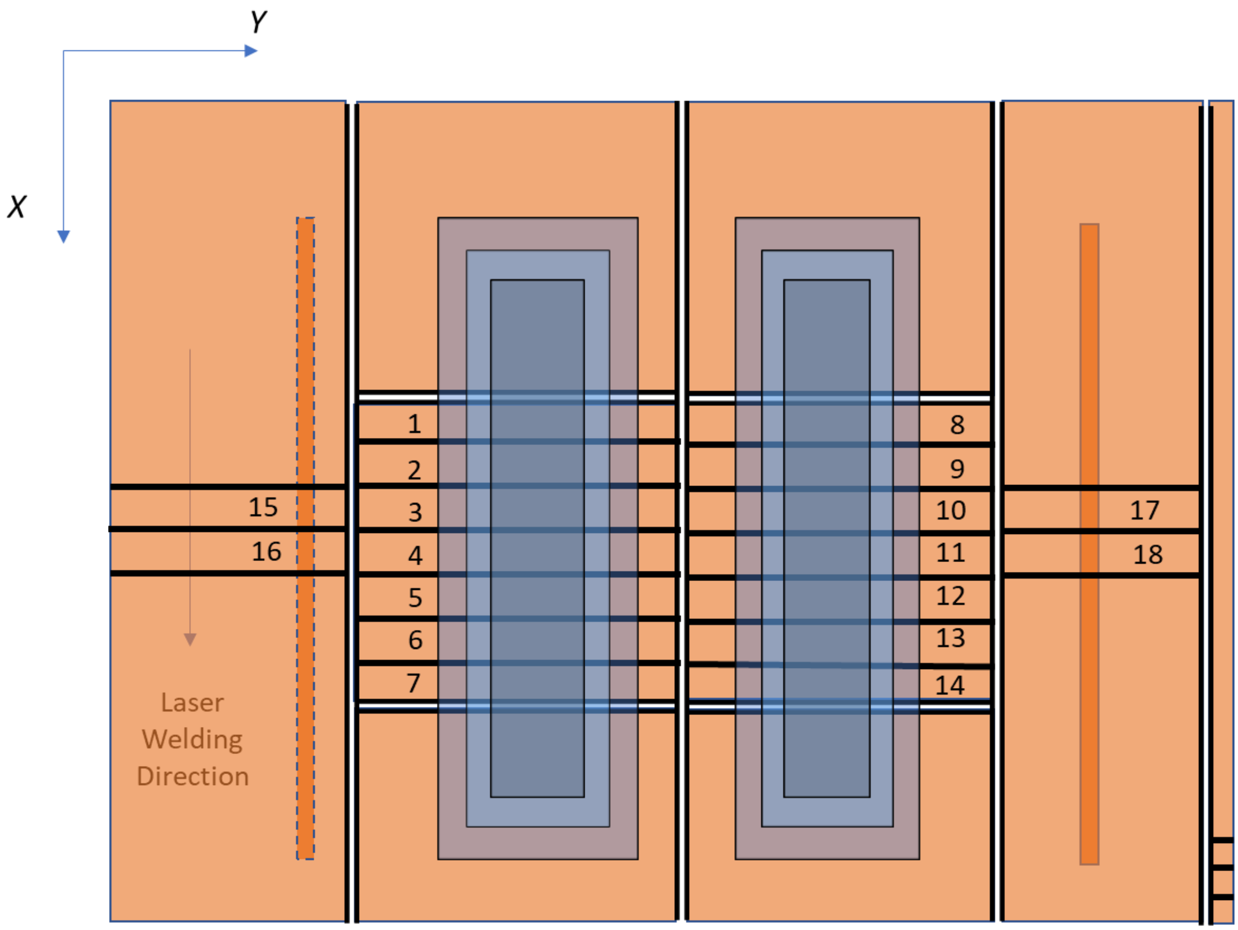
ABSI	No	Yes	No	Yes	No	No
ABSI laser power (W)	N/A	2000	N/A	368	N/A	N/A
ABSI laser diameter (mm)	N/A	7.5	N/A	7.5	N/A	N/A

2.3 Preliminary weld quality inspections

The preliminary weld quality inspection was conducted right after each clad was completed using the inline camera in the laser system.

2.4 Coupon cutting plan for subsequent microstructural characterizations

The laser welded coupons will be cut into multiple slices for subsequent microstructural characterizations and helium measurements using the approved cutting procedure (Appendix A). **Figure 4** illustrates the position of the cuts.



