



Pinch Weld Testing to Support Change in Manufacturing Oil at the KCP

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Publication Date: 21 February 2008

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Document: WSRC-STI-2009-00041

Title: Pinch Weld Testing to Support Change in Manufacturing Oil at the KCP

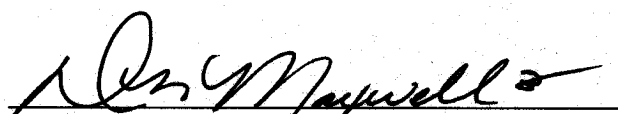
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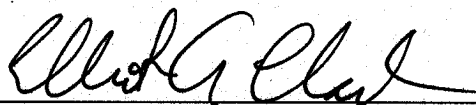
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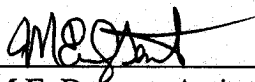
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Background

This task supports the change from an oil mixture termed 50:50 oil (an equal parts mixture of Milpro 634 and Pennex N47) to a new oil mixture (Castrol Illocut 334). This change was necessitated by a KCP vendor no longer supplying the Pennex N47 component of the 50-50. In order to continue production of machined parts, a detailed process was followed to ensure that high quality parts could be manufactured and that the cutting oil selected would provide acceptable human performance characteristics, e.g., skin irritability, smell, etc. A prime consideration in changing the oil was that no apparent change in the pinch weldability of the fill stems fabricated using the new oil and process parameters, if any, be observed.

A two part approach, as detailed in the plan shown in Appendix B, was used to qualify the effect of the process on pinch weld characteristics. In the first phase, ref. 1., the weld parameter window was defined using fill stems made from 304L, 21-6-9, and 316 stainless steel. These weld conditions were then subsequently used for the Castrol Illocut 334 machined fill stems. The results of this activity are reported in this document. A follow-on task of welding in the facility was requested by one of the design agencies and this will be completed and reported separately.

Method

Twelve fill stems of each material were manufactured using the improved KCP process with Castrol Illocut 334 oil. These stems were provided to SRS where they were examined using a forward looking borescope, pinch welded using 12 cycles and a 3/16" radius electrode in an LF-7 simulated reservoir with a standard LF-7 basket and confined pinch weld fixture at the conditions determined appropriate from the 50-50 oil stems, and then inspected using radiography, metrology, pressure testing, and metallography per the requirements in Ref. 2, a method that was used to originally qualify the 50-50 oil stems. The methods and inspection criteria detailed therein were used for several other studies, references 3-5. The pressure testing was done at pressures appropriate to the materials and pressure was held for 15 minutes per the high pressure laboratory procedure L9.4-8303. The samples were destructively analyzed by standard metallographic techniques. The samples were etched electrolytically with oxalic acid and examined at magnifications needed to determine the bond rating to the procedure, ref. 6. Note that a different pinch weld inspector was used for this phase of the testing, consequently, there may be a slight change in the baseline. However, it was previously shown in a bond rating consistency study that there is an 85% correlation between inspectors. Furthermore, if there was any question regarding the bond rating interpretation, the Expert from the Defense Programs Metallography facility was consulted and was the final arbitrator for the bond rating.

Results

Type 304L stainless steel

The type 304L stainless steel fill stems are welded between 3500 and 3900 A as was verified in phase 1 of this work, ref. 1 and the previous fill stem manufacturing and pinch weld processing task, ref. 3-5. The target current values were achieved by welding at nominal voltages of 345, 364, and 382V for 12 cycles, at a nominal force of 1250 lbs. The actual voltage, current, and weld force are listed in Table 1.

In addition to the process data, the weld quality metrics are also contained within Table 1. It can be seen that the closure length exceeds the minimum requirement (0.100 inch), the thickness is within the acceptable range, and bond ratings all meet the requirement of class 1 or 2. There is a mixture of solid state, partial liquation, and full nugget formation obtained for the weld conditions used in this task, this range of structure and weld output was observed previously (refs 3 & 4).

Although weld energy is not one of the weld parameters monitored, it can sometime be useful in determining the cause for scatter of response variables in the weld data. The closure length, weld energy, and dynamic resistance as a function of weld voltage are plotted in Fig. 1. It can be seen that the weld energy and closure length increase with weld heat, as expected, whereas the dynamic resistance decreases with increasing voltage. The cause of the reduction in dynamic resistance is likely due to the relatively small change in weld voltage, 0.068 V compared to the larger change in weld current 460A over this range. Sample A098 exhibits a somewhat anomalous behavior with a nominal voltage of 345 V, but a current that is about 5% higher than the other samples. This sample exhibited the onset of melting.

Metallographic examination was completed for each sample. Micrographs from typical cold, nominal, and hot welded stems are shown in Figure 2. The cold welds were typically solid state or exhibited a minor amount of incipient melting, the nominal welds exhibited from moderate melting to nugget formation, and the hot welds exhibited significant amounts of melting and extensive nugget formation. All of the type 304L stainless steel fill stem microstructures are included as Appendix C.

Type 316 stainless steel

The type 316 SS fill stems were welded at nominally 330, 343, and 363 volts or corresponding currents of 3300, 3500, and 3700A, as indicated in Table 2. This range is about 100 A cooler than the original set-up welds in an attempt to reduce the extent of melting developed. This range provides a more desirable weld range of about 30V. The weld closure length data and other weld quality parameters are shown in Fig. 3. As was the case for the Type 304L SS stems, the closure length and weld energy increase with increased weld voltage, while the dynamic resistance decreases with increased voltage. The closure length of sample B078 lies somewhat above the expected trend line. This sample was welded at a current that is about 100A higher

than the other three stems and the longer closure, longer extrusion and high energy are all consistent with a higher weld current for this sample.

The samples were all examined metallographically and bond rated. Micrographs from a typical cold, nominal, and hot weld are shown in Fig. 4. These images indicate a solid state bond with evidence of a bond line, class 2, to a nugget, class 1. These welds are consistent with the 50-50 oil manufactured stem welds. The weld micrographs are shown in Appendix D.

21-6-9 stainless steel

The 21-6-9 stems were welded at 347, 358, and 370 V or nominally 3500, 3600, and 3750 A. The weld range is consistent with the set-up welds that exhibited bond ratings of 1 to 3, ref. 2. The weld quality metrics are shown in Fig. 5 and as expected, there is an increase in weld closure length with increased voltage, an increase in weld energy, and a reduction in dynamic resistance.

The typical microstructures are shown in Fig. 6, and all of weld micrographs are contained in Appendix E. The 21-6-9 welds exhibit some solid state welds, but the majority are nuggets. The welds ranged from class 2 to class 1 bonds.

Summary

A proposed change in cutting oil was precipitated by a future lack of supply of one of the constituents of the currently used 50-50 oil. A series of tests including human factor, machining use, and drilling capability was conducted at the KCP. The final acceptance of the processing change is validation that no adverse effects are observed during pinch welding. To affect the change, a set of ten test stems of each material was welded. The welds were inspected using common testing methods including dimensional, radiography, pressure testing, and metallography with bond rating. The three materials were welded at conditions internally consistent for the alloy. The energy of welding and the resultant weld closure for the three alloys are shown in Fig. 7. This graph shows evidence of a non-linear relationship with a maximum closure length that approaches 0.180 inch. This “limit” has been observed previously for welds made using a 3/32 inch radius electrode and was attributed to geometric constraints of the fixturing and weld electrodes.

Table 4 comprises a direct correlation between the 50-50 oil stems and the Castrol Illocut 334. The weld data are arranged to show that the weld conditions for 50-50 produce similar weld output for the Castrol.

Conclusion

There is no observable difference in the pinch weldability of test fill stems machined with 50-50 and Castrol Illocut 334. This oil does not appear to have any effect on the pinch weld characteristics and, based on this work, there are no outstanding testing issues that need to be addressed prior to recommending this oil for acceptance to the design agencies.

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5. WSRC-STI-2006-00158, "Validation Study for Fill Stem Manufacturing and Pinch Weld Processing", P. Korinko & K Arnold (KCP), Aug. 2006.
6. SOP MTF-4.15, Metallurgical Evaluation of Reclamation Welds, August 1997.

Acknowledgements

Numerous people assisted in this task to make it successful. T. Curtis and L. Thacker provided metallurgical support and bond rating inspection. G. Crowe and W. Good and others in the high pressure lab supported the pressurization testing. B. West provided technical review and liaison with the DP radiography staff. The DP Radiography staff provided rapid response for examination and inspection. N. Miller provided material and data transport. C. Kestin consulted on the bond rating and metallographic sample examination. Special thanks to DP Management for providing financial support for us to complete this task.

Type 304L Weld Metrics

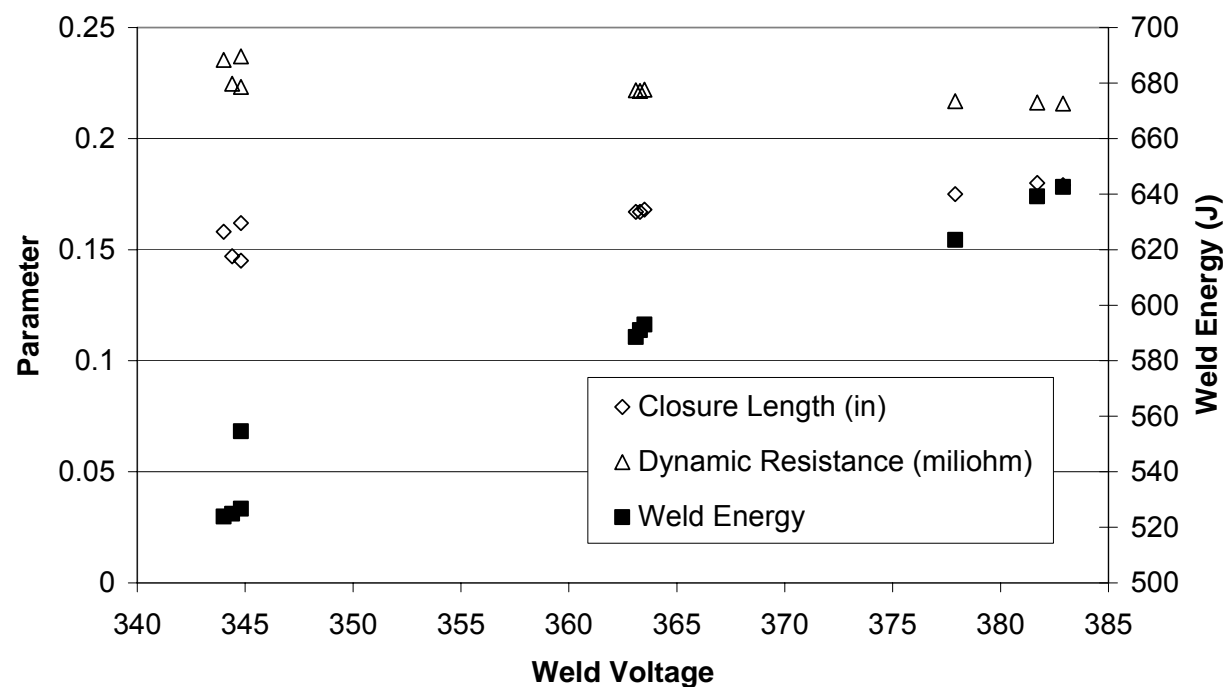


Figure 1. Weld metrics for Type 304L SS.

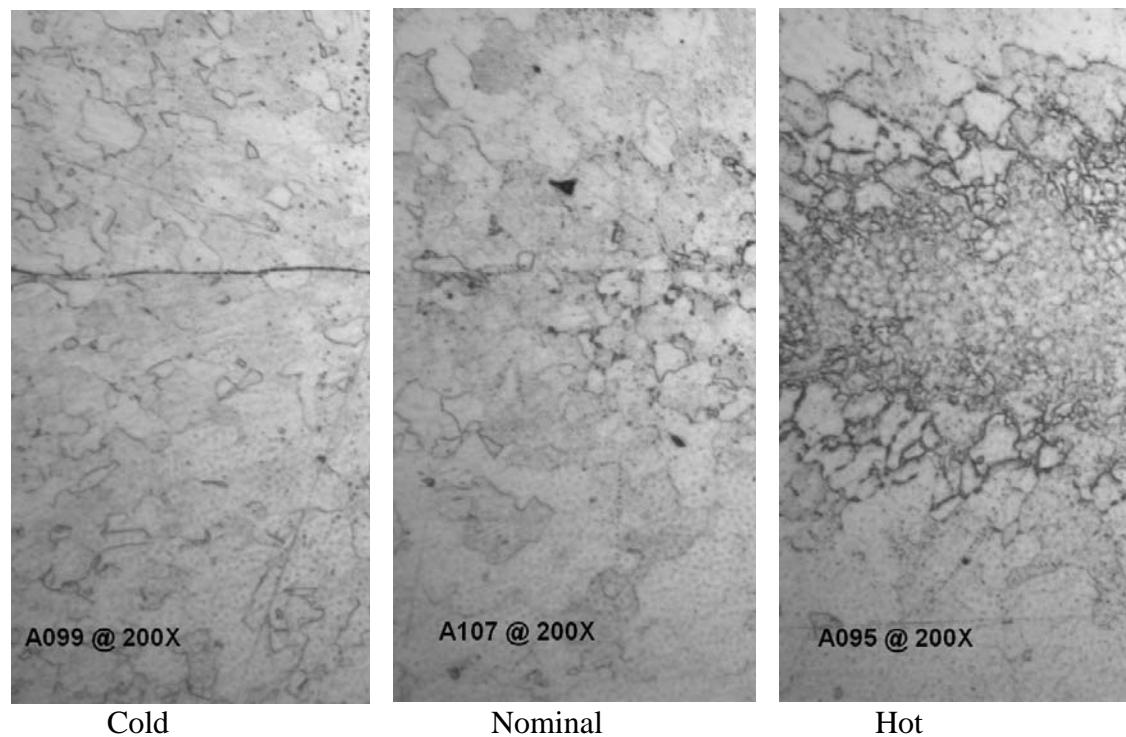


Figure 2. Typical micrographs for cold, nominal and hot welds in Type 304L SS PW.

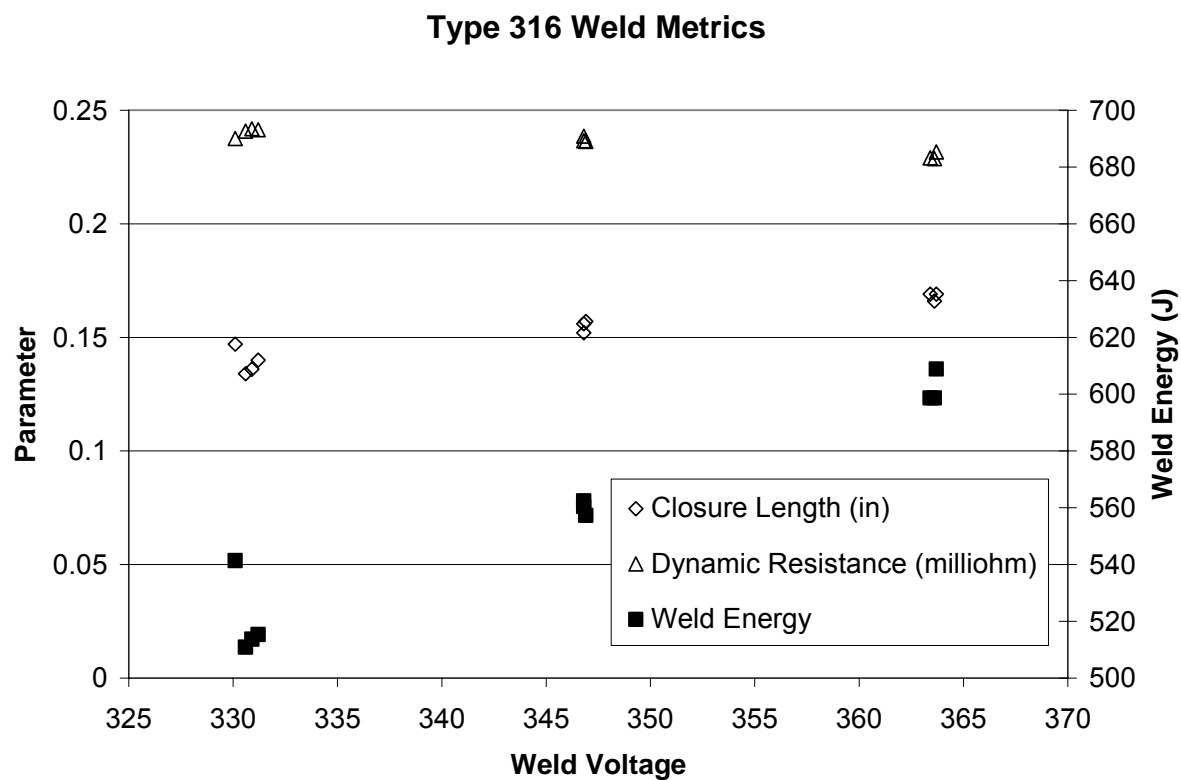


Figure 3. Weld metrics for Type 316 SS.

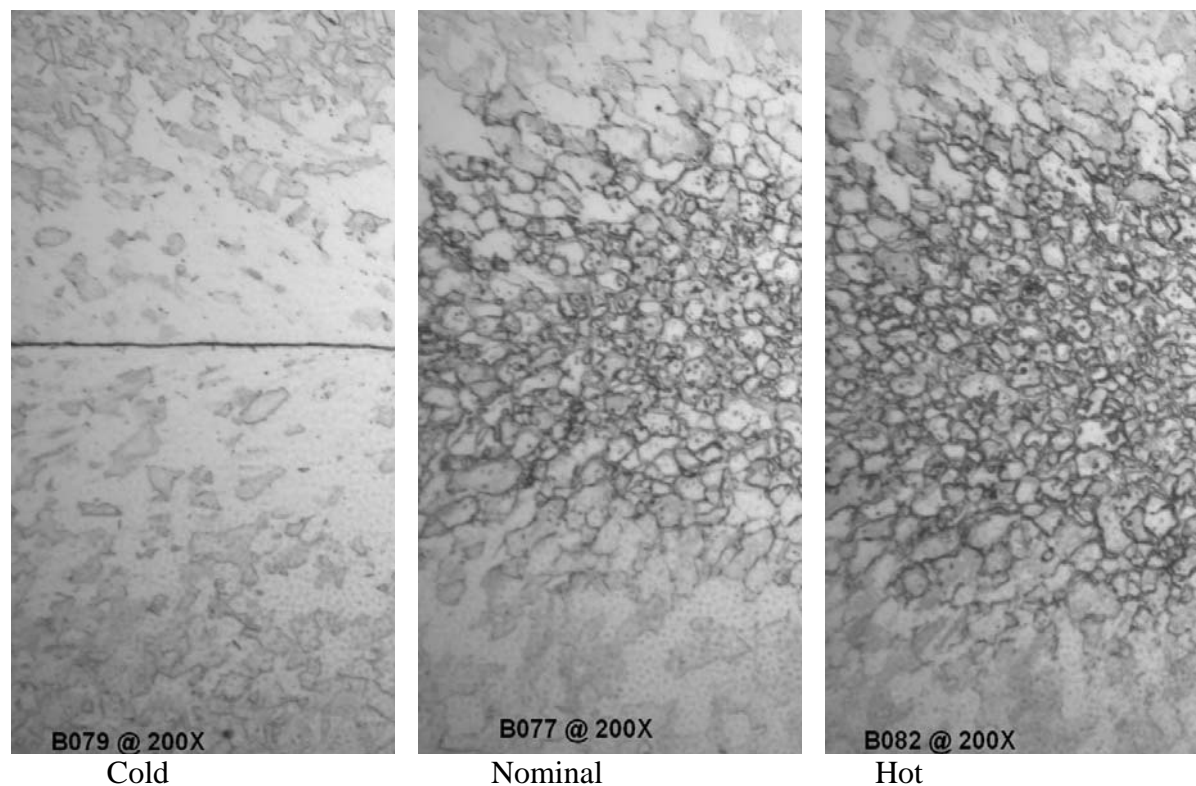


Figure 4. Typical micrographs for cold, nominal and hot welds in Type 316 SS PW.

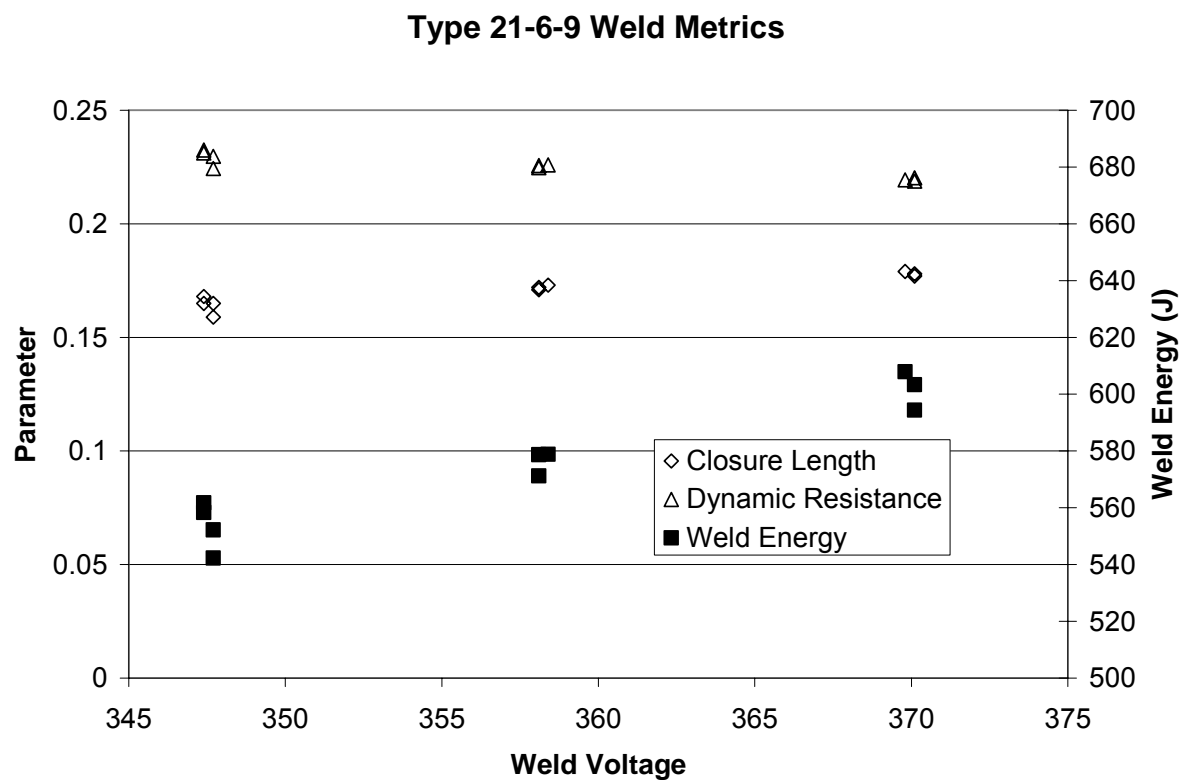


Figure 5. Weld Metrics for 21-6-9 SS

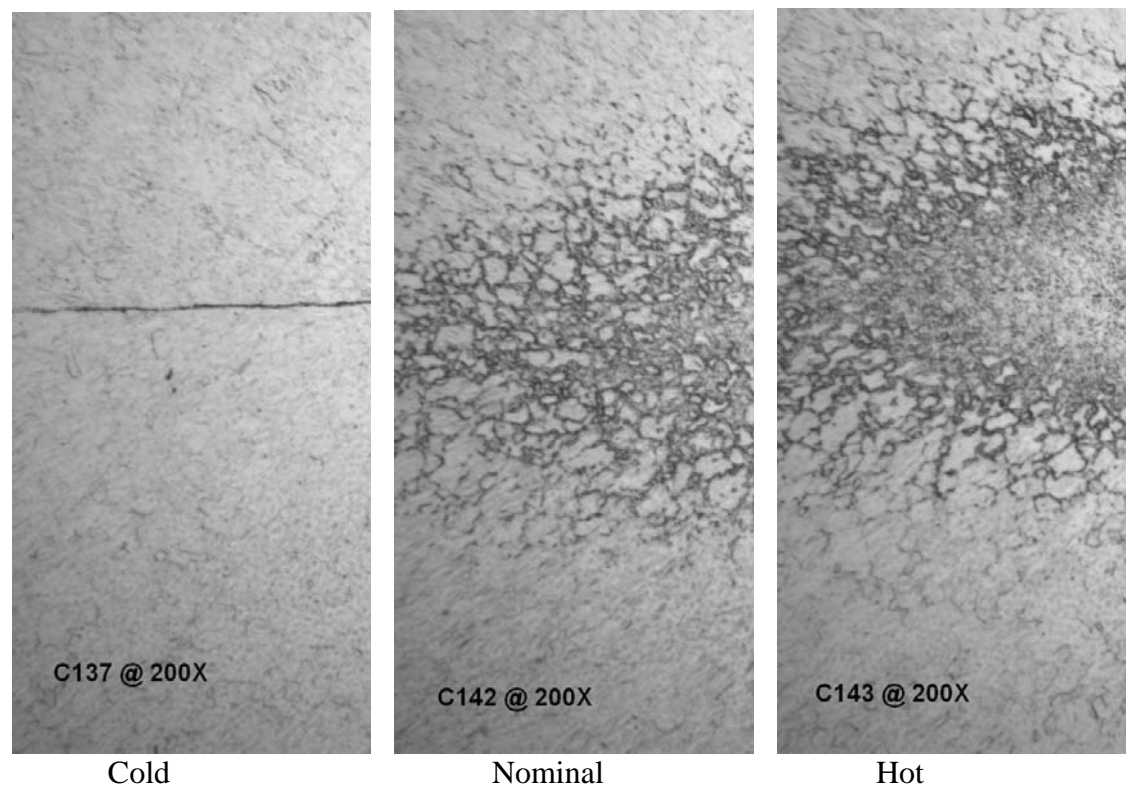


Figure 6. Typical micrographs for cold, nominal and hot welds in 21-6-9 SS PW.

