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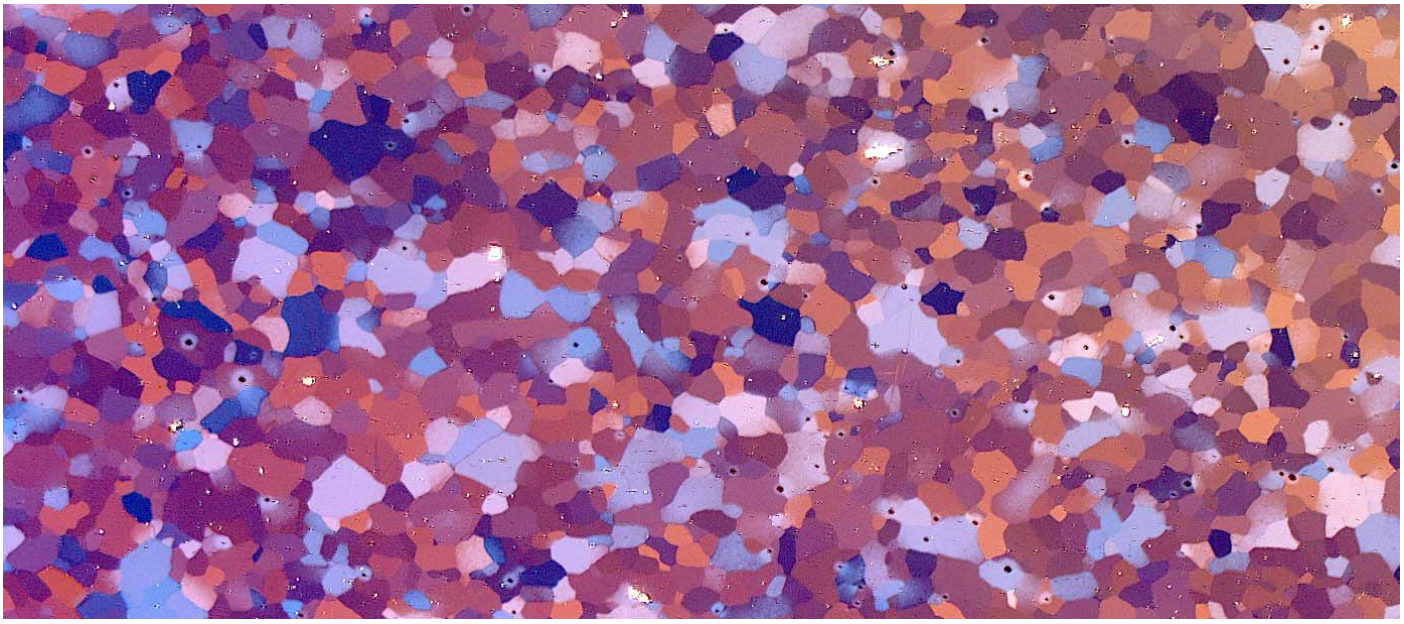
Metallography Job# 13234



LOS ALAMOS NATIONAL LABORATORY
SIGMA DIVISION

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METALLOGRAPHIC CHARACTERIZATION OF WROUGHT DEPLETED URANIUM

Metallography Job# 13234

Abstract

Metallographic characterization was performed on wrought depleted uranium (DU) samples taken from the longitudinal and transverse orientations from specific locations on two specimens. Characterization of the samples included general microstructure, inclusion analysis, grain size analysis, and microhardness testing. Comparisons of the characterization results were made to determine any differences based on specimen, sample orientation, or sample location. In addition, the characterization results for the wrought DU samples were also compared with data obtained from the metallographic characterization of cast DU samples previously characterized. No differences were observed in microstructure, inclusion size, morphology, and distribution, or grain size in regard to specimen, location, or orientation for the wrought depleted uranium samples. However, a small difference was observed in average hardness with regard to orientation at the same locations within the same specimen. The longitudinal samples were slightly harder than the transverse samples from the same location of the same specimen. This was true for both wrought DU specimens. Comparing the wrought DU sample data with the previously characterized cast DU sample data, distinct differences in microstructure, inclusion size, morphology and distribution, grain size, and microhardness were observed. As expected, the microstructure of the wrought DU samples consisted of small recrystallized grains which were uniform, randomly oriented, and equiaxed with minimal twinning observed in only a few grains. In contrast, the cast DU microstructure consisted of large irregularly shaped grains with extensive twinning observed in most grains. Inclusions in the wrought DU samples were elongated, broken and cracked and light and dark phases were observed in some inclusions. The mean inclusion area percentage for the wrought DU samples ranged from 0.08% to 0.34% and the average density from all wrought DU samples was 1.62E+04/cm^2. Inclusions in the cast DU samples were equiaxed and intact with light and dark phases observed in some inclusions. The mean inclusion area percentage for the cast DU samples ranged from 0.93% to 1.00% and the average density from all wrought DU samples was 2.83E+04/cm^2. The average mean grain area from all wrought DU samples was 141 μm^2 while the average mean grain area from all cast DU samples was 1.7 mm^2. The average Knoop microhardness from all wrought DU samples was 215 HK and the average Knoop microhardness from all cast DU samples was 264 HK.

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Introduction

Ten wrought depleted uranium (DU) samples were submitted for metallographic characterization. The samples were taken from two different orientations (transverse and longitudinal) from two different specimens identified as 116 and 195. The samples were assigned metallography number 13234 and further identified by the following format:

13234-AAA-BB-CD
AAA = Specimen ID (116 or 195) BB = Sample Location (0, 45, 90)
C = Mount Number (1 – 5) D = Orientation (T for Transverse and L for Longitudinal)

Because all samples were similar in size, the machining marks were used as a guide to determine orientation. Edges that cut across the machining marks were designated as longitudinal orientation and edges that were parallel to the machining marks were designated as transverse orientation.

The characterization consisted of microstructure imaging, inclusion analysis, grain size analysis, and microhardness testing.

The characterization results were compared between the two specimens (116 and 145), between different locations (0, 45, 90), and between orientations (Transverse and Longitudinal). In addition, the results were also compared with the results for cast DU samples that had previously been characterized under metallography job number 13052.

Sample Preparation

Mounting- The samples were mounted as received in Epon 815-C epoxy. The epoxy was poured over the samples in a vacuum chamber at ~23 inHg (584 mm Hg) and cured overnight in a pressure chamber at ~1000 psig (6.9 MPa).

Grinding- The samples were ground using progressively finer grinding papers (see Table 1). All grinding was performed by hand on a Buehler grinding wheel. Samples were periodically rotated 90 degrees during the grinding process.

Grinding Paper	Lubricant	Platen Speed	Time
320 grit	Water	High	~ 1 minutes
600 grit	Water	High	~ 1.5 minutes
800 grit	Water	Low	~ 1.5 minutes

Table 1. Sample grinding parameters.

Mechanical Polishing- The samples were polished with progressively finer diamond suspensions on Struers polishing cloths (see Table 2). Sample polishing was performed on a Struers Tegramin-25 semi-automatic polisher with user-programmed recipes.

Suspension	Polishing Time	Force	Polishing Cloth	Platen Speed	Head Rotation
3μm	3 minutes	20 N	MOL	150 RPM	Counter-rotation
1μm	3 minutes	20 N	MOL	150 RPM	Counter-rotation
1μm	3 minutes	20 N	NAP	150 RPM	Counter-rotation
¼ μm	4 minutes	20 N	NAP	150 RPM	Co-rotation

Table 2. Sample polishing parameters. User-programmed DU recipe.

Electropolishing- Electropolishing was performed to remove surface irregularities and to make the microstructure more visible under polarized light (see Table 3). Allowing the samples to oxidize in air for 15 – 30 minutes after electropolishing improved contrast between grains. Because the samples oxidized relatively quickly, the image quality generally degraded after 90 – 120 minutes (see Figure 1). However, three samples, 13234-195-0-3T, 13234-195-45-4L and 13234-195-45-4T, benefitted from oxidizing in air overnight revealing the microstructure in bright field instead of polarized light (see Figure 2). Multiple attempts to duplicate these results with the other samples were unsuccessful.

Electropolish Solution	Voltage Applied	Time Voltage Applied
45% Ethanol 27.5% Ethylene Glycol 27.5% Phosphoric Acid (Note: Electropolish solution stirred for entire process)	10 VDC	4 Minutes Total (Note: Samples polished for 30 seconds, rotated 180°, and polished an additional 30 seconds. This process was repeated for 2 minutes. The samples were rinsed in water and isopropanol and the process repeated for an additional 2 minutes. Samples were rinsed in water and isopropanol and dipped in the electropolish solution (no voltage applied) for ~15 sec and rinsed with water and isopropanol.)

Table 3. Electropolish Technique.

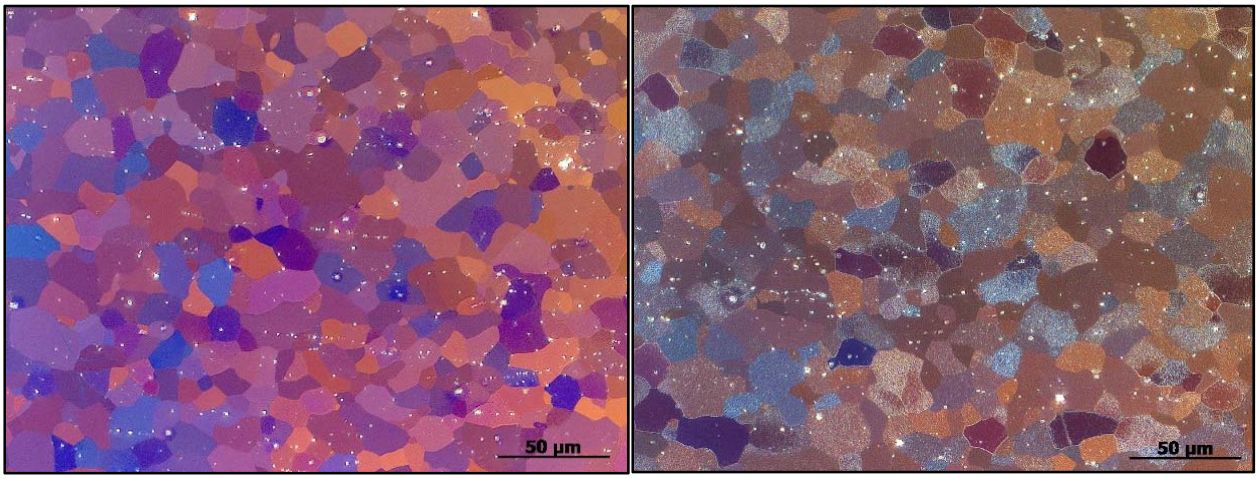


Figure 1. Changes in image quality due to oxidation buildup after ~ 90 minutes. Polarized light images.

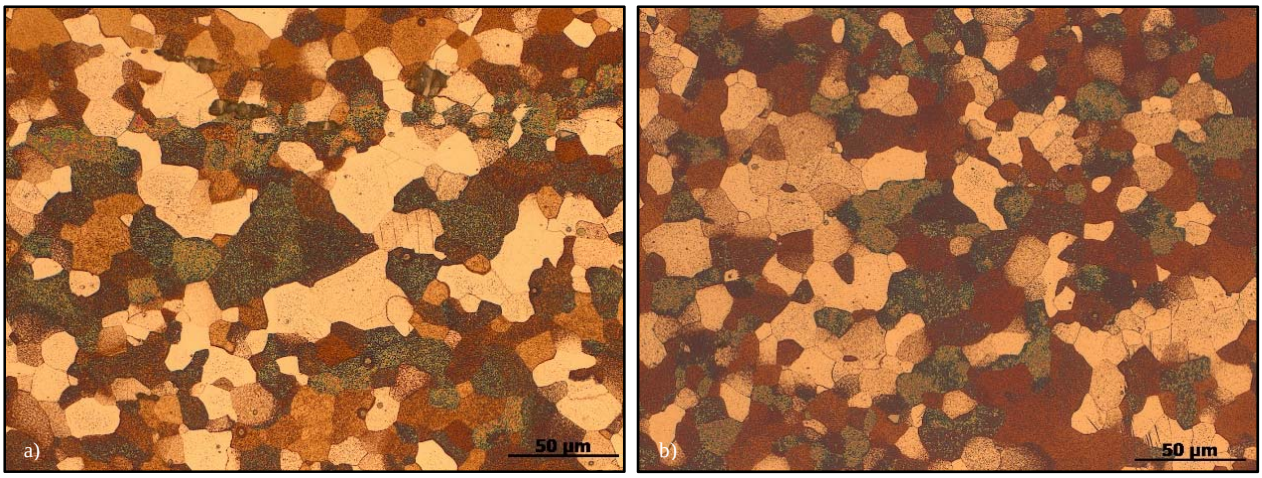


Figure 2. Overnight oxidation in air. Bright field images @ 500x. a).13234-195-45-4L b). 13234-195-45-4T.

General Microstructure

The microstructure observed in all ten samples is typical of wrought DU with recrystallized grains which appeared uniform, randomly oriented, and equiaxed in all samples. Smaller grains were observed interspersed among the larger grains throughout the sample. There was no noticeable difference in microstructure between any of the ten samples observed regardless of specimen (116 or 195), location (0, 45, or 90), or orientation (transverse or longitudinal) (see Fig. 3).

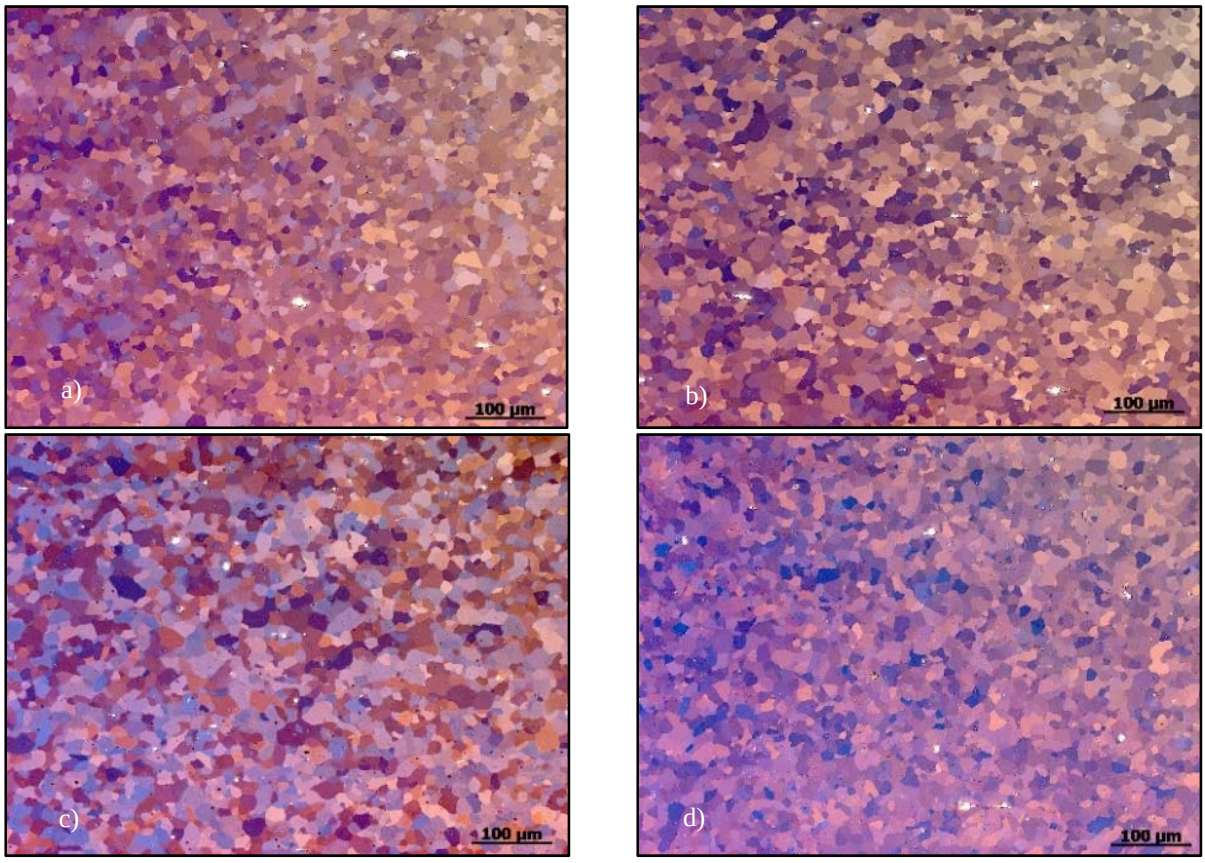


Figure 3. Typical microstructure @ 200x. a) 13234-116-45-1T. b) 13234-116-90-2L.
c) 13234-195-0-3L. d) 13234-195-90-5T. Polarized light images.

Twinning was almost non-existent in the wrought DU samples and was only visible in a few grains in each of the samples at magnifications greater than 200x. The twinning is difficult to see in the polarized light images but is more visible in the three samples, 13234-195-0-3T, 13234-195-45-4L, and 13234-195-45-4T, which had oxidized overnight and were micrographed with bright field (see Fig. 4).

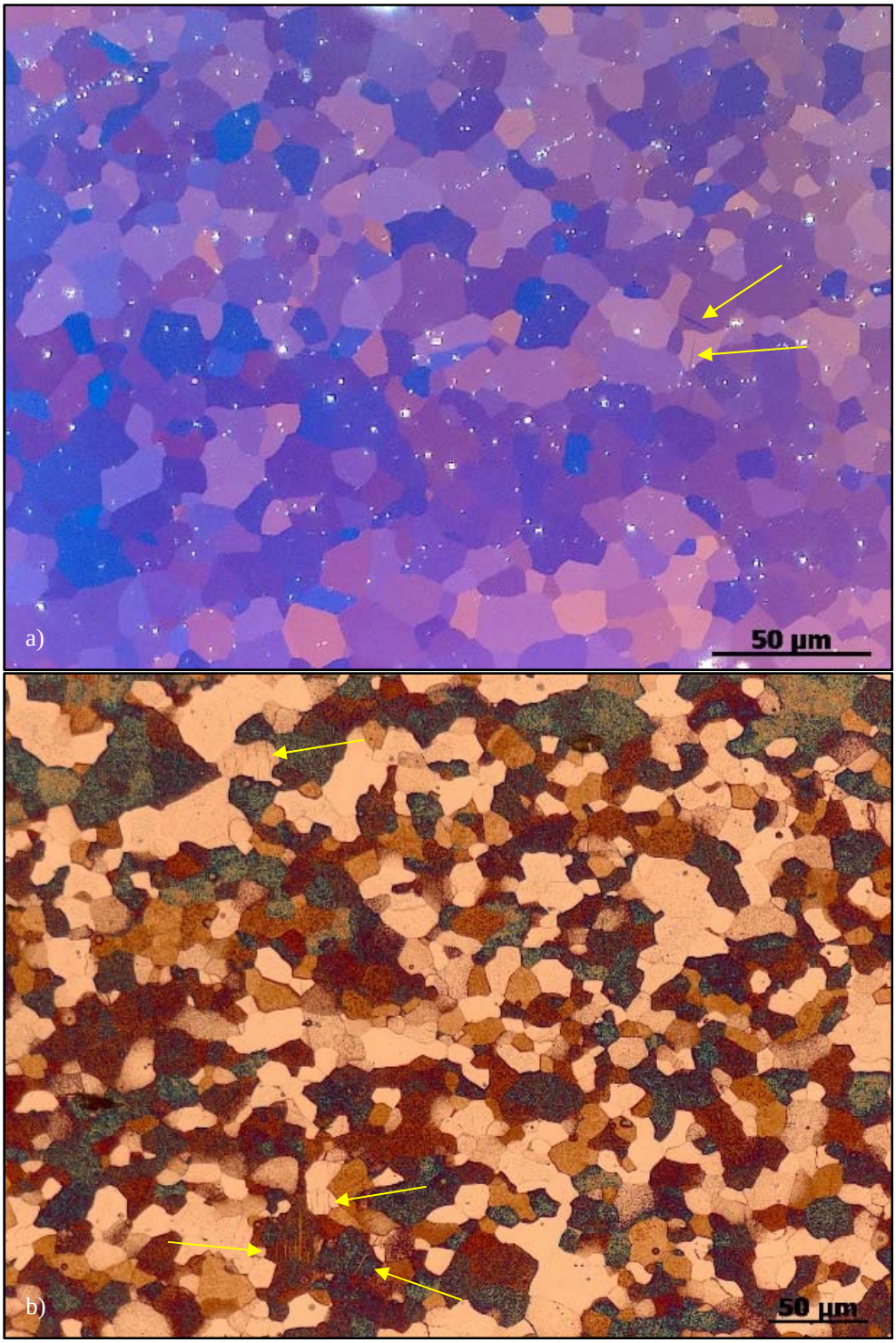


Figure 4. Typical twinning observed. Yellow arrows indicate areas with twinning.
a) 13234-195-90-5T @ 500x. Polarized light. b) 13234-195-45-4L @ 500x. Bright field.

When comparing grain size and shape between the wrought DU samples and the cast DU samples previously characterized, the difference becomes readily apparent with the cast DU having much larger, irregularly shaped grains and more twinning, Grains and twinning in the cast DU samples are easily observed at very low magnification (25x) (see Fig. 5).