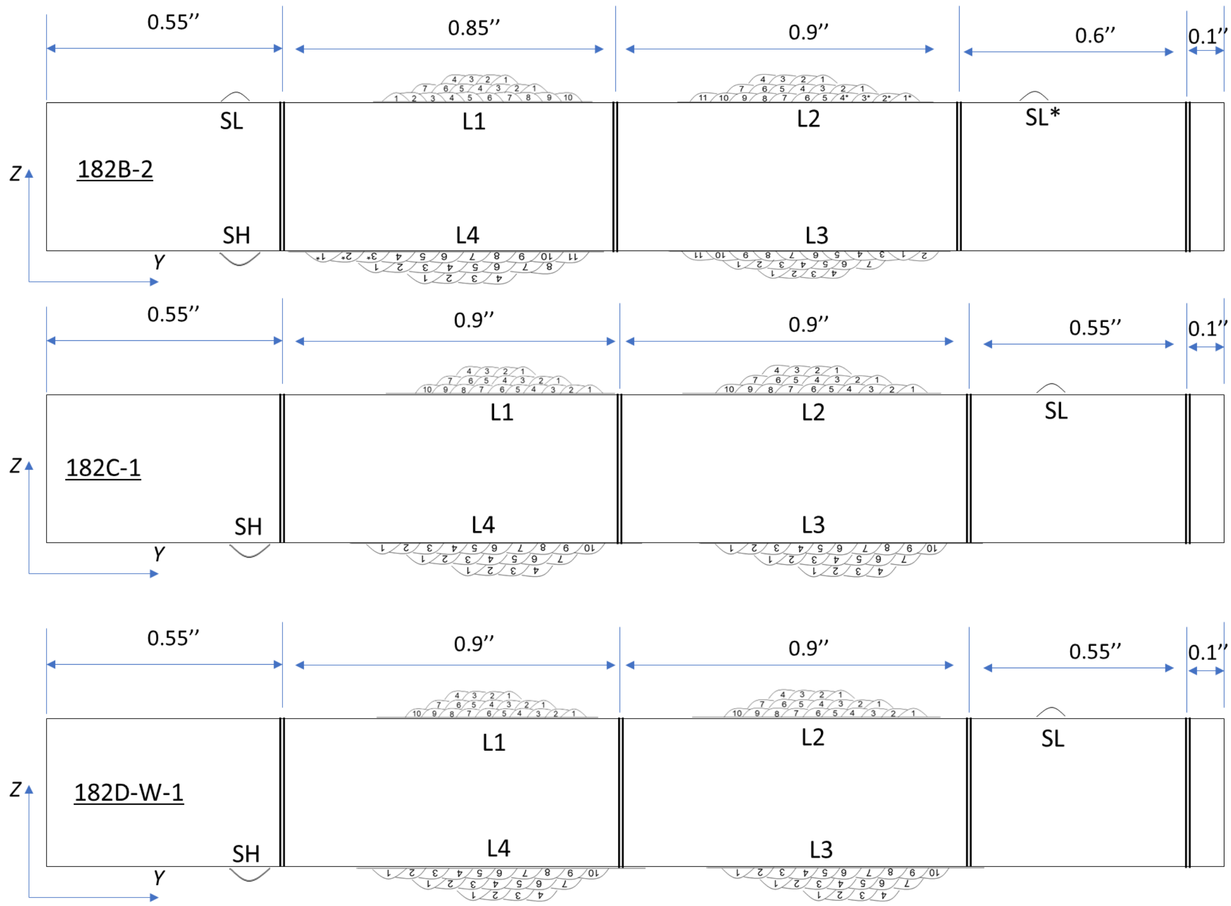
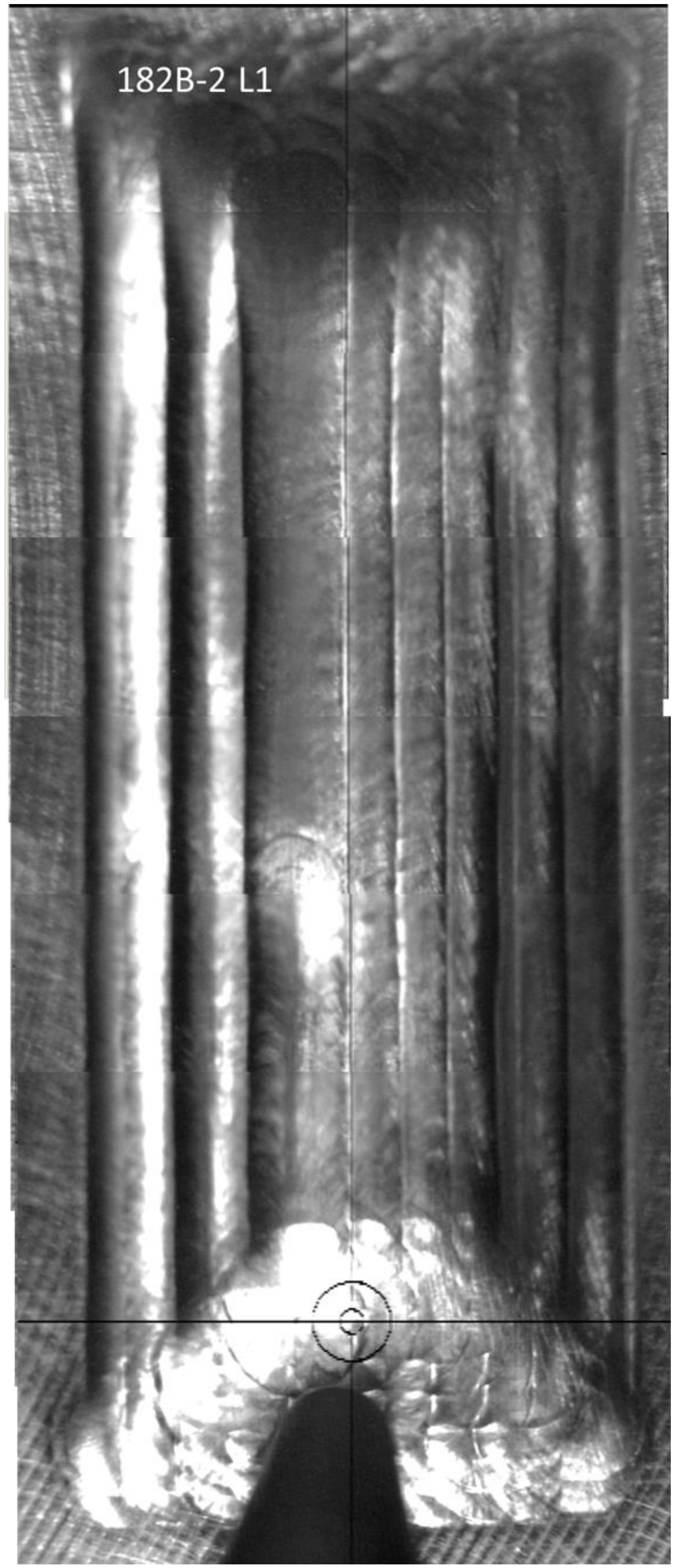
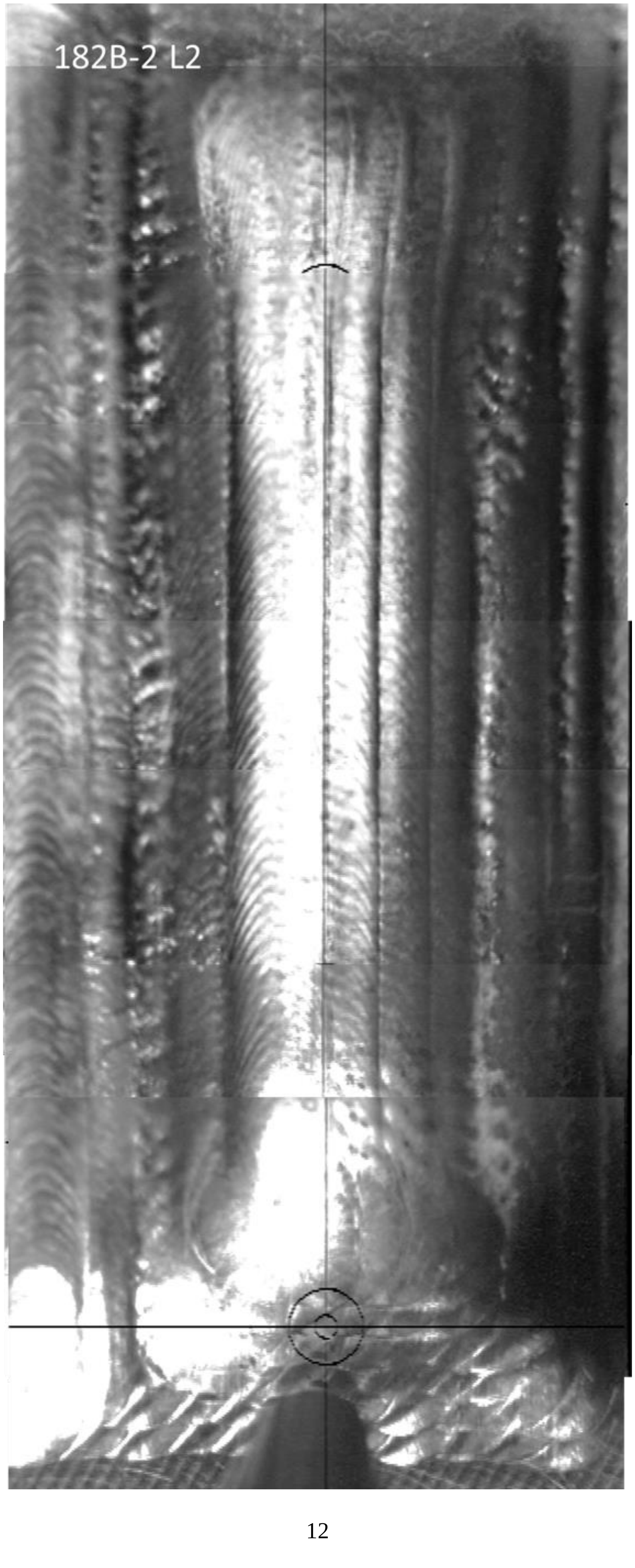