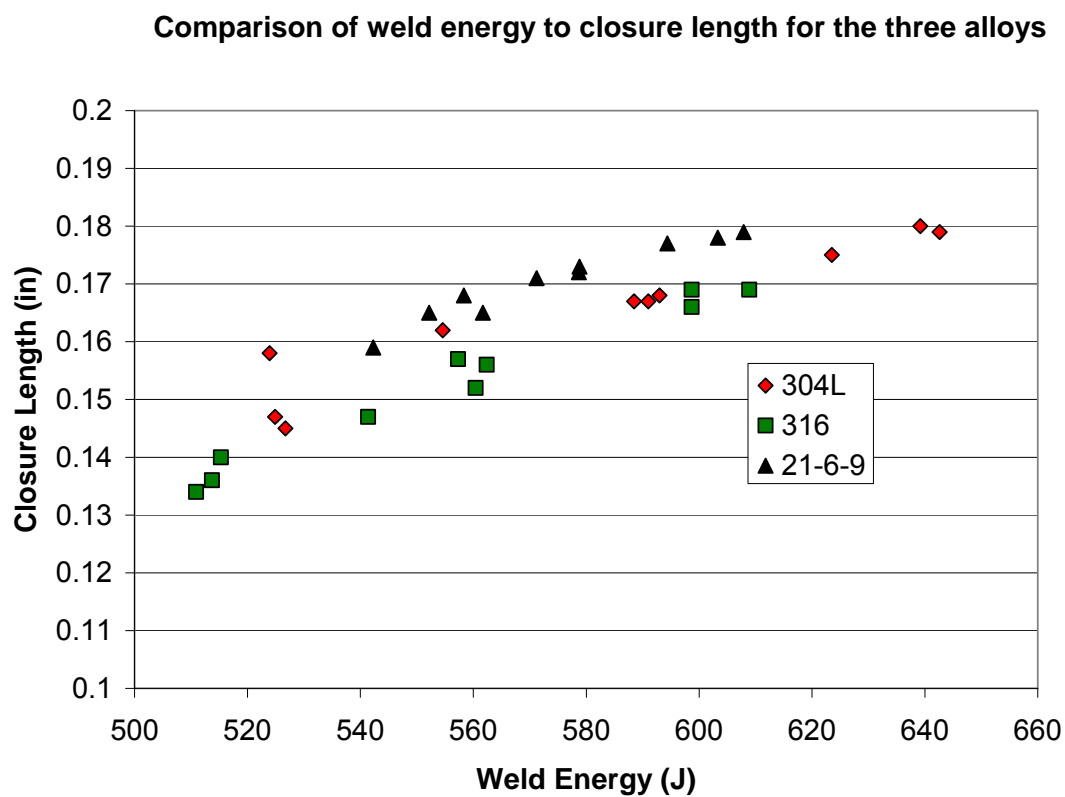


Figure 7. Comparison of weld closure length vs. weld energy for all three alloys.

Table 1. Type 304L weld conditions and results.

ID	Volt (V)	Force (lbs)	Press. (psi)	Stat. Res. (mΩ)	Dyn. Res. (mΩ)	Weld Current (A)	Weld Energy (J)	Weld Volt (V)	Displ. (in)	Closure (in)	Extr. (in)	Com. Rad.	BR	Comments Met.
A098	344.8	1261	109.1	0.3146	0.2370	3467.0	554.6	0.822	0.0666	0.162	0.013		1	
A099	344.0	1257	108.7	0.3090	0.2354	3456.3	523.9	0.813	0.0677	0.158	0.010		2	Disc. line
A100	344.8	1255	108.6	0.2872	0.2232	3480.4	526.7	0.777	0.0681	0.145	0.002		2	Disc. line
A106	344.4	1250	108.2	0.2960	0.2247	3475.1	524.9	0.781	0.0684	0.147	0.001		2	Disc. line
A097	363.5	1252	108.3	0.2984	0.2220	3694.6	593.0	0.820	0.0662	0.168	0.010		1	Nugget
A107	363.3	1254	108.5	0.2925	0.2214	3693.6	591.0	0.818	0.0673	0.167	0.011		2	Melting
A108	363.1	1249	108.1	0.2938	0.2217	3693.5	588.5	0.819	0.0675	0.167	0.009		2	Disc line
A095	381.7	1251	108.3	0.2934	0.2162	3898.6	639.2	0.843	0.0657	0.180	0.018		1	Nugget
A104	377.9	1251	108.2	0.3021	0.2168	3859.8	623.5	0.837	0.0664	0.175	0.014		1	Nugget
A105	382.9	1252	108.3	0.3082	0.2157	3916.4	642.6	0.845	0.0665	0.179	0.017		1	Nugget

Table 2. Type 316 weld conditions and results.

ID	Volt (V)	Force (lbs)	Press. (psi)	Stat. Res. (mΩ)	Dyn. Res. (mΩ)	Weld Current (A)	Weld Energy (J)	Weld Volt (V)	Displ. (in)	Closure (in)	Extr. (in)	Comm. Rad.	BR	Comments Met.
B078	330.1	1251	108.3	0.3162	0.2376	3421.9	541.4	0.813	0.0661	0.147	0.005		2	Melting
B079	330.6	1253	108.5	0.3144	0.2408	3300.5	510.9	0.795	0.0659	0.134	0.002		2	Almost Cont line
B080	330.9	1250	108.2	0.3185	0.2419	3301.2	513.7	0.799	0.0648	0.136	0.001		2	Disc line
B089	331.2	1252	108.3	0.3144	0.2415	3307.9	515.3	0.799	0.0658	0.140	0.003		2	Disc line
B076	346.8	1250	108.2	0.3180	0.2386	3480.4	562.4	0.830	0.0653	0.156	0.010		1	Nugget
B077	346.9	1255	108.7	0.3177	0.2363	3481.4	557.3	0.823	0.0665	0.157	0.006		1	Nugget
B081	346.8	1255	108.6	0.3073	0.2366	3480.8	560.4	0.824	0.0661	0.152	0.007		2	Disc line
B082	363.6	1255	108.6	0.3123	0.2287	3668.8	598.7	0.839	0.0646	0.166	0.013		1	Nugget
B083	363.4	1250	108.1	0.3175	0.2291	3666.3	598.7	0.840	0.0657	0.169	0.015		1	Nugget
B084	363.7	1253	108.5	0.3267	0.2317	3669.3	608.9	0.850	0.0652	0.169	0.018		1	Nugget

Table 3. 21-6-9 weld conditions and results.

ID	Volt (V)	Force (lbs)	Press. (psi)	Stat. Res. (mΩ)	Dyn. Res. (mΩ)	Weld Current (A)	Weld Energy (J)	Weld Volt (V)	Displ. (in)	Closure (in)	Extr. (in)	Comm. Rad.	BR	Comments Met.
C137	347.7	1498	128.8	0.2887	0.2244	3522.3	542.3	0.790	0.0670	0.159	0.006		2	Disc. line
C138	347.7	1499	128.9	0.3087	0.2297	3515.0	552.2	0.807	0.0661	0.165	0.010		1	Nugget
C140	347.4	1498	128.7	0.3062	0.2312	3512.3	561.7	0.812	0.0666	0.165	0.011		1	Nugget
C141	347.4	1499	128.9	0.3125	0.2325	3513.1	558.3	0.817	0.0656	0.168	0.011		1	Nugget
C142	358.1	1503	129.2	0.3050	0.2247	3625.9	571.2	0.815	0.0654	0.171	0.013		1	Nugget
C144	358.1	1498	128.7	0.2993	0.2257	3630.6	578.7	0.819	0.0657	0.172	0.012		1	Nugget
C146	358.4	1503	129.1	0.3089	0.2259	3630.9	578.8	0.820	0.0651	0.173	0.013		1	Nugget
C139	370.1	1500	128.9	0.3045	0.2203	3771.0	594.4	0.831	0.0660	0.177	0.014		1	Nugget
C143	369.8	1499	128.8	0.2946	0.2194	3764.8	607.9	0.826	0.0652	0.179	0.013		1	Nugget
C149	370.1	1498	128.7	0.2910	0.2188	3767.0	603.3	0.824	0.0656	0.178	0.015		1	Nugget

Table 4. Comparison of weld metrics and weld quality metrics for the two oils.

Set-up Welds 50-50 Oil						Castrol Oil					
304L ID	Volt (V)	Weld Current (A)	Closure (in)	BR	Met Com.	ID	Volt (V)	Weld Current (A)	Clos. (in)	BR	Met Com.
X0119	345.7	3467	0.162	2	Disc line	A098	344.8	3467	0.162	1	
X0116	345.7	3469	0.154	2	Disc line	A099	344.0	3456.3	0.158	2	Disc. line
						A100	344.8	3480.4	0.145	2	Disc. line
						A106	344.4	3475.1	0.147	2	Disc. line
						A097	363.5	3694.6	0.168	1	Nugget
						A107	363.3	3693.6	0.167	2	Melting
						A108	363.1	3693.5	0.167	2	Disc line
						A095	381.7	3898.6	0.180	1	Nugget
X0115	381.5	3876	0.180	1	Nugget	A104	377.9	3859.8	0.175	1	Nugget
X0120	381.9	3870	0.183	1	Nugget	A105	382.9	3916.4	0.179	1	Nugget
316 ID	Volt (V)	Weld Current (A)	Closure (in)	BR	Met Com.	ID	Volt (V)	Weld Current (A)	Clos. (in)	BR	Met Com.
B051	330.3	3315.5	0.145	2	Disc line with melt	B078	330.1	3421.9	0.147	2	Melting
B053	330.6	3317.9	0.147	2	Disc line with melt	B079	330.6	3300.5	0.134	2	Almost Cont line
						B080	330.9	3301.2	0.136	2	Disc line
						B089	331.2	3307.9	0.140	2	Disc line
B050	344.2	3448	0.154	2	Disc line with melt	B076	346.8	3480.4	0.156	1	Nugget
B057	344.4	3447	0.155	2	Disc line with melt	B077	346.9	3481.4	0.157	1	Nugget
B058	344.4	3449	0.156	2	Disc line with melt	B081	346.8	3480.8	0.152	2	Disc line
B055	363.7	3668	0.170	1	Nugget	B082	363.6	3668.8	0.166	1	Nugget
B059	363.9	3672	0.168	1	Nugget	B083	363.4	3666.3	0.169	1	Nugget
B060	364.2	3672	0.17	1	Nugget	B084	363.7	3669.3	0.169	1	Nugget
21-6-9 ID	Volt (V)	Weld Current (A)	Closure (in)	BR	Met Com.	ID	Volt (V)	Weld Current (A)	Clos. (in)	BR	Met Com.
C103	347.1	3495	0.161	2	Disc line	C137	347.7	3522.3	0.159	2	Disc. line
C104	347.2	3491	0.161	2	Disc line	C138	347.7	3515	0.165	1	Nugget
C101	347.4	3497	0.158	3	Almost cont line	C140	347.4	3512.3	0.165	1	Nugget
						C141	347.4	3513.1	0.168	1	Nugget
						C142	358.1	3625.9	0.171	1	Nugget
						C144	358.1	3630.6	0.172	1	Nugget
						C146	358.4	3630.9	0.173	1	Nugget
C105	369.9	3744	0.177	1	Nugget	C139	370.1	3771	0.177	1	Nugget
C102	370.7	3758	0.180	1	Nugget	C143	369.8	3764.8	0.179	1	Nugget
C109	371	3760	0.180	1	Nugget	C149	370.1	3767	0.178	1	Nugget

Appendix A Fill stem manufacturing changes and pinch weld qualifications

SRNL-MST-2007-00066

Fill Stem Manufacturing Changes and Pinch Weld Qualifications

To: C. Cadden, B. Meyer, K. Arnold, D. Grote, J. McGrath, W. West, S. Mazurek, J. McCowan, S. West, M. Dupont, D. Maxwell

Based on previous discussions from the Stem Team the following protocol is recommended to ensure that manufacturing changes that are not expected to result in the need for a full qualification in the tritium facility. In order to accomplish this task with the fewest reasonable number of stems, the following plan is tendered:

1. Determine weld conditions on the SRNL prototypic welder for 316 stainless steel fill stems that produce class 1 and 2 bonds. Test stems of the PRJ706566-102 will be used. The stems will be machined with 50/50 cutting oil
 - A. Preliminary conditions for 316 based on email dated 3-6-07 from B. West
 - 3/16" electrode, 1250 lbs +/- 50 lbs, current from 3300-3700 A for WR weld conditions
 - Weld in 2 atm of Nitrogen or deuterium
 - Weld one stem each at 3300 A and 3500A and 3700A
 - Proof test at 40ksi
 - X-ray for closure length, extrusion, and geometry
 - Transverse metallographic examination
 - B. Based on these conditions either increase or decrease current (voltage) range for welds, weld a new set to if range is changed.
 - Weld three 50/50 test stems at the low and high conditions, with current at low and force at high and current at high with force low, to ensure suitable weld parameters
2. Determine weld conditions on the SRNL prototypic welder for 21-6-9 stainless steel fill stems that produce class 1 and 2 bonds.
 - A. Preliminary conditions for 21-6-9 based on email dated 3-6-07 from B. West
 - 3/16" electrode, 1500 lbs, current from 3750 to 4150 A for WR weld conditions (this simulates M conditions).
 - Weld one stem each at 3750 A, 3950A, and 4150A
 - Weld in 2 atmospheres of Nitrogen or deuterium
 - Proof test at 60 KSI
 - X-ray for closure length, extrusion, and geometry
 - Transverse metallographic examination
 - B. Based on these conditions either increase or decrease current (voltage) range for welds.
 - Weld three 50/50 test stems at the low and high conditions, with current at low and force at high and current at high with force low, to ensure suitable weld parameters
3. Use current range established during fill stem project for 304L (3500-3900) A.

Based on these conditions weld three 50/50 test stems at the low and high conditions, with current at low and force at high and current at high with force low, to ensure suitable weld parameters

Using these conditions, weld a total of ten stems of each material manufactured using modified, i.e., changed cutting oil, process. Weld four stems at “cold” condition, three at midpoint (nominal) condition, and three at “hot” condition, varying force opposite of current. Use standard suite of non-destructive and destructive tests to ensure acceptable quality.

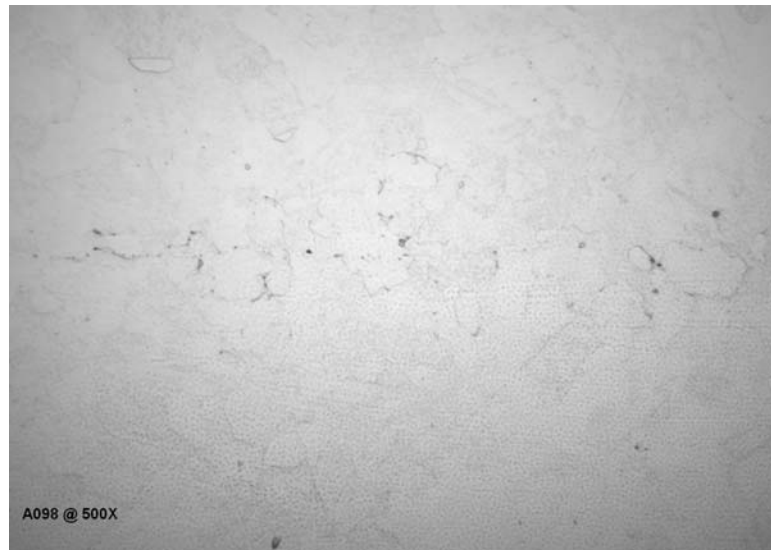
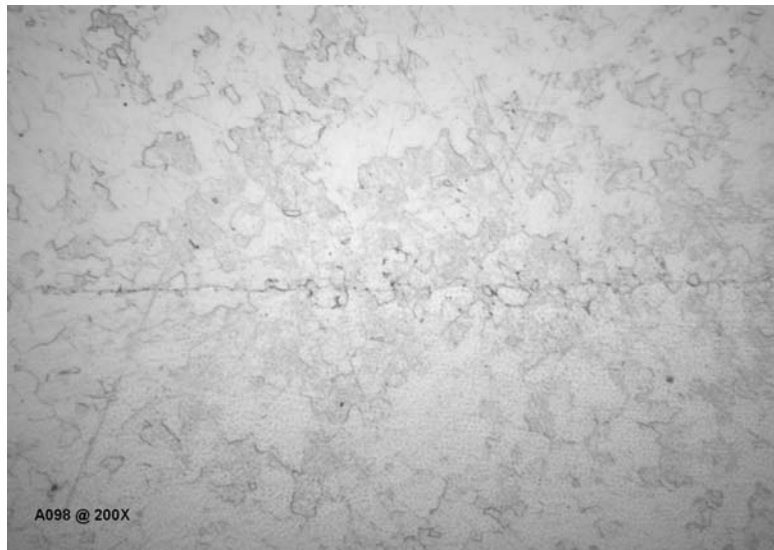
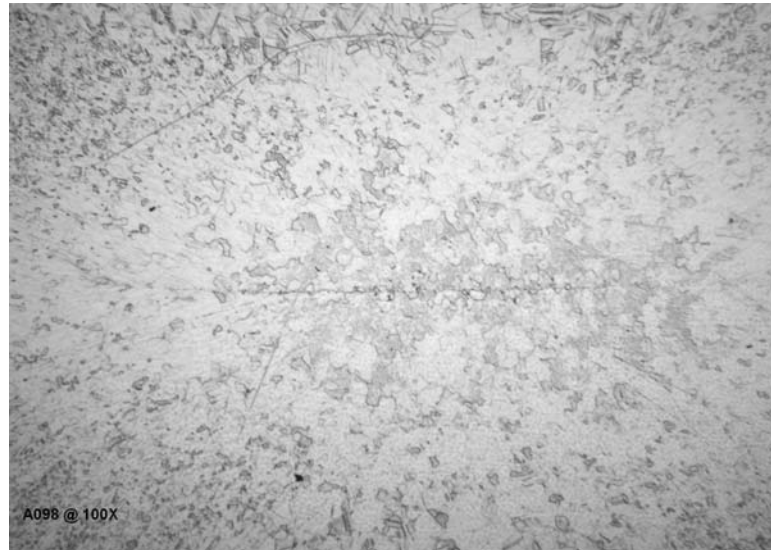
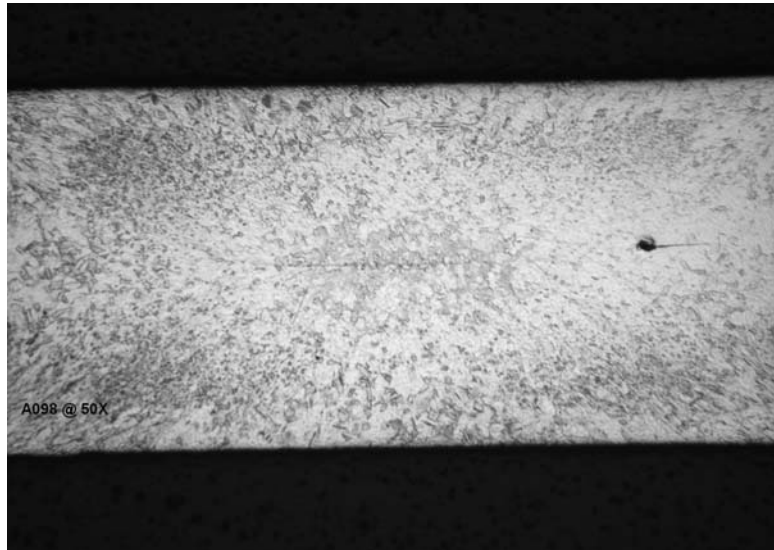
Upon successful completion of these tasks, issue report(s) detailing the work that was completed and circulate to stakeholders. Include recommendation indicating approval of process for WR components.

The Tritium Facility will weld qualification stems as part of their normal quality assurance program for equipment validation prior to loading reservoirs. A full re-qualification of the process will not be required.