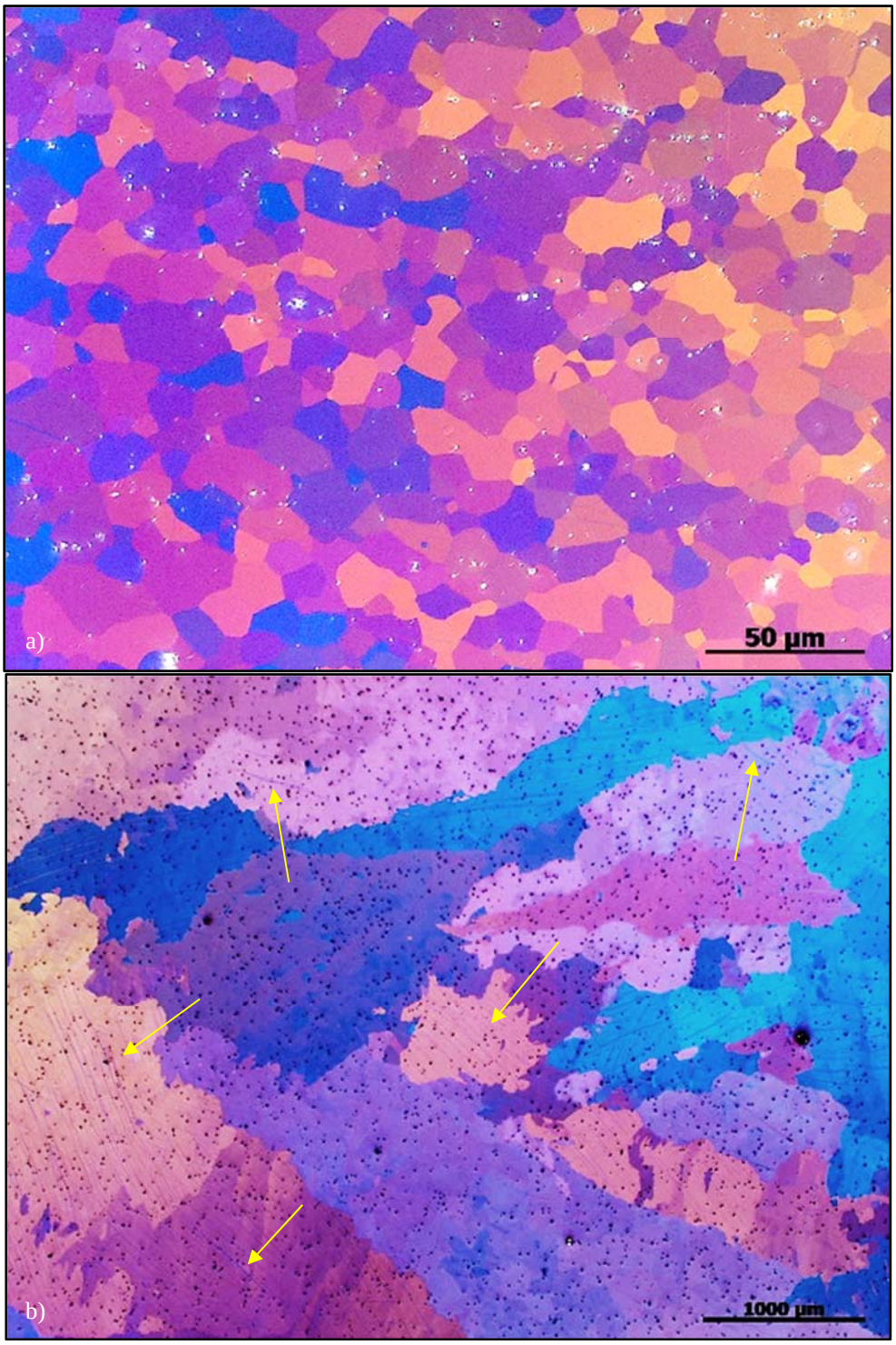


Figure 5. Grain size and shape comparison between wrought DU (top) and cast DU (bottom). Twinning is much more prevalent in the cast DU (Yellow arrows). Note the difference in scales. a) Wrought DU 13234-116-45-1L @ 500x. Polarized light. b) Cast DU 13052-2 @ 25x. Polarized light.

Inclusion Analysis

Numerous inclusions were observed in all wrought DU samples. The samples were prepared for imaging on a scanning electron microscope (SEM) using the preparation steps listed above. To prevent erosion of the inclusions which could affect the inclusion analysis results, the samples were not electropolished prior to taking SEM images.

In general, the inclusions were broken and cracked. Some of the broken fragments were removed during the grinding and polishing steps associated with sample preparation. Many of the inclusions were elongated and inclusion stringers were common (see Fig. 8).

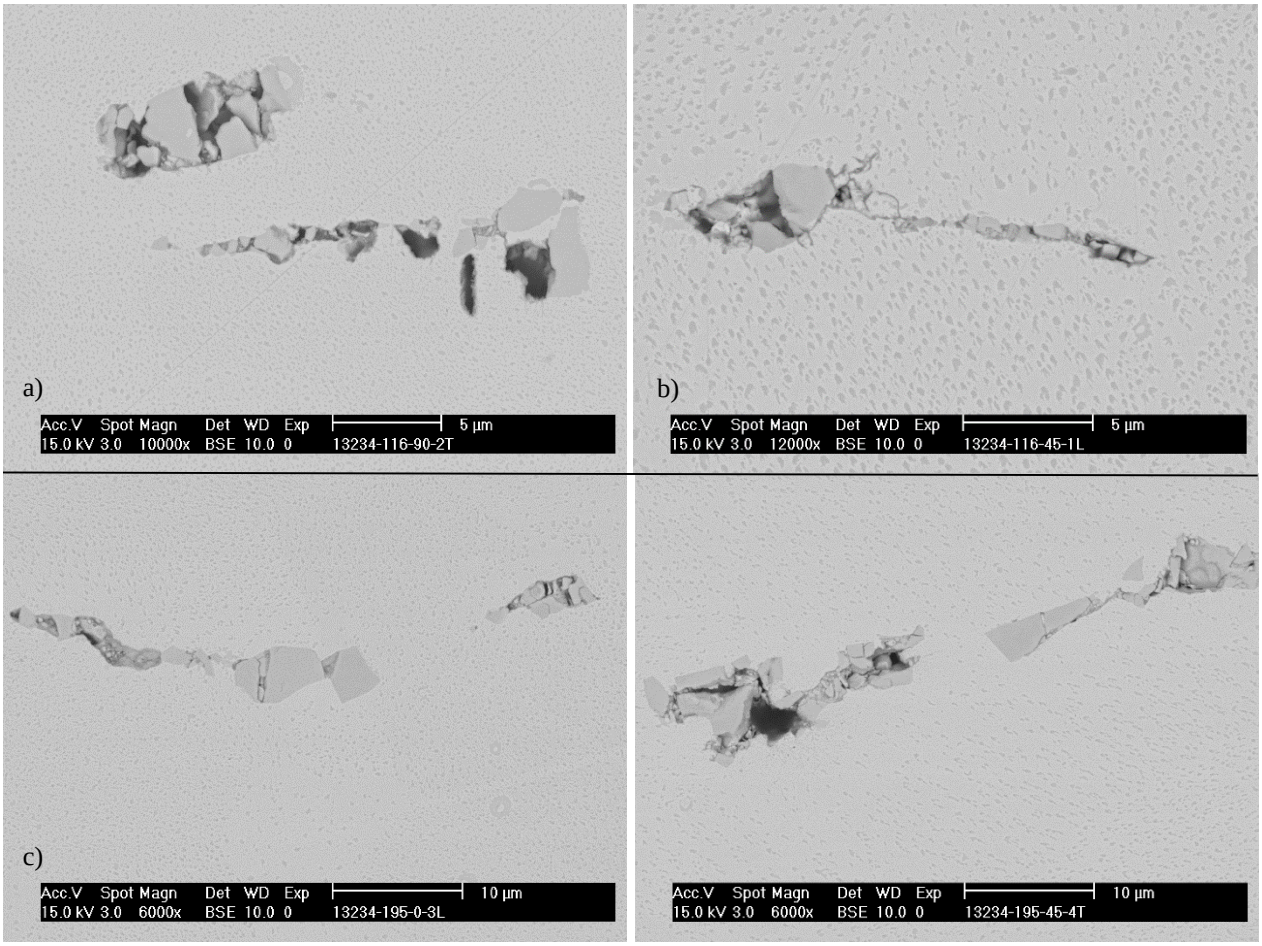


Figure 8. Typical elongated and cracked inclusions. Note the different scales in the micrographs.
a) 13234-116-90-2T. b) 13234-116-45-1L. c) 13234-195-0-3L. d) 13234-195-45-4T.

Additionally, some inclusions appeared to have a darker second phase and possibly a lighter third phase (see Fig. 9). Very dark inclusions were observed in some of the samples from the 195 specimen (See Fig. 10). Further analysis using Electron Probe Microanalysis (EPMA) or Transmission Electron Microscopy (TEM) would be needed to determine the elemental composition of the darker and lighter colored phases.

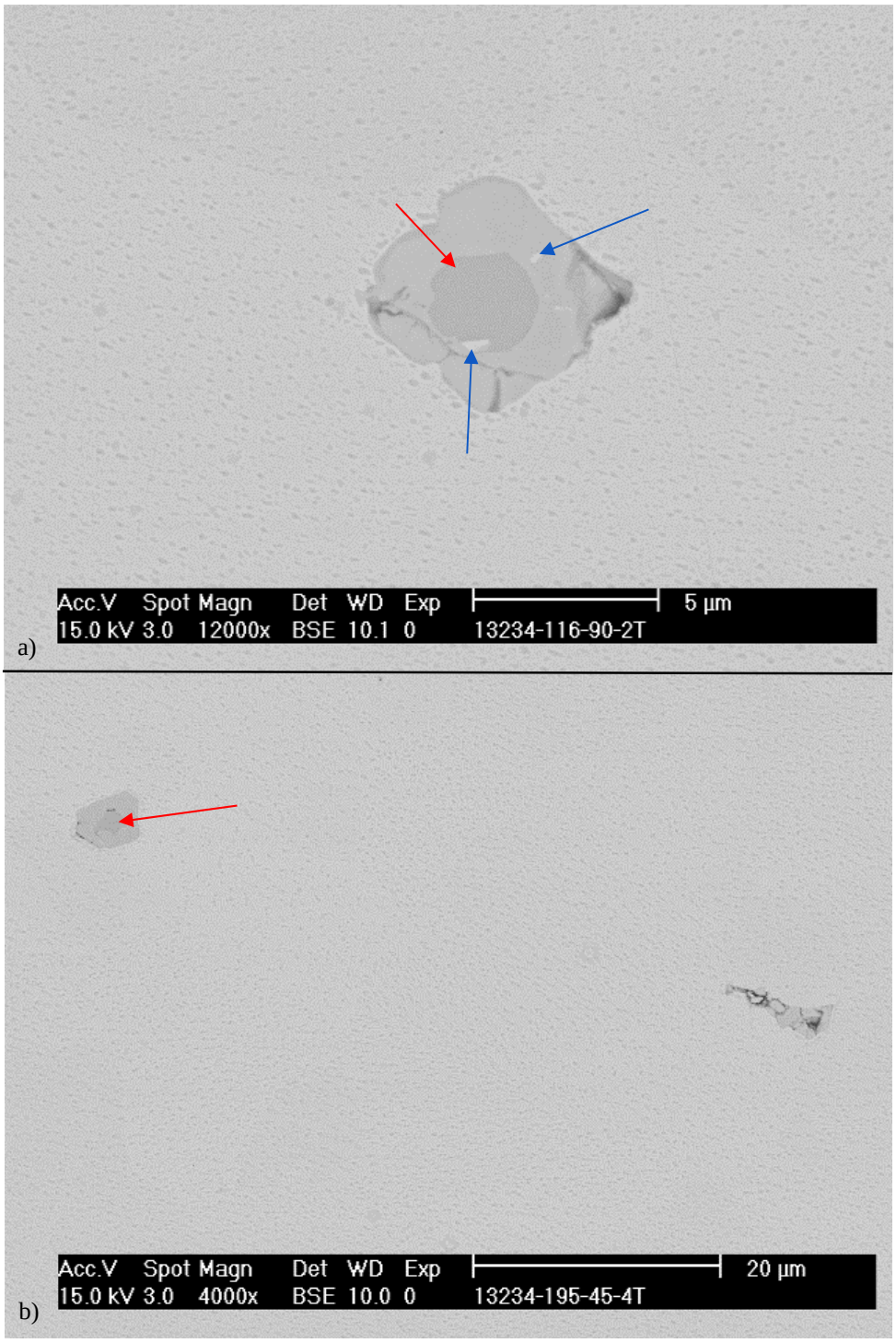


Figure 9. Darker second phase (red arrows) and lighter third phase (blue arrows) observed in some inclusions. a) 13234-116-90-2T. b) 13234-195-45-4T.

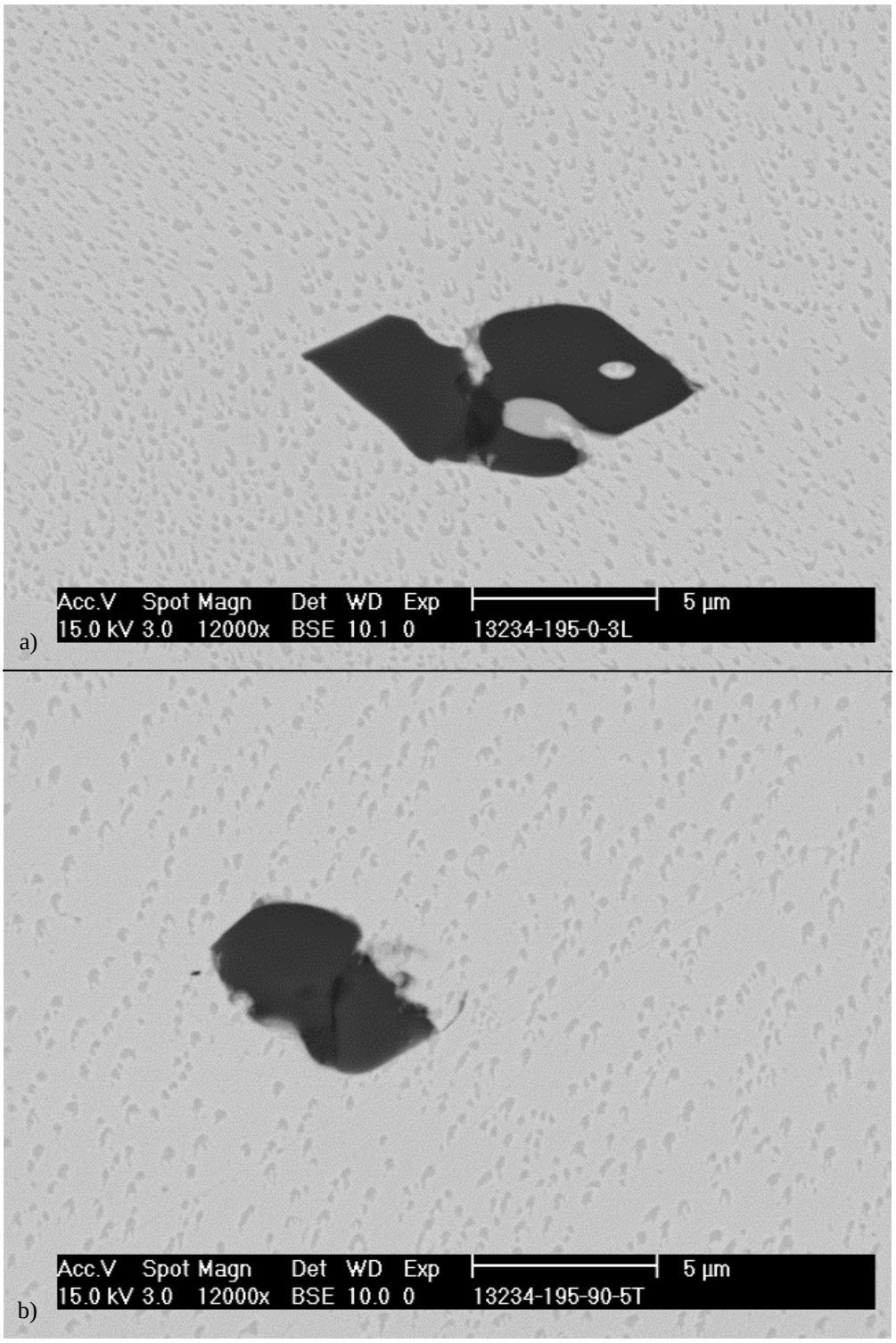


Figure 10. Darker inclusions observed in some samples from the 195 specimen.
a) 13234-195-0-3L. b) 13234-195-90-5T.

The typical inclusions in the cast DU samples previously characterized under metallography number 13052 are slightly larger, more densely packed within a given area, and more equal in their dimensions when compared with the typical inclusions of the wrought DU (See Fig. 11). Light and dark phases also observed in some inclusions.

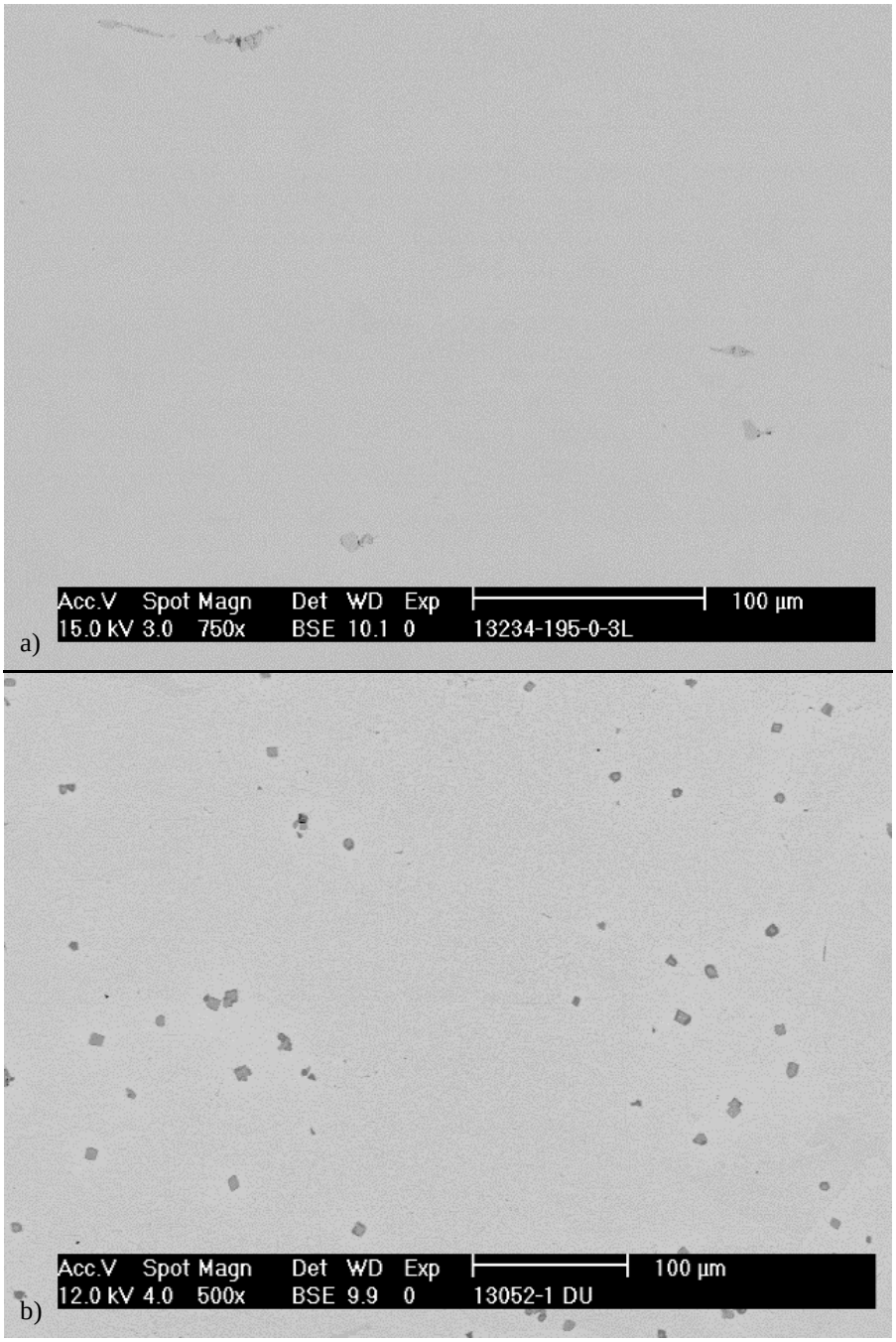


Figure 11. Comparison between inclusions in wrought DU (a) and cast DU (b).