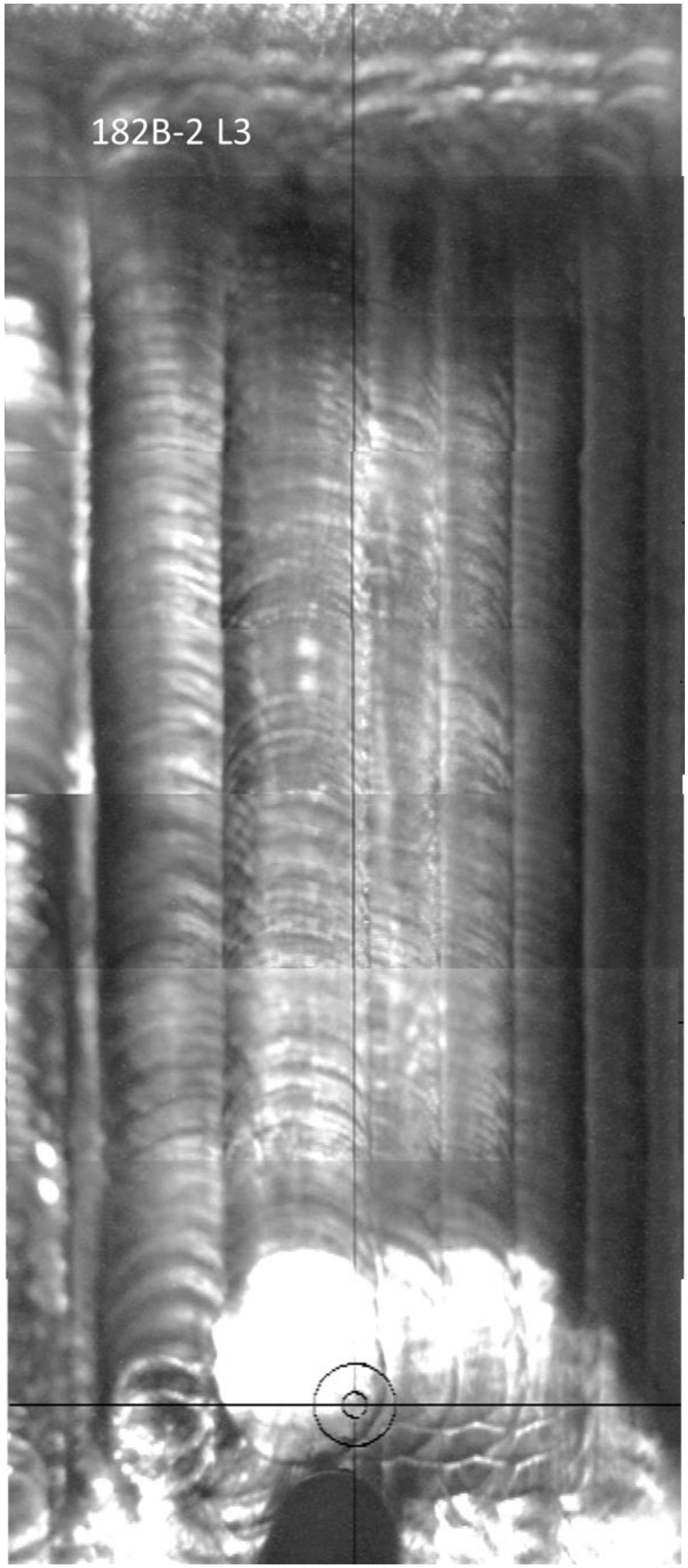
Figure 4 The drawing of the cut

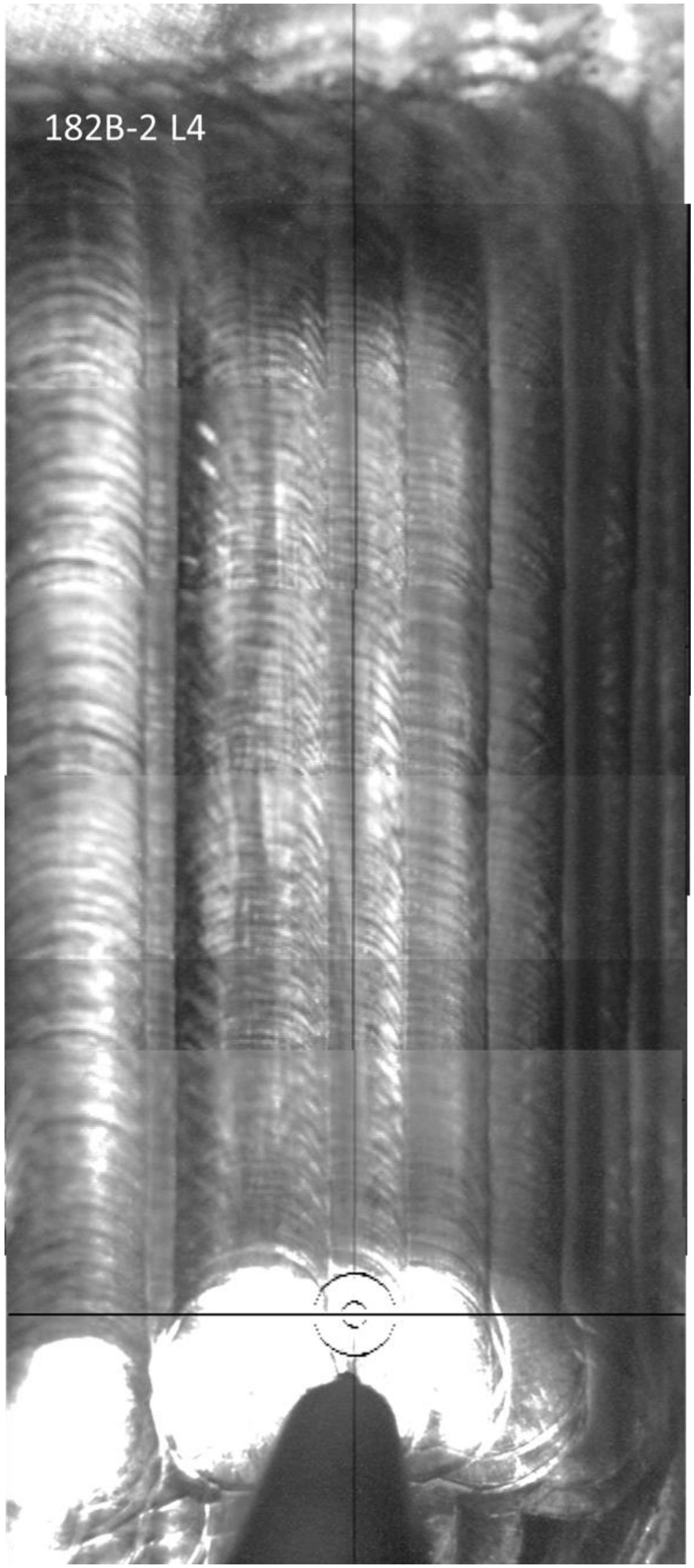
3. RESULTS AND DISCUSSION

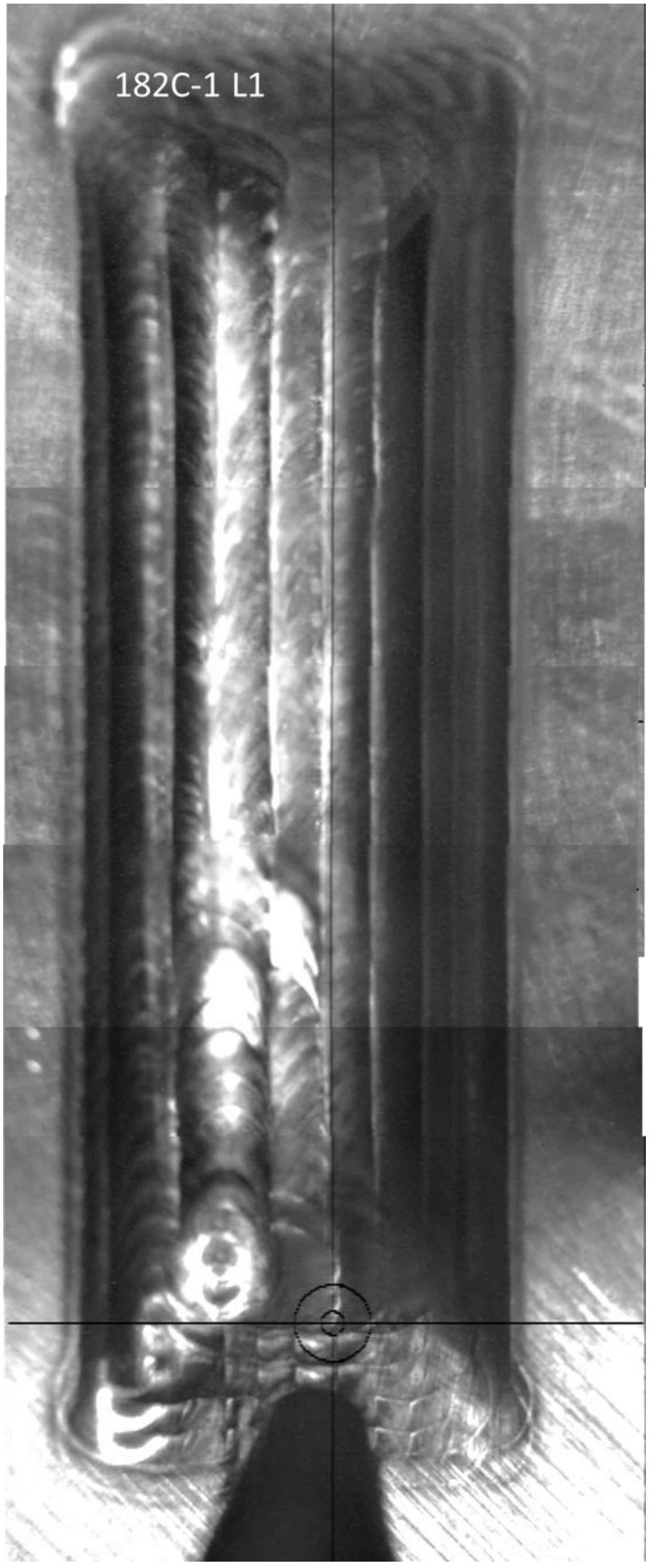
Figure 5 shows the surface weld quality of twelve weld clads after completion of each clad using the in-line camera on the laser system. It appears that uniform and smooth weld beads were produced, and no macroscopic cracking (i.e, greater than millimeter size) was observed under visual inspection. More detailed microstructural evaluations using optical and electric microscopes will be performed in the future.