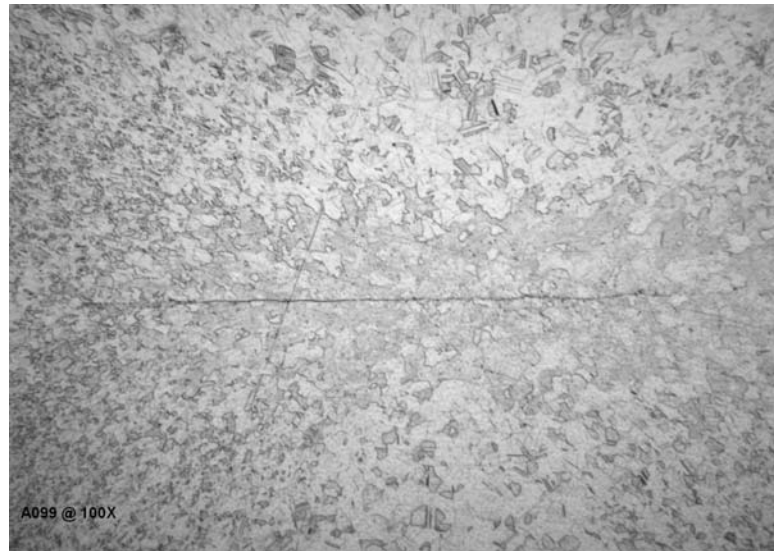
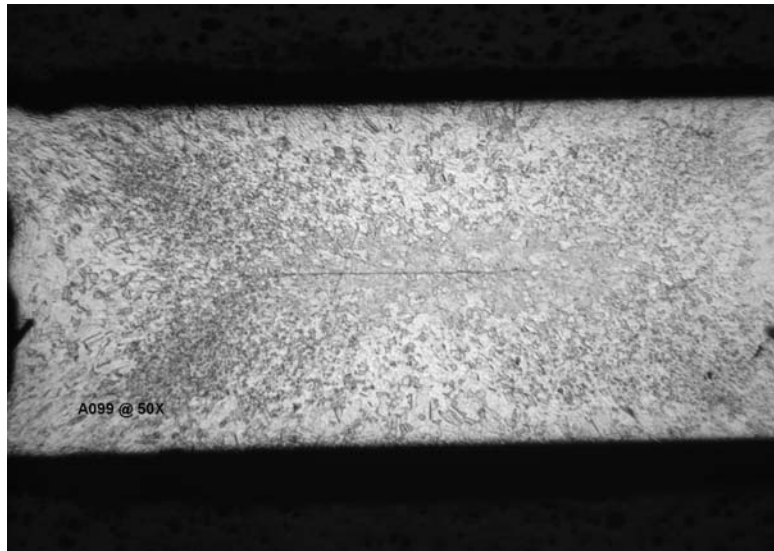
Test stems needed:

Type	Quantity	Cutting Fluid	Purpose
21-6-9	6	50/50	Weld window tuning
21-6-9	6	50/50	Low and high validation
21-6-9	12	New	Process verification (and 2 contingency)
316	6	50/50	Weld window tuning
316	6	50/50	Low and high validation
316	12	New	Process verification (and 2 contingency)
304L	6	50/50	Low and high validation
304L	12	New	Process verification (and 2 contingency)

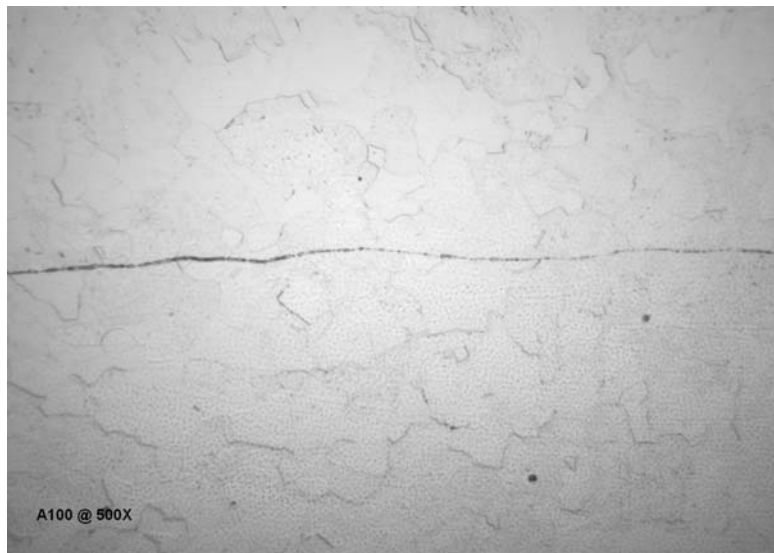
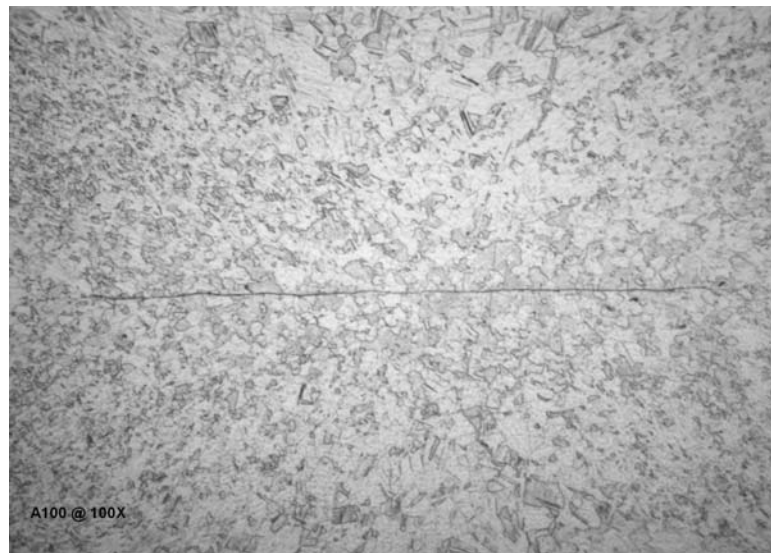
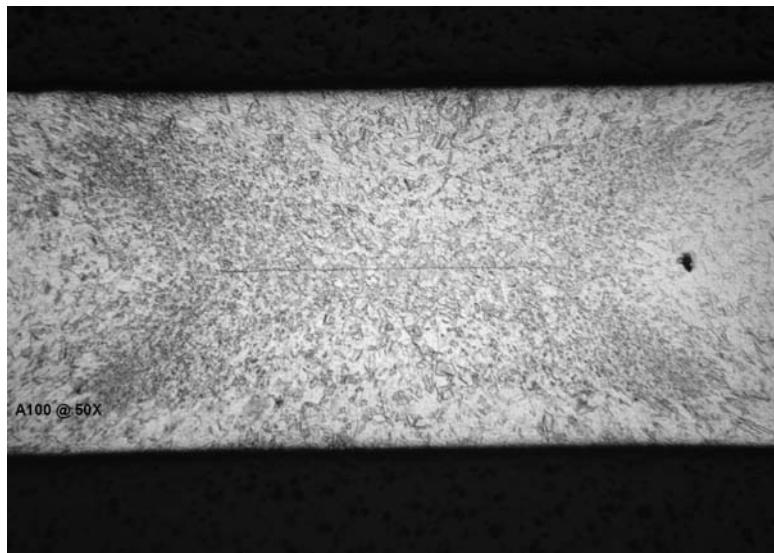
Appendix B. Microstructures of 304L Stainless Steel pinch welds



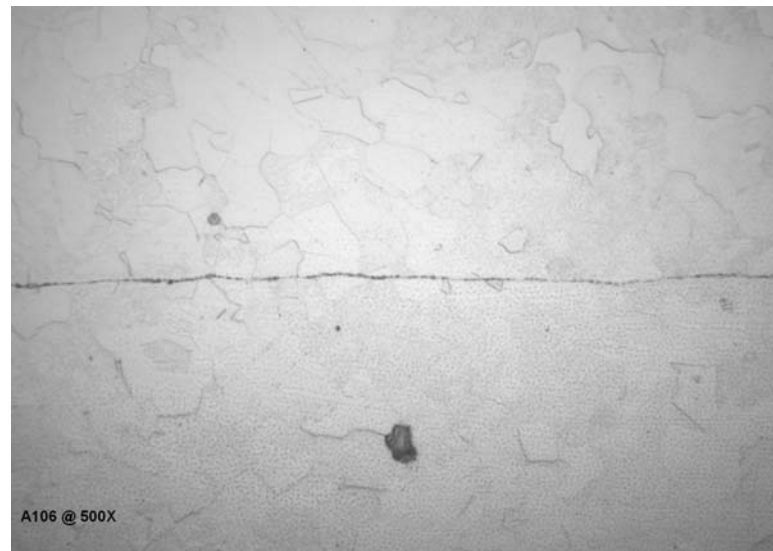
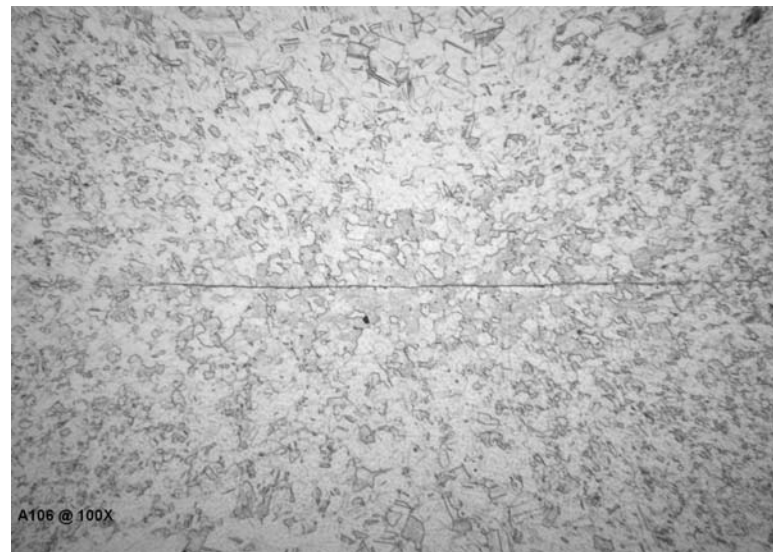
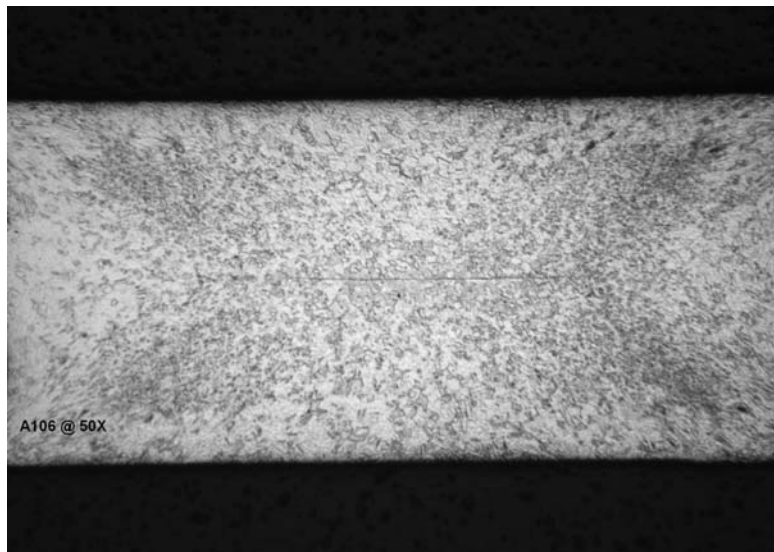
A098 Cold



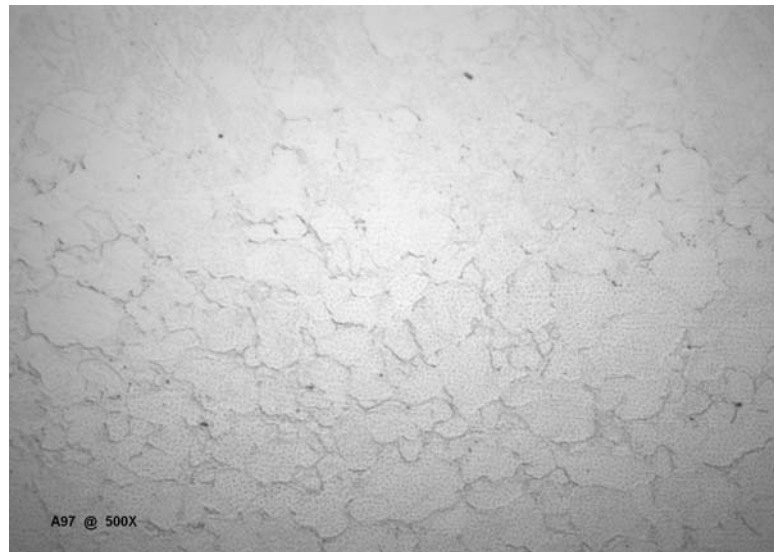
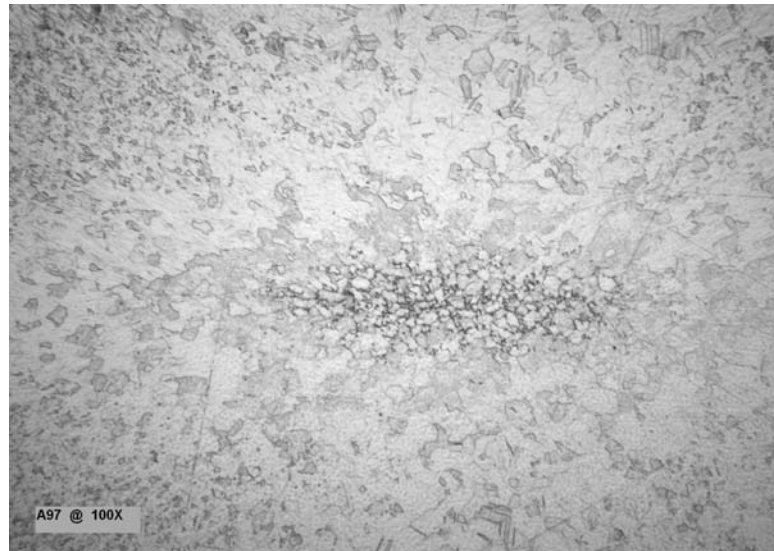
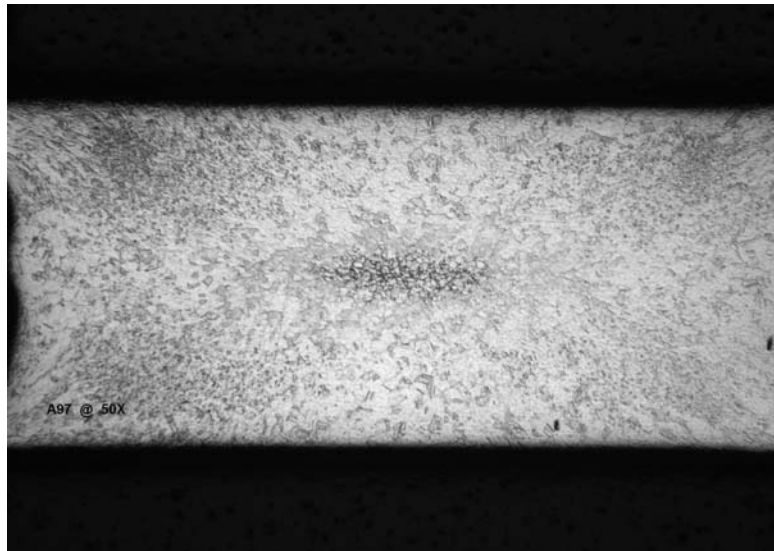
A099 Cold



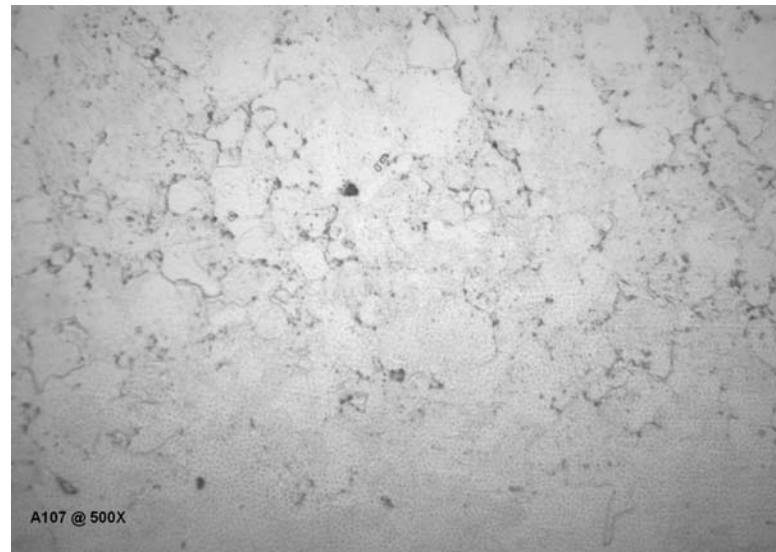
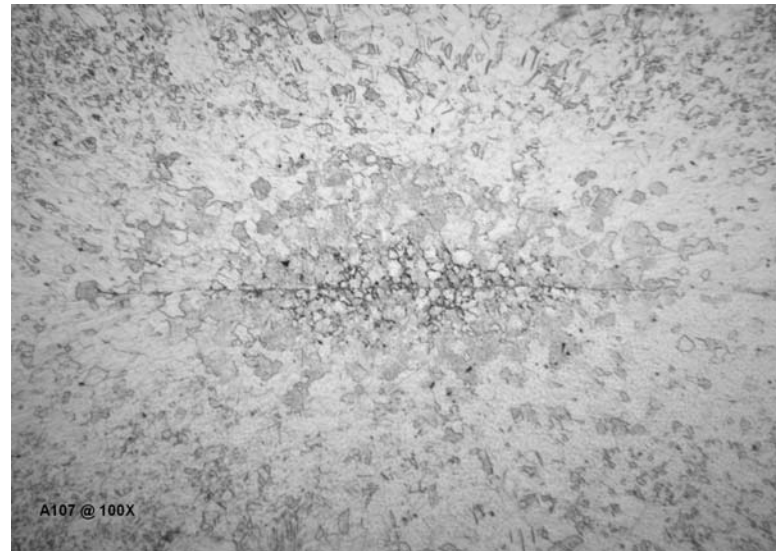
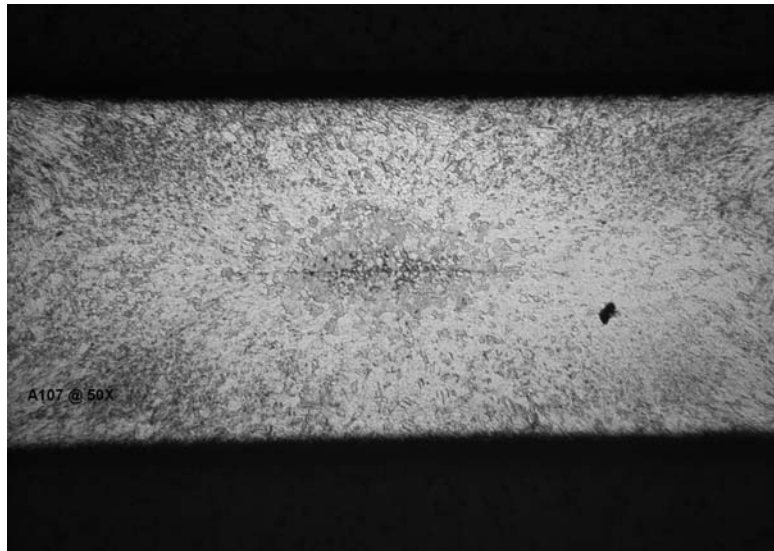
A100 Cold



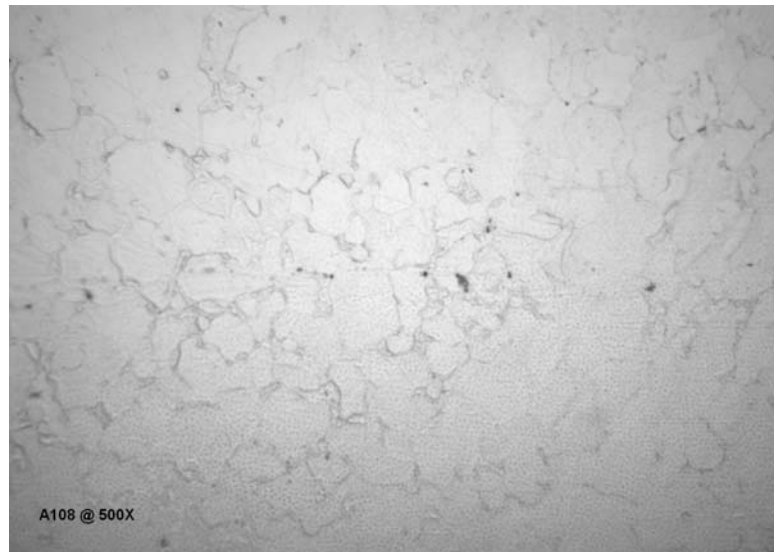
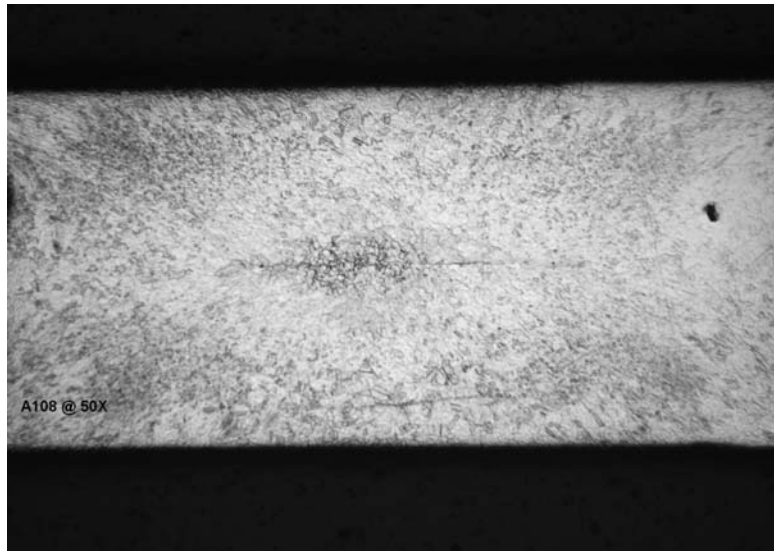
A106 Cold