Analysis of the inclusions in the wrought DU samples consisted of taking 750x SEM micrographs from seven random locations (fields) across each sample. The micrographs were taken with the backscatter detector to maximize the contrast between the inclusion and parent material. Each SEM micrograph was converted to a black and white, binary image using Image J. Using the binary images created with Image J, a Clemex analysis routine was created and the inclusions were assigned to the red bit plane (see Fig. 12). To exclude the SEM data box, the area of the measurement field was specified within the Clemex routine to include only the area located within the pink box (See Fig. 12c).

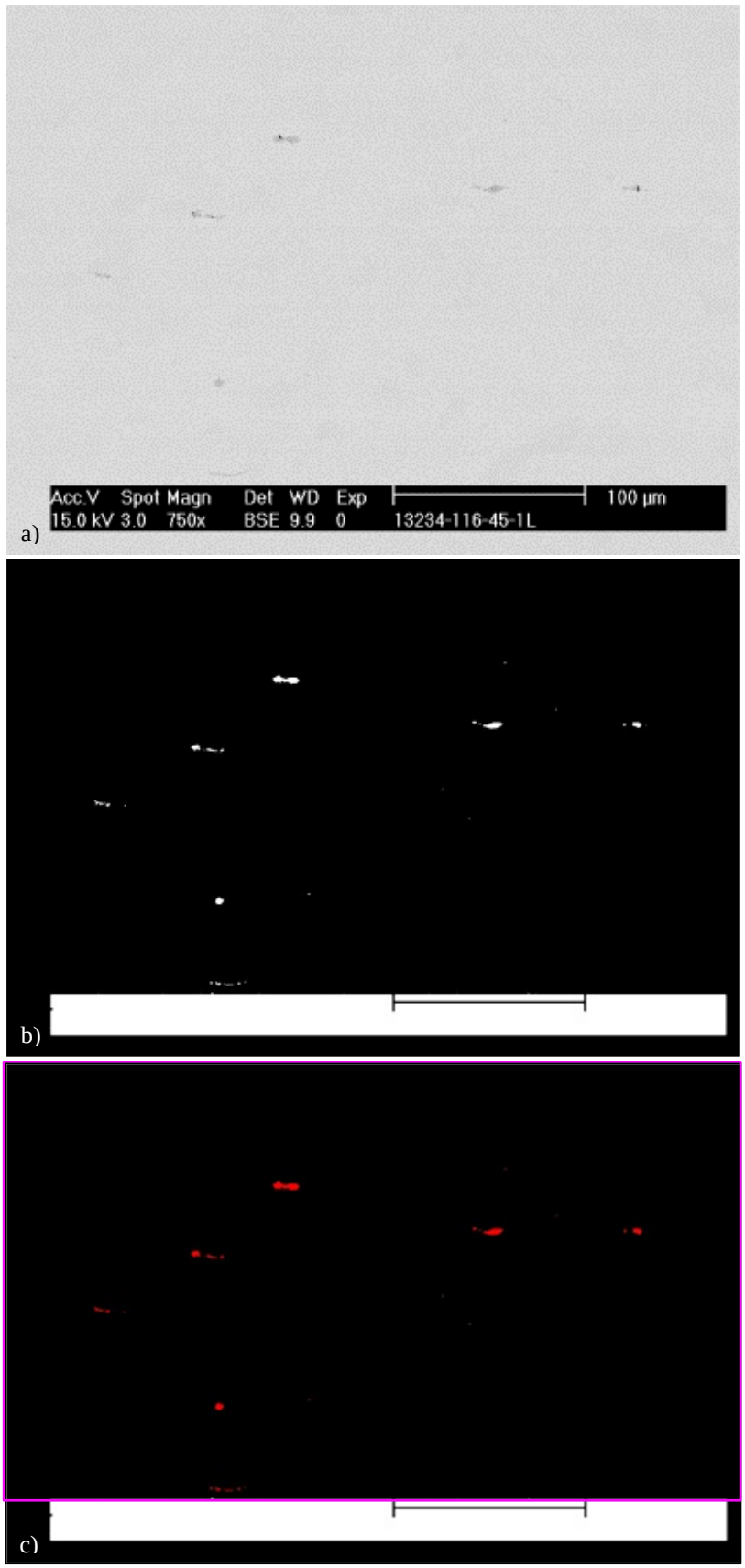


Figure 12. a) SEM image. b) Image J binary image. c) Clemex analyzed image.

During analysis, the Clemex software generates field and object measurements. Field measurements combine all of the objects within a field and take one overall measurement for each field. Each field was analyzed for total inclusion area, average inclusion area, and area percentage of inclusions. The analyzed data was plotted to compare the field data between all of the wrought DU samples (see Figs. 13, 14, and 15). (See Appendix A for field measurement data for each of the individual wrought DU samples).

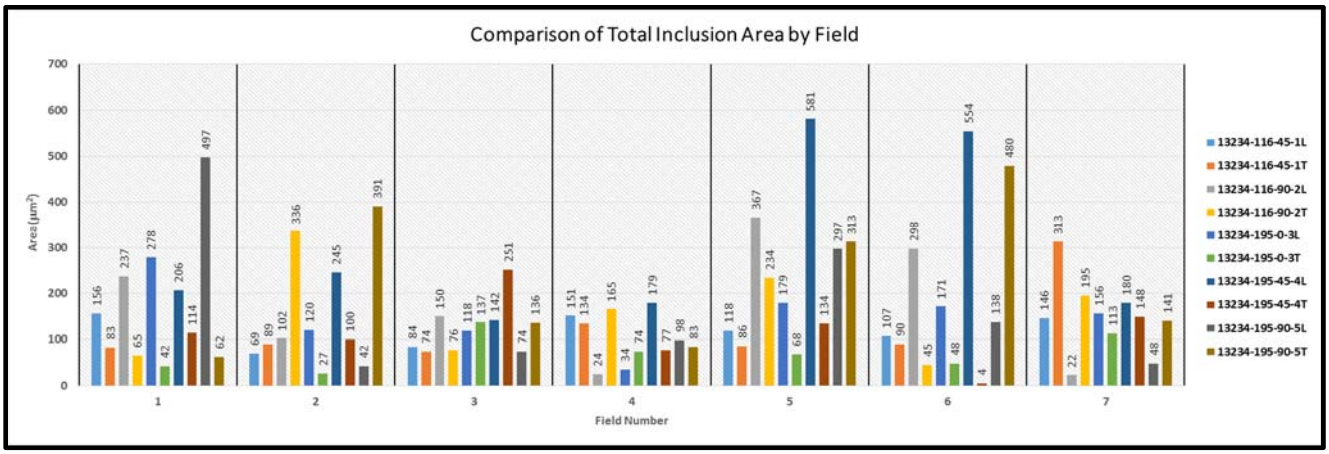


Figure 13. Comparison of total inclusion area between all wrought DU samples.

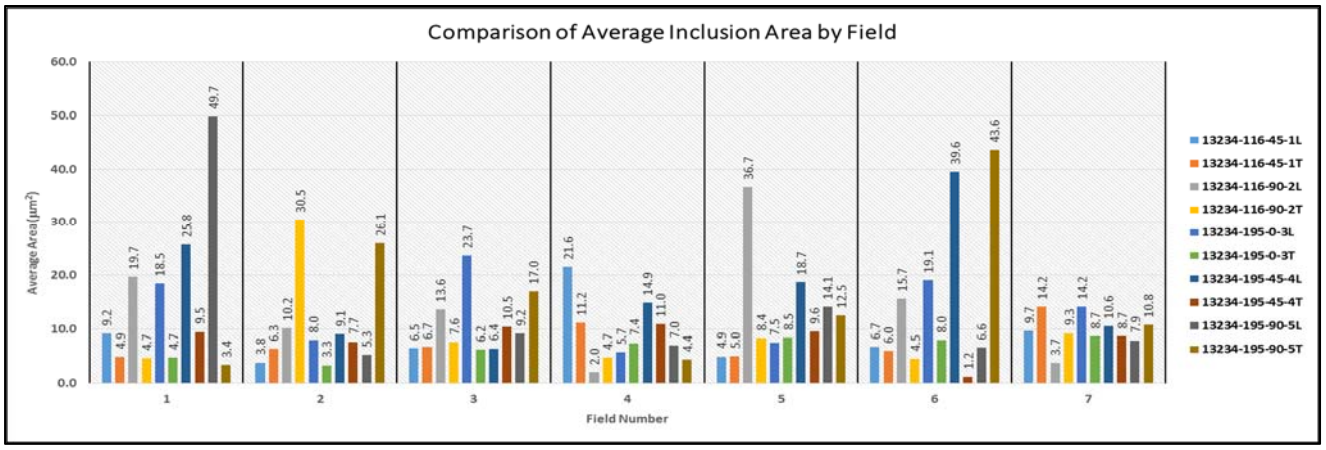


Figure 14. Comparison of average inclusion area between all wrought DU samples.

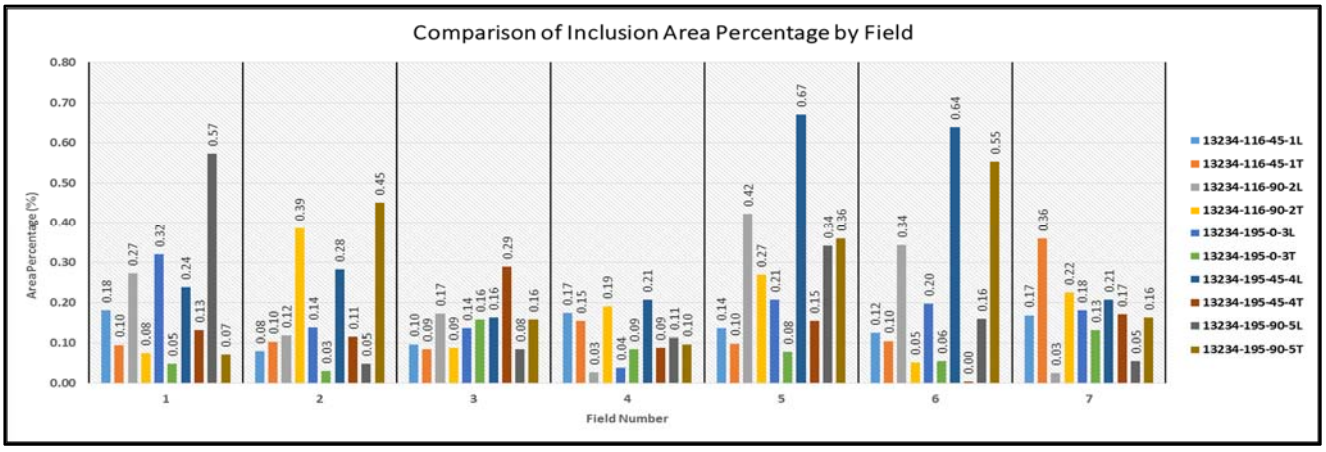


Figure 15. Comparison of inclusion area percentage between all wrought DU samples.

In addition, field measurements for the mean total inclusion area and mean area percentage were plotted for each of the wrought DU samples and the cast DU samples (See Figs. 16 and 17). In mean total inclusion area measurements, the cast DU samples exceeded the measurements of the wrought DU samples on average by a factor greater than 10. Similarly, in mean inclusion area percentage measurements, the cast DU samples exceeded the measurements of the wrought DU samples on average by a factor of 5. Among the wrought DU samples, samples 13234-195-45-4L and 13234-195-90-5T had the highest mean total inclusion areas and mean inclusion area percentages. Among the wrought DU samples, there did not appear to be any correlation between mean inclusion area, or mean inclusion area percentage, with regard to specimen, location, or orientation.

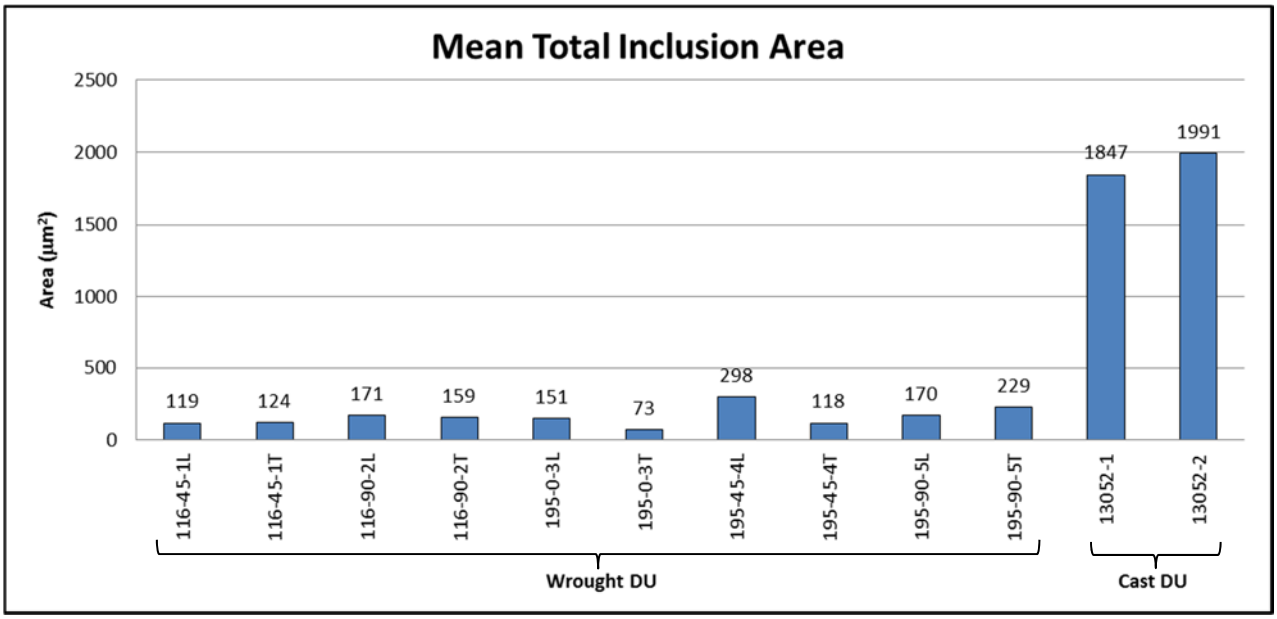


Figure 16. Mean total area of inclusions comparison between wrought DU and cast DU samples.

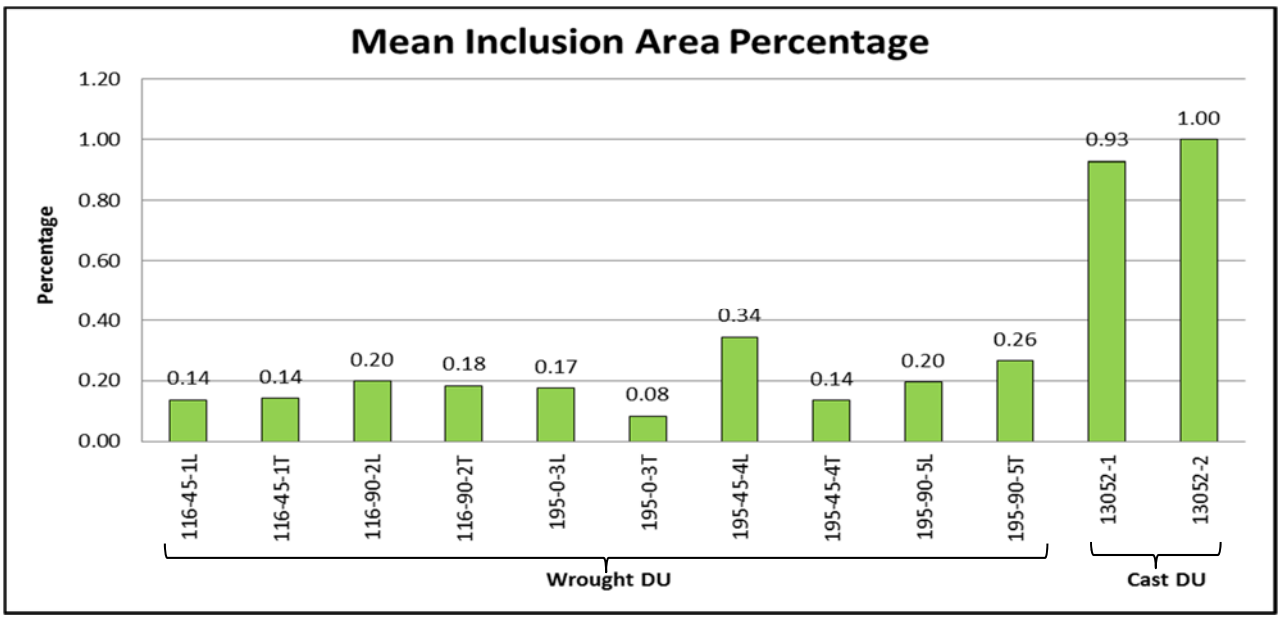
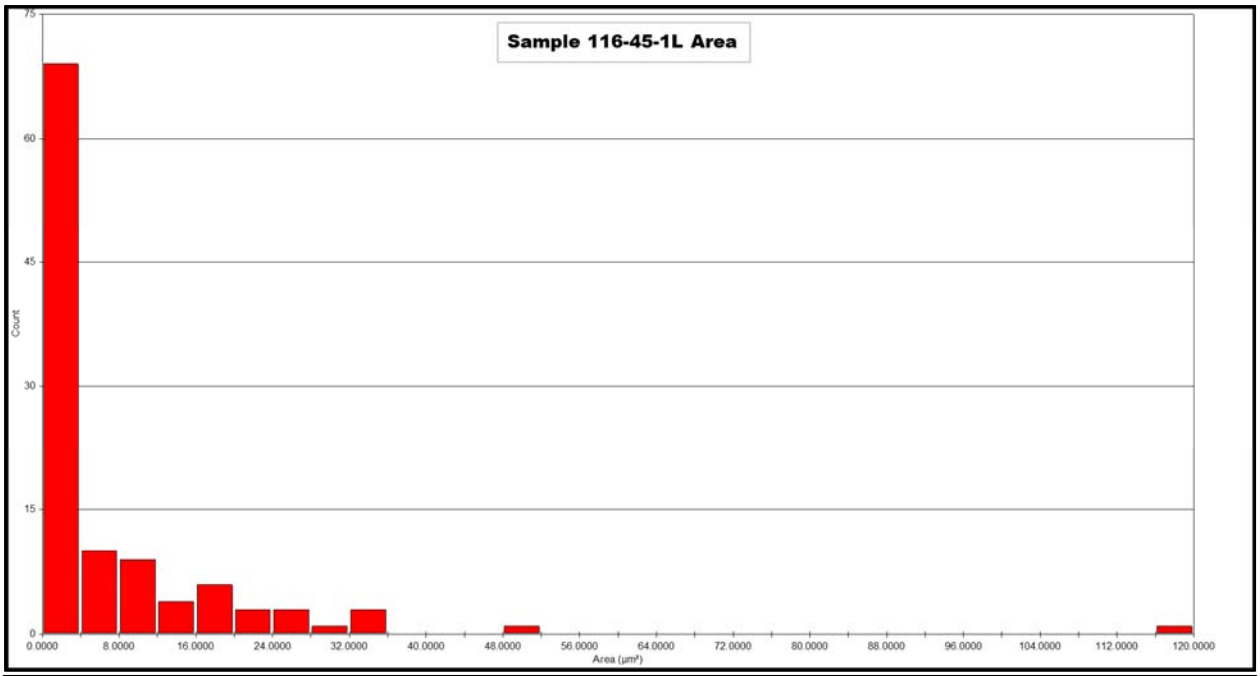


Figure 17. Mean total area percentage of inclusions comparison between wrought DU and cast DU samples.

Object measurements measure each object (inclusions) assigned to a specified bit plane from every field and creates a distribution plot, a table of bin sizes, and a table of statistics. For all samples, the area and circular diameter of each inclusion was measured and plotted (see Fig. 18). (See Appendix B for object measurement data for each of the individual wrought DU samples).



Area (µm²) From	To	Count	%	Cumulative %
0	4	69	63	63
4	8	10	9	72
8	12	9	8	80
12	16	4	4	84
16	20	6	5	89
20	24	3	3	92
24	28	3	3	95
28	32	1	1	95
32	36	3	3	98
36	40	0	0	98
40	44	0	0	98
44	48	0	0	98
48	52	1	1	99
52	56	0	0	99
56	60	0	0	99
60	64	0	0	99
64	68	0	0	99
68	72	0	0	99
72	76	0	0	99
76	80	0	0	99
80	84	0	0	99
84	88	0	0	99
88	92	0	0	99
92	96	0	0	99
96	100	0	0	99
100	104	0	0	99
104	108	0	0	99
108	112	0	0	99
112	116	0	0	99
116	120	1	1	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	119.31 µm²
Mean:	7.56 µm²
Std Dev.:	14.34 µm²
Sum:	831.67 µm²
Count:	110
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Figure 18. Example of object measurement data for 13234-116-45-1L.

The inclusion density throughout the samples was calculated by I_t/A_t, where:
I_t = total number of inclusions counted for all 7 fields
A_t = total field area in cm^2 (area inside pink box times 7 fields)

Using the equation above, the inclusion density was calculated for each of the wrought DU samples and the results were compared with the density calculations for the cast DU samples (See Table 4).