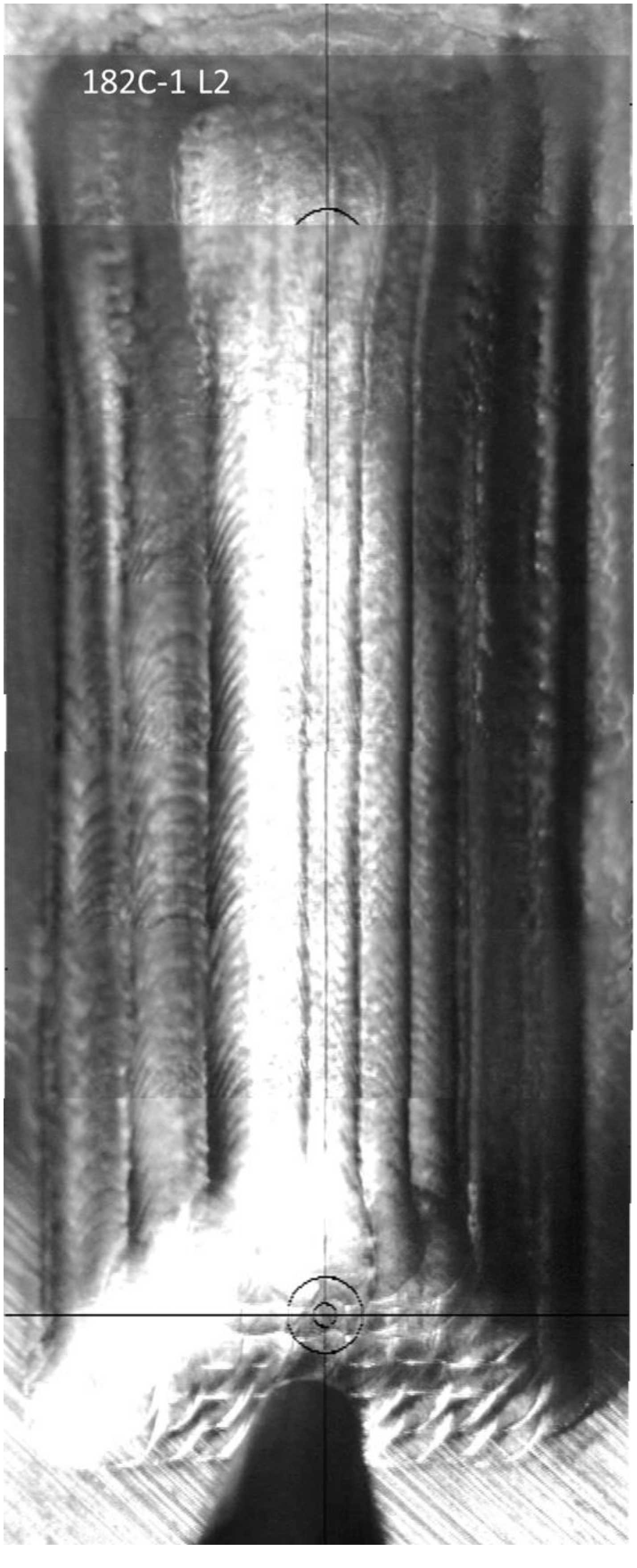

182B-2 L1

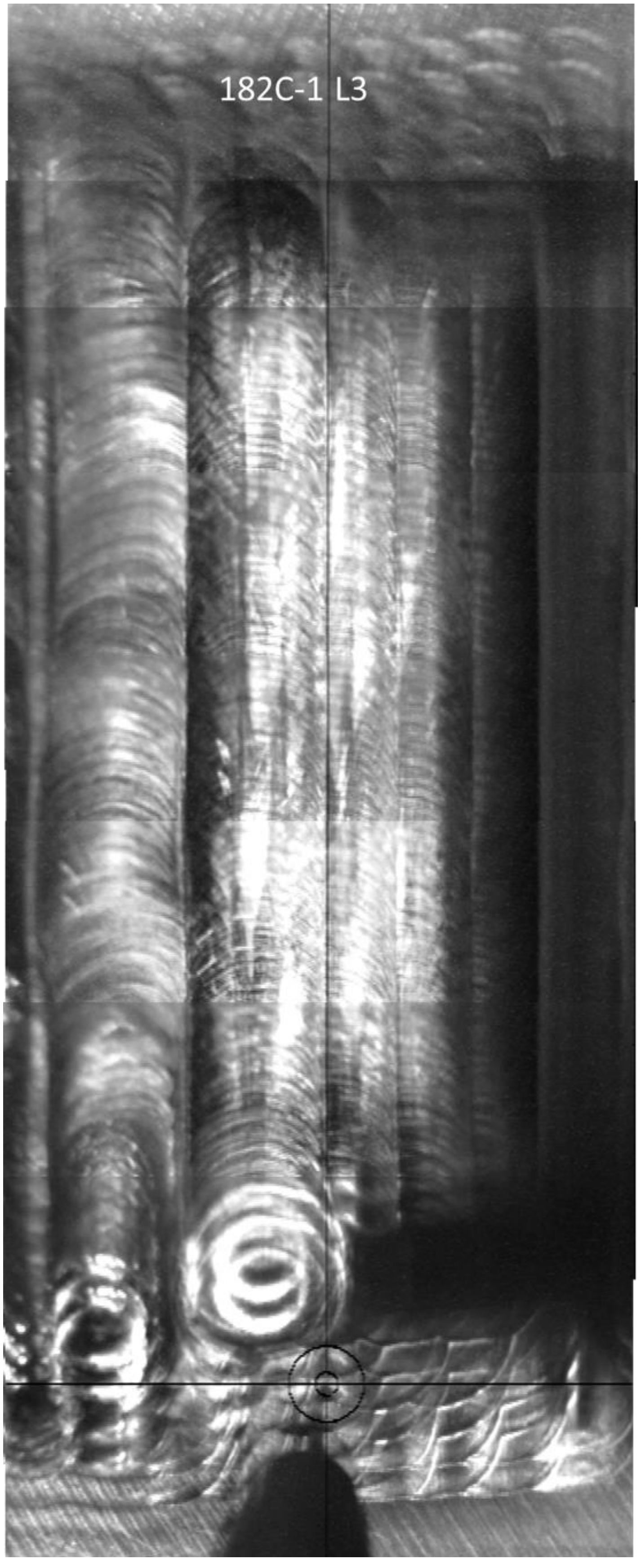

182B-2 L2


182B-2 L3


182B-2 L4


182C-1 L1