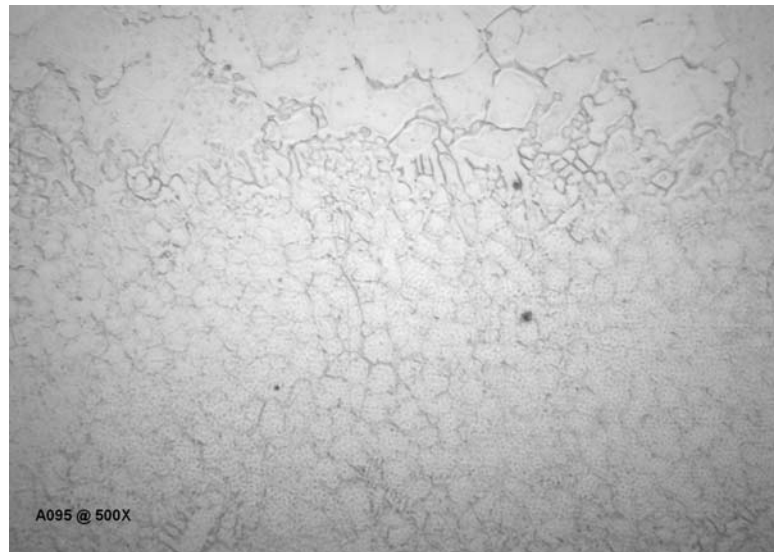
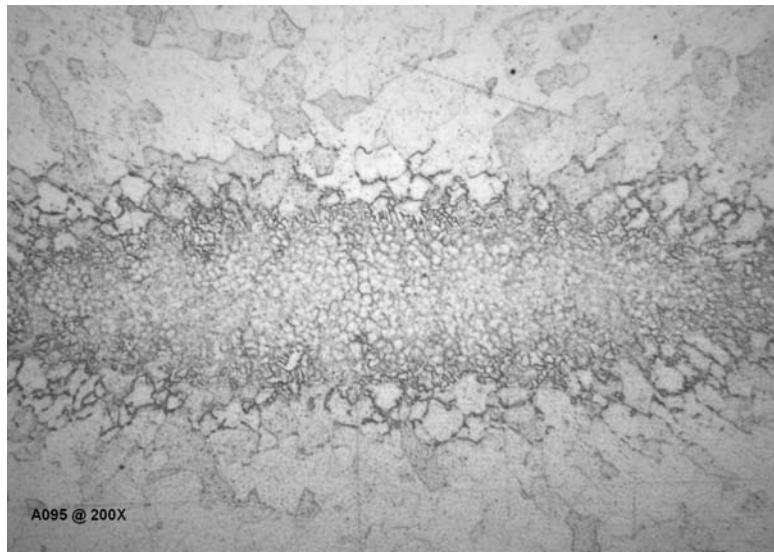
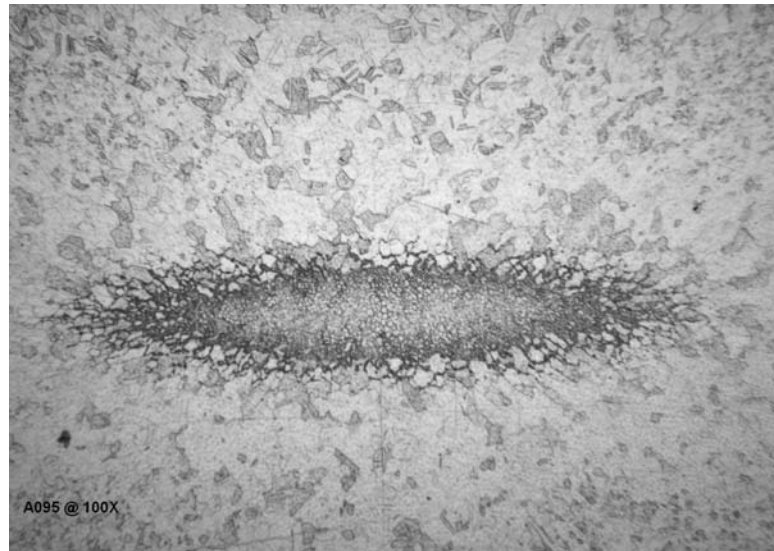
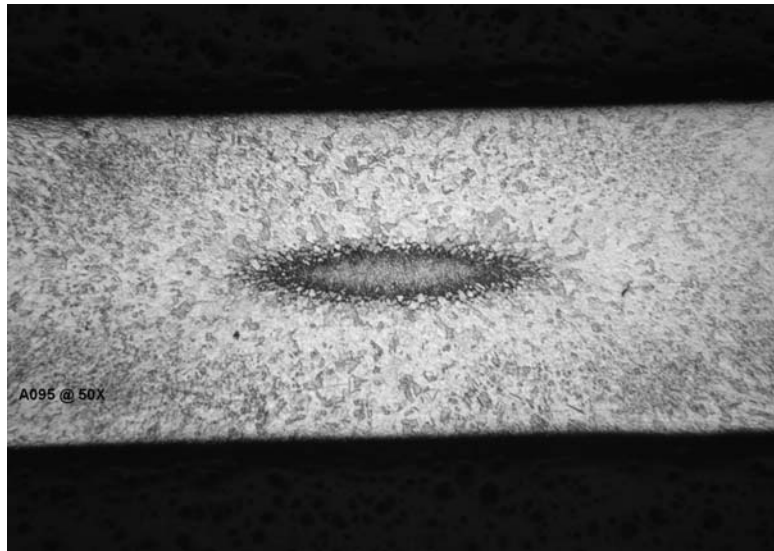
A097 Nominal



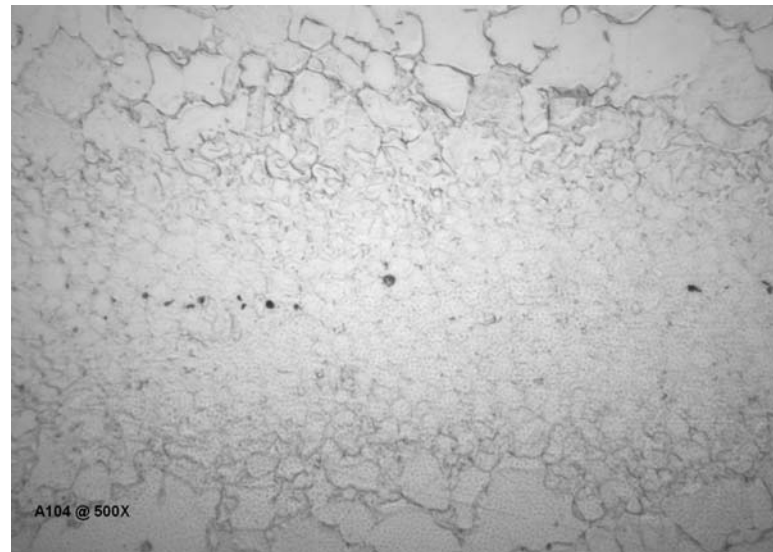
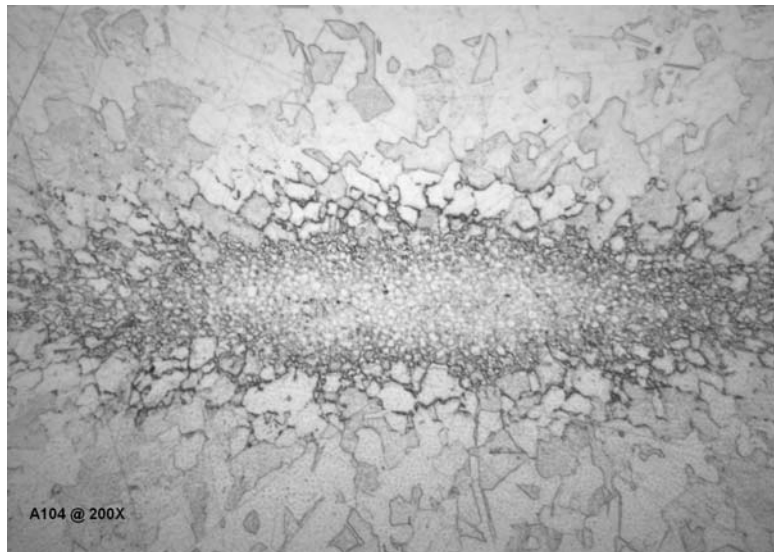
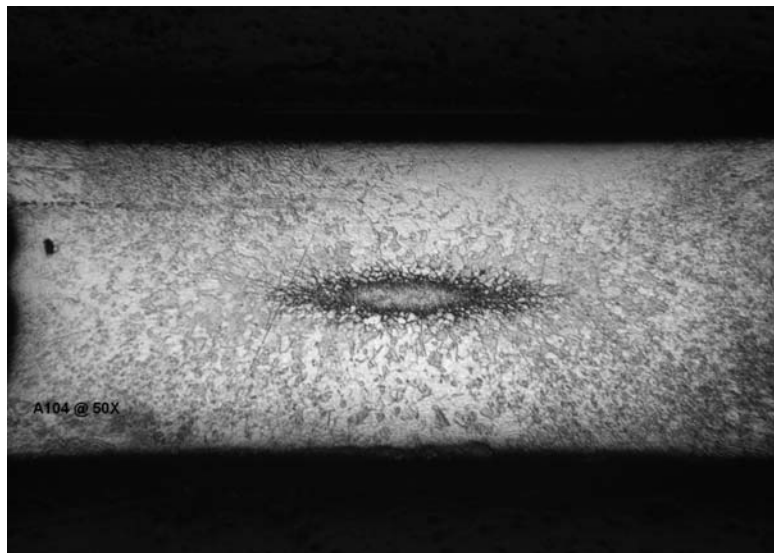
A107 Nominal



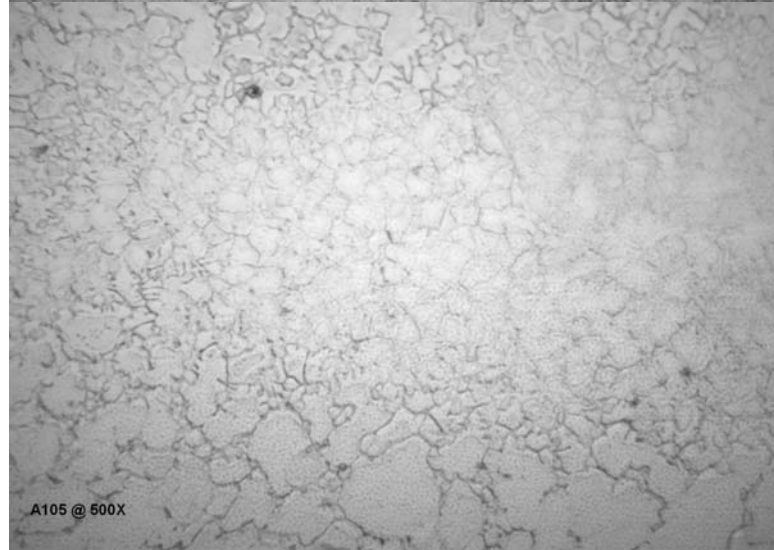
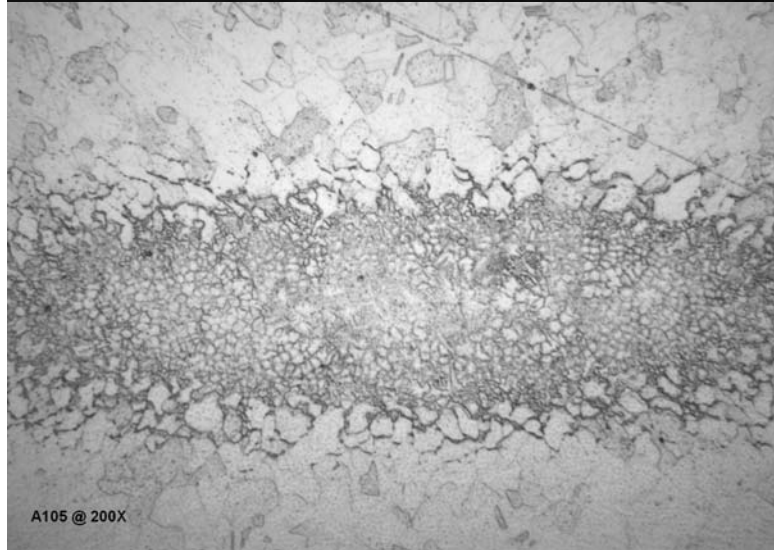
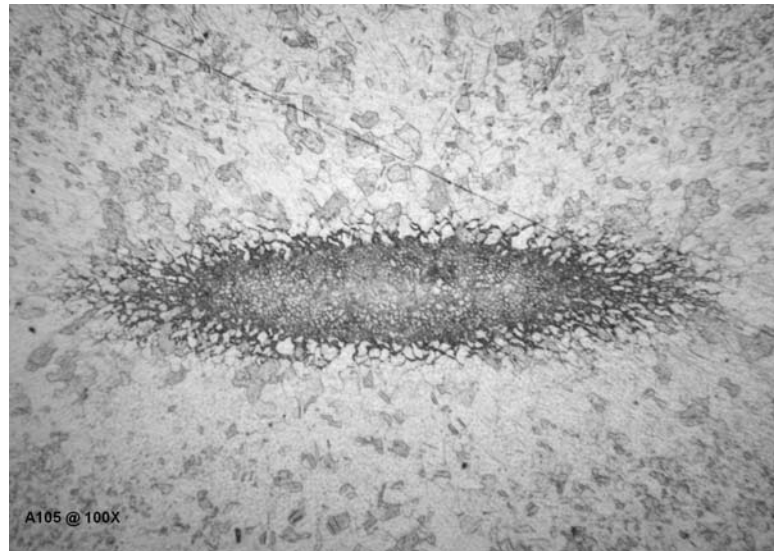
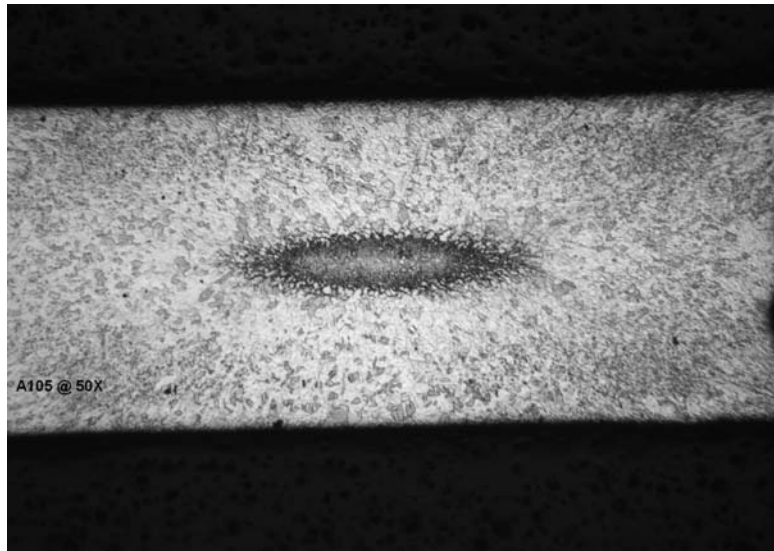
A108 Nominal



A095 Hot

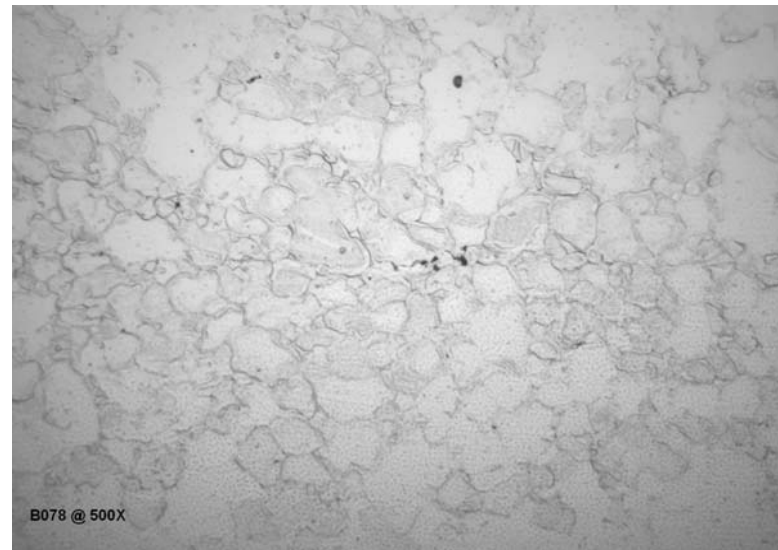
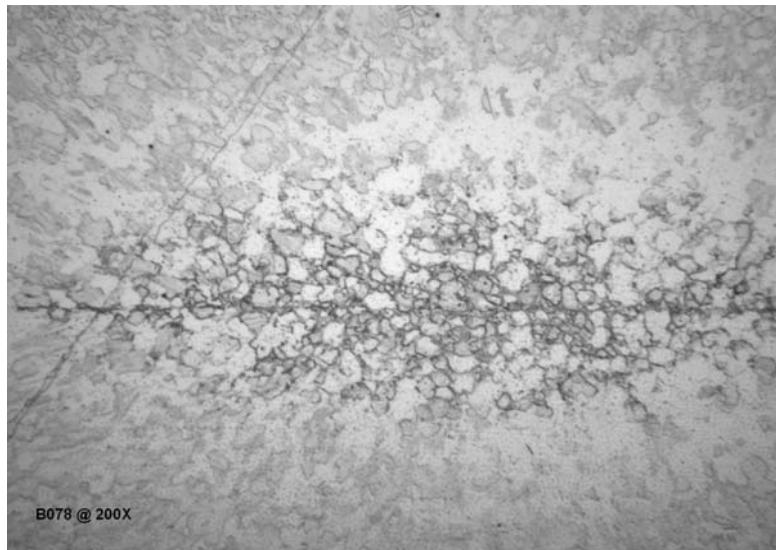
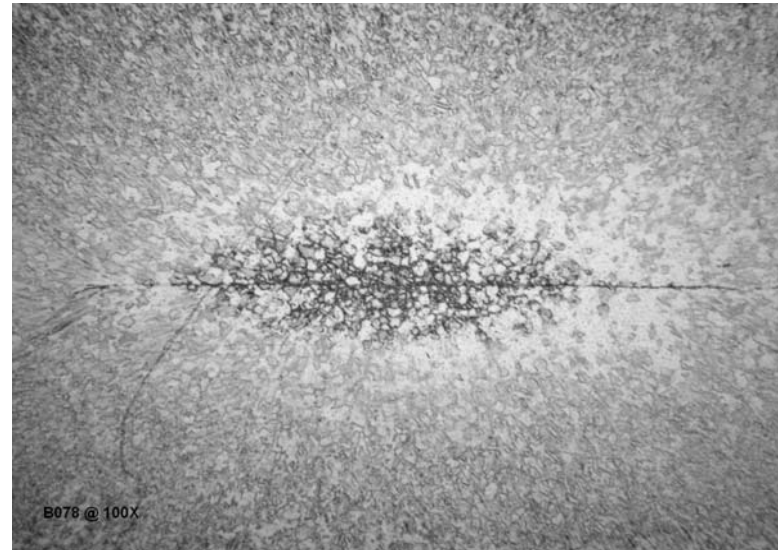
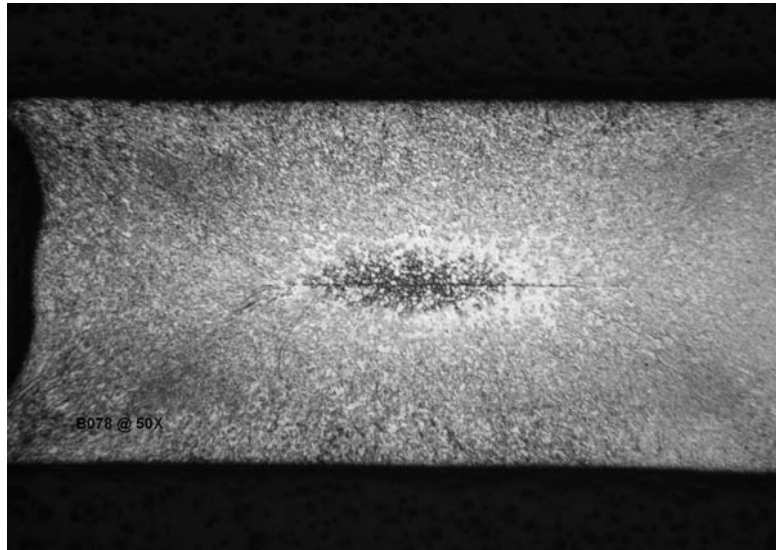


A104 Hot

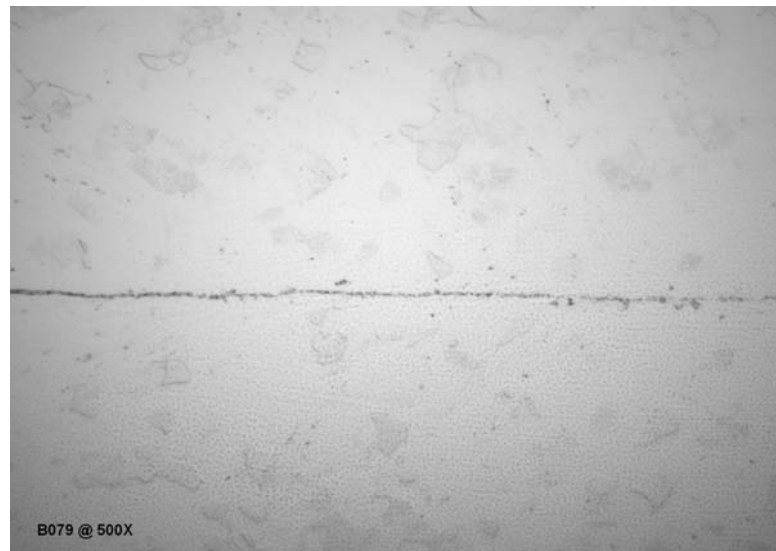
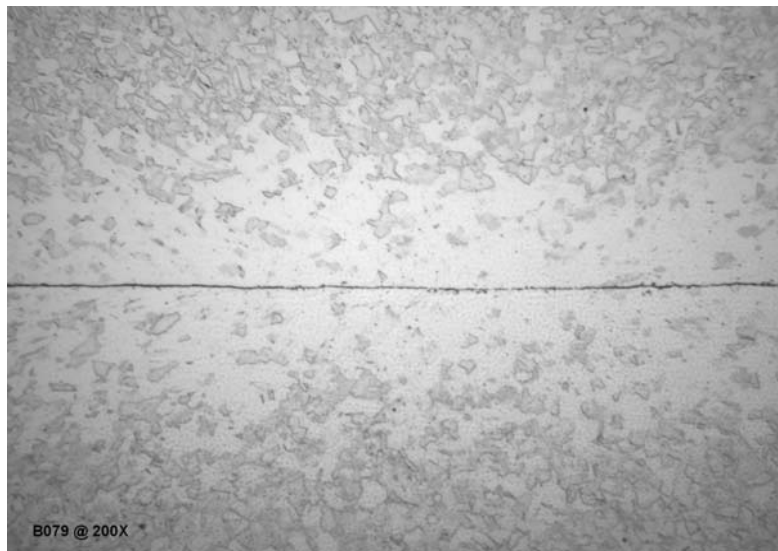
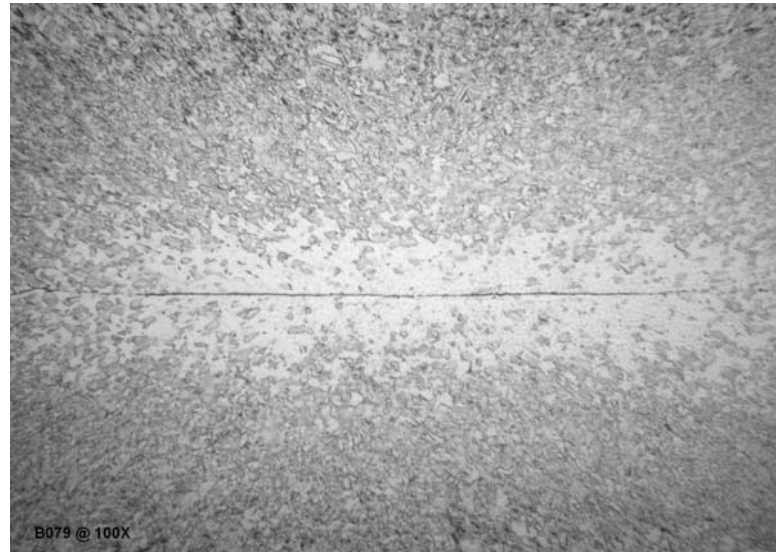
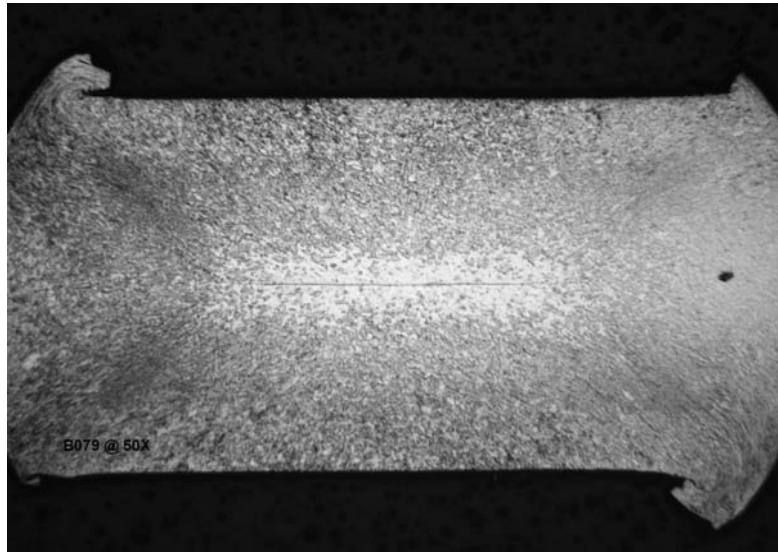