	Sample ID	Total Inclusion Count	Field Area (μm^2)	Total Field Area (μm^2)	Total Field Area (cm^2)	Density ($1/cm^2$)
Wrought DU	13234-116-45-1L	110	86691.344	606839.41	0.0061	1.81E+04
	13234-116-45-1T	108	86691.344	606839.41	0.0061	1.78E+04
	13234-116-90-2L	80	86691.344	606839.41	0.0061	1.32E+04
	13234-116-90-2T	129	86691.344	606839.41	0.0061	2.13E+04
	13234-195-0-3L	85	86691.344	606839.41	0.0061	1.40E+04
	13234-195-0-3T	76	86691.344	606839.41	0.0061	1.25E+04
	13234-195-45-4L	131	86691.344	606839.41	0.0061	2.16E+04
	13234-195-45-4T	90	86691.344	606839.41	0.0061	1.48E+04
	13234-195-90-5L	88	86691.344	606839.41	0.0061	1.45E+04
	13234-195-90-5T	88	86691.344	606839.41	0.0061	1.45E+04
Cast DU	13052-1	385	199071	1393503.8	0.0139	2.77E+04
	13052-2	402	199071	1393503.8	0.0139	2.89E+04

Table 4. Density comparison between wrought and cast DU samples.

Grain Size Analysis

Grains were best observed using polarized light after electropolishing the samples.
For each sample, a series of five micrographs were taken with polarized light at 500x magnification from random locations across each sample. Using Zeiss AxioVision software, a combined chord pattern was overlaid across each micrograph and the intersections between the chords and the grain boundaries were manually marked (see Fig. 19). (See Appendix C for Axiovison grain size data generated for each of the wrought DU samples).

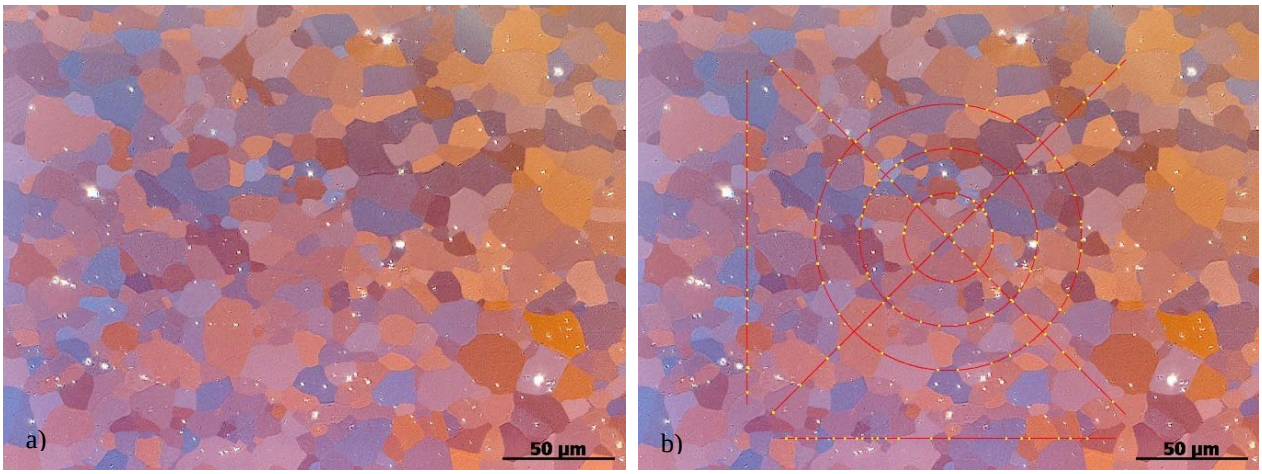


Figure 19. a) Original 500x polarized light micrograph. b) Image with red combined chord overlay. Yellow dots indicate grain boundary intersections.

The Zeiss AxioVision software calculates an ASTM E 112 grain size number (G) for each image and then calculates a mean grain size number for the entire sample (See Table 5). It is important to note that as the grain size number increases, the actual grain size decreases.

ASTM E 112 Grain Size Number						
Sample ID	Image 1	Image 2	Image 3	Image 4	Image 5	Mean Grain Size Number
13234-116-45-1L	10.0	10.0	10.0	9.5	10.0	9.9
13234-116-45-1T	10.5	10.0	10.0	10.0	10.0	10.1
13234-116-90-2L	10.0	10.0	9.5	9.5	10.0	9.8
13234-116-90-2T	10.0	10.0	10.0	10.0	9.5	9.9
13234-195-0-3L	9.5	9.5	9.5	9.5	9.5	9.5
13234-195-0-3T	10.0	10.0	10.0	9.5	9.5	9.8
13234-195-45-4L	10.0	9.5	10.0	10.0	10.0	9.9
13234-195-45-4T	10.0	9.5	10.0	10.5	9.5	9.9
13234-195-90-5L	10.0	9.5	10.0	10.0	9.5	9.8
13234-195-90-5T	10.0	10.0	10.0	10.0	10.0	10.0

Table 5. Grain size number (G) for each image from each sample and mean grain size number for entire sample.

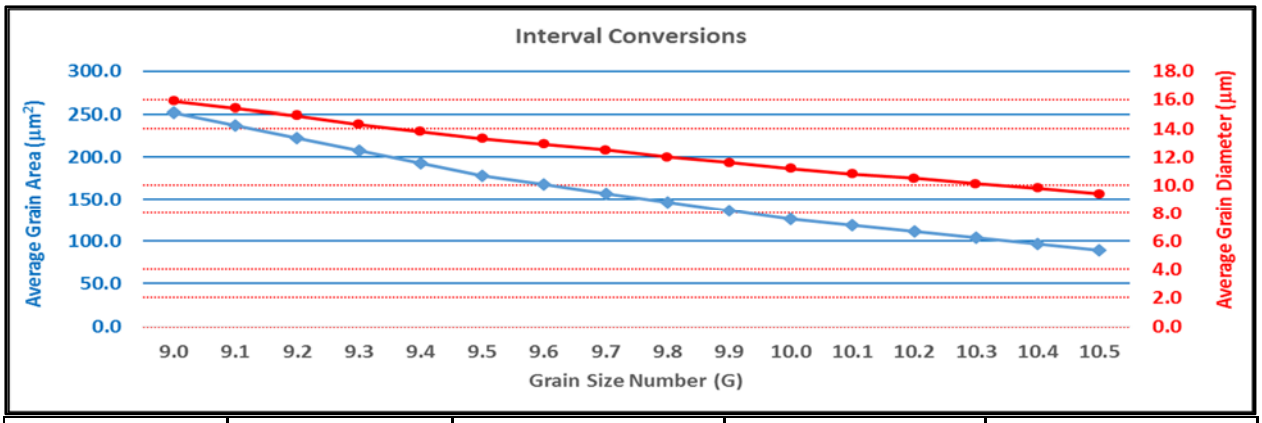
Because the grains are uniform, randomly oriented, and equiaxed, Table 4 in ASTM E112-13 [1] was used to convert the mean grain size number (G) to an approximate average grain area and an approximate grain diameter. Because Table 4 of ASTM E112-13 [1] is divided into 0.5 intervals of G and the measured data for the wrought DU samples fell in to 0.1 intervals of G, calculations were made to estimate the approximate average grain area and diameter of each sample.

The 0.1 intervals of G in relation to average grain area and average grain diameter were calculated by $(G_1 - G_2)/5$ intervals, where:

G_1 = the value for average grain area (or average grain diameter) for a given value of G, as listed in Table 4 of ASTM E112-13 [1]
G_2 = the value for average grain area (or average grain diameter) for the next higher given value of G, as listed in Table 4 of ASTM E112-13 [1]

Example: (252 μm^2 - 178 μm^2)/5 intervals = 14.8 μm^2 per interval, where 252 μm^2 is the average grain area listed in Table 4 of ASTM E 112-96 [1] for grain size number (G) 9.0 and 178 μm^2 is the average grain area listed in Table 4 of ASTM E112-13 [1] for grain size number (G) 9.5.

Furthermore, since the conversion scale is not linear, the formula above was applied to each pair of values for G listed in Table 4 of ASTM E112-13 [1] to determine the appropriate interval value to be applied to the given values for average grain area and average grain diameter for each 0.1 increment of G (See Table 6).



Grain Size Number (G)	Calculated Average Grain Area per Table 4, ASTM E112-13 [1] (μm^2)	Calculated Intervals for average grain area between values of G (μm^2) $(G_1 - G_2)/5$ Intervals	Calculated Average Grain Diameter per Table 4, ASTM E112-13 [1] (μm)	Calculated Intervals for average grain diameter between values of G (μm) $(G_1 - G_2)/5$ Intervals
9.0	**252.0**	14.8	**15.9**	0.52
9.1	237.2	14.8	15.4	0.52
9.2	222.4	14.8	14.9	0.52
9.3	207.6	14.8	14.3	0.52
9.4	192.8	14.8	13.8	0.52
9.5	**178.0**	10.4	**13.3**	0.42
9.6	167.6	10.4	12.9	0.42
9.7	157.2	10.4	12.5	0.42
9.8	146.8	10.4	12.0	0.42
9.9	136.4	10.4	11.6	0.42
10.0	**126.0**	7.38	**11.2**	0.36
10.1	118.6	7.38	10.8	0.36
10.2	111.2	7.38	10.5	0.36
10.3	103.9	7.38	10.1	0.36
10.4	96.5	7.38	9.8	0.36
10.5	**89.1**		**9.4**	
Note: Bold values indicate values taken directly from ASTM E112-13, Table 4 [1]				

Table 6. Calculated values for average grain area and average diameter for 0.1 intervals of G.

Using Table 6, the calculated values for average grain area and average grain diameter were then plotted for each sample (See Fig. 20).

Grain size was fairly uniform between all of the wrought DU samples with an average grain area ranging from 119 μm^2 to 178 μm^2 with 7 of the 10 samples ranging from ~ 136 μm^2 to ~147 μm^2. The average grain diameter ranging from 10.8 µm to 13.3 µm. By contrast, the cast DU samples previously characterized had approximate mean grain areas of 2 mm^2 and 1.37 mm^2 for samples 13052-1 and 13052-2, respectively. Because some area was cut off of the very large grains in the cast DU samples by the edge of the micrograph frame, the grain area is listed as approximate.

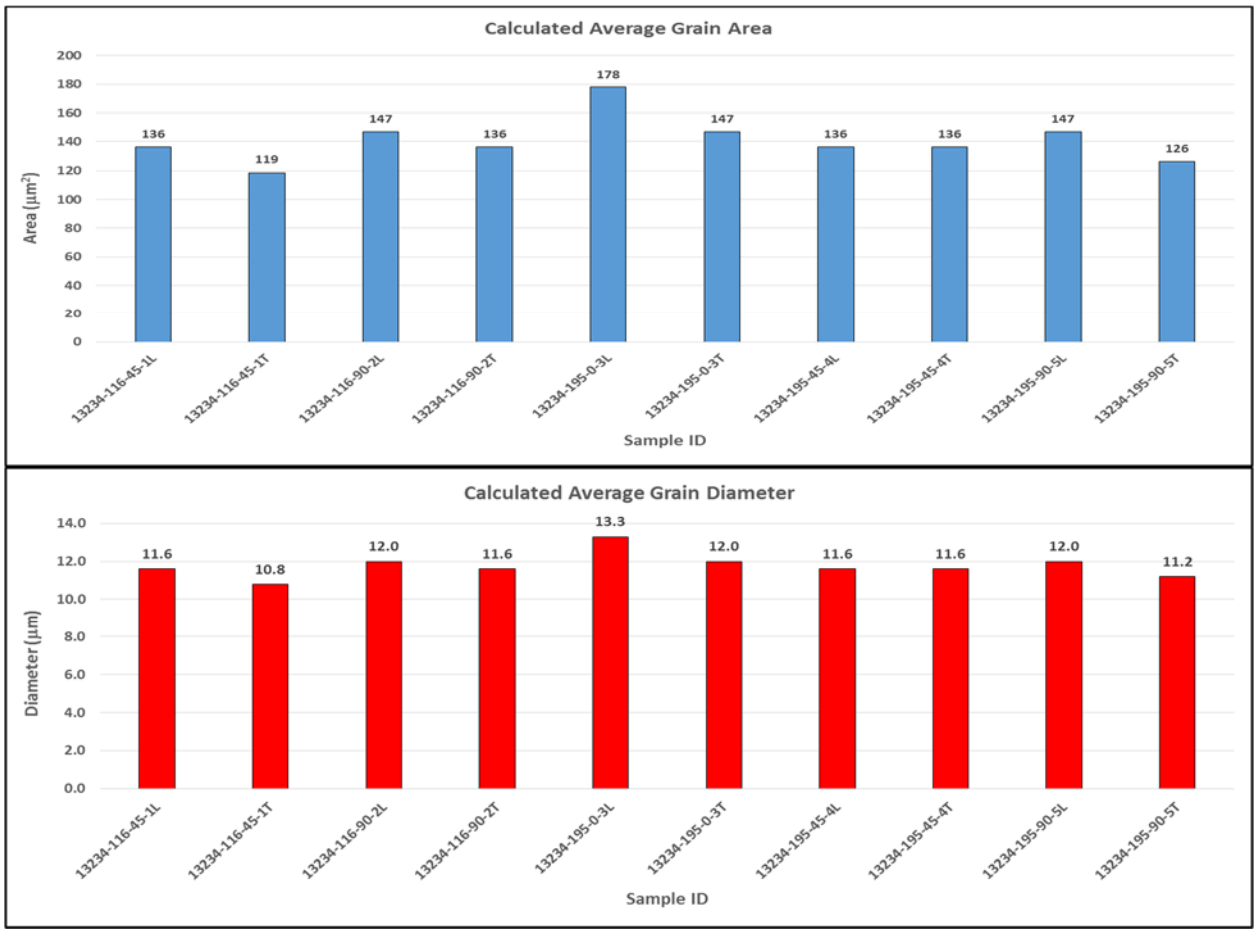
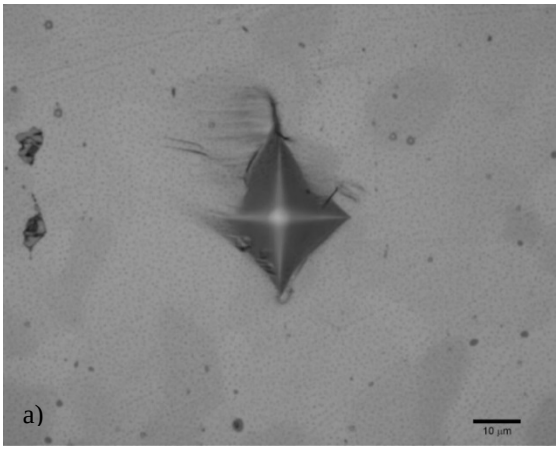


Figure 20. Comparison of values for average grain area and diameter in wrought DU samples.

Microhardness Testing

Prior to testing, the samples were ground and mechanically polished as described above in Sample Preparation. All testing was performed on a Struers Durascan 70 microhardness tester. Vickers microhardness testing was attempted on several samples with poor results. Many indents were misshapen and difficult or impossible to measure. A series of tests were performed on test blocks to verify tester performance and all tests passed indicating that the misshapen indents were related to DU material properties, not the test equipment.

Using ASTM E384 [2] as a guide, Knoop microhardness was performed instead of Vickers. Samples were reprepared as described above in Sample Preparation and a series of 20 test points were automatically and uniformly distributed along the length of each sample with the long axis of the Knoop indentation in the direction of the through-thickness. The test load applied was 100 gram force (gf) with a 12 second dwell time. Prior to testing, each test point location was checked to ensure that indentations would not be placed on an inclusion or other surface irregularity. After testing, the indents were slightly misshaped. However, the length of the indent, which is used to determine Knoop hardness values, was not compromised (See Fig. 21). The Knoop indents ranged from 72 µm to 93 µm in length and covered seven to nine grains.



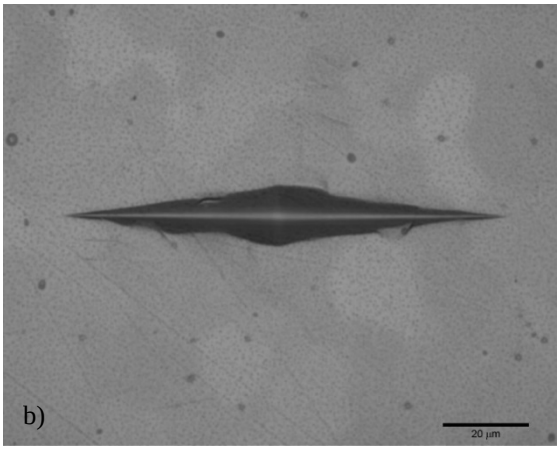
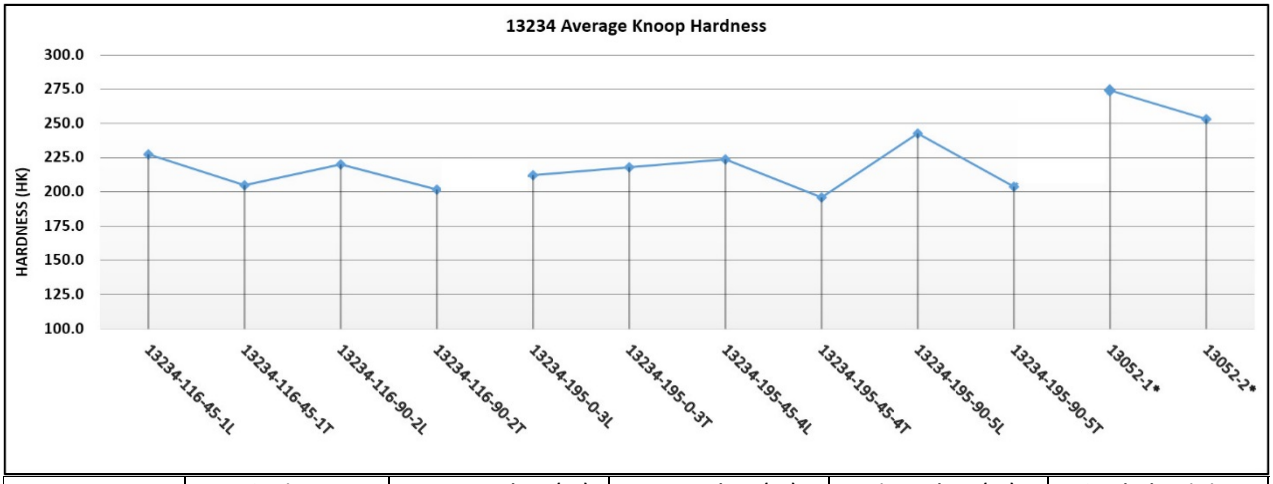


Figure 21. a) Example of misshaped Vickers indent. b) Typical Knoop indent

The indents were auto-measured by the equipment software and corrected by the operator as needed. Hardness data was exported to an Excel spreadsheet where it was plotted. The data points were averaged for each sample to obtain an overall hardness value and the overall hardness value was plotted (See Table 7). (See Appendix D for microhardness data generated for each of the wrought DU samples).



	Specimen	Average Hardness (HK)	Max. Hardness (HK)	Min. Hardness (HK)	Standard Deviation
116 Specimen Wrought DU	13234-116-45-1L	227.2	260	210	15.5
	13234-116-45-1T	204.6	235	173	20.3
	13234-116-90-2L	220.2	257	195	18.8
	13234-116-90-2T	201.8	239	157	21.7
195 Specimen Wrought DU	13234-195-0-3L	211.9	253	176	22.9
	13234-195-0-3T	217.9	265	155	27.7
	13234-195-45-4L	223.8	265	184	24.1
	13234-195-45-4T	196.0	235	164	16.5
	13234-195-90-5L	242.6	297	209	23.1
	13234-195-90-5T	203.8	236	173	21.1
13052 Specimens Cast DU	13052-1*	274.0	308	244	20.9
	13052-2*	253.0	309	184	44.3
	* Values converted from Vickers (HV) to Knoop (HK) using ASTM E140 [3] standard hardness conversion tables. Values are approximate.				

Table 7. Average Knoop Hardness Values

For the wrought DU samples, average hardness ranged from 196 HK for sample 13234-195-45-4T to 243 HK for sample 13234-195-90-5L. These values were consistent with hardness data from similar wrought DU samples reported by R.J. McCabe and D.F. Teter [4]. (Note: The McCabe/Teter hardness data was reported as Vickers hardness. The Vickers hardness values were converted to Knoop using ASTM E140 [3] standard hardness conversion tables).

The average hardness for the transversely oriented samples was lower than the average microhardness from the longitudinally oriented samples from the same location and specimen. The difference in average microhardness between the transverse and longitudinal orientations of specimen 116 ranged from 18 HK to 22 HK for locations 90 and 45, respectively. The difference in average microhardness between the transverse and longitudinal orientations of specimen 195 ranged from 28 HK to 39 HK for locations 45 and 90, respectively. The one exception was sample 13234-195-0 with only a 6 HK difference in average microhardness between the transverse sample and the longitudinal sample where the average hardness of the transverse sample was slightly higher than the average hardness of the longitudinal sample (See Table 7).

Vickers microhardness was performed on the previously analyzed cast DU samples (13052-1 and 13052-2). Using ASTM E140 [3] standard hardness conversion tables, the Vickers (HV) values were converted to Knoop (HK) values. The converted data was plotted and compared to the data from the wrought DU samples (See Table 7).