182C-1 L2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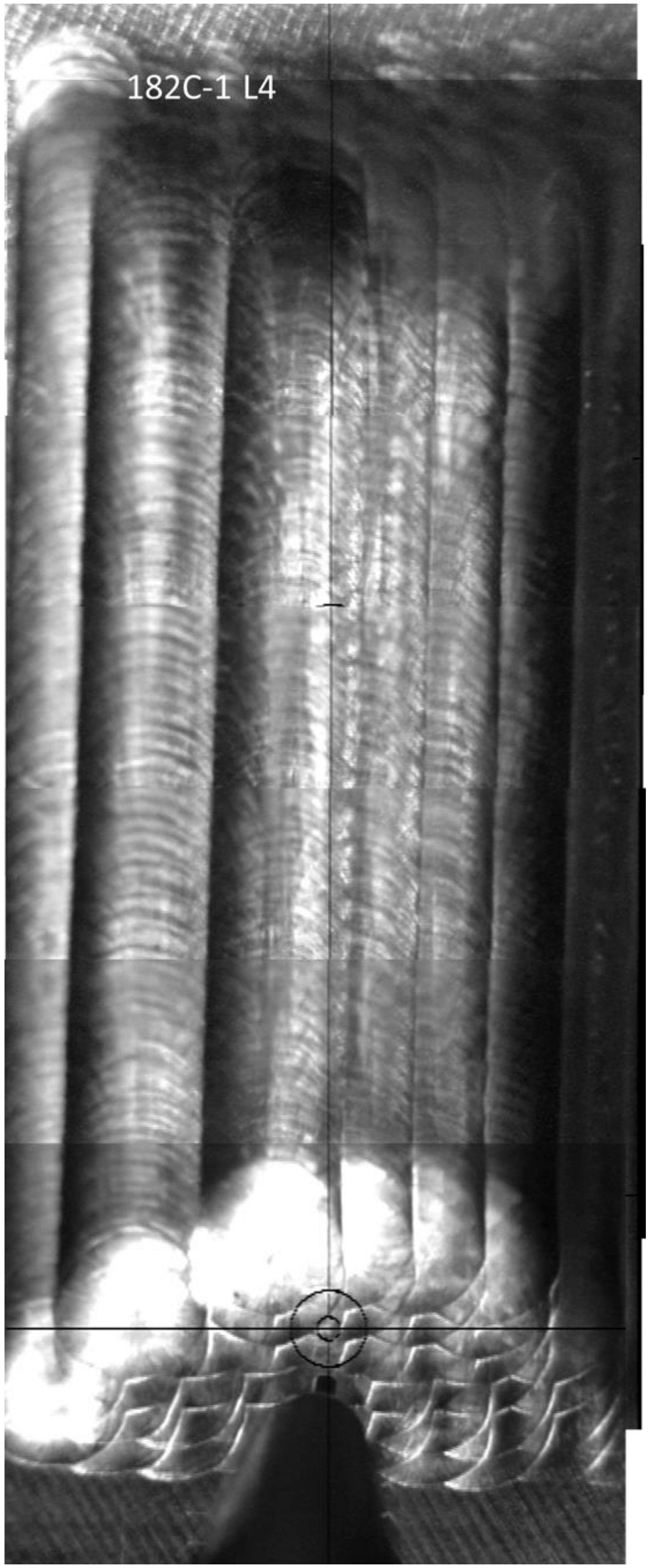
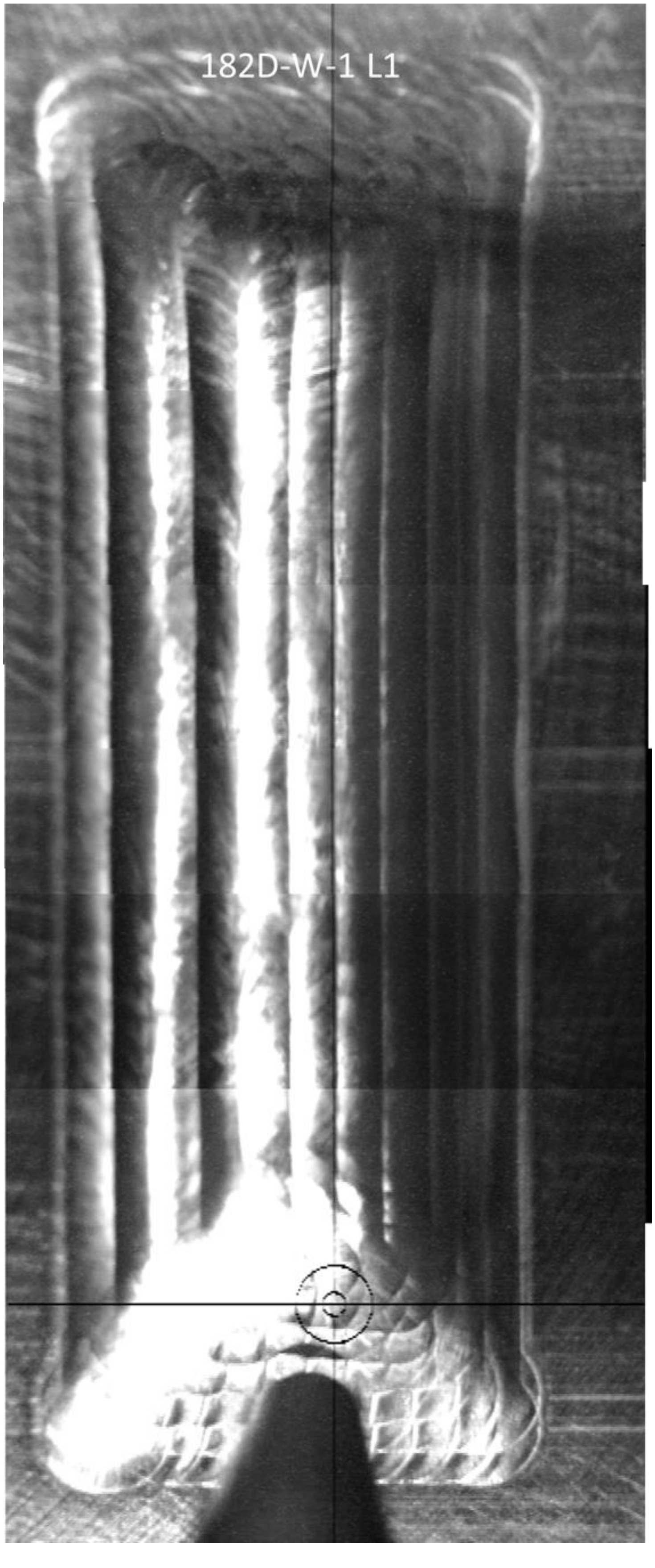
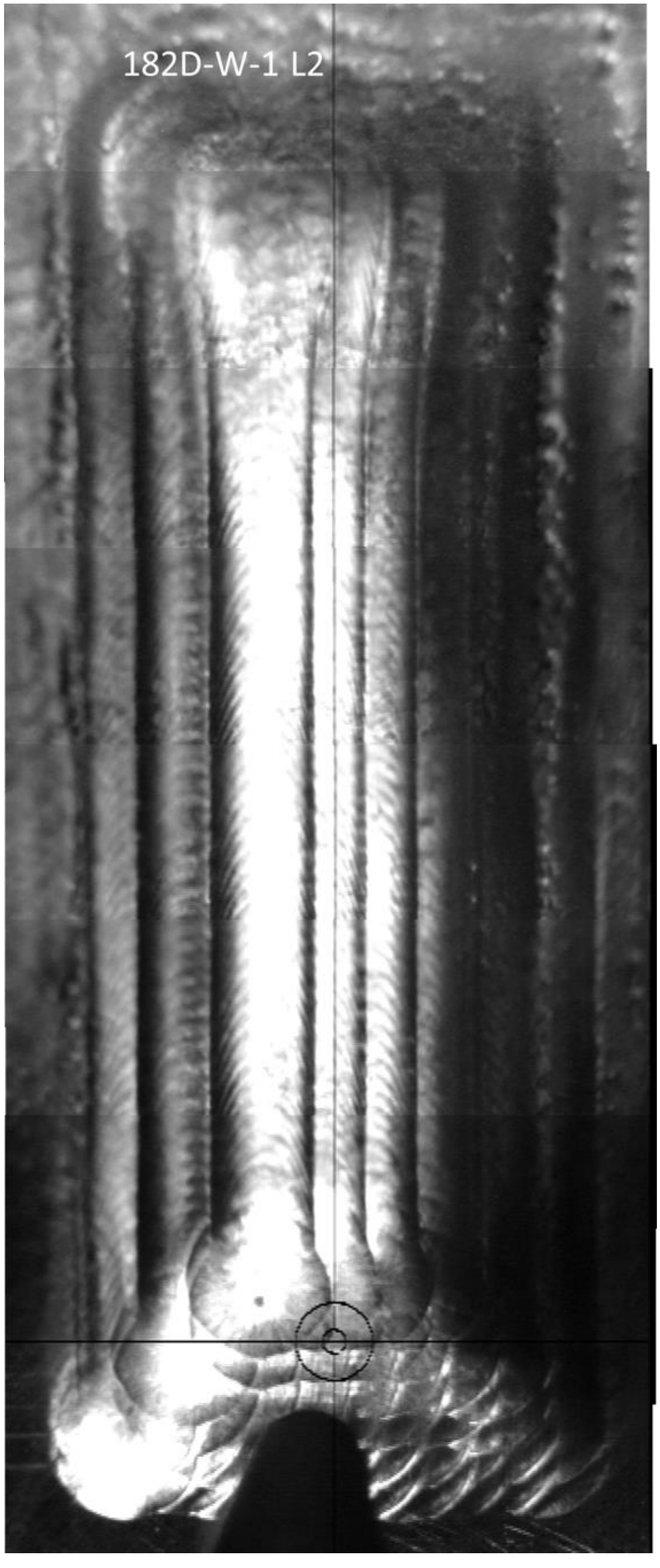