A105 Hot

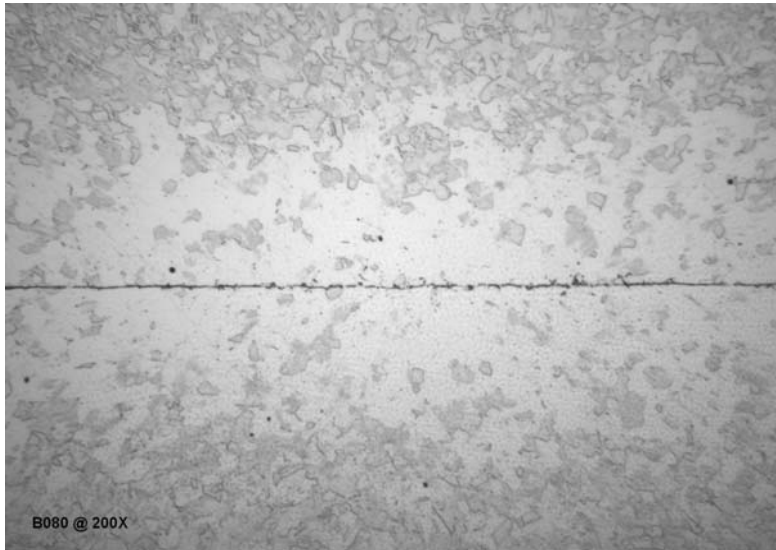
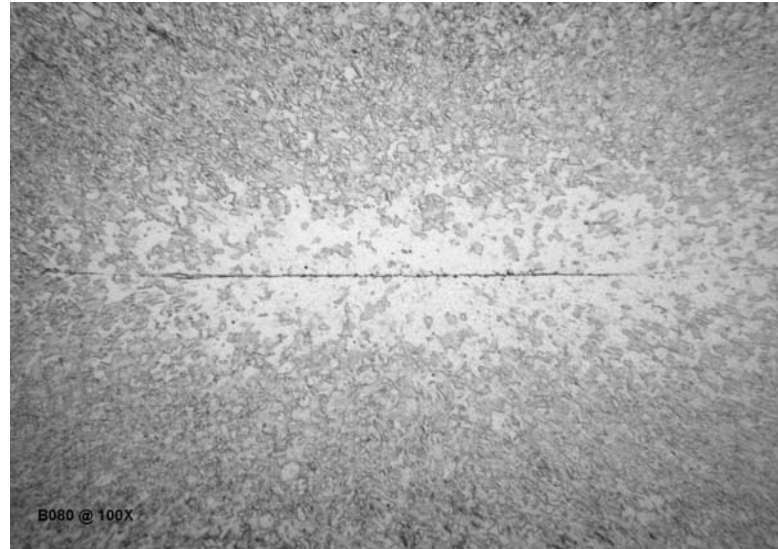
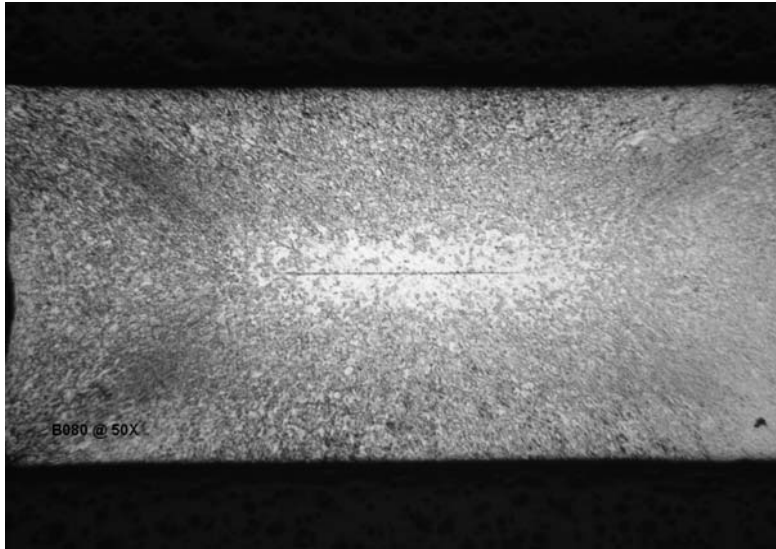
Appendix C. Type 316 Stainless Steel pinch weld microstructures.



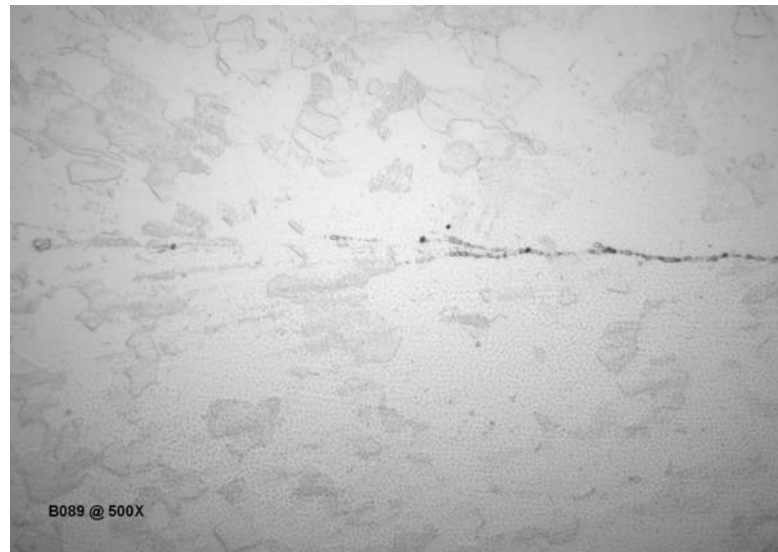
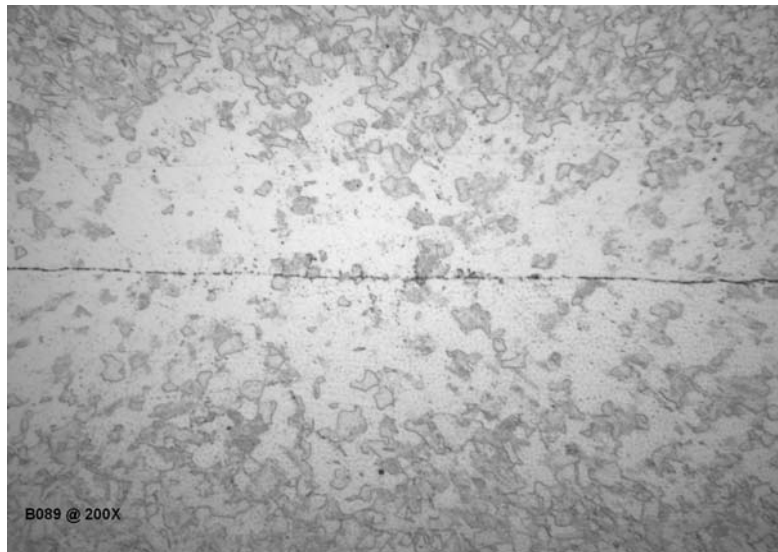
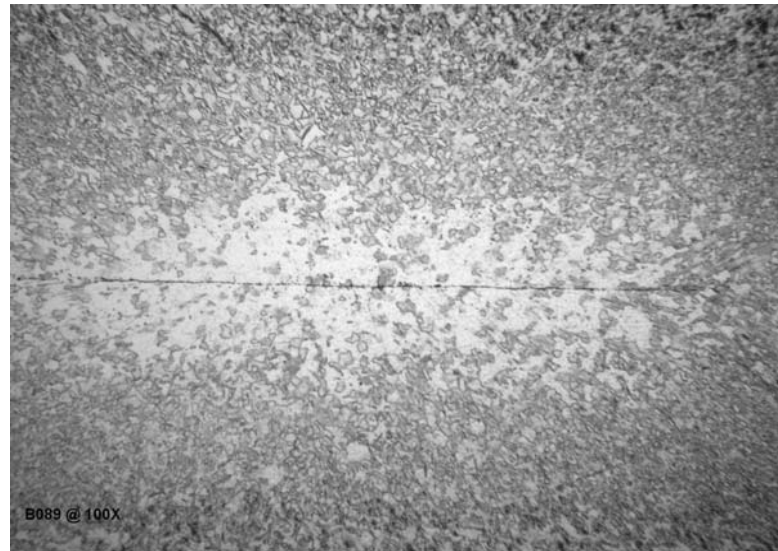
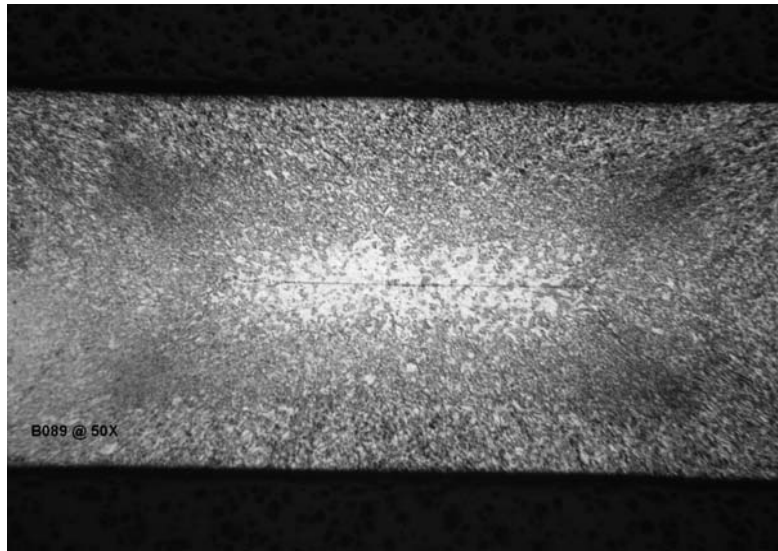
B078 Cold



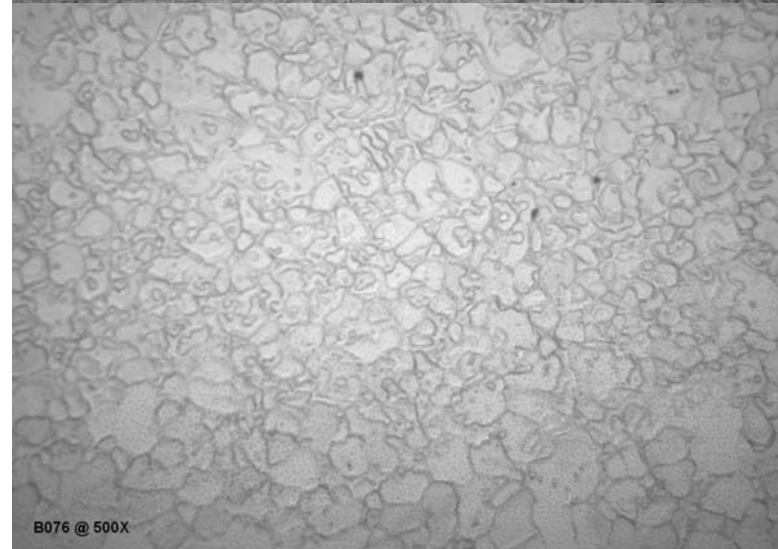
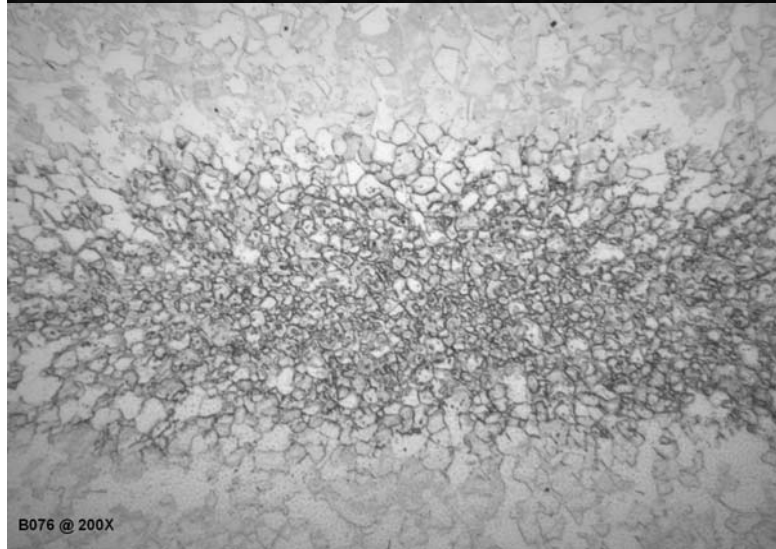
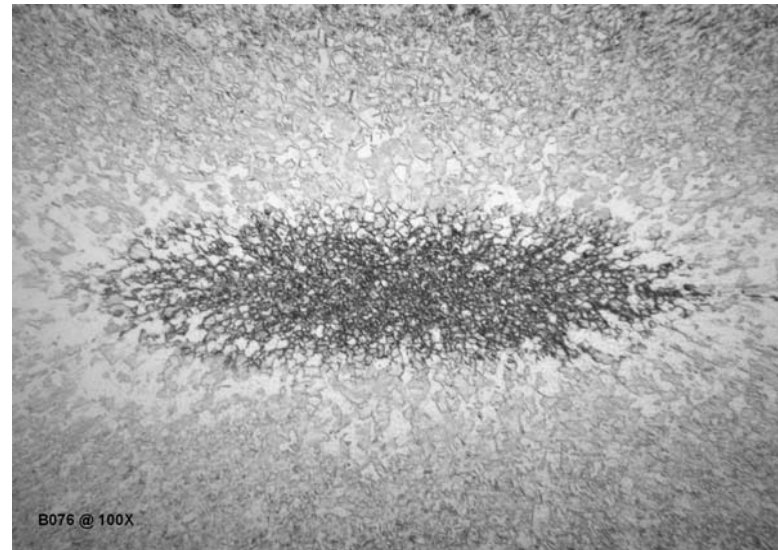
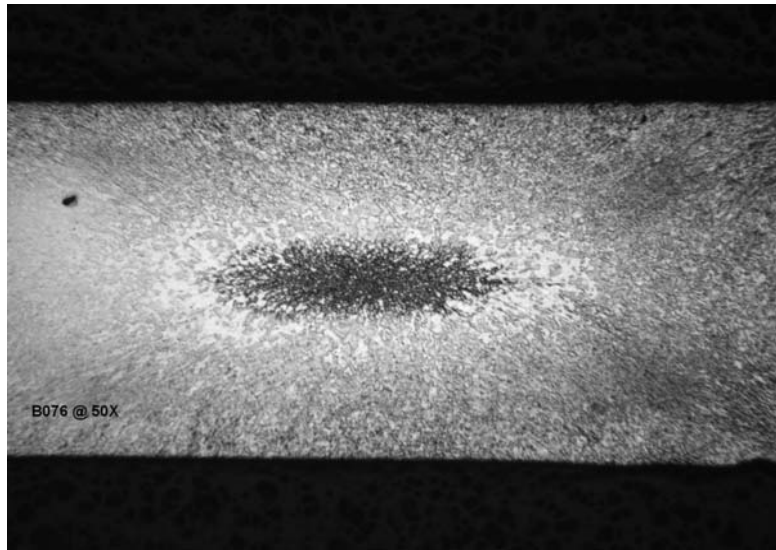
B079 Cold



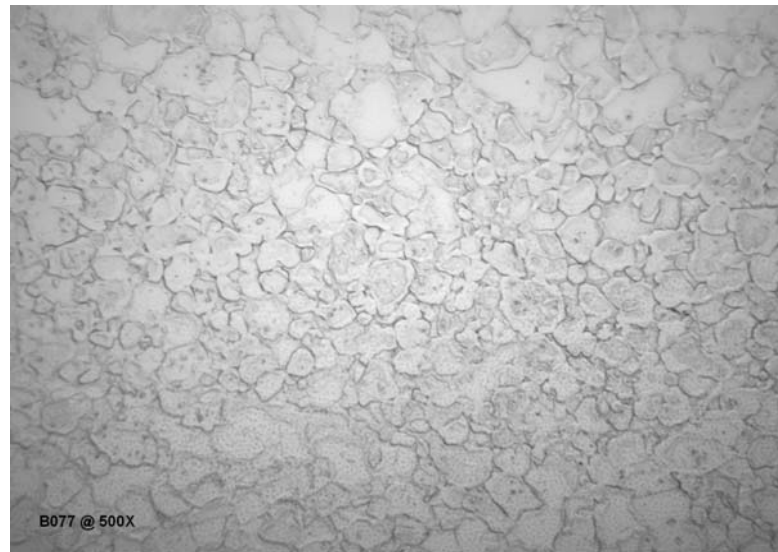
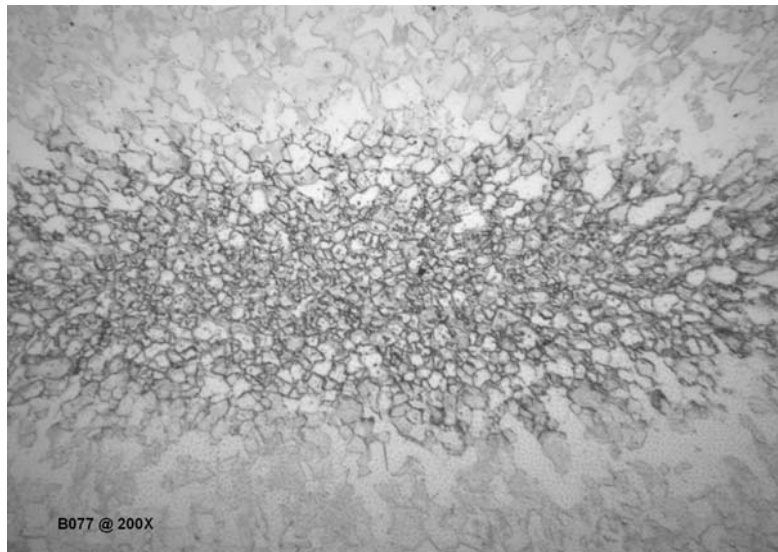
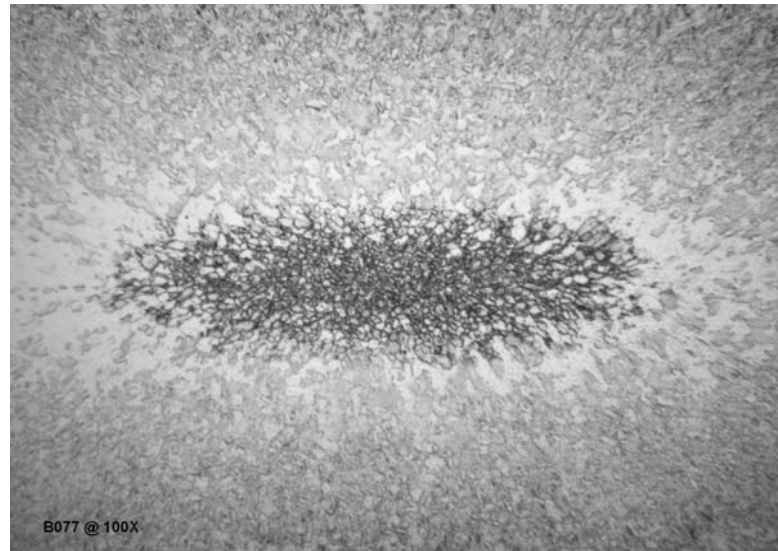
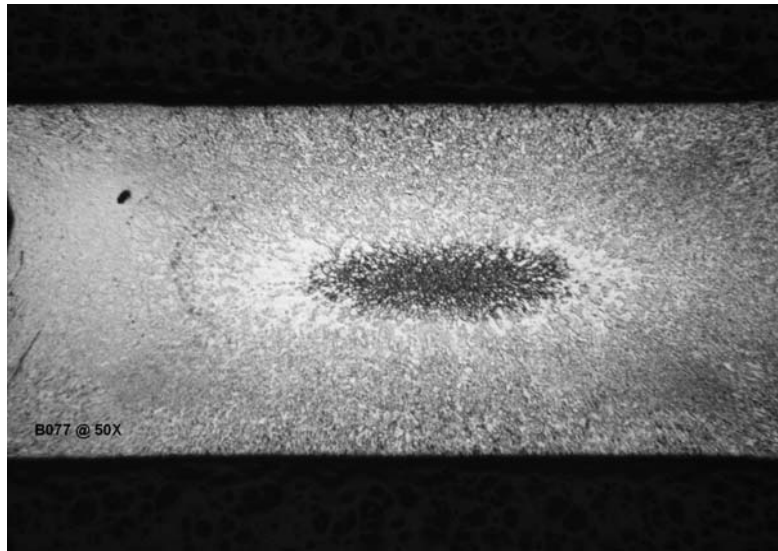
B080 Cold