There was a 21 HK difference between the two cast DU samples. When compared with the wrought DU samples, the cast DU samples 13052-1 and 13052-1 were harder by approximately 31 HK and 10 HK, respectively, above the wrought DU sample 13234-195-90-5L which had the highest average hardness of ~243 HK.

Summary

In summary, the samples tested were wrought depleted uranium with similar microstructure observed between all samples regardless of location and orientation (See Table 8). Recrystallized grains which appeared uniform, randomly oriented, and equiaxed were observed in all ten samples. Very little twinning was observed and only within a few grains in each sample. Twinning could only be observed at magnifications greater than 200x. This was a sharp contrast to the microstructure of the cast DU samples (Metallography Number 13052) which had been characterized previously. The cast DU samples had very large and irregularly shaped grains with significant twinning observed in most of the grains. Furthermore, the twinning and grain size could be observed at very low magnification (~25x).

Inclusions in all of the wrought DU samples were broken, cracked, and elongated. Some inclusions appeared to have a darker second phase and possibly a lighter third phase. Microprobe analysis or TEM analysis would be needed to determine the elemental composition of the different phases. Very dark inclusions were observed in some of the samples from the 195 specimen. In contrast to the inclusions observed in the wrought DU samples, inclusions in the cast DU samples previously characterized were slightly larger, more densely packed within a given area, and more equal in their dimensions.

Grain size was fairly uniform between all of the wrought DU samples with an average grain area ranging from 119 μm^2 to 178 μm^2 with 70% of the samples ranging from ~ 136 μm^2 to ~147 μm^2. The average grain diameter ranging from 10.8 μm to 13.3 μm. By contrast, the cast DU samples previously characterized had mean grain areas of 2 mm^2 and 1.37 mm^2 for samples 13052-1 and 13052-2, respectively.

While no differences were observed in microstructure, inclusion size, morphology, and distribution, or grain size in regard to specimen, location, or orientation for the wrought depleted uranium samples, a small difference was observed in average hardness with regard to orientation at the same locations within the same specimen. This was true for both wrought DU specimens.

Knoop microhardness was performed on all of the wrought DU samples and average hardness ranged from 196 HK to 243 HK. The average hardness for the transversely oriented samples was lower than the average microhardness from the longitudinally oriented samples from the same location and specimen. The average microhardness for specimen 116 at location 45 was 227 HK for the longitudinal sample and 205 HK for the transverse sample. At location 90 of specimen 116, the average microhardness was 220 HK for the longitudinal sample and 202 HK for the transverse sample. The average microhardness for specimen 195 at location 45 was 224 HK for the longitudinal sample and 196 HK for the transverse sample. At location 90 of specimen 195, the average microhardness was 243 HK for the longitudinal sample and 204 HK for the transverse sample. The one exception was the longitudinal and transverse samples from location 0 of specimen 195 which had an average hardness of 212 HK and 218 HK, respectively.

Vickers microhardness was performed previously on the cast DU samples. Using ASTM E140 [3] standard for hardness conversion tables, the Vickers hardness values were converted to Knoop values. When compared with the wrought DU samples, the cast DU samples were slightly harder.

The average microhardness for sample13052-1was 274 HK and for sample 13052-2, the average microhardness was 253 HK.

Material	Wrought DU										Cast DU	
Specimen	116				195						13052-1	13052-2
Location	45		90		0		45		90			
Orientation	L	T	L	T	L	T	L	T	L	T		
Mean Inclusion Area Percentage (%)*	0.14	0.14	0.20	0.18	0.17	0.08	0.34	0.14	0.20	0.26	0.93	1.00
Average Inclusion Density (1/cm^2)	1.81E+04	1.78E+04	1.32E+04	2.13E+04	1.40E+04	1.25E+04	2.16E+04	1.48E+04	1.45E+04	1.45E+04	2.77E+04	2.89E+04
Mean Grain Size Number (G)	9.9	10.1	9.8	9.9	9.5	9.8	9.9	9.9	9.8	10.0	N/A	N/A
Average Grain Area (µm^2)	136	119	147	136	178	147	136	136	147	126	2.00E+06**	1.37E+06**
Average Grain Diameter (µm)	11.6	10.8	12.0	11.6	13.3	12.0	11.6	11.6	12.0	11.2	N/A	N/A
Average Knoop Microhardness (HK)	227	205	220	202	212	218	224	196	243	204	274***	253***
Average Vickers Microhardness (HV)	211***	189***	204***	186***	196***	202***	208***	180***	230***	188***	262	240
Overall Microstructure	Small recrystallized grains which are uniform, randomly oriented, and equiaxed. Minimal twinning observed in only a few grains.										Very large and irregular shaped grains with extensive twinning throughout the grains.	
Overall Inclusion Morphology, Size and Distribution	Inclusions elongated, broken and cracked. Stringers common. Light and dark phases observed in some inclusions. Mean total inclusion area percentage range: 0.08 - 0.34 %. Average density from all wrought DU samples: 1.62E+04/cm^2.										Inclusions generally equiaxed and intact. No stringers observed. Light and dark phases observed in some inclusions. Mean total inclusion area percentage range: 0.93 - 1.00 %. Average density from both cast DU samples: 2.83E+04/cm^2	
Overall Grain Size	1. Averaged mean grain size number from all wrought DU samples: 9.9 2. Averaged mean grain area from all wrought DU samples: 141 µm^2 3. Averaged mean grain diameter from all wrought DU samples: 11.8 µm										Averaged mean grain area from both cast DU samples: 1.69E+06 µm^2	
Overall Knoop Microhardness	Averaged microhardness from both wrought DU specimens: 215 HK										Averaged microhardness from both cast DU samples: 264 HK	

Table 8. Results Summary. *Representative of volume %. ** Values are approximate due to some grain area cut off by edge of micrograph. *** Values converted between Knoop and Vickers scales using ASTM E140 [3] standard hardness conversion tables.

Acknowledgements

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References

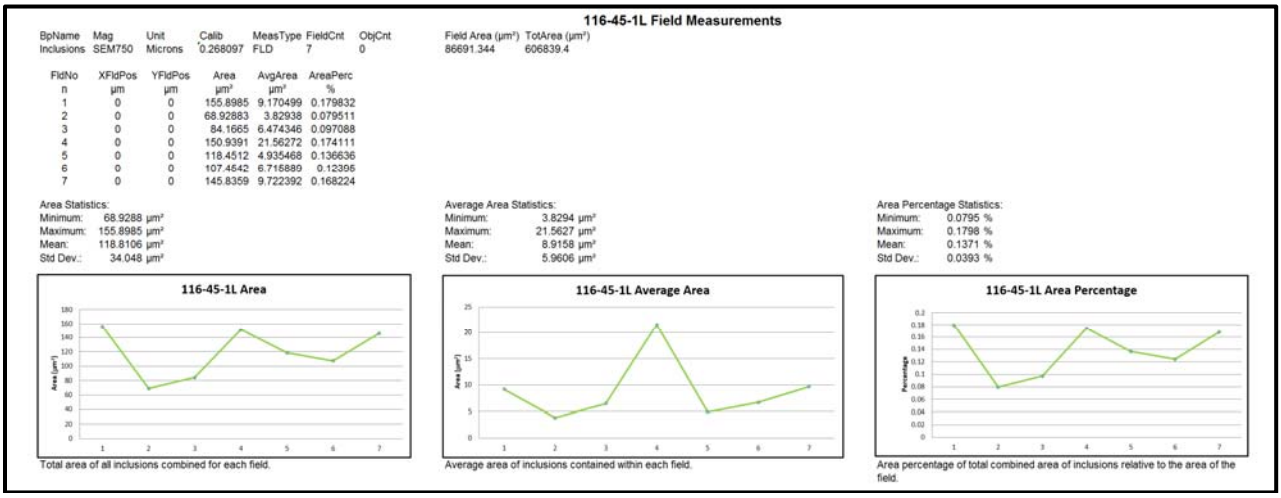
[1] ASTM Standard E112-13, “Standard Test Methods for Determining Grain Size,” ASTM International, West Conshohocken, PA, 2013, DOI:10.1520/E0112-13, www.astm.org.

[2] ASTM Standard E384-17, “Standard Test Method for Microindentation Hardness of Materials,” ASTM International, West Conshohocken, PA, 2017, DOI:10.1520/E0384-17, www.astm.org.

[3] ASTM Standard E140 Rev B, “Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness,” ASTM International, West Conshohocken, PA, 2013, DOI:10.1520/E0140-12B, www.astm.org.

[4] R.J. McCabe and D.F. Teter: Journal of Microscopy Vol. 223 (2006), "Analysis of Recrystallized Volume Fractions in Uranium Using Electron Backscatter Diffraction", p. 38

Appendix A - Inclusion Analysis Field Measurements



116-45-1L Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	155.8985	9.170499	0.179832
2	0	0	68.92883	3.82938	0.079511
3	0	0	84.1665	6.474346	0.097088
4	0	0	150.9391	21.56272	0.174111
5	0	0	118.4512	4.935468	0.136636
6	0	0	107.4542	6.715889	0.12395
7	0	0	145.8359	9.722392	0.168224

Area Statistics:
Minimum: 68.9288 µm²
Maximum: 155.8985 µm²
Mean: 118.8106 µm²
Std Dev.: 34.048 µm²

Average Area Statistics:
Minimum: 3.8294 µm²
Maximum: 21.5627 µm²
Mean: 8.9158 µm²
Std Dev.: 5.9606 µm²

Area Percentage Statistics:
Minimum: 0.0795 %
Maximum: 0.1798 %
Mean: 0.1371 %
Std Dev.: 0.0393 %

116-45-1L Area

Total area of all inclusions combined for each field.

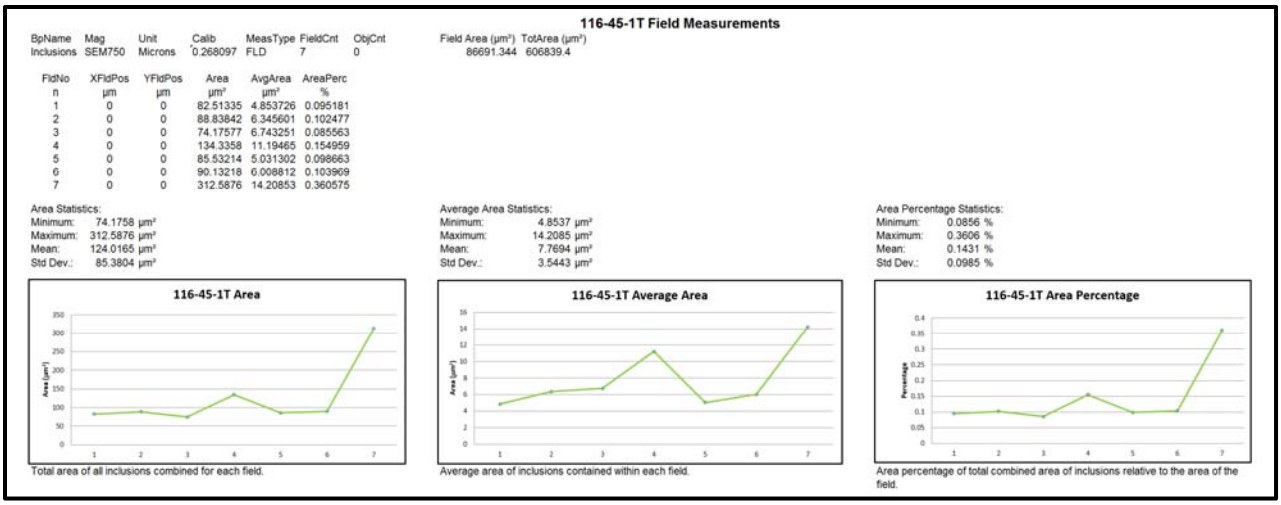
116-45-1L Average Area

Average area of inclusions contained within each field.

116-45-1L Area Percentage

Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-116-45-1L inclusion field measurement data.



116-45-1T Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	82.51335	4.853726	0.095181
2	0	0	88.83842	6.345601	0.102477
3	0	0	74.17577	6.743251	0.085563
4	0	0	134.3358	11.19465	0.154959
5	0	0	85.53214	5.031302	0.098663
6	0	0	90.13218	6.008812	0.103969
7	0	0	312.5876	14.20853	0.360575

Area Statistics:
Minimum: 74.1758 µm²
Maximum: 312.5876 µm²
Mean: 124.0165 µm²
Std Dev.: 85.3804 µm²

Average Area Statistics:
Minimum: 4.8537 µm²
Maximum: 14.2085 µm²
Mean: 7.7694 µm²
Std Dev.: 3.5443 µm²

Area Percentage Statistics:
Minimum: 0.0856 %
Maximum: 0.3606 %
Mean: 0.1431 %
Std Dev.: 0.0985 %

116-45-1T Area

Total area of all inclusions combined for each field.

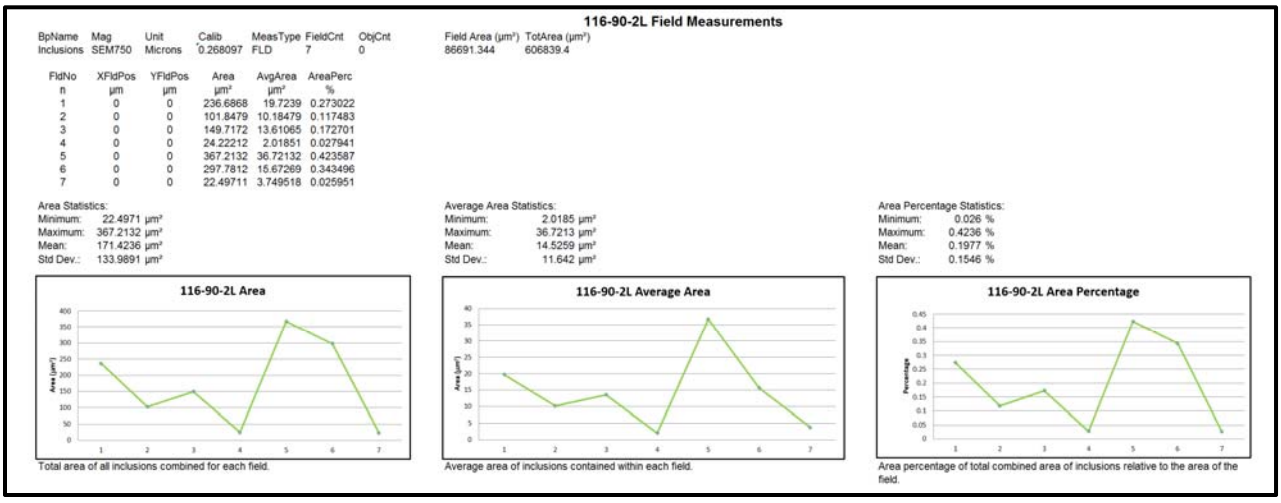
116-45-1T Average Area

Average area of inclusions contained within each field.

116-45-1T Area Percentage

Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-116-45-1T inclusion field measurement data.



116-90-2L Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	236.6868	19.7239	0.273022
2	0	0	101.8479	10.18479	0.117483
3	0	0	149.7172	13.61065	0.172701
4	0	0	24.22212	2.01851	0.027941
5	0	0	367.2132	36.72132	0.423587
6	0	0	297.7812	15.67269	0.343496
7	0	0	22.49711	3.749518	0.025951

Area Statistics:
Minimum: 22.4971 µm²
Maximum: 367.2132 µm²
Mean: 171.4236 µm²
Std Dev.: 133.9891 µm²

Average Area Statistics:
Minimum: 2.0185 µm²
Maximum: 36.7213 µm²
Mean: 14.5259 µm²
Std Dev.: 11.642 µm²

Area Percentage Statistics:
Minimum: 0.026 %
Maximum: 0.4236 %
Mean: 0.1977 %
Std Dev.: 0.1546 %

116-90-2L Area

Total area of all inclusions combined for each field.

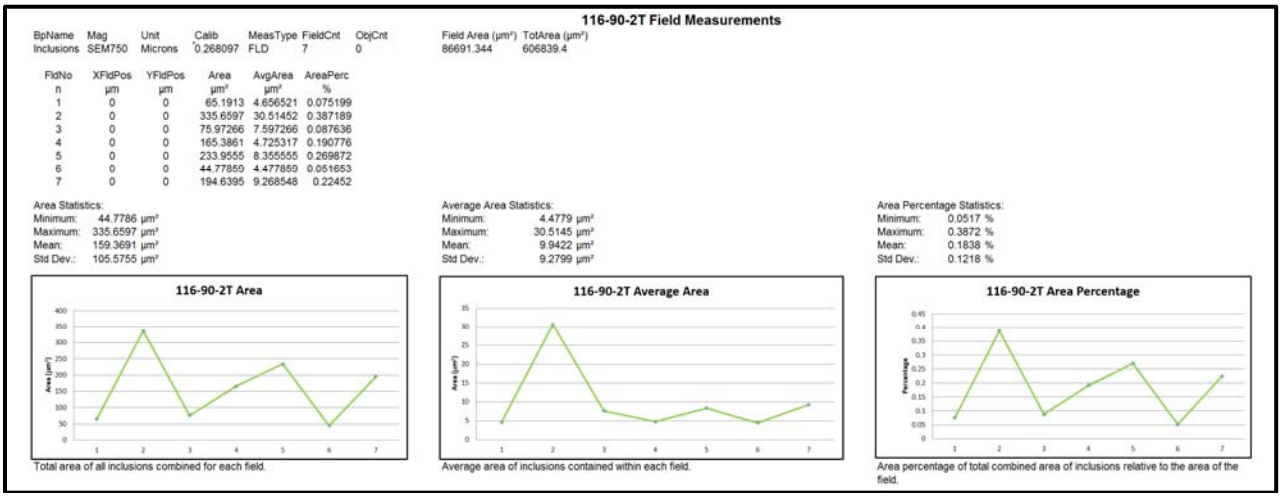
116-90-2L Average Area

Average area of inclusions contained within each field.

116-90-2L Area Percentage

Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-116-90-2L inclusion field measurement data.



116-90-2T Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

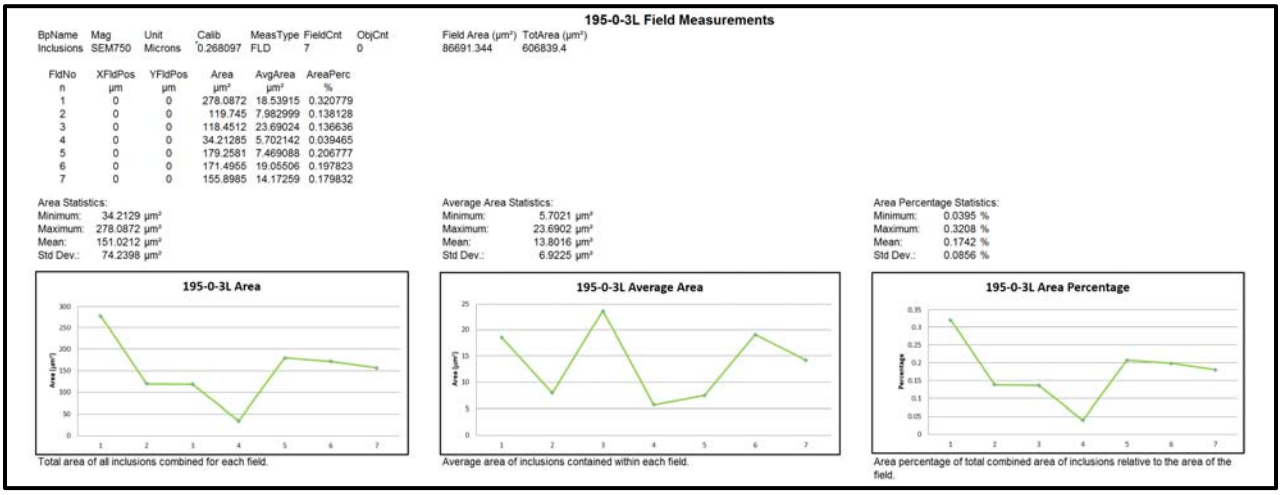
FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	65.1913	4.656521	0.075199
2	0	0	335.6597	30.51452	0.387189
3	0	0	75.97266	7.597266	0.087636
4	0	0	165.3861	4.725317	0.190776
5	0	0	233.9555	8.355555	0.269872
6	0	0	44.77859	4.477859	0.051653
7	0	0	194.6395	9.268548	0.22452

Area Statistics:
Minimum: 44.7786 µm²
Maximum: 335.6597 µm²
Mean: 159.3691 µm²
Std Dev.: 105.5755 µm²

Average Area Statistics:
Minimum: 4.4779 µm²
Maximum: 30.5145 µm²
Mean: 9.9422 µm²
Std Dev.: 9.2799 µm²

Area Percentage Statistics:
Minimum: 0.0517 %
Maximum: 0.3872 %
Mean: 0.1838 %
Std Dev.: 0.1218 %

Sample 13234-116-90-2T inclusion field measurement data.