182C-1 L4


182D-W-1 L1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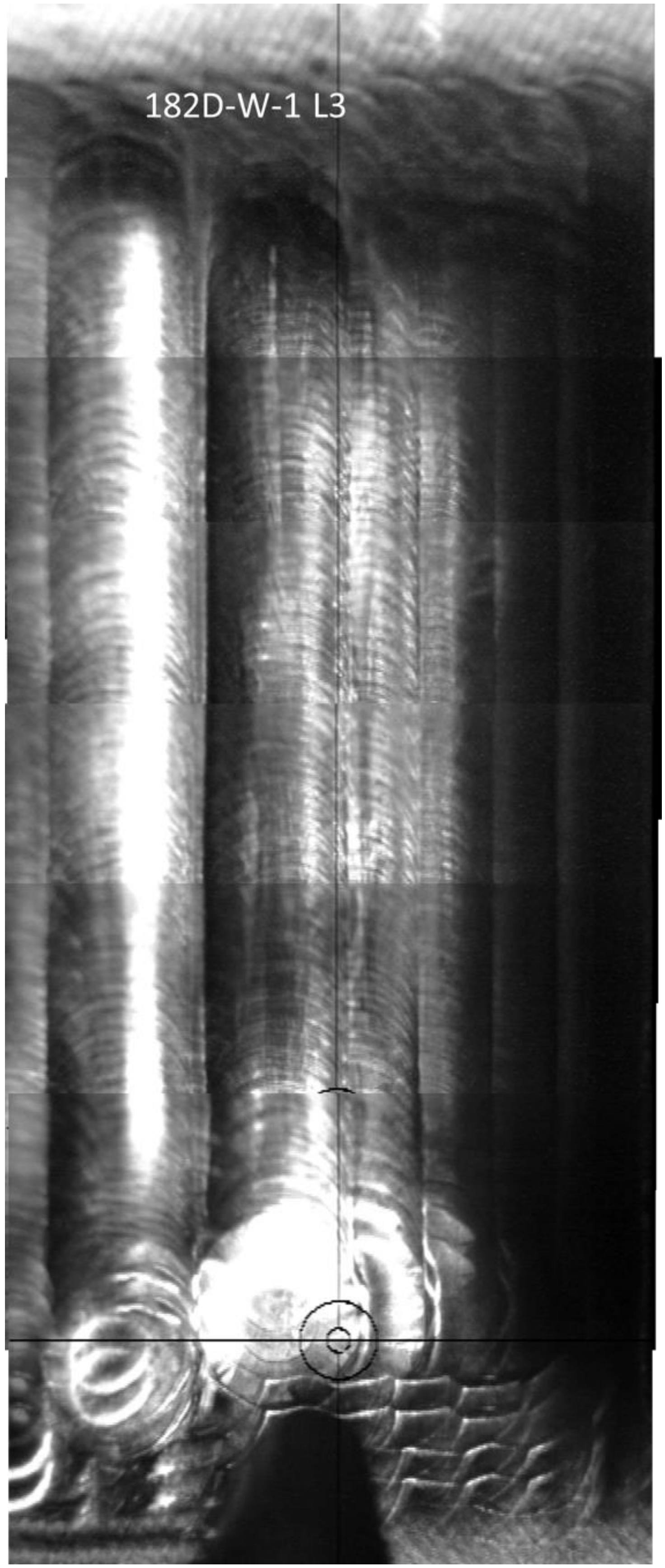

182D-W-1 L3

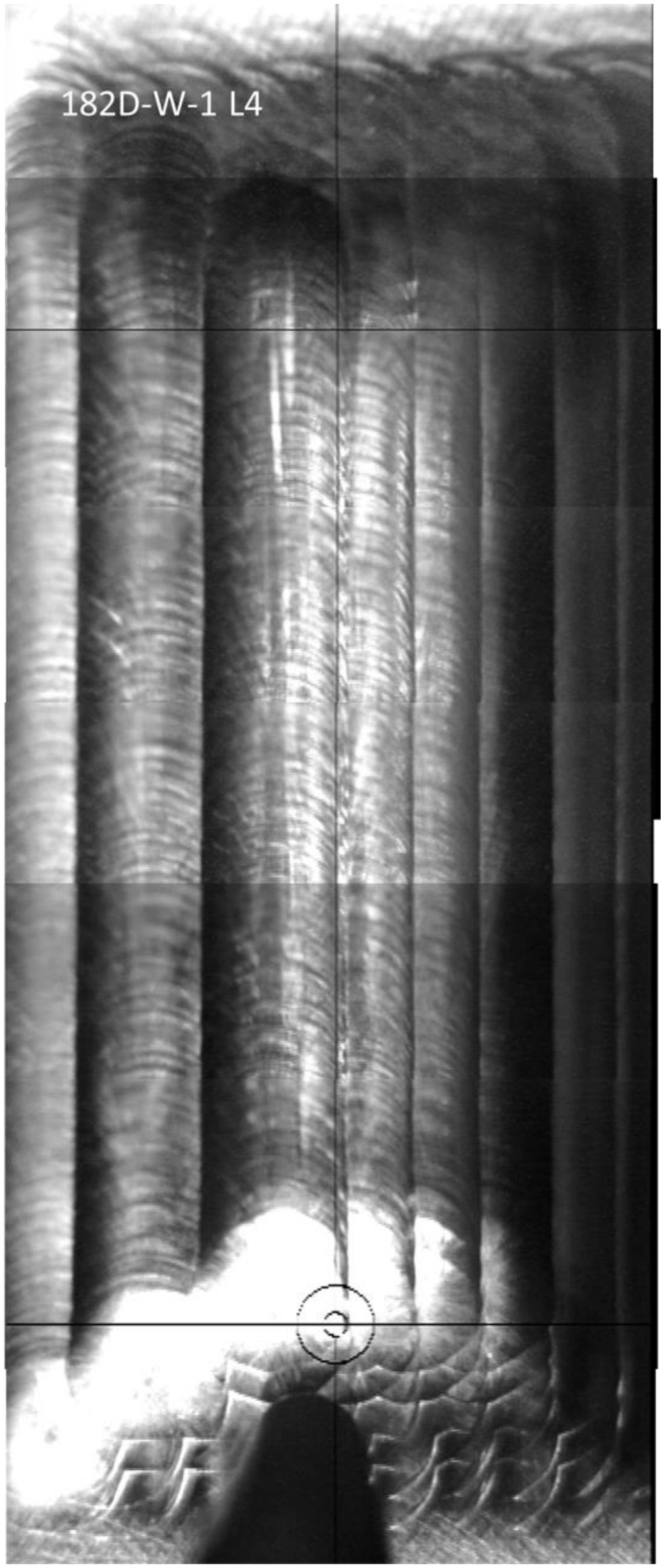


Figure 5 Initial surface inspection of the welded Alloy 182 coupons.

Since the fast-speed, low-heat single-pass weld SL* on 182B-2 coupon was welded using an incorrect wire feed speed (13.1 inch/min), which was significantly lower than the expected wire feed speed (50 in/min), the profile of the resultant weld bead was much different from the one (SL) welded using the correct parameters as shown in **Figure 6**.

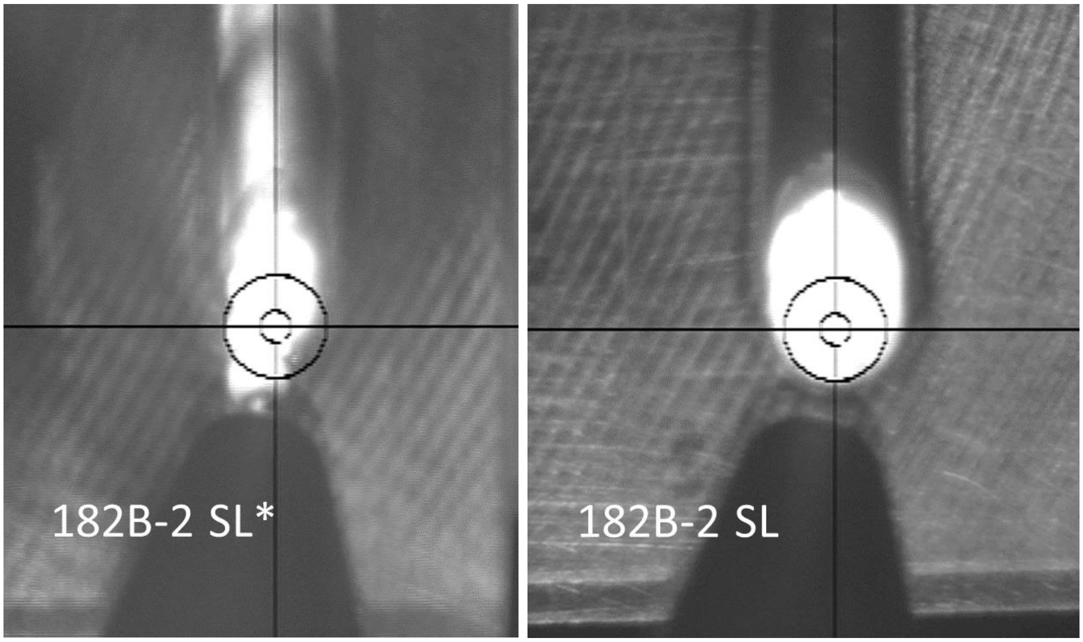


Figure 6 Fast-speed low-heat single-pass weld bead produced on 182B-2 (targeted 5 wppm boron) coupon by incorrect wire feed speed (SL*: 13.1 inch/min) versus correct wire feed speed (SL: 50 inch/min).