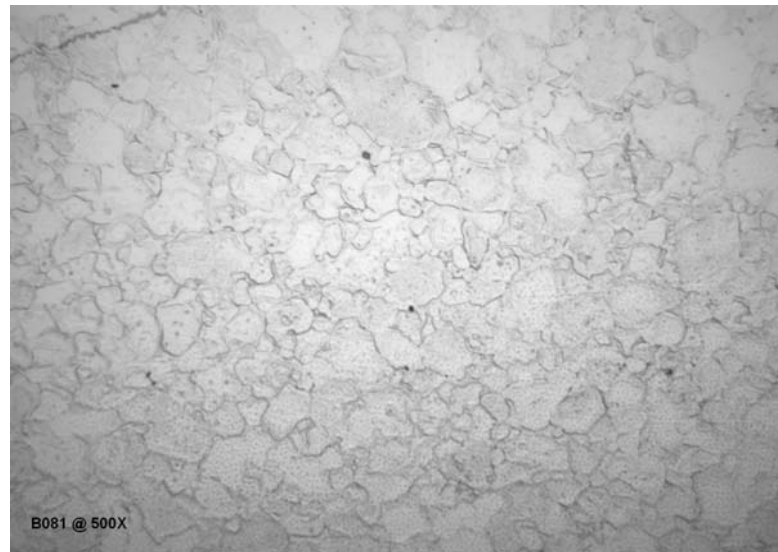
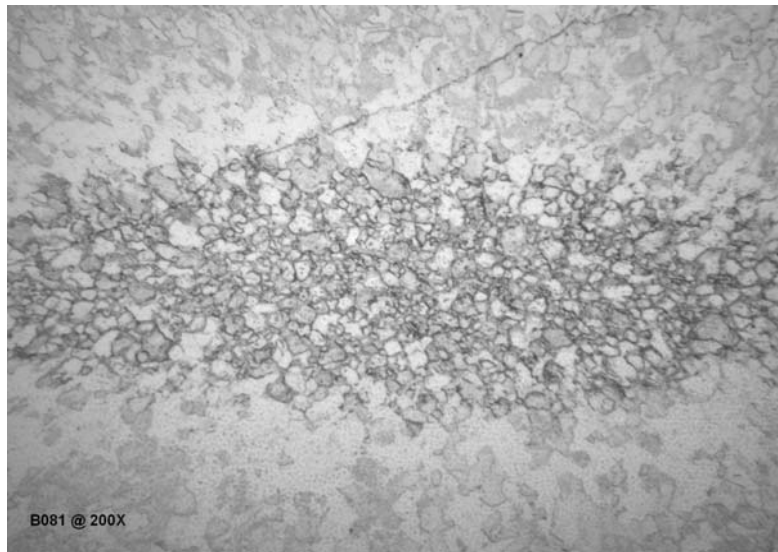
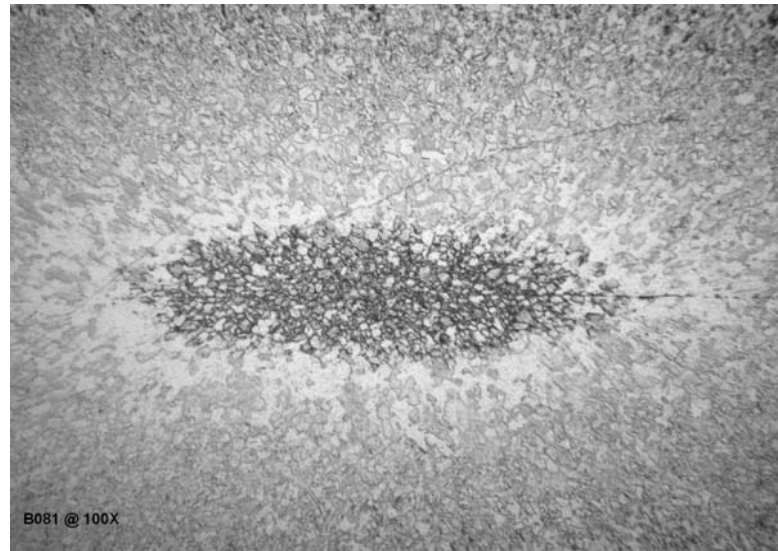
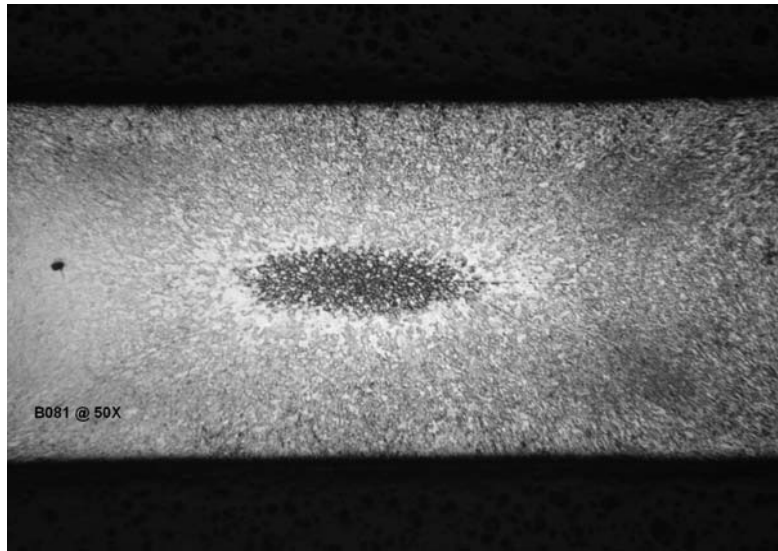
B089 Cold



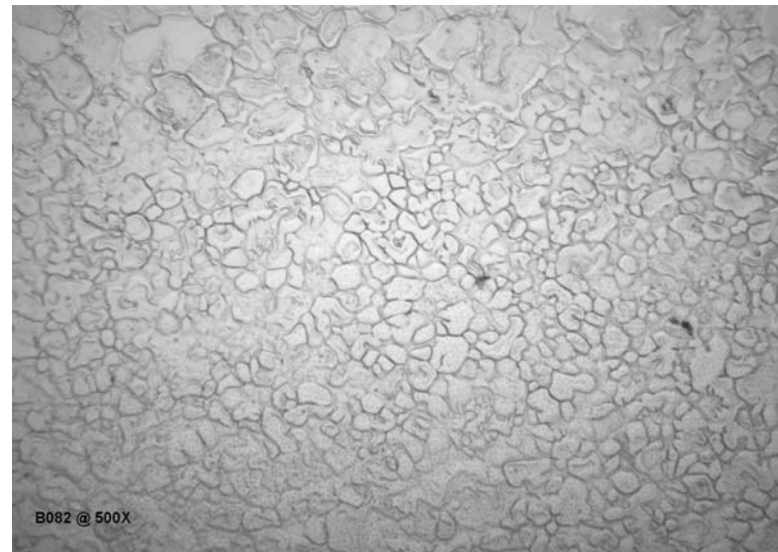
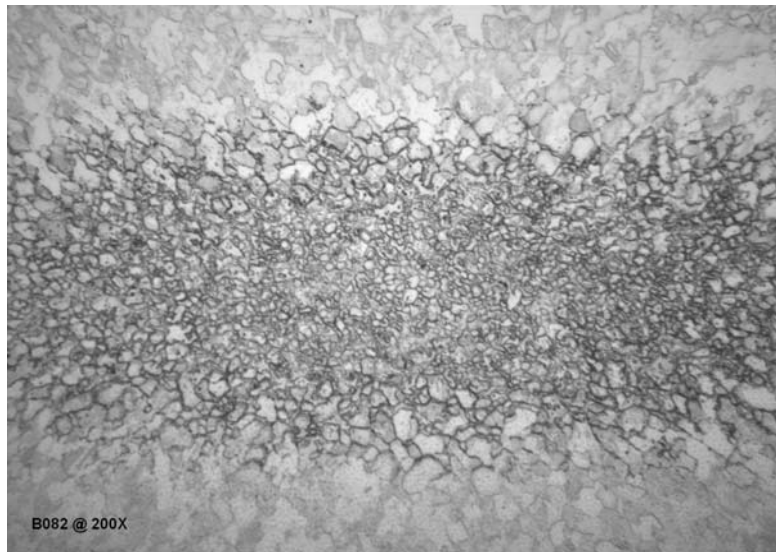
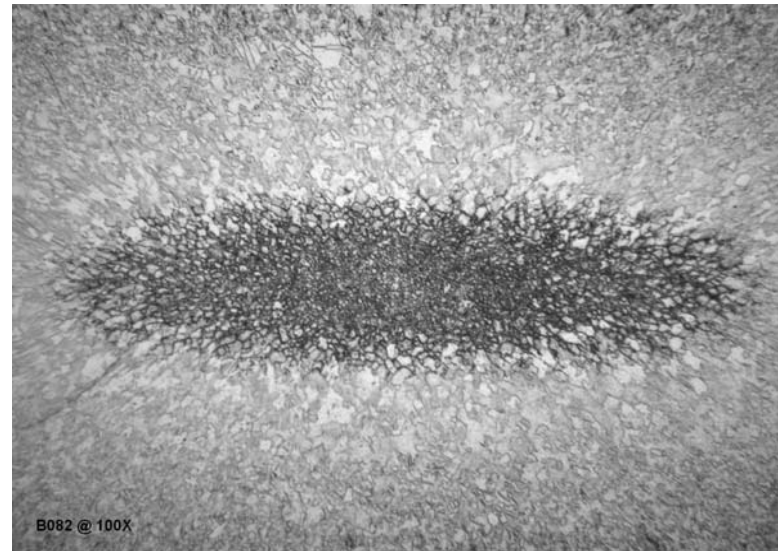
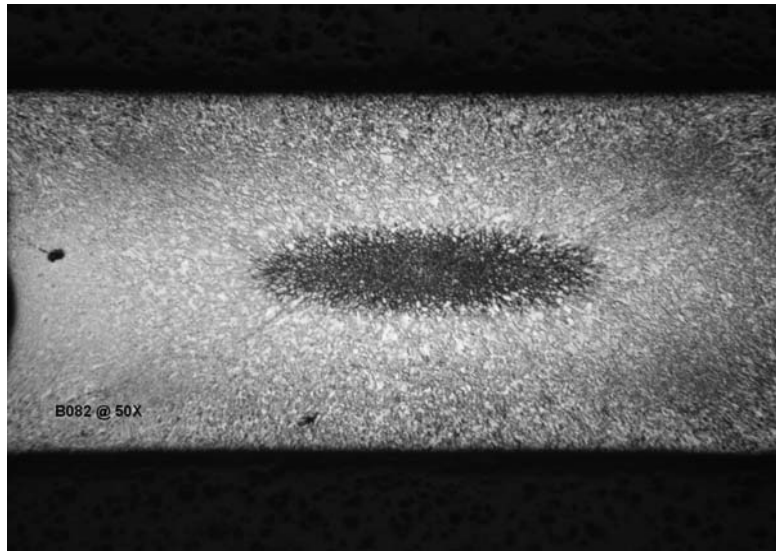
B076 Nominal



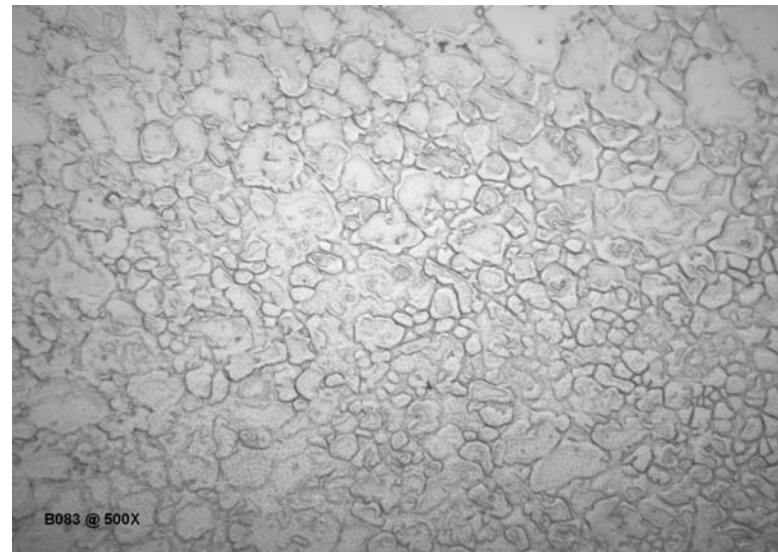
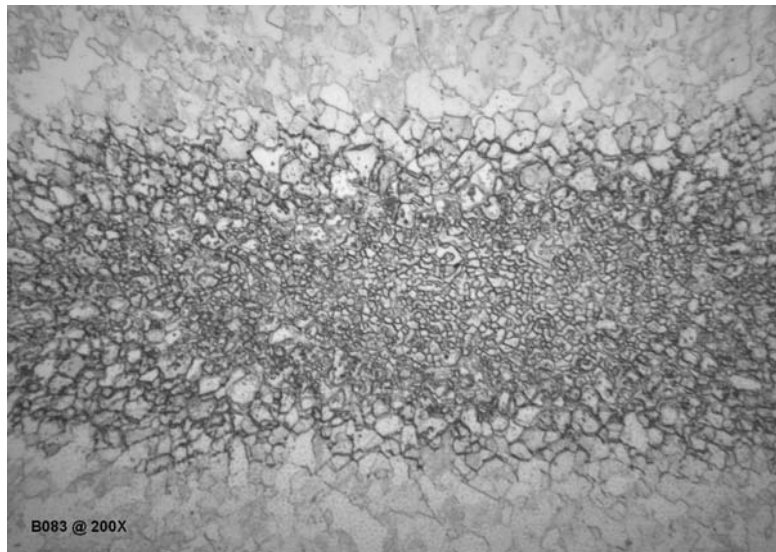
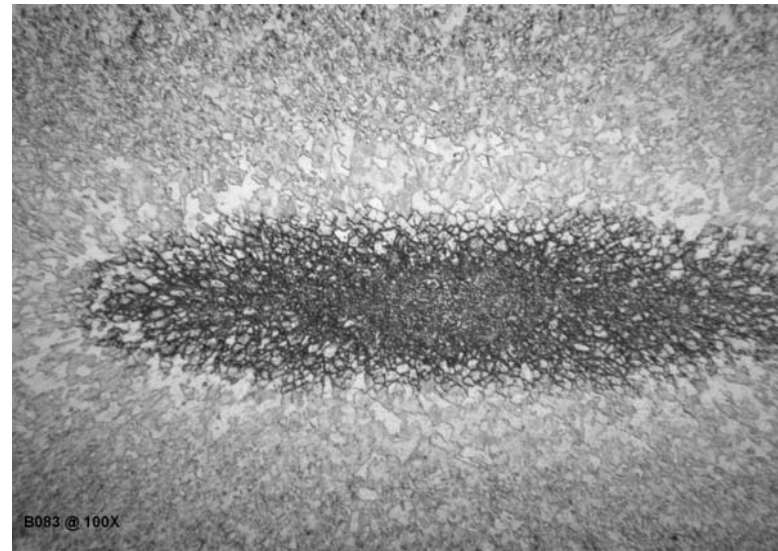
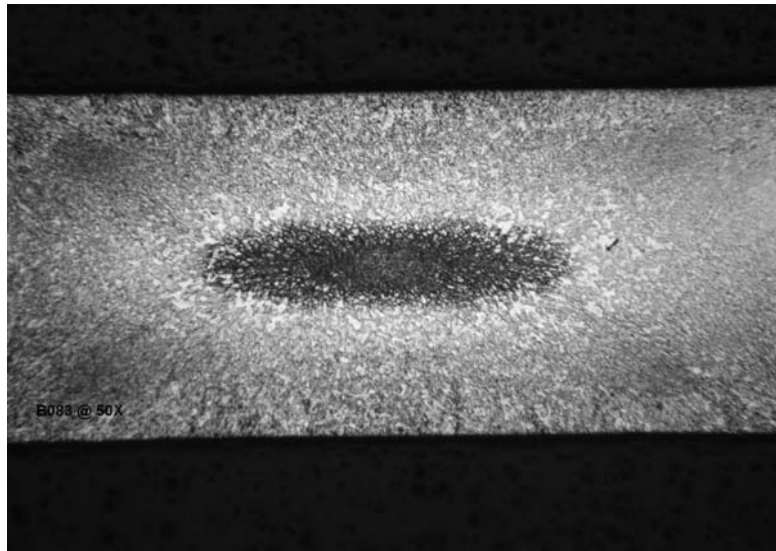
B077 Nominal



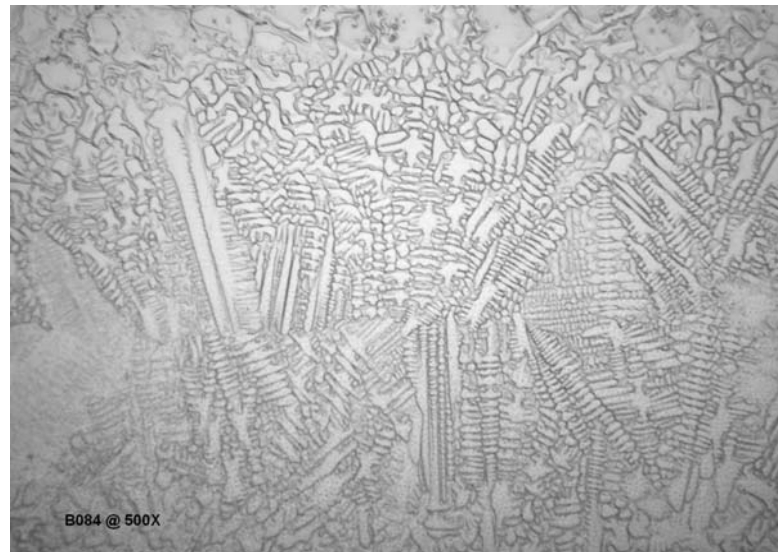
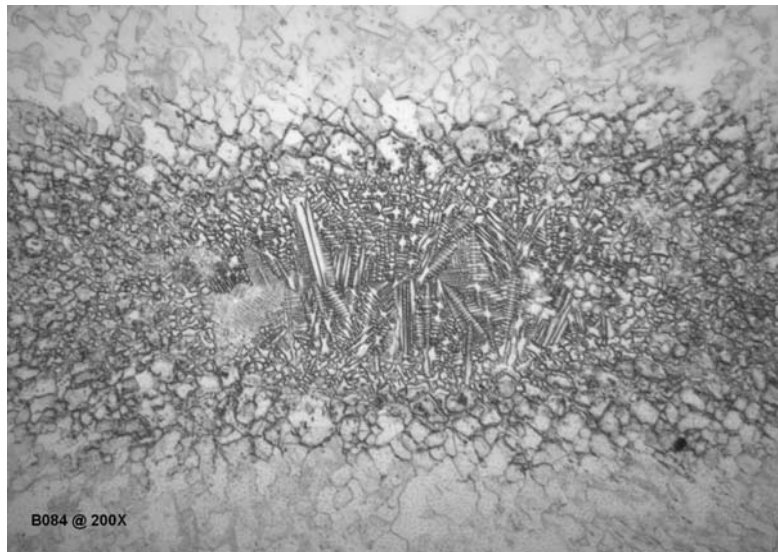
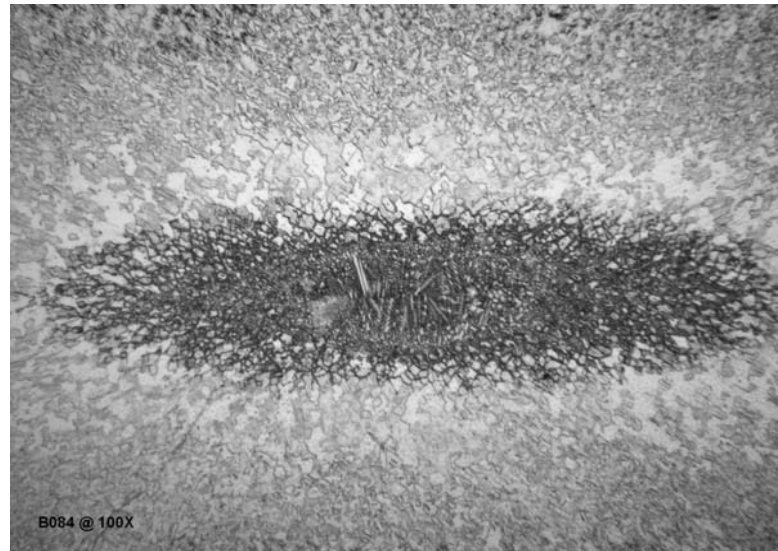
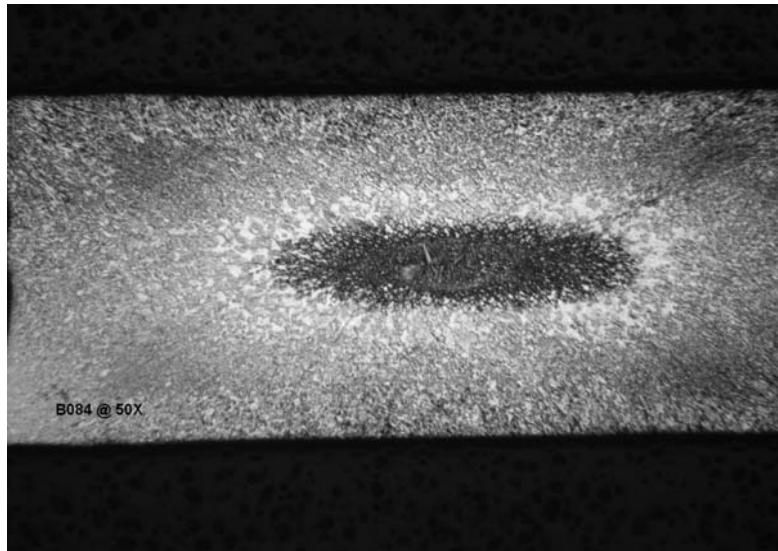
B081 Nominal



B082 Hot

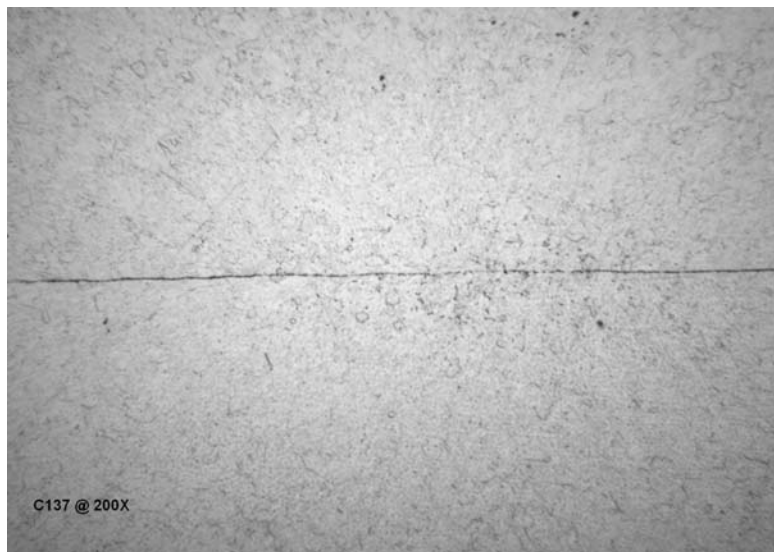
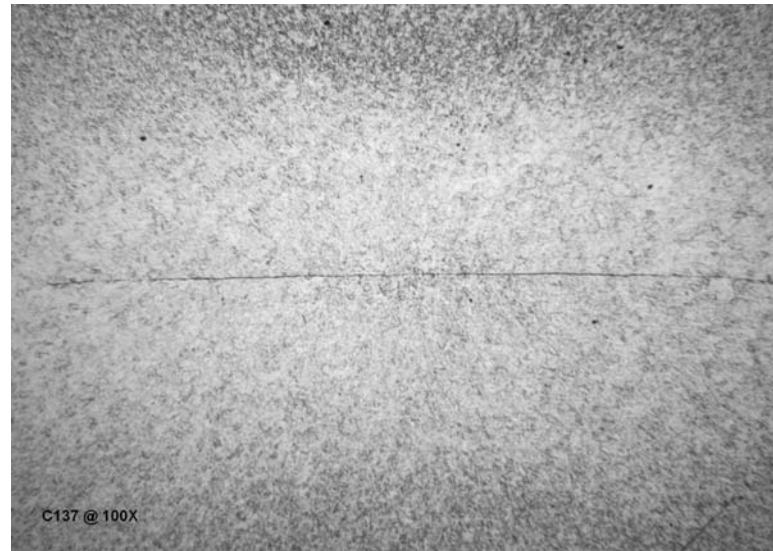
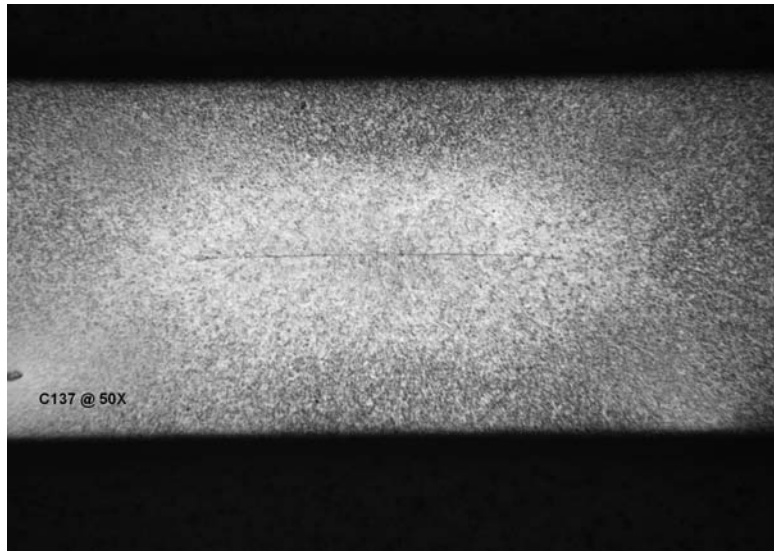