195-0-3L Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

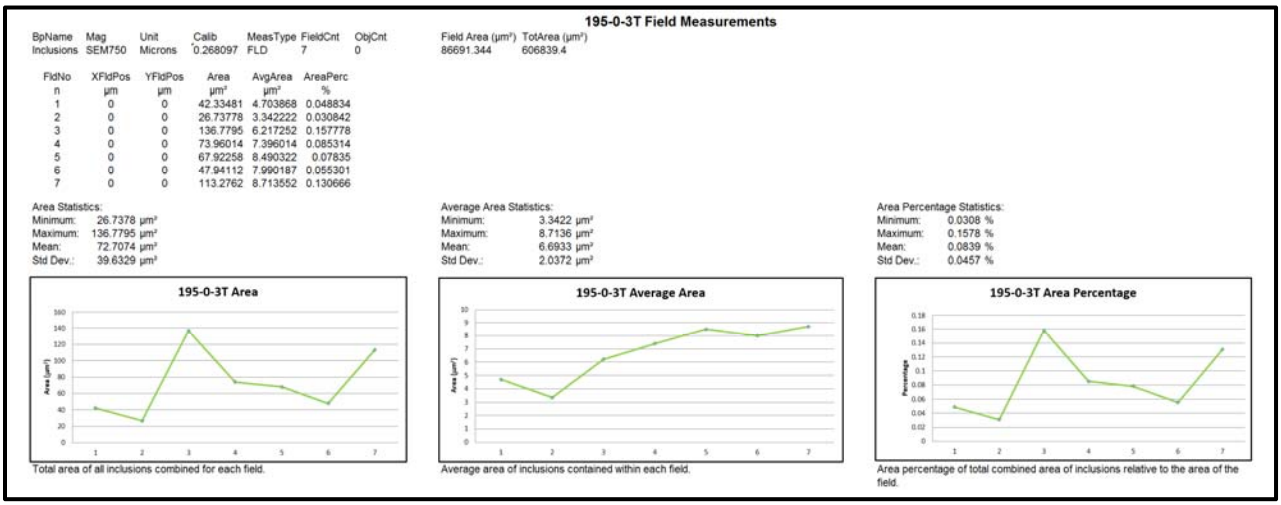
FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	278.0872	18.53915	0.320779
2	0	0	119.745	7.982999	0.138128
3	0	0	118.4512	23.69024	0.136636
4	0	0	34.21285	5.702142	0.039465
5	0	0	179.2581	7.469088	0.206777
6	0	0	171.4955	19.05506	0.197823
7	0	0	155.8985	14.17259	0.179832

Area Statistics:
Minimum: 34.2129 µm²
Maximum: 278.0872 µm²
Mean: 151.0212 µm²
Std Dev.: 74.2398 µm²

Average Area Statistics:
Minimum: 5.7021 µm²
Maximum: 23.6902 µm²
Mean: 13.8016 µm²
Std Dev.: 6.9225 µm²

Area Percentage Statistics:
Minimum: 0.0395 %
Maximum: 0.3208 %
Mean: 0.1742 %
Std Dev.: 0.0856 %

Sample 13234-195-0-3L inclusion field measurement data.



195-0-3T Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

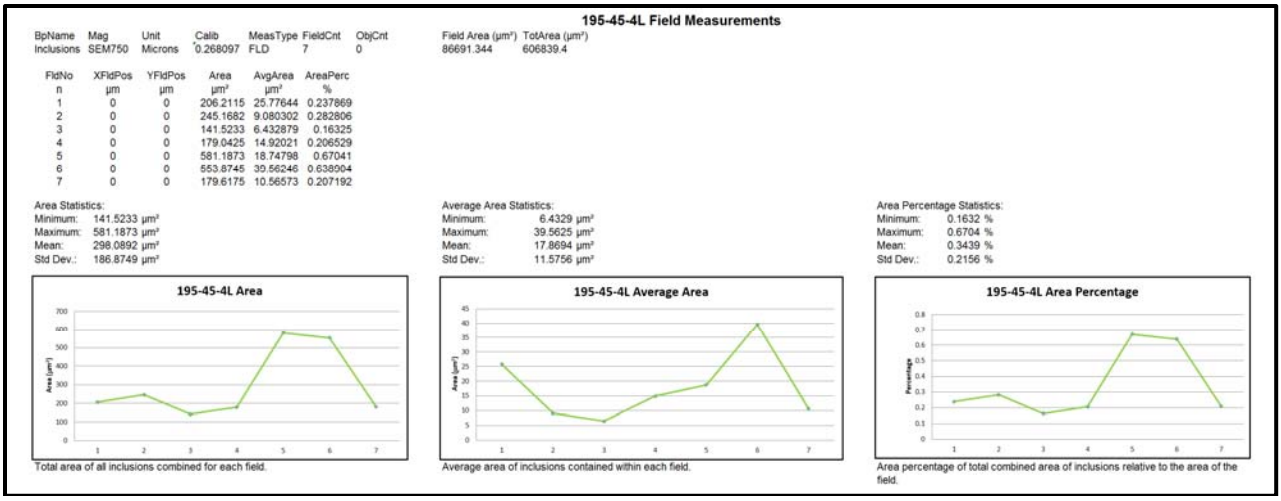
FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	42.33481	4.703868	0.048834
2	0	0	26.73778	3.342222	0.030842
3	0	0	136.7795	6.217252	0.157778
4	0	0	73.96014	7.396014	0.085314
5	0	0	67.92258	8.490322	0.07835
6	0	0	47.94112	7.990187	0.055301
7	0	0	113.2762	8.713552	0.130666

Area Statistics:
Minimum: 26.7378 µm²
Maximum: 136.7795 µm²
Mean: 72.7074 µm²
Std Dev.: 39.6329 µm²

Average Area Statistics:
Minimum: 3.3422 µm²
Maximum: 8.7136 µm²
Mean: 6.6933 µm²
Std Dev.: 2.0372 µm²

Area Percentage Statistics:
Minimum: 0.0308 %
Maximum: 0.1578 %
Mean: 0.0839 %
Std Dev.: 0.0457 %

Sample 13234-195-0-3T inclusion field measurement data.



195-45-4L Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	206.2115	25.77644	0.237869
2	0	0	245.1682	9.080302	0.282806
3	0	0	141.5233	6.432879	0.16325
4	0	0	179.0425	14.92021	0.206529
5	0	0	581.1873	18.74798	0.67041
6	0	0	553.8745	39.56246	0.638904
7	0	0	179.6175	10.56573	0.207192

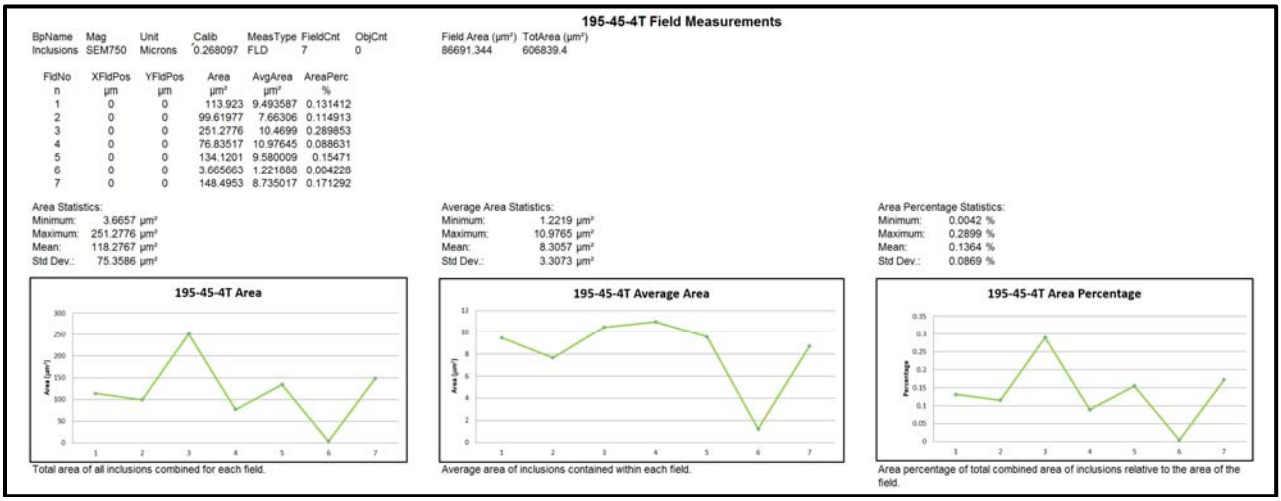
Area Statistics:
Minimum: 141.5233 µm²
Maximum: 581.1873 µm²
Mean: 298.0892 µm²
Std Dev.: 186.8749 µm²

Average Area Statistics:
Minimum: 6.4329 µm²
Maximum: 39.5625 µm²
Mean: 17.8694 µm²
Std Dev.: 11.5756 µm²

Area Percentage Statistics:
Minimum: 0.1632 %
Maximum: 0.6704 %
Mean: 0.3439 %
Std Dev.: 0.2156 %

Total area of all inclusions combined for each field. | Average area of inclusions contained within each field. | Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-195-45-4L inclusion field measurement data.



195-45-4T Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	113.923	9.493587	0.131412
2	0	0	99.61977	7.66306	0.114913
3	0	0	251.2776	10.4699	0.289853
4	0	0	76.83517	10.97645	0.088631
5	0	0	134.1201	9.580009	0.15471
6	0	0	3.665663	1.221888	0.004228
7	0	0	148.4953	8.735017	0.171292

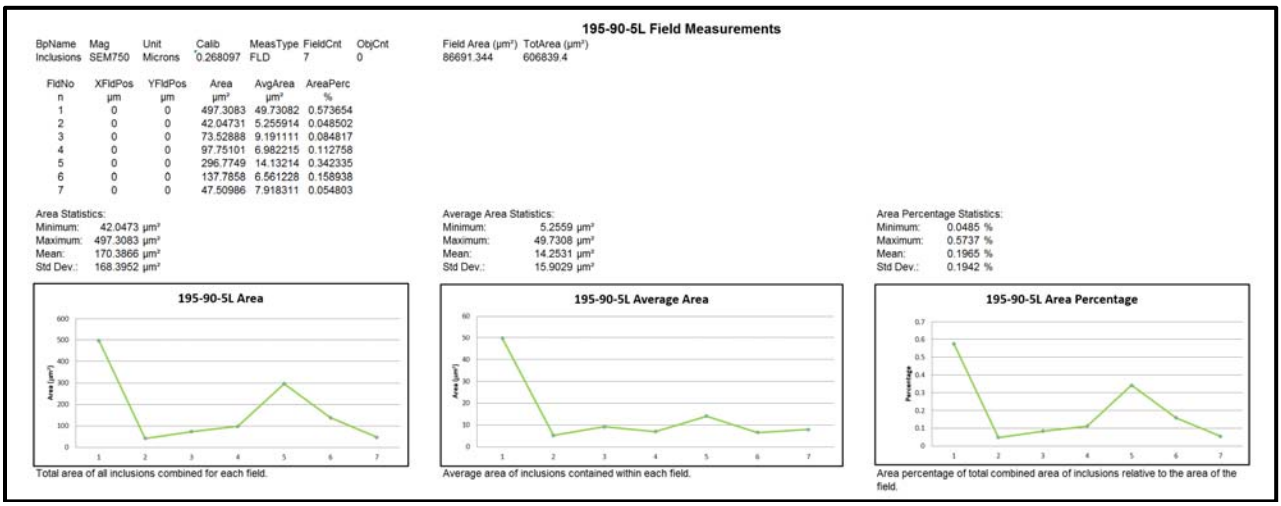
Area Statistics:
Minimum: 3.6657 µm²
Maximum: 251.2776 µm²
Mean: 118.2767 µm²
Std Dev.: 75.3586 µm²

Average Area Statistics:
Minimum: 1.2219 µm²
Maximum: 10.9765 µm²
Mean: 8.3057 µm²
Std Dev.: 3.3073 µm²

Area Percentage Statistics:
Minimum: 0.0042 %
Maximum: 0.2899 %
Mean: 0.1364 %
Std Dev.: 0.0869 %

Total area of all inclusions combined for each field. | Average area of inclusions contained within each field. | Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-195-45-4T inclusion field measurement data.



195-90-5L Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	497.3083	49.73082	0.573654
2	0	0	42.04731	5.255914	0.048502
3	0	0	73.52888	9.191111	0.084817
4	0	0	97.75101	6.982215	0.112758
5	0	0	296.7749	14.13214	0.342335
6	0	0	137.7858	6.561228	0.158938
7	0	0	47.50986	7.918311	0.054803

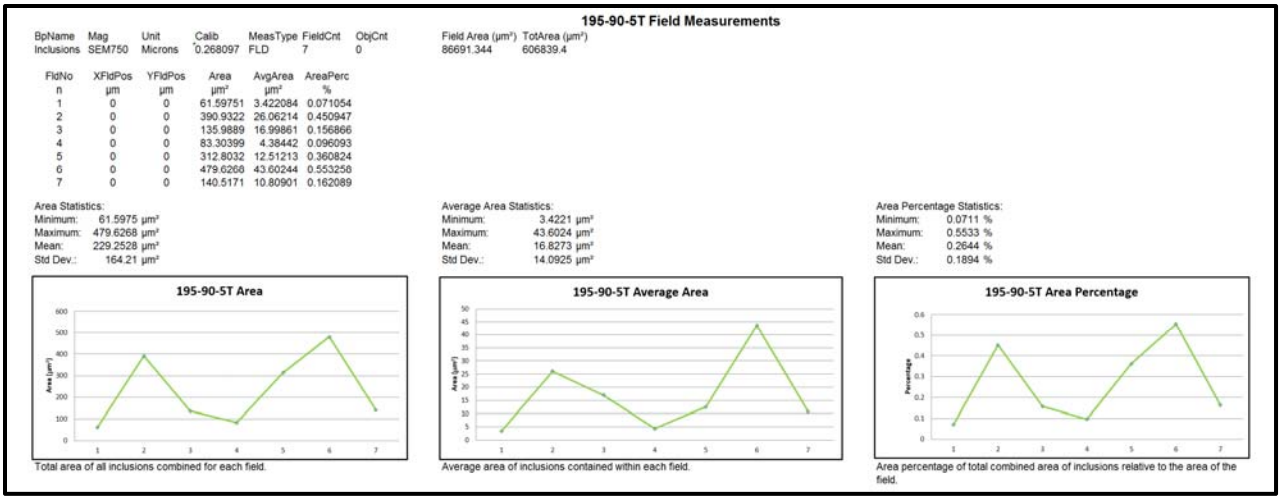
Area Statistics:
Minimum: 42.0473 µm²
Maximum: 497.3083 µm²
Mean: 170.3866 µm²
Std Dev.: 168.3952 µm²

Average Area Statistics:
Minimum: 5.2559 µm²
Maximum: 49.7308 µm²
Mean: 14.2531 µm²
Std Dev.: 15.9029 µm²

Area Percentage Statistics:
Minimum: 0.0485 %
Maximum: 0.5737 %
Mean: 0.1965 %
Std Dev.: 0.1942 %

Total area of all inclusions combined for each field. | Average area of inclusions contained within each field. | Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-195-90-5L inclusion field measurement data.



195-90-5T Field Measurements

BpName	Mag	Unit	Calib	MeasType	FieldCnt	ObjCnt	Field Area (µm²)	TotArea (µm²)
Inclusions	SEM750	Microns	0.268097	FLD	7	0	86691.344	606839.4

FldNo	XFldPos	YFldPos	Area	AvgArea	AreaPerc
n	µm	µm	µm²	µm²	%
1	0	0	61.59751	3.422084	0.071054
2	0	0	390.9322	26.06214	0.450947
3	0	0	135.9889	16.99861	0.156866
4	0	0	83.30399	4.38442	0.096093
5	0	0	312.8032	12.51213	0.360824
6	0	0	479.6268	43.60244	0.553258
7	0	0	140.5171	10.80901	0.162089

Area Statistics:
Minimum: 61.5975 µm²
Maximum: 479.6268 µm²
Mean: 229.2528 µm²
Std Dev.: 164.21 µm²

Average Area Statistics:
Minimum: 3.4221 µm²
Maximum: 43.6024 µm²
Mean: 16.8273 µm²
Std Dev.: 14.0925 µm²

Area Percentage Statistics:
Minimum: 0.0711 %
Maximum: 0.5533 %
Mean: 0.2644 %
Std Dev.: 0.1894 %

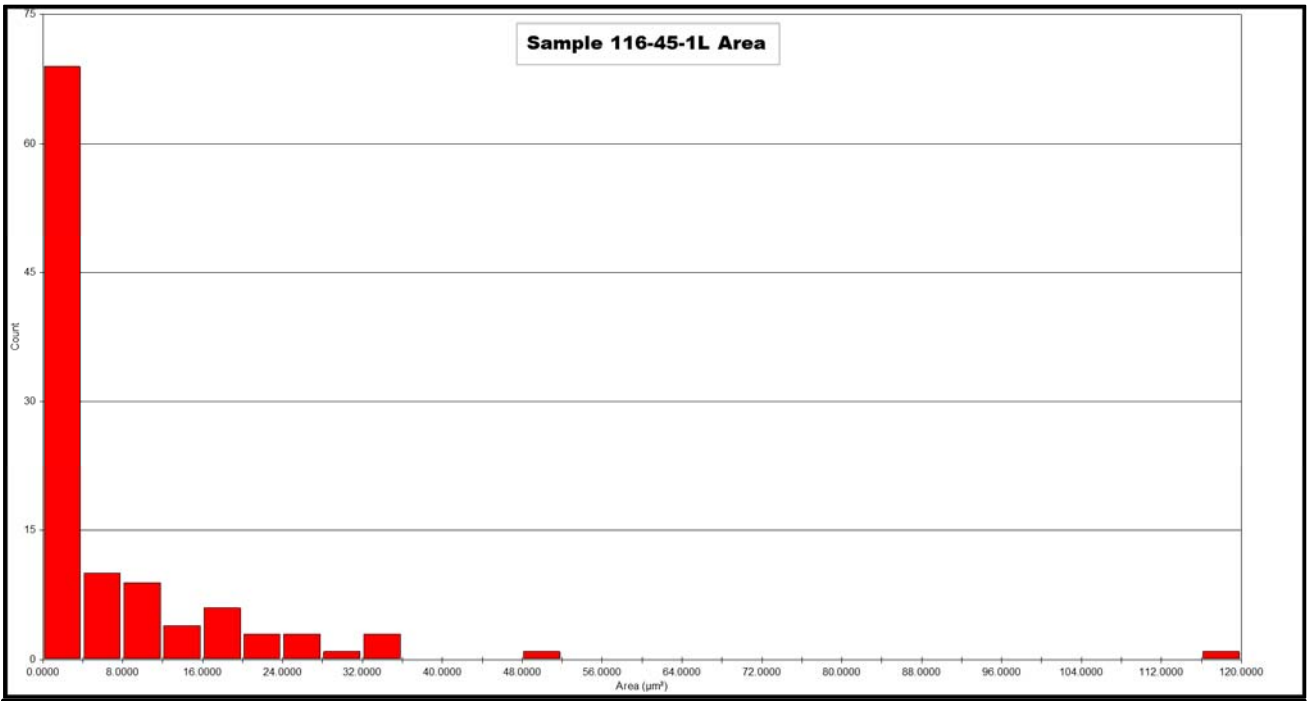
Total area of all inclusions combined for each field.

Average area of inclusions contained within each field.

Area percentage of total combined area of inclusions relative to the area of the field.

Sample 13234-195-90-5T inclusion field measurement data.