It is noted that unstable weld pool occurred towards the end of weld passes 4-6 at the first layer of clad L1 on 182D-W-1 coupon due to surface contamination as shown in **Figure 7.**

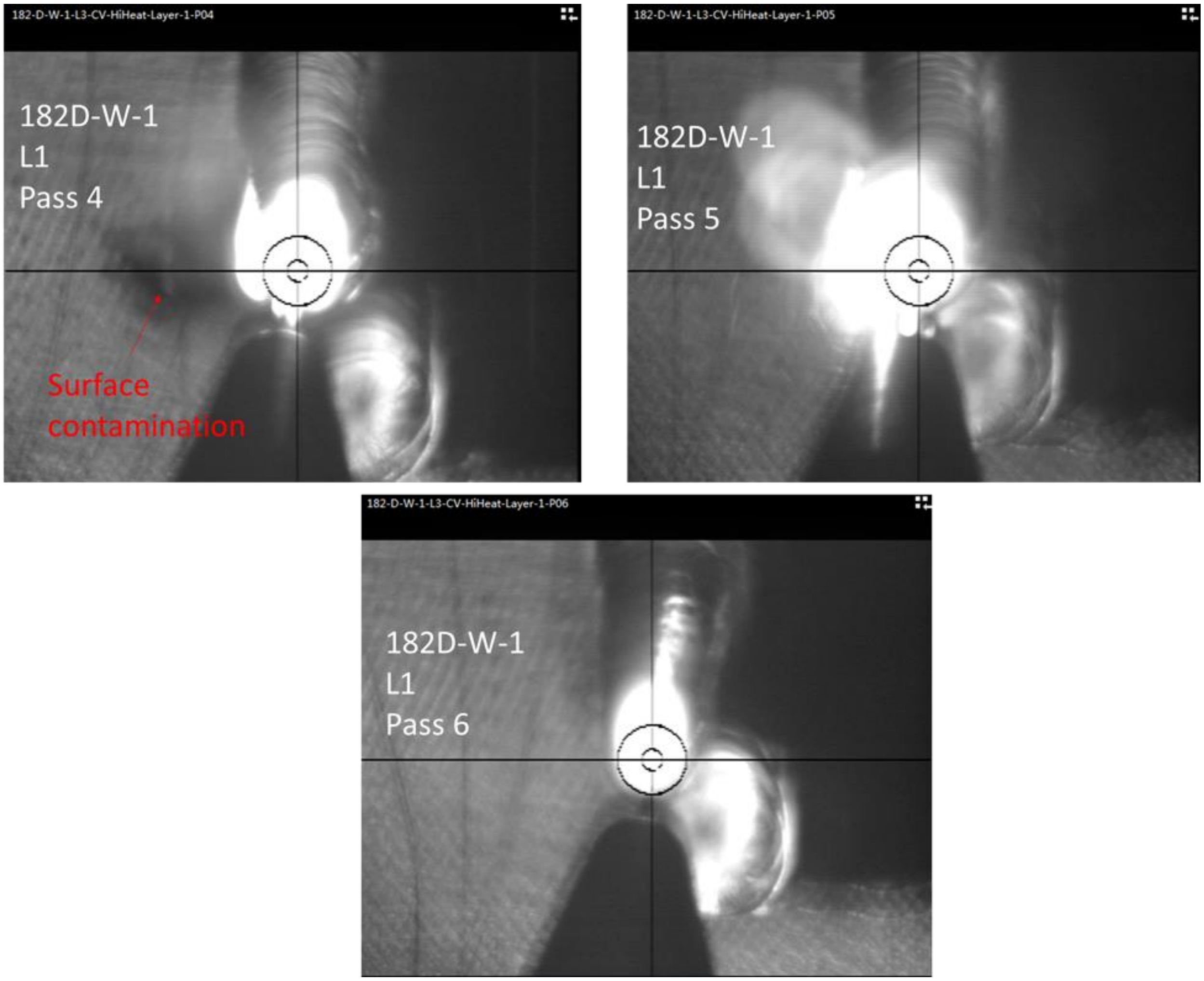


Figure 7 Unstable weld pool towards the end of weld passes 4-6 at the first layer of clad L1 on 182D-W-1 coupon due to surface contamination

4. SUMMARY

This report summarizes the welding campaign on irradiated Ni-base alloy 182 with doped boron concentration at 5, 10 and 20 wppm. Various laser welding parameters (weld speed, effective heat input, wire feed speed, with and without ABSI technique) were applied to study the influence on the formation of HeIC. Preliminary surface inspection using the inline camera system indicates no surface cracking was formed. Detailed microstructural characterizations will be performed in the future.

5. APPENDIX A (LASER WELDED COUPON CUTTING PROCEDURE)

Laser Welded Coupon Cutting Procedure (Approved)

Materials Joining Group
Materials Science and Technology Division
Oak Ridge TN 37831

Document No: MST-MP&J-LaserCut-01
Revision No: 1
Page: 1 of 15

STANDARD OPERATING PROCEDURE

Title: Laser Welded Coupon Cutting at Building 3025E

Prepared by:	Roger G. Miller (Digitally signed by Roger G. Miller Date: 2020.01.22) Roger Miller, Staff Member Materials Processing and Joining Group	Date
Approved by:	Zhili Feng (Digitally signed by Zhili Feng Date: 2020.01.25 16:27:55 -05'00') Zhili Feng, Group Leader Materials Joining	Date
QA Approval:	[signature] Mark C. Vance, Quality Representative Performance Analysis and Quality	Date 2/4/2020
DSO Approval:	Tracy Strader (Digitally signed by Tracy Strader Date: 2020.01.27) Tracy W. Strader, Research Support Group Leader Materials Science and Technology Division	Date
3025E Approvals:	[signature] Clay Morris, IMET Facility Supervisor Non-reactor Nuclear Facilities Division	Date 2/3/2020

STANDARD OPERATING PROCEDURE

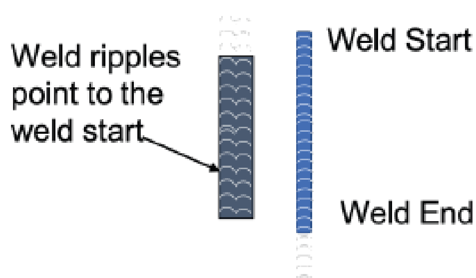
1 Purpose

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 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 laser weld.
- Questions concerning the weld start or weld direction can occur during cutting. The following diagram may be used to assist the operator. The weld ripples may be difficult to see but they always point to the weld start.



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

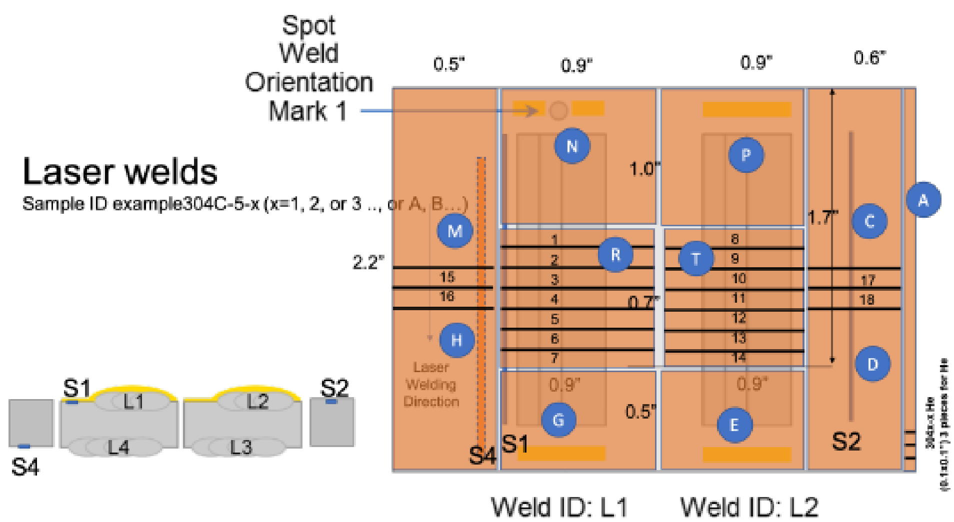
A cutting plan and layout will be supplied with each specimen. Only the samples identified in the cutting plan require cutting and labeling. The cutting plan supplied with the specimen will supersede the cutting instructions below which provides the details the cutting of a large number of samples.

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: 304C-5-1, for the metallographic specimen location #1 cut from coupon 304C-5 that contains welds L1 and L4, or 304C-5 He, for helium measurement specimens. Excess welded material will be labeled with the coupon ID and the letter designation as shown below to identify the welds and stored separately. Excess trimmed, un-welded material may be stored in either welded section container. Label the containers and samples, according to those provided in cutting plan traveler and layout, specific for each weld/specimen.

The complete list of labeled containers required for coupon 304C-5, as an example, will be contained in the cutting plan provided for the coupon being sectioned. In the following diagram a total of 18 possible metallographic samples and three helium measurement samples may be obtained from one coupon. Up to 11 pieces of excess material identified by letter designation will be labeled and stored. Some letter identifications are not used as they may be confused with a numeric identification or similar letter identifications.