B083 Hot

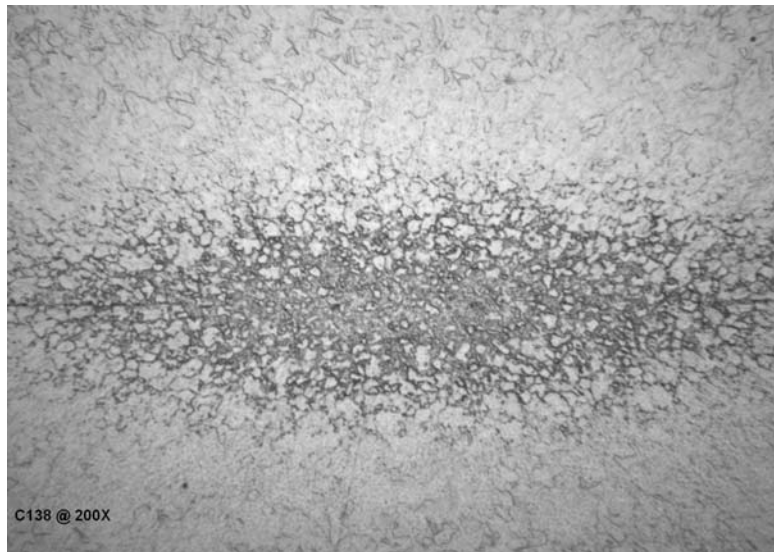
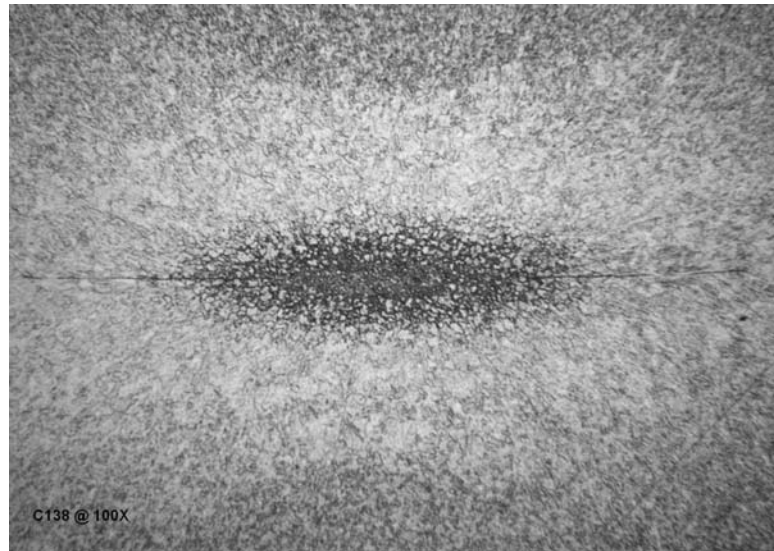
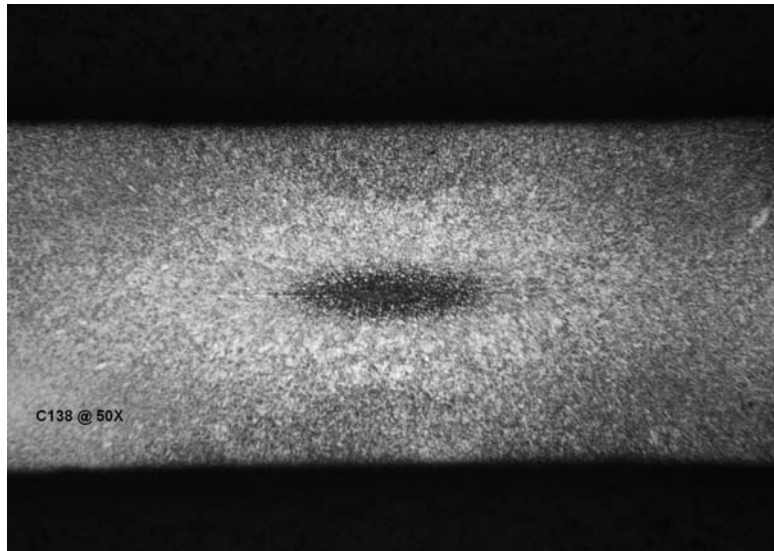


B084 Hot

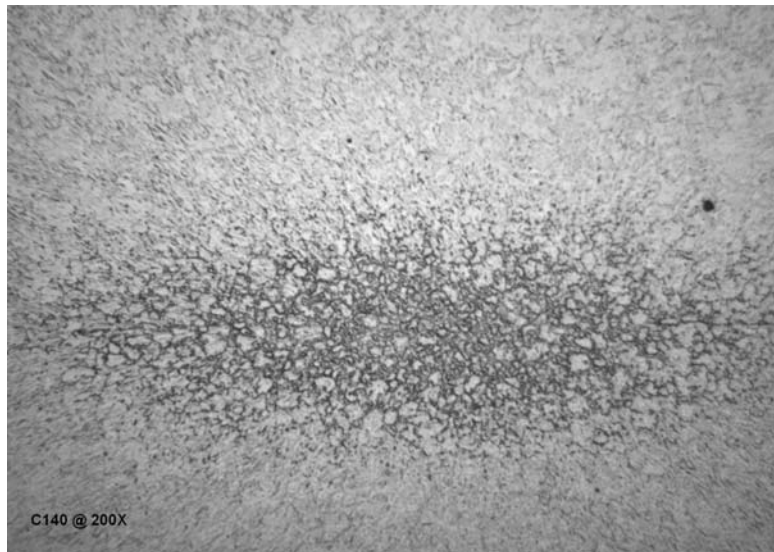
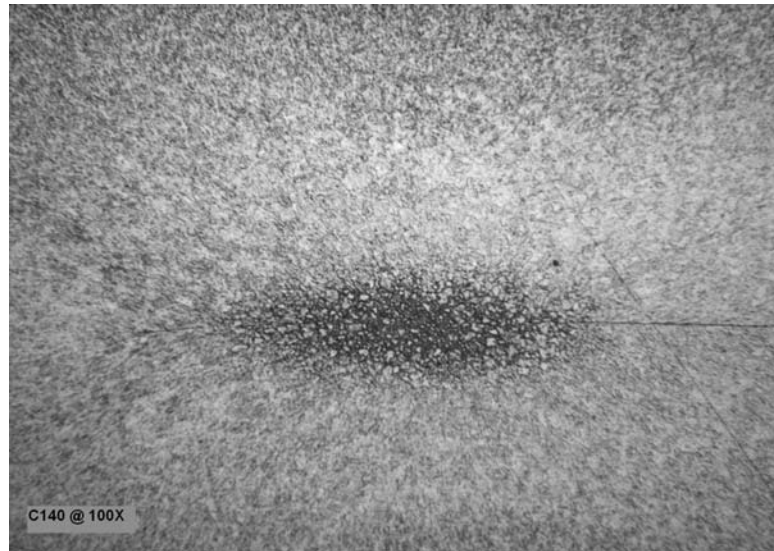
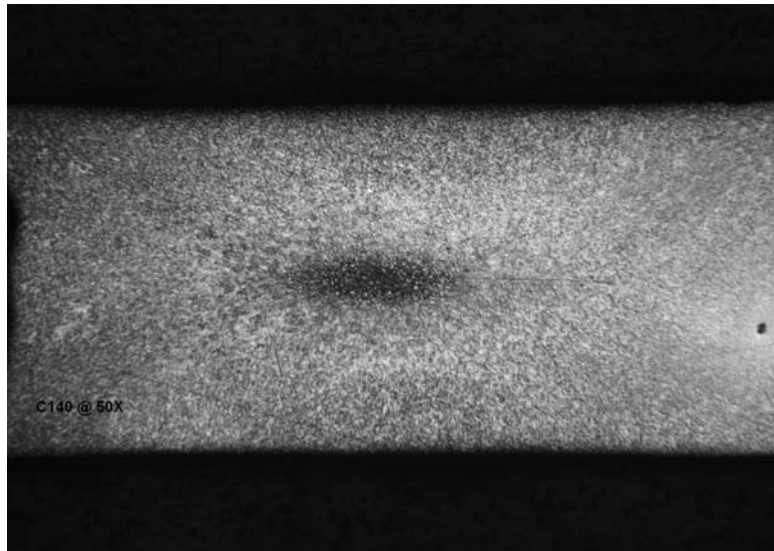
Appendix D. 21-6-9 pinch weld microstructure



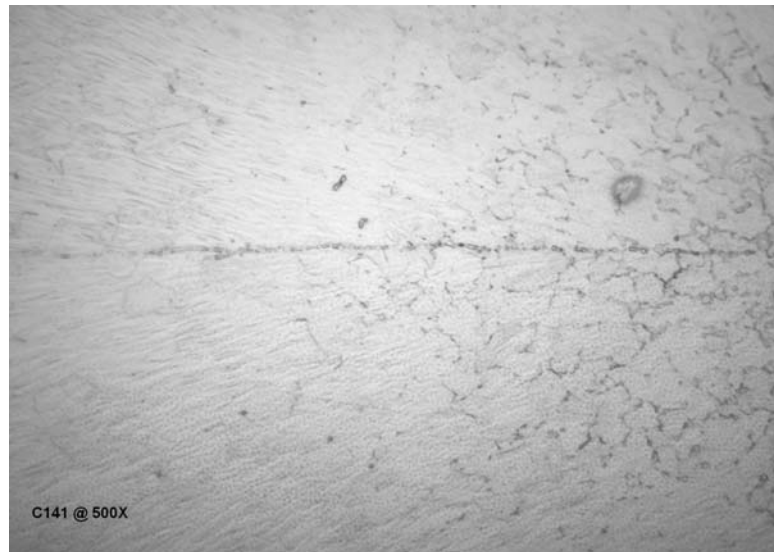
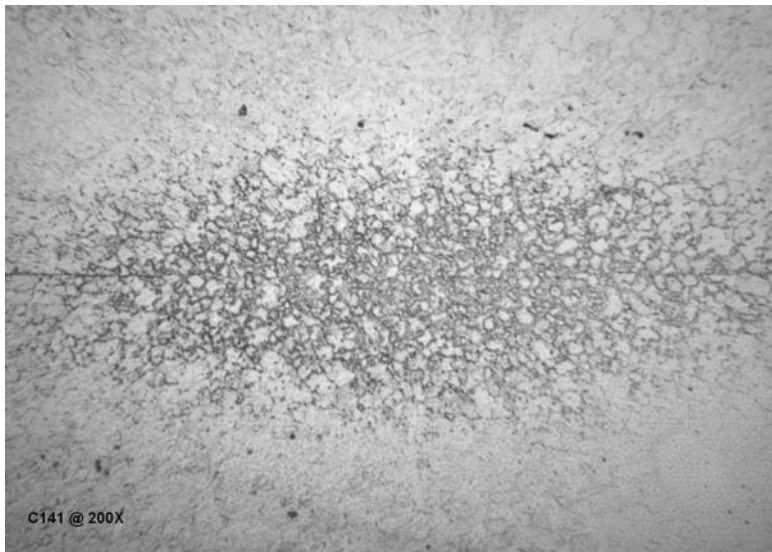
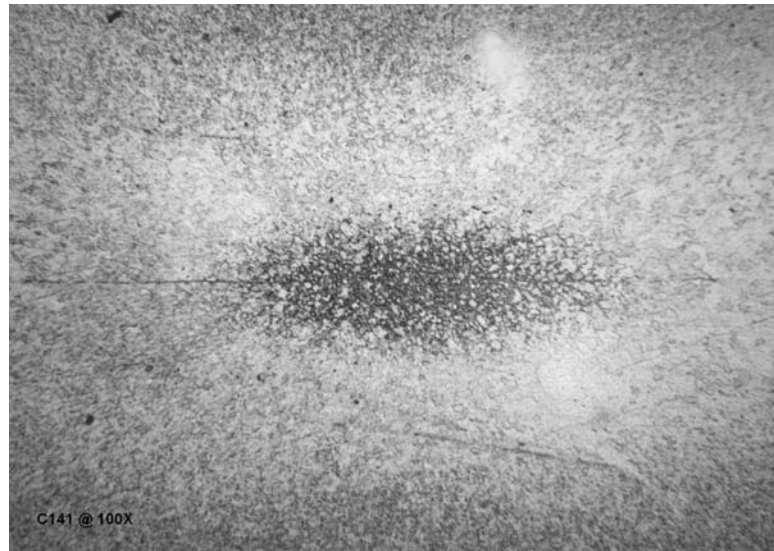
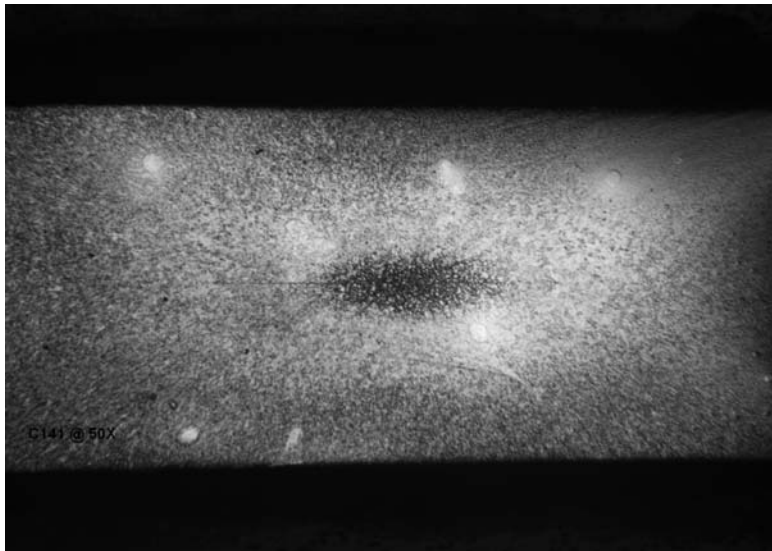
C137 Cold



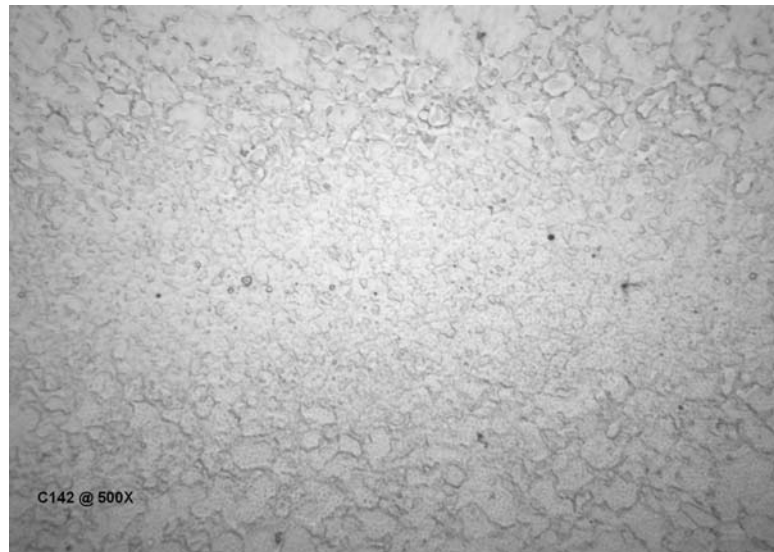
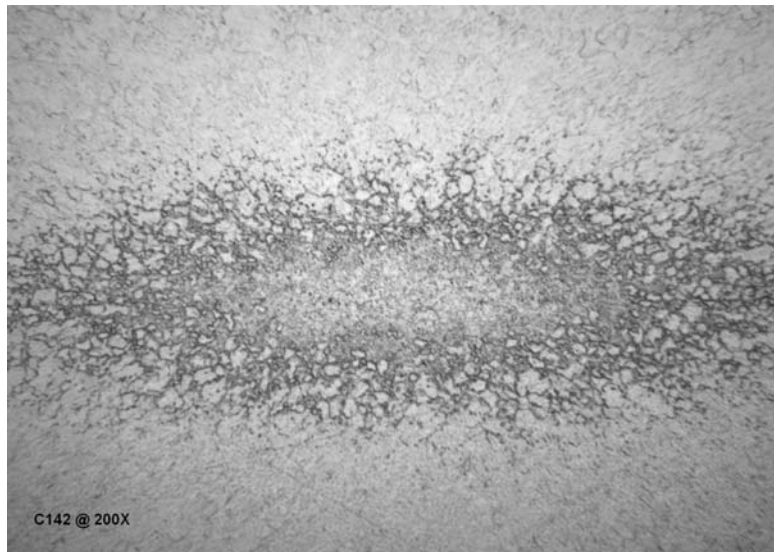
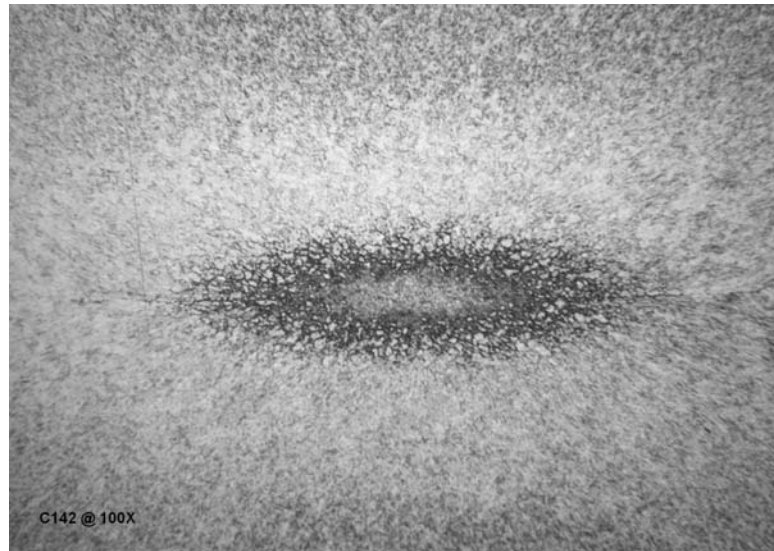
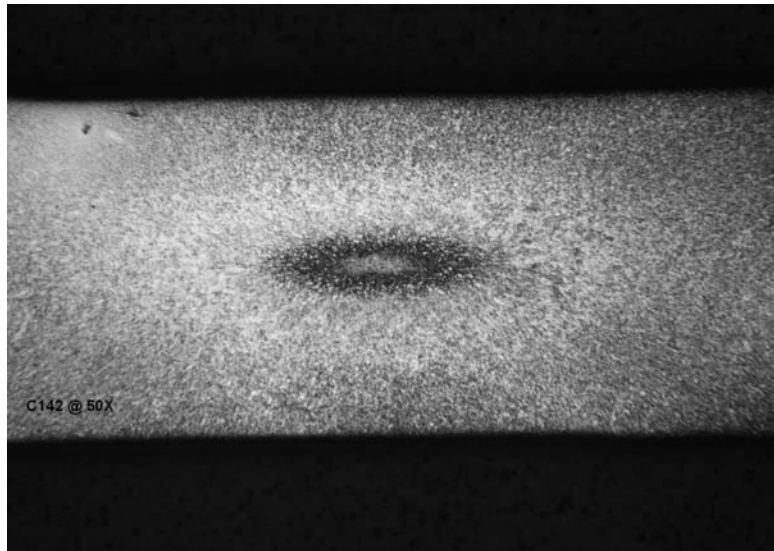
C138 Cold