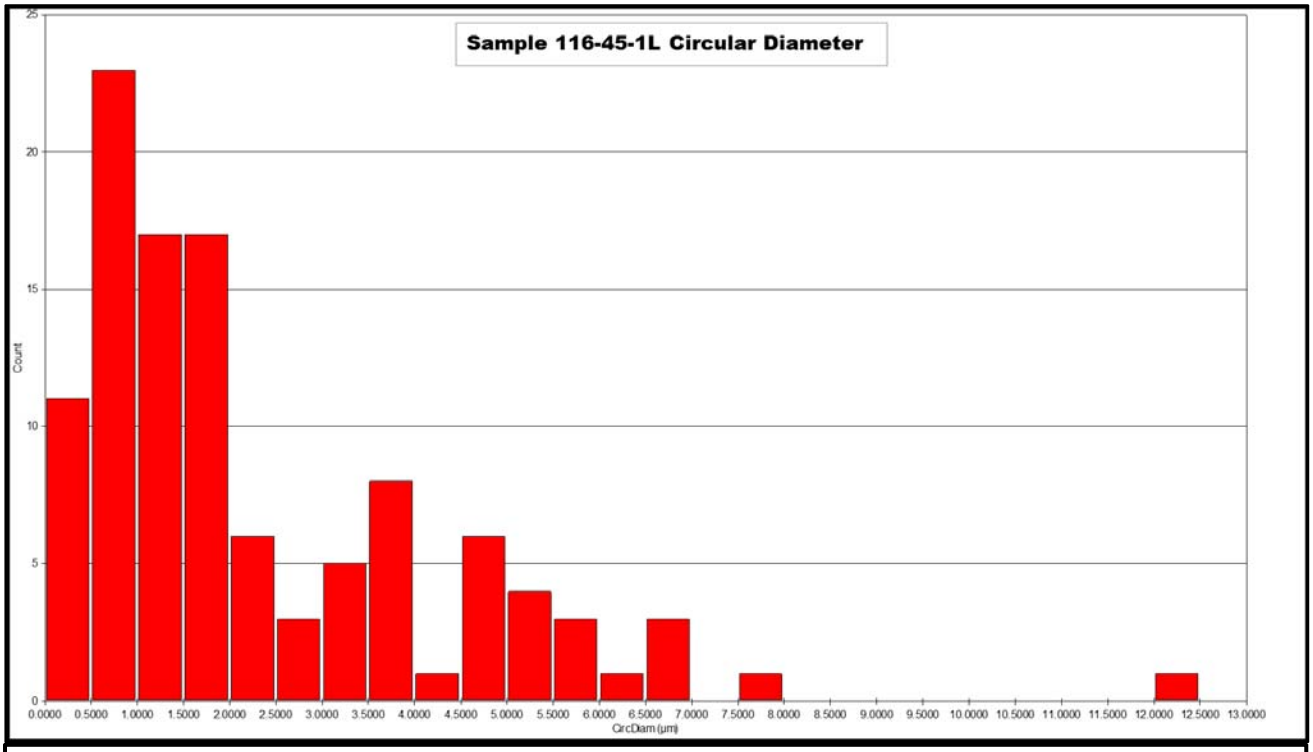
Appendix B - Inclusion Analysis Object Measurements



Area (µm²) From	To	Count	%	Cumulative %
0	4	69	63	63
4	8	10	9	72
8	12	9	8	80
12	16	4	4	84
16	20	6	5	89
20	24	3	3	92
24	28	3	3	95
28	32	1	1	95
32	36	3	3	98
36	40	0	0	98
40	44	0	0	98
44	48	0	0	98
48	52	1	1	99
52	56	0	0	99
56	60	0	0	99
60	64	0	0	99
64	68	0	0	99
68	72	0	0	99
72	76	0	0	99
76	80	0	0	99
80	84	0	0	99
84	88	0	0	99
88	92	0	0	99
92	96	0	0	99
96	100	0	0	99
100	104	0	0	99
104	108	0	0	99
108	112	0	0	99
112	116	0	0	99
116	120	1	1	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	119.31 µm²
Mean:	7.56 µm²
Std Dev.:	14.34 µm²
Sum:	831.67 µm²
Count:	110
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

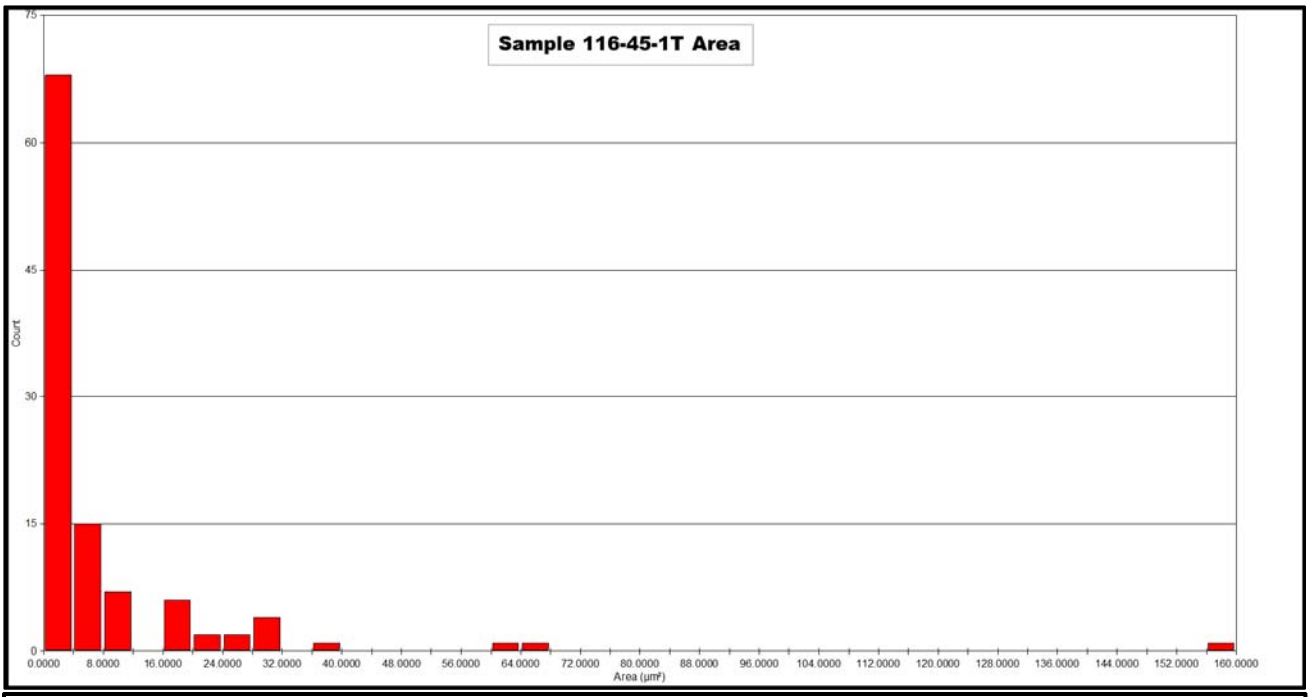
Sample 13234-116-45-1L inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	11	10	10
0.5	1	23	21	31
1	1.5	17	15	46
1.5	2	17	15	62
2	2.5	6	5	67
2.5	3	3	3	70
3	3.5	5	5	75
3.5	4	8	7	82
4	4.5	1	1	83
4.5	5	6	5	88
5	5.5	4	4	92
5.5	6	3	3	95
6	6.5	1	1	95
6.5	7	3	3	98
7	7.5	0	0	98
7.5	8	1	1	99
8	8.5	0	0	99
8.5	9	0	0	99
9	9.5	0	0	99
9.5	10	0	0	99
10	10.5	0	0	99
10.5	11	0	0	99
11	11.5	0	0	99
11.5	12	0	0	99
12	12.5	1	1	100
12.5	13	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	12.33 µm
Mean:	2.34 µm
Std Dev.:	2.04 µm
Sum:	257.89 µm
Count:	110
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

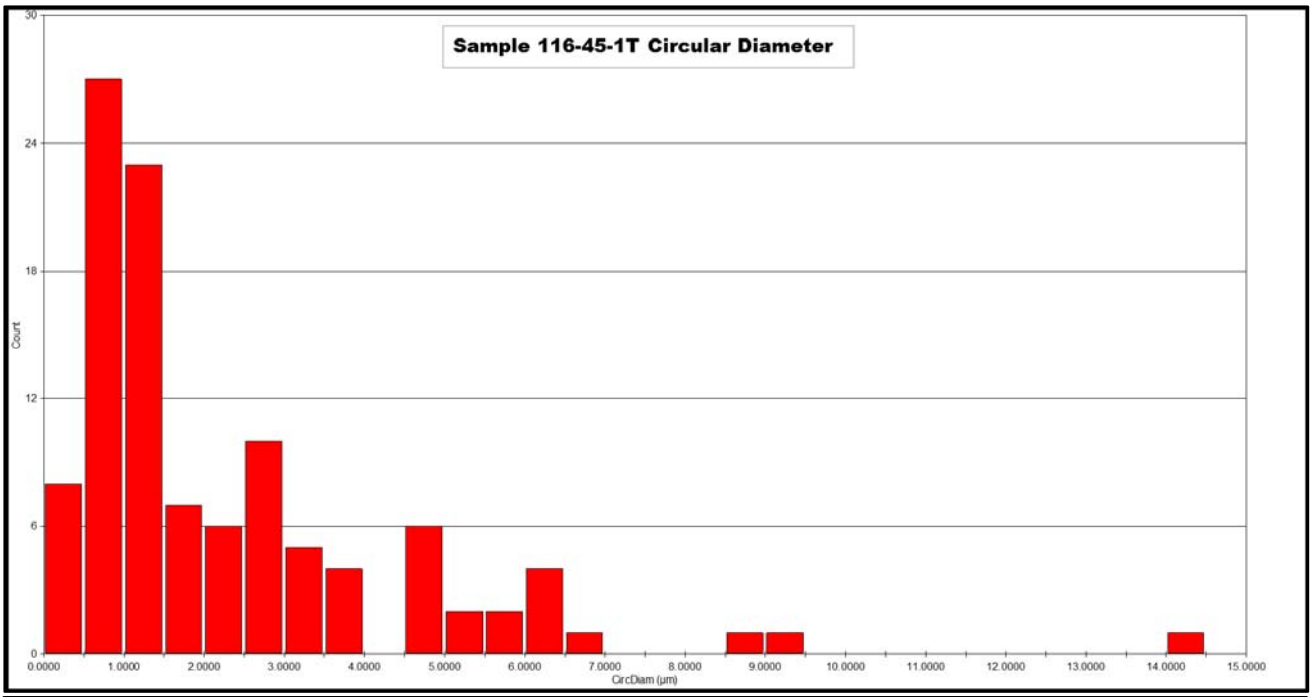
Sample 13234-116-45-1L inclusion circular diameter object measurement data.



Area (µm²) From	To	Count	%	Cumulative %
0	4	68	63	63
4	8	15	14	77
8	12	7	6	83
12	16	0	0	83
16	20	6	6	89
20	24	2	2	91
24	28	2	2	93
28	32	4	4	96
32	36	0	0	96
36	40	1	1	97
40	44	0	0	97
44	48	0	0	97
48	52	0	0	97
52	56	0	0	97
56	60	0	0	97
60	64	1	1	98
64	68	1	1	99
68	72	0	0	99
72	76	0	0	99
76	80	0	0	99
80	84	0	0	99
84	88	0	0	99
88	92	0	0	99
92	96	0	0	99
96	100	0	0	99
100	104	0	0	99
104	108	0	0	99
108	112	0	0	99
112	116	0	0	99
116	120	0	0	99
120	124	0	0	99
124	128	0	0	99
128	132	0	0	99
132	136	0	0	99
136	140	0	0	99
140	144	0	0	99
144	148	0	0	99
148	152	0	0	99
152	156	0	0	99
156	160	1	1	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	158.77 µm²
Mean:	8.04 µm²
Std Dev.:	18.52 µm²
Sum:	868.12 µm²
Count:	108
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

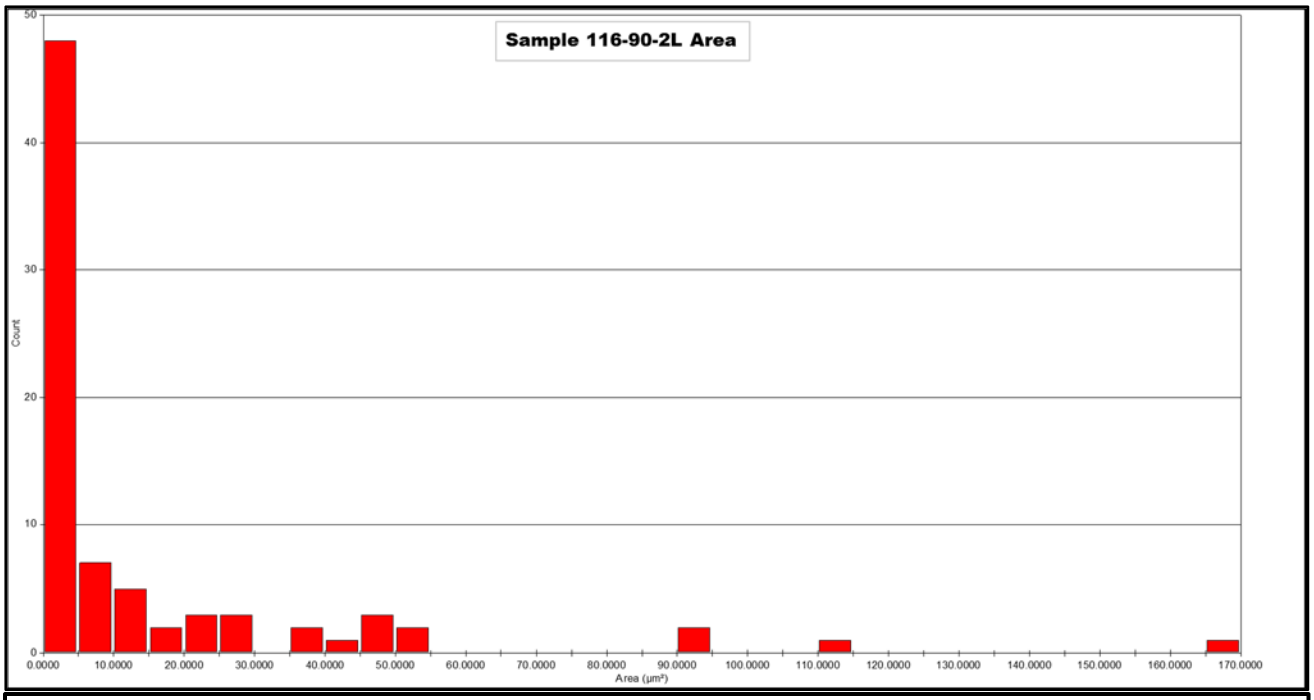
Sample 13234-116-45-1T inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	8	7	7
0.5	1	27	25	32
1	1.5	23	21	54
1.5	2	7	6	60
2	2.5	6	6	66
2.5	3	10	9	75
3	3.5	5	5	80
3.5	4	4	4	83
4	4.5	0	0	83
4.5	5	6	6	89
5	5.5	2	2	91
5.5	6	2	2	93
6	6.5	4	4	96
6.5	7	1	1	97
7	7.5	0	0	97
7.5	8	0	0	97
8	8.5	0	0	97
8.5	9	1	1	98
9	9.5	1	1	99
9.5	10	0	0	99
10	10.5	0	0	99
10.5	11	0	0	99
11	11.5	0	0	99
11.5	12	0	0	99
12	12.5	0	0	99
12.5	13	0	0	99
13	13.5	0	0	99
13.5	14	0	0	99
14	14.5	1	1	100
14.5	15	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	14.22 µm
Mean:	2.32 µm
Std Dev.:	2.22 µm
Sum:	250.15 µm
Count:	108
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

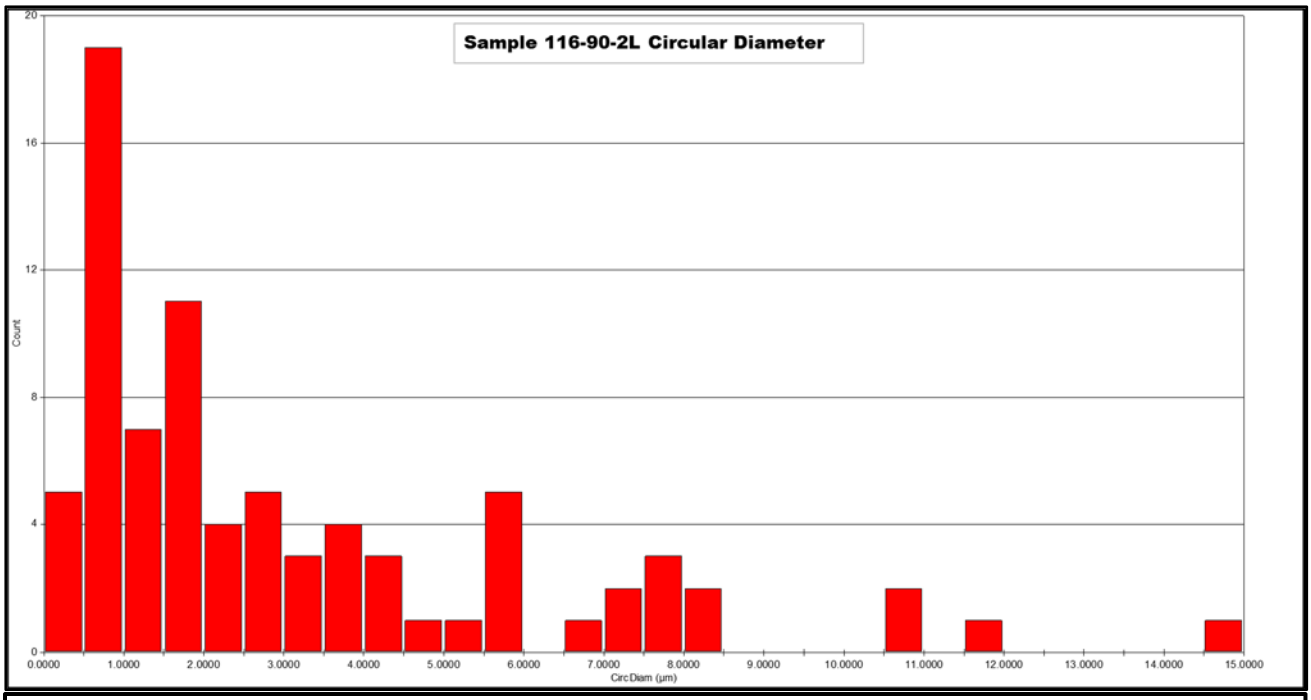
Sample 13234-116-45-1T inclusion circular diameter object measurement data.



Area (µm²) From	To	Count	%	Cumulative %
0	5	48	60	60
5	10	7	9	69
10	15	5	6	75
15	20	2	3	78
20	25	3	4	81
25	30	3	4	85
30	35	0	0	85
35	40	2	3	88
40	45	1	1	89
45	50	3	4	93
50	55	2	3	95
55	60	0	0	95
60	65	0	0	95
65	70	0	0	95
70	75	0	0	95
75	80	0	0	95
80	85	0	0	95
85	90	0	0	95
90	95	2	3	98
95	100	0	0	98
100	105	0	0	98
105	110	0	0	98
110	115	1	1	99
115	120	0	0	99
120	125	0	0	99
125	130	0	0	99
130	135	0	0	99
135	140	0	0	99
140	145	0	0	99
145	150	0	0	99
150	155	0	0	99
155	160	0	0	99
160	165	0	0	99
165	170	1	1	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	168.26 µm²
Mean:	15.00 µm²
Std Dev.:	28.20 µm²
Sum:	1199.97 µm²
Count:	80
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

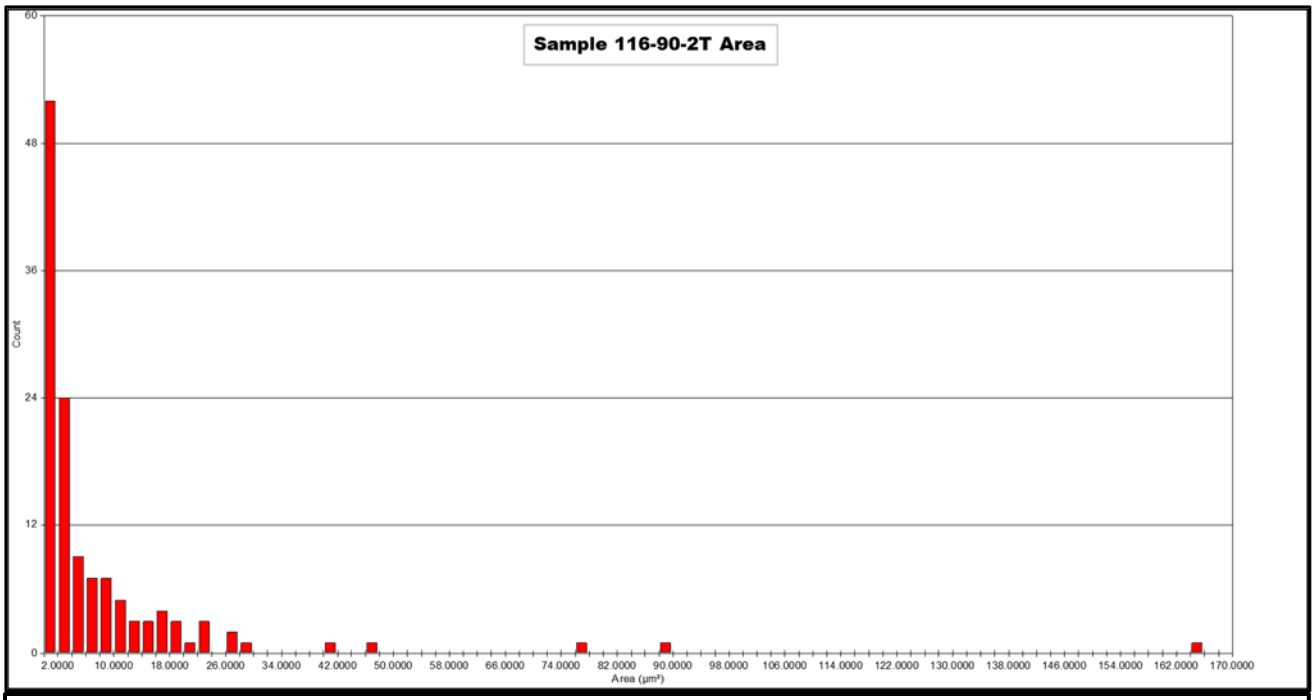
Sample 13234-116-90-2L inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	5	6	6
0.5	1	19	24	30
1	1.5	7	9	39
1.5	2	11	14	53
2	2.5	4	5	58
2.5	3	5	6	64
3	3.5	3	4	68
3.5	4	4	5	73
4	4.5	3	4	76
4.5	5	1	1	78
5	5.5	1	1	79
5.5	6	5	6	85
6	6.5	0	0	85
6.5	7	1	1	86
7	7.5	2	3	89
7.5	8	3	4	93
8	8.5	2	3	95
8.5	9	0	0	95
9	9.5	0	0	95
9.5	10	0	0	95
10	10.5	0	0	95
10.5	11	2	3	98
11	11.5	0	0	98
11.5	12	1	1	99
12	12.5	0	0	99
12.5	13	0	0	99
13	13.5	0	0	99
13.5	14	0	0	99
14	14.5	0	0	99
14.5	15	1	1	100

Statistics:	
Minimum:	0.43 µm
Maximum:	14.64 µm
Mean:	3.14 µm
Std Dev.:	3.06 µm
Sum:	251.06 µm
Count:	80
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Sample 13234-116-90-2L inclusion circular diameter object measurement data.