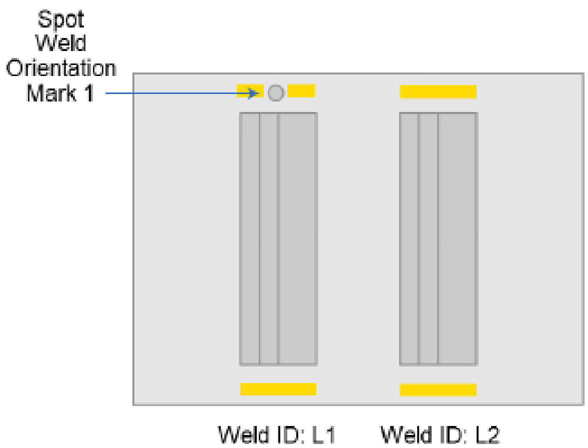


Cutting may proceed if operators are confident that the band saw clamp is properly positioned, relative to the saw blade. If there has been activity that would disturb the positioning since last use of the saw, such as a blade change or movement of the positioning dial on the clamp, the positioning must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

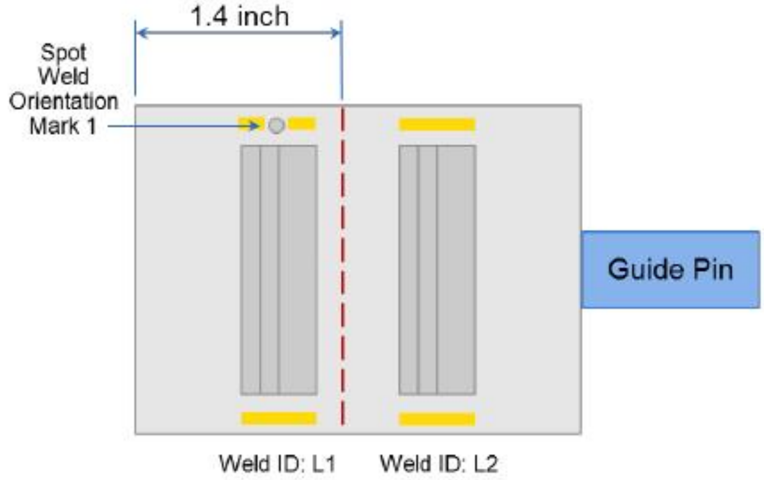
5.1 Verify and Mark Coupon

1. Verify the coupon identity by checking the ID stamped on the 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.



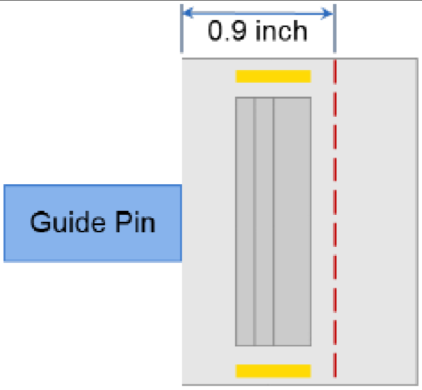
5.2 Cut 1 – Cuts the coupon into two pieces.

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.

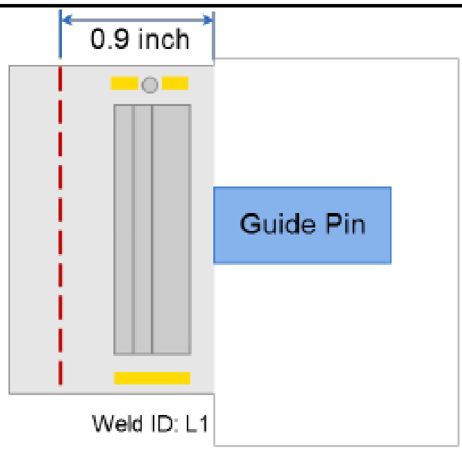
1. Set guide pin **B** to mark **7**.
2. Clamp the laser welded coupon section containing the L2/L3 welds with the cut end firmly in contact with the guide pin such that Cut 2 is located as specified in the following figure. The welded section should be seated in the upper portion of the clamp.
3. Turn 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. Label excess section per the cutting plan (example: 304C-5-C)
8. Store cut off piece with excess welded sections when all cutting is complete.



Weld ID: L2

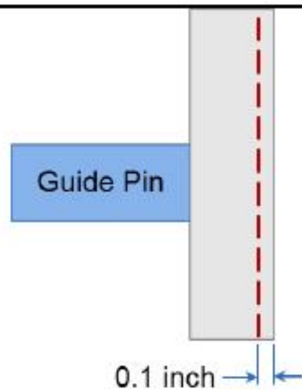
5.4 Cut 3 – Trims excess material from the L1/L4 welded section.

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. Label excess section per the cutting plan (example: 304C-5-M)
8. Store cut off piece with excess welded sections when all cutting is complete.



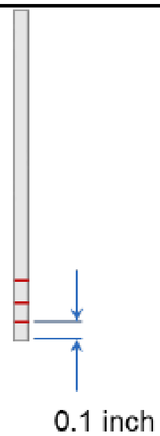
5.5 Cut 4 – Creates a sliver from the larger trimmed excess section.

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.



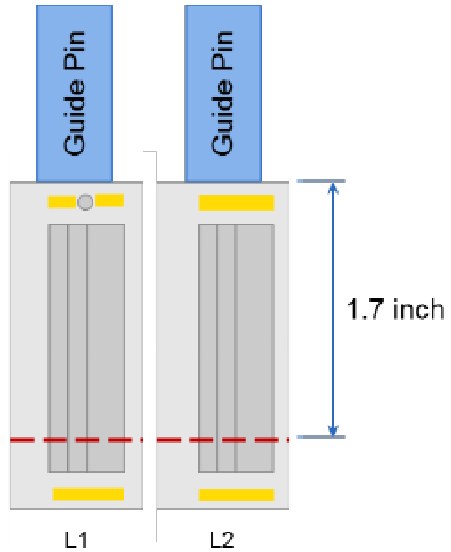
5.6 Cut 5 – Cuts small specimens from sliver. To be repeated three times with a slow speed saw. This step may be delayed until the end, following all band saw cuts, or performed simultaneously with the remaining band saw cuts.

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 and the supplied cutting plan for the coupon being sectioned. An example identification is 304C-5 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.



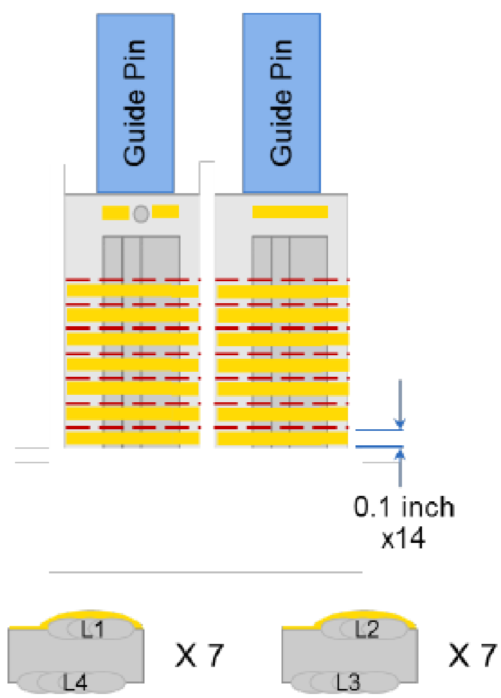
5.8 Apply additional markings.

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 up to 14 times. Cut weld cross-sections.

1. Set guide pin **B** to marks **3**, **4**, **5**, **6**, **7**, **8**, and **9** sequentially, as needed depending on the cutting plan supplied, 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 Alloy-Boron-Serial# (example: 304C-5-7).
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 up to seven cuts will be made on each of two welded sections depending on the supplied cutting plan,
9. Excess welded sections should be stored and labeled as specified at the beginning of Section 5.

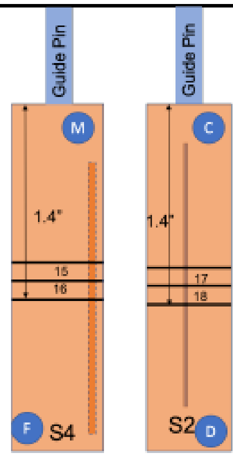


5.10 Cut 8 – To be repeated up to 6 times. Cut weld cross-sections of single pass welds S2 or S4.

1. Set guide pin **B** to marks **6**, **7**, and **8** sequentially, as needed depending on the cutting plan supplied, starting with mark **6**.
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 single pass S2 weld section will be Alloy-Boron-Serial# (example: 304C-5-18).

10. If this is not the 6th cut of Section 5.10, return to the top of Section 5.10 and repeat. A total of up to three cuts will be made on each of single pass welded sections depending on the supplied cutting plan,

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 identifying the samples that will be removed 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

MJ Group Leader ______________________ Date ________

MST Division Safety Officer ______________________ Date ________

2nd Re-Review

MJ Group Leader ______________________ Date ________

MST Division Safety Officer ______________________ Date ________

6. REFERNECES

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