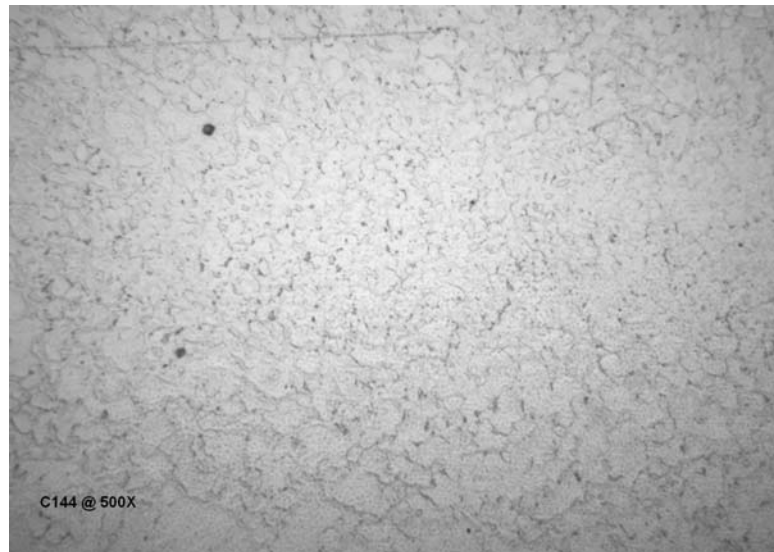
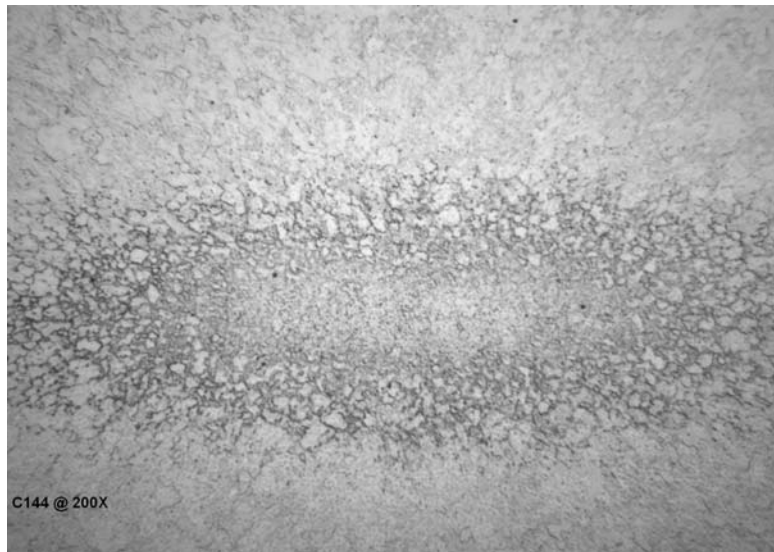
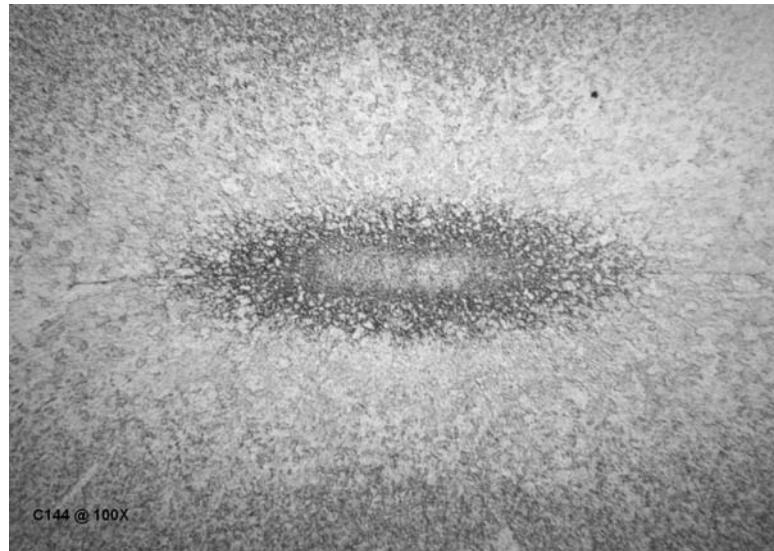
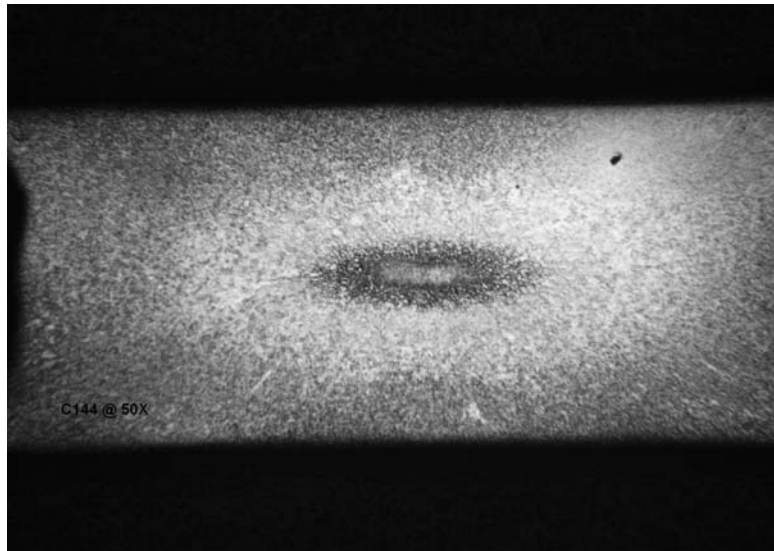
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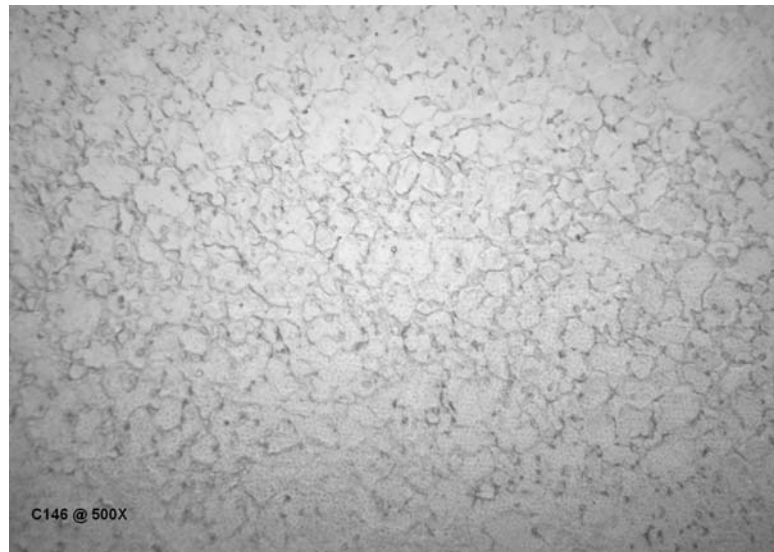
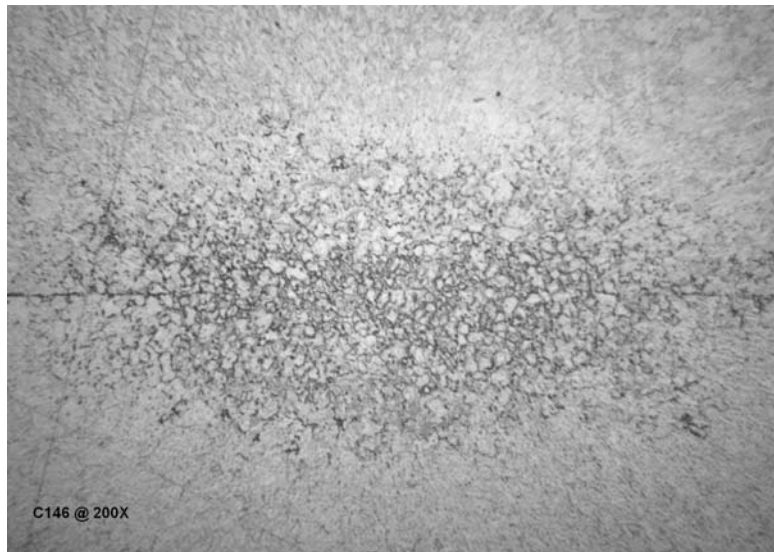
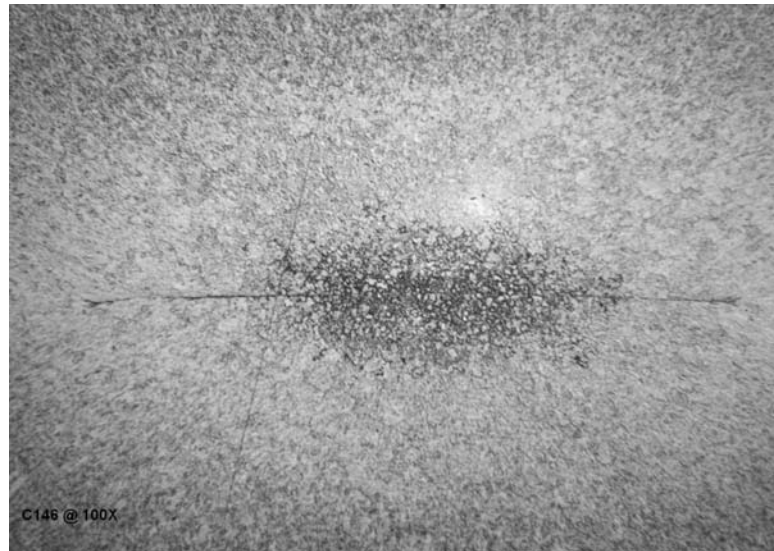
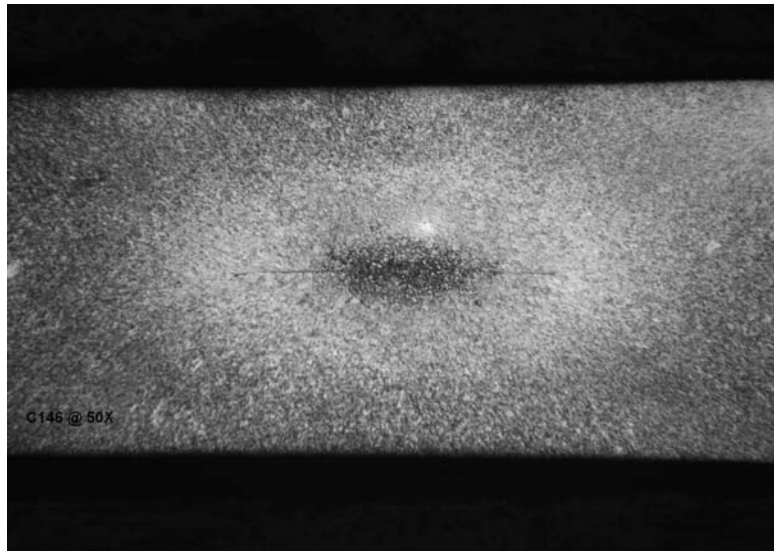
C141 Cold



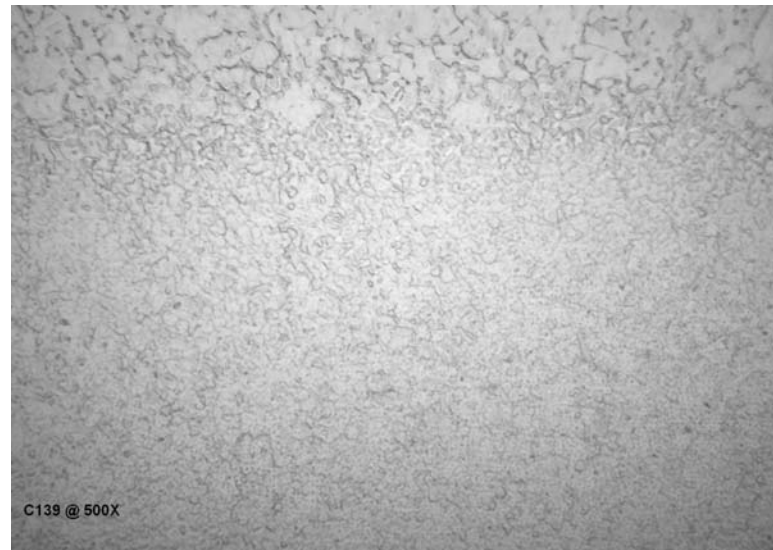
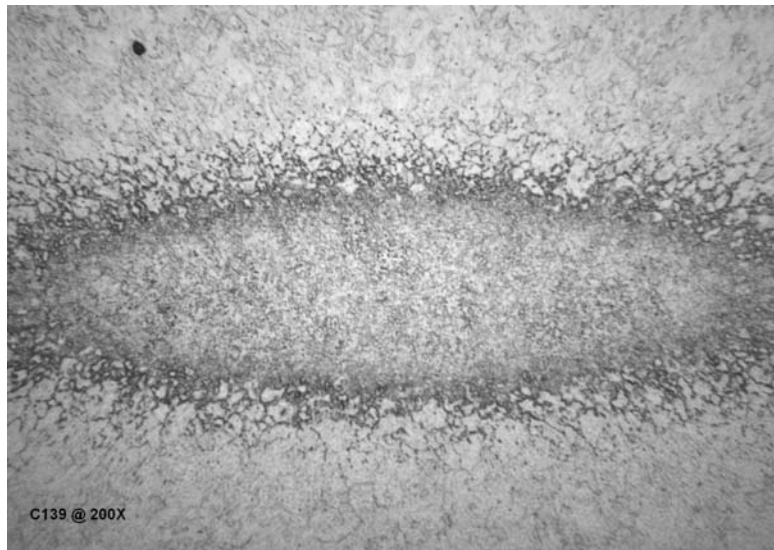
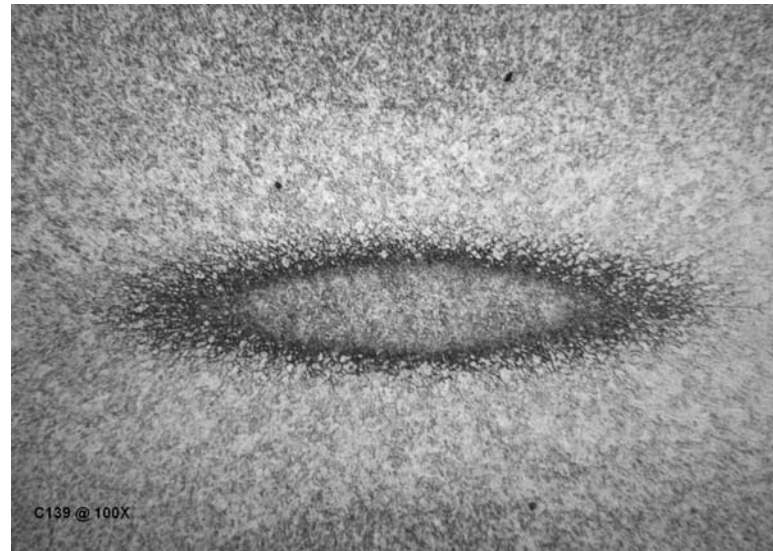
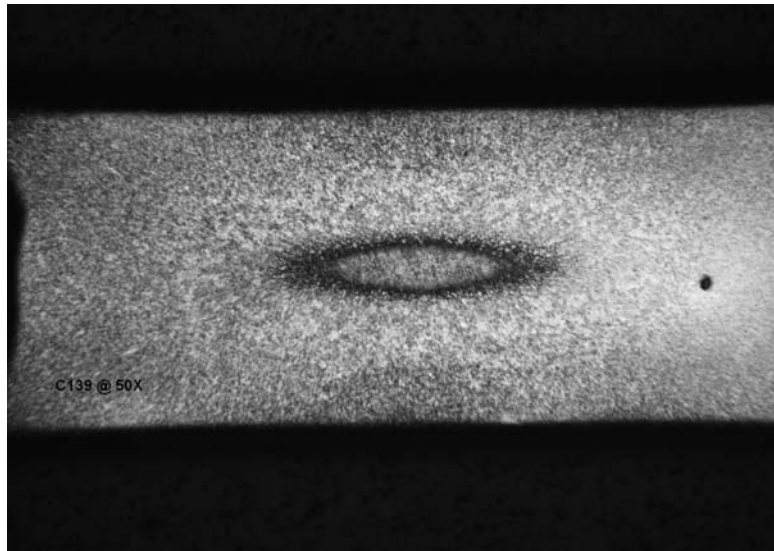
C142 Nominal



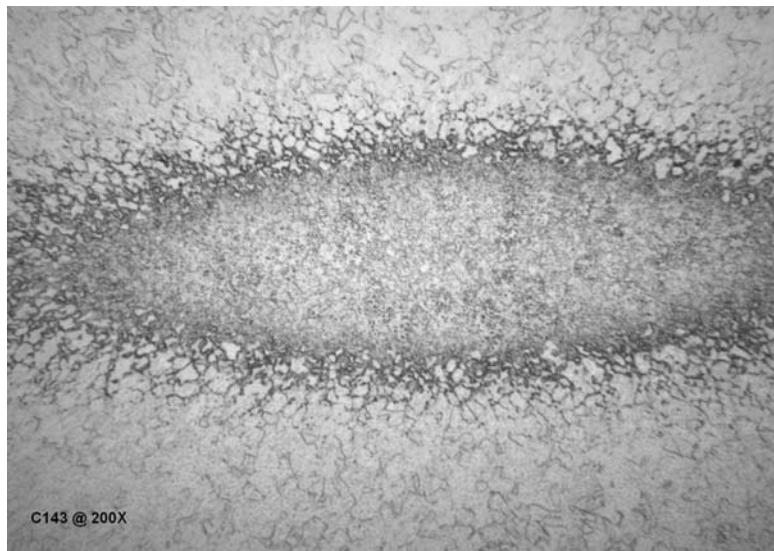
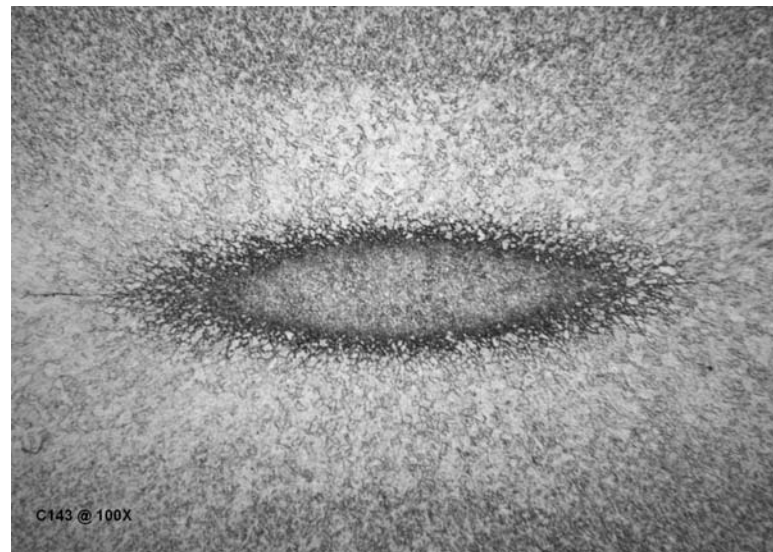
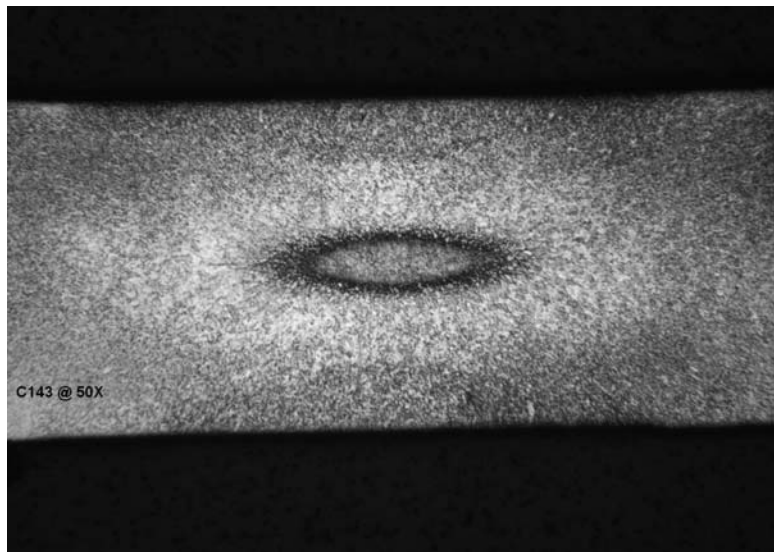
C144 Nominal



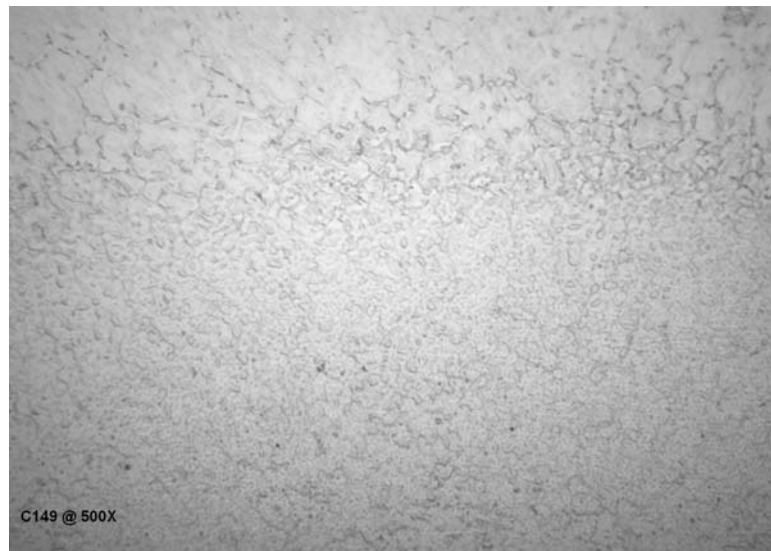
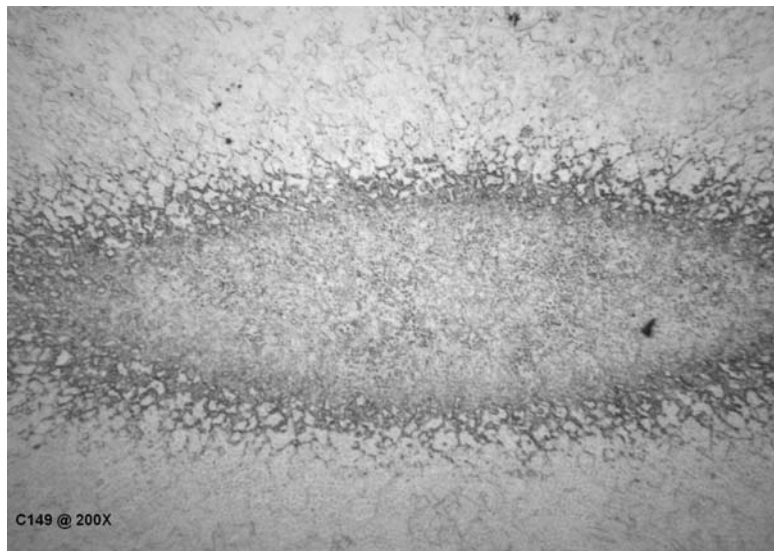
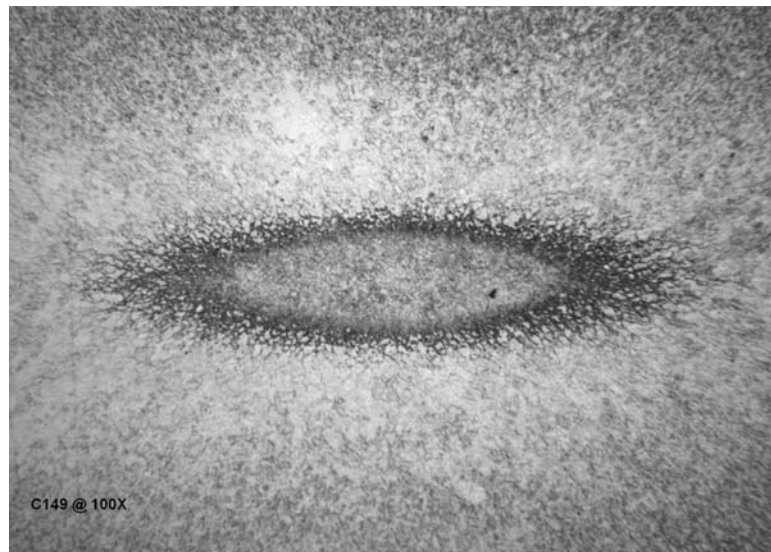
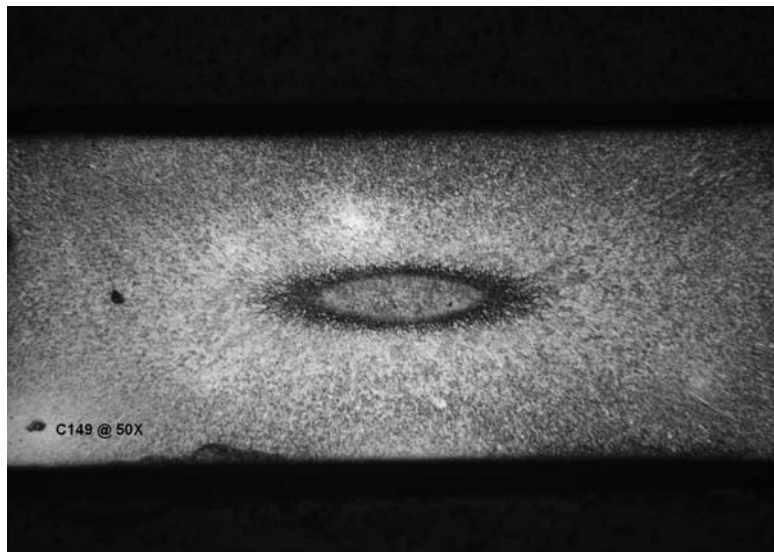
C146 Nominal



C139 Hot



C143 Hot



C149 Hot