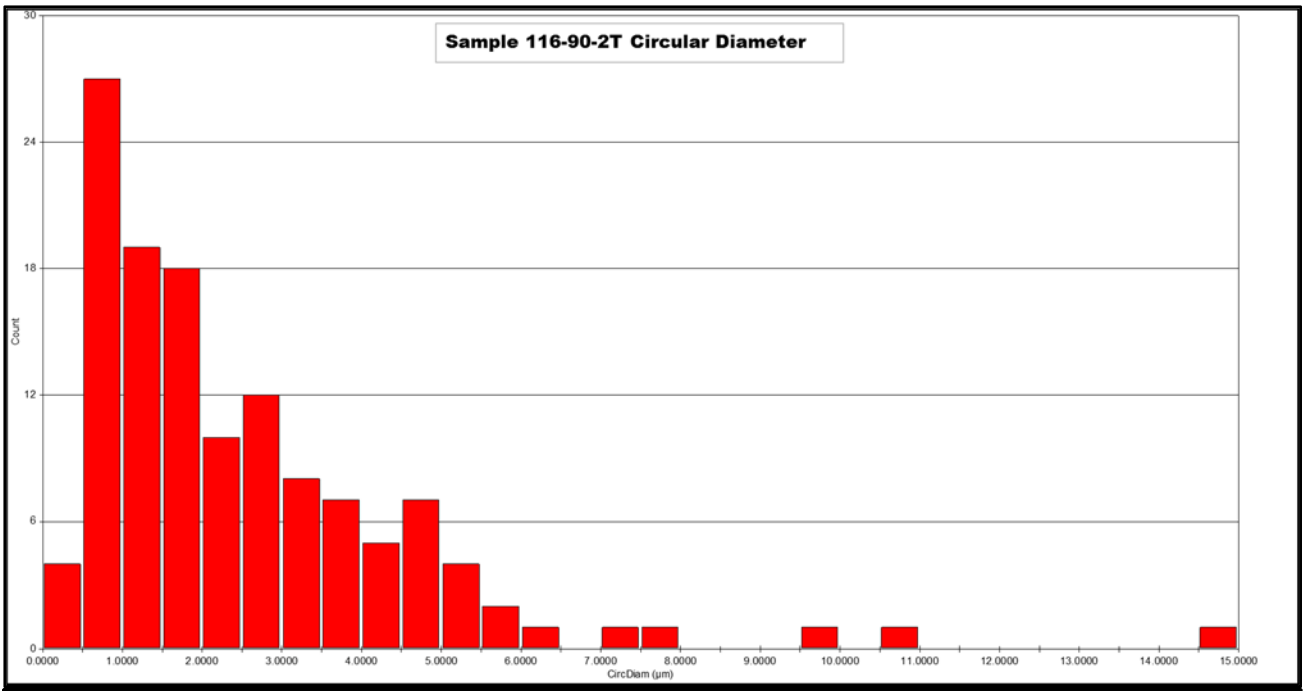


Area (µm²) From	To	Count	%	Cumulative %
0	2	52	40	40
2	4	24	19	59
4	6	9	7	66
6	8	7	5	71
8	10	7	5	77
10	12	5	4	81
12	14	3	2	83
14	16	3	2	85
16	18	4	3	88
18	20	3	2	91
20	22	1	1	91
22	24	3	2	94
24	26	0	0	94
26	28	2	2	95
28	30	1	1	96
30	32	0	0	96
32	34	0	0	96
34	36	0	0	96
36	38	0	0	96
38	40	0	0	96
40	42	1	1	97
42	44	0	0	97
44	46	0	0	97
46	48	1	1	98
48	50	0	0	98
50	52	0	0	98
52	54	0	0	98
54	56	0	0	98
56	58	0	0	98
58	60	0	0	98
60	62	0	0	98
62	64	0	0	98
64	66	0	0	98
66	68	0	0	98
68	70	0	0	98
70	72	0	0	98
72	74	0	0	98
74	76	0	0	98
76	78	1	1	98
78	80	0	0	98
80	82	0	0	98
82	84	0	0	98
84	86	0	0	98

Area (µm²) From	To	Count	%	Cumulative %
86	88	0	0	98
88	90	1	1	99
90	92	0	0	99
92	94	0	0	99
94	96	0	0	99
96	98	0	0	99
98	100	0	0	99
100	102	0	0	99
102	104	0	0	99
104	106	0	0	99
106	108	0	0	99
108	110	0	0	99
110	112	0	0	99
112	114	0	0	99
114	116	0	0	99
116	118	0	0	99
118	120	0	0	99
120	122	0	0	99
122	124	0	0	99
124	126	0	0	99
126	128	0	0	99
128	130	0	0	99
130	132	0	0	99
132	134	0	0	99
134	136	0	0	99
136	138	0	0	99
138	140	0	0	99
140	142	0	0	99
142	144	0	0	99
144	146	0	0	99
146	148	0	0	99
148	150	0	0	99
150	152	0	0	99
152	154	0	0	99
154	156	0	0	99
156	158	0	0	99
158	160	0	0	99
160	162	0	0	99
162	164	0	0	99
164	166	1	1	100
166	168	0	0	100
168	170	0	0	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	165.46 µm²
Mean:	8.65 µm²
Std Dev.:	18.77 µm²
Sum:	1115.58 µm²
Count:	129
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

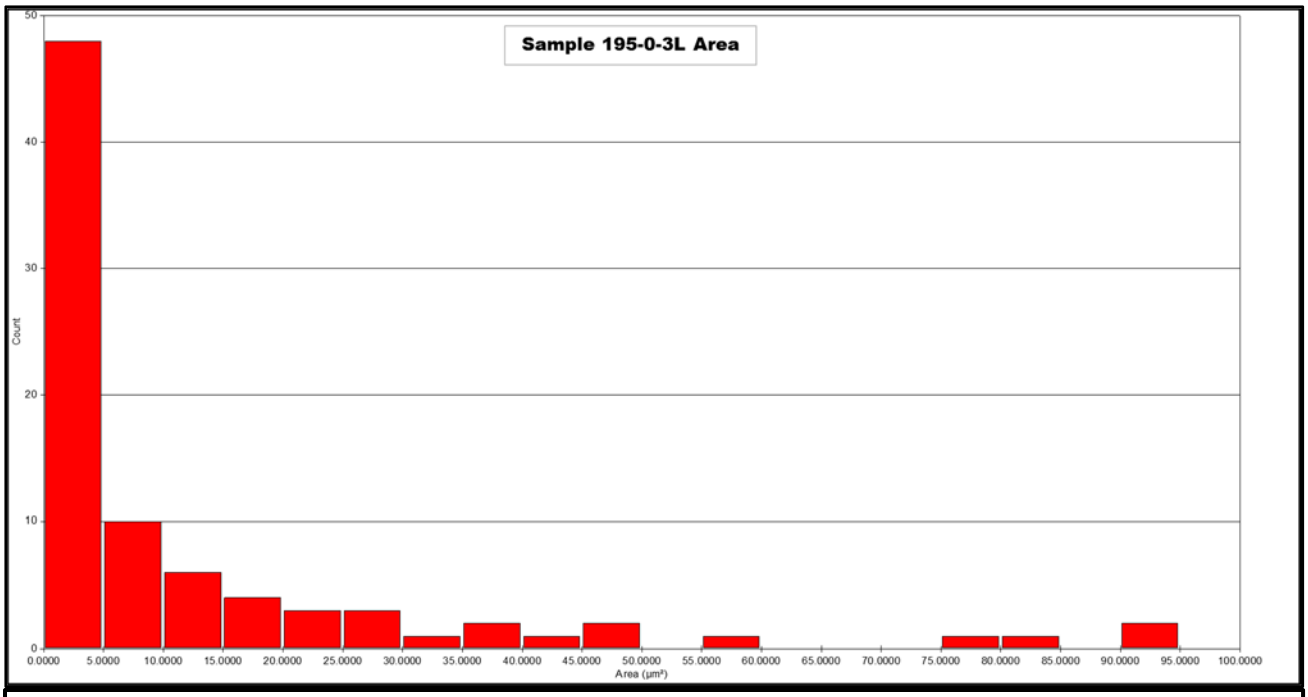
Sample 13234-116-90-2T inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	4	3	3
0.5	1	27	21	24
1	1.5	19	15	39
1.5	2	18	14	53
2	2.5	10	8	60
2.5	3	12	9	70
3	3.5	8	6	76
3.5	4	7	5	81
4	4.5	5	4	85
4.5	5	7	5	91
5	5.5	4	3	94
5.5	6	2	2	95
6	6.5	1	1	96
6.5	7	0	0	96
7	7.5	1	1	97
7.5	8	1	1	98
8	8.5	0	0	98
8.5	9	0	0	98
9	9.5	0	0	98
9.5	10	1	1	98
10	10.5	0	0	98
10.5	11	1	1	99
11	11.5	0	0	99
11.5	12	0	0	99
12	12.5	0	0	99
12.5	13	0	0	99
13	13.5	0	0	99
13.5	14	0	0	99
14	14.5	0	0	99
14.5	15	1	1	100

Statistics:	
Minimum:	0.43 µm
Maximum:	14.51 µm
Mean:	2.53 µm
Std Dev.:	2.16 µm
Sum:	326.31 µm
Count:	129
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

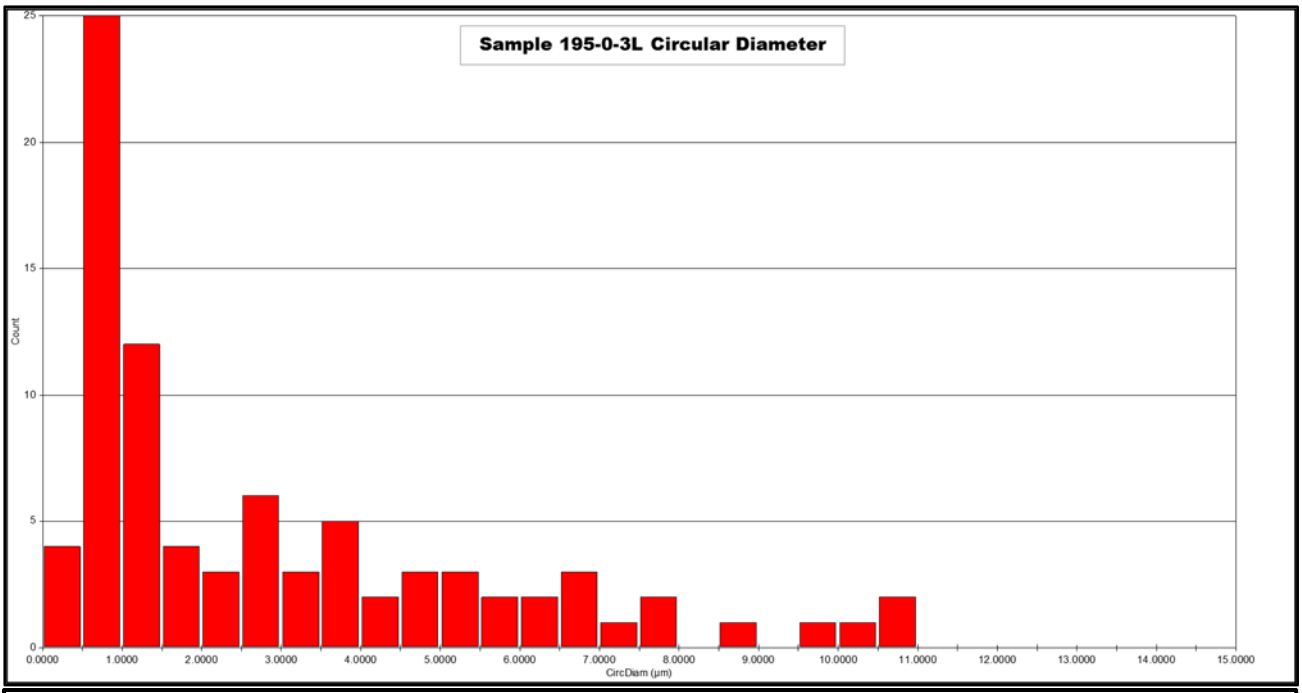
Sample 13234-116-90-2T inclusion circular diameter object measurement data.



Area (µm²) From	To	Count	%	Cumulative %
0	5	48	56	56
5	10	10	12	68
10	15	6	7	75
15	20	4	5	80
20	25	3	4	84
25	30	3	4	87
30	35	1	1	88
35	40	2	2	91
40	45	1	1	92
45	50	2	2	94
50	55	0	0	94
55	60	1	1	95
60	65	0	0	95
65	70	0	0	95
70	75	0	0	95
75	80	1	1	96
80	85	1	1	98
85	90	0	0	98
90	95	2	2	100
95	100	0	0	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	91.64 µm²
Mean:	12.44 µm²
Std Dev.:	20.87 µm²
Sum:	1057.15 µm²
Count:	85
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

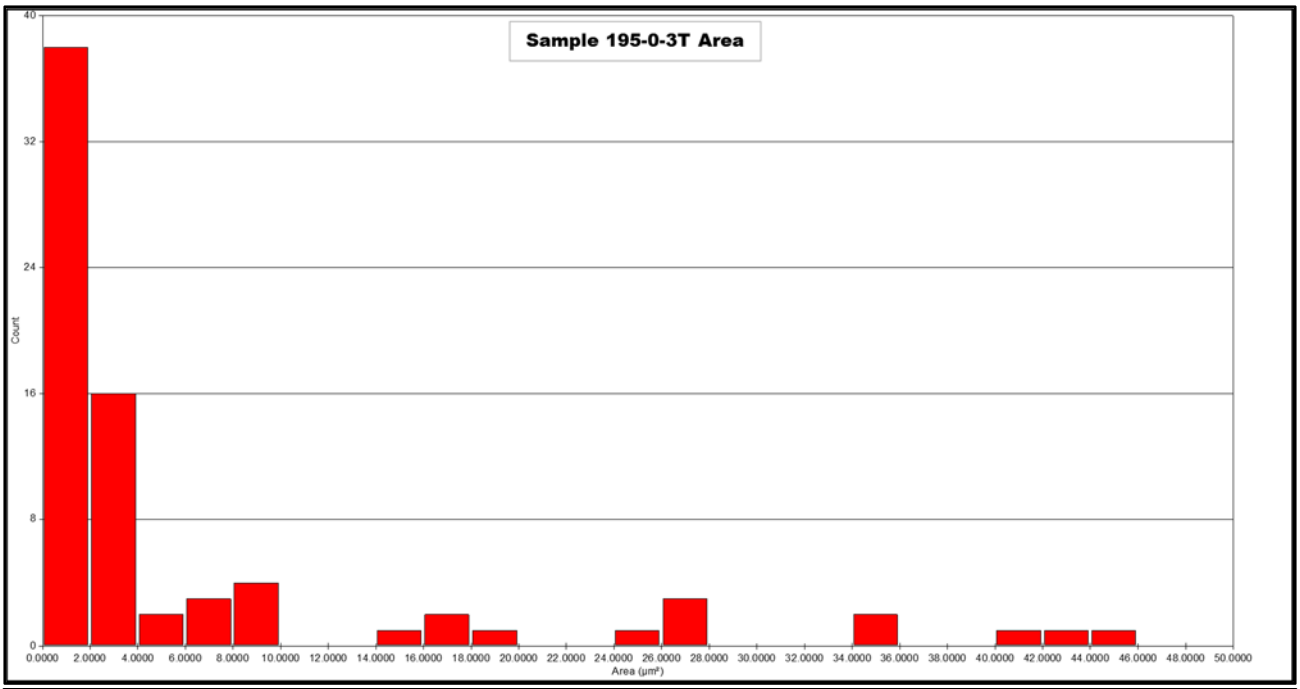
Sample 13234-195-0-3L inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	4	5	5
0.5	1	25	29	34
1	1.5	12	14	48
1.5	2	4	5	53
2	2.5	3	4	56
2.5	3	6	7	64
3	3.5	3	4	67
3.5	4	5	6	73
4	4.5	2	2	75
4.5	5	3	4	79
5	5.5	3	4	82
5.5	6	2	2	85
6	6.5	2	2	87
6.5	7	3	4	91
7	7.5	1	1	92
7.5	8	2	2	94
8	8.5	0	0	94
8.5	9	1	1	95
9	9.5	0	0	95
9.5	10	1	1	96
10	10.5	1	1	98
10.5	11	2	2	100
11	11.5	0	0	100
11.5	12	0	0	100
12	12.5	0	0	100
12.5	13	0	0	100
13	13.5	0	0	100
13.5	14	0	0	100
14	14.5	0	0	100
14.5	15	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	10.80 µm
Mean:	2.91 µm
Std Dev.:	2.73 µm
Sum:	247.22 µm
Count:	85
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

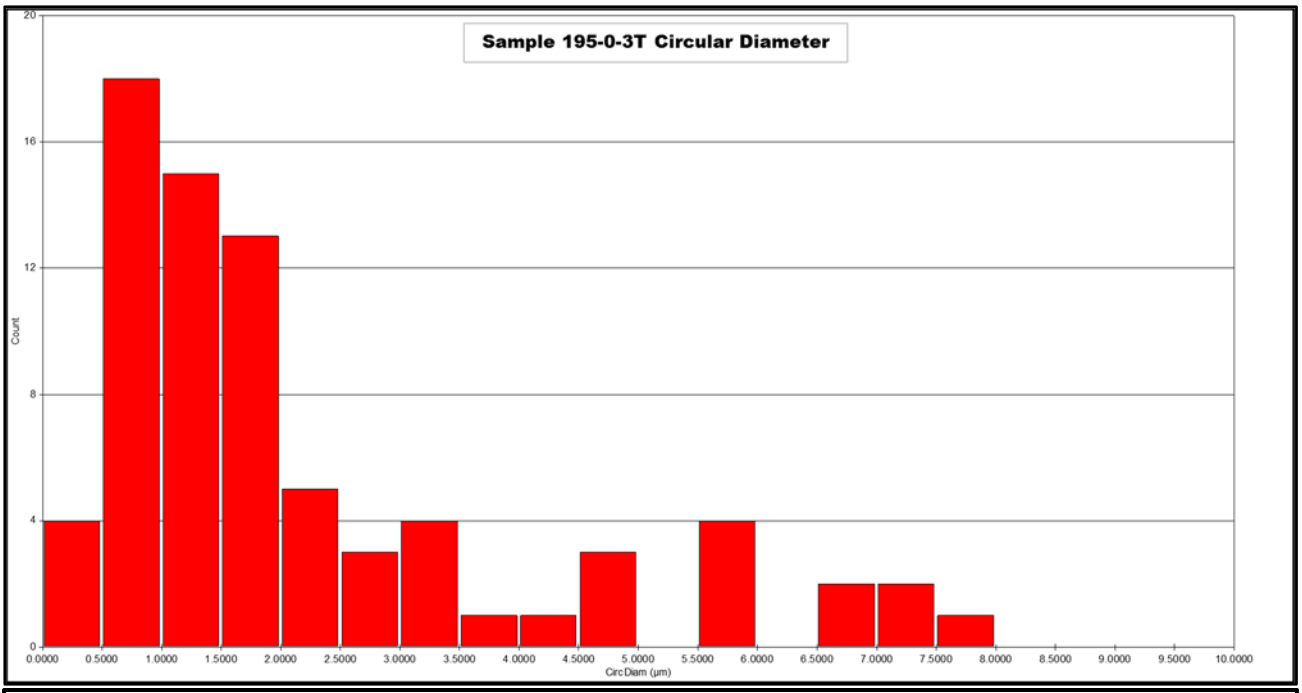
Sample 13234-195-0-3L inclusion circular diameter object measurement data.



Area (µm²) From	To	Count	%	Cumulative %
0	2	38	50	50
2	4	16	21	71
4	6	2	3	74
6	8	3	4	78
8	10	4	5	83
10	12	0	0	83
12	14	0	0	83
14	16	1	1	84
16	18	2	3	87
18	20	1	1	88
20	22	0	0	88
22	24	0	0	88
24	26	1	1	89
26	28	3	4	93
28	30	0	0	93
30	32	0	0	93
32	34	0	0	93
34	36	2	3	96
36	38	0	0	96
38	40	0	0	96
40	42	1	1	97
42	44	1	1	99
44	46	1	1	100
46	48	0	0	100
48	50	0	0	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	45.28 µm²
Mean:	6.70 µm²
Std Dev.:	11.13 µm²
Sum:	508.95 µm²
Count:	76
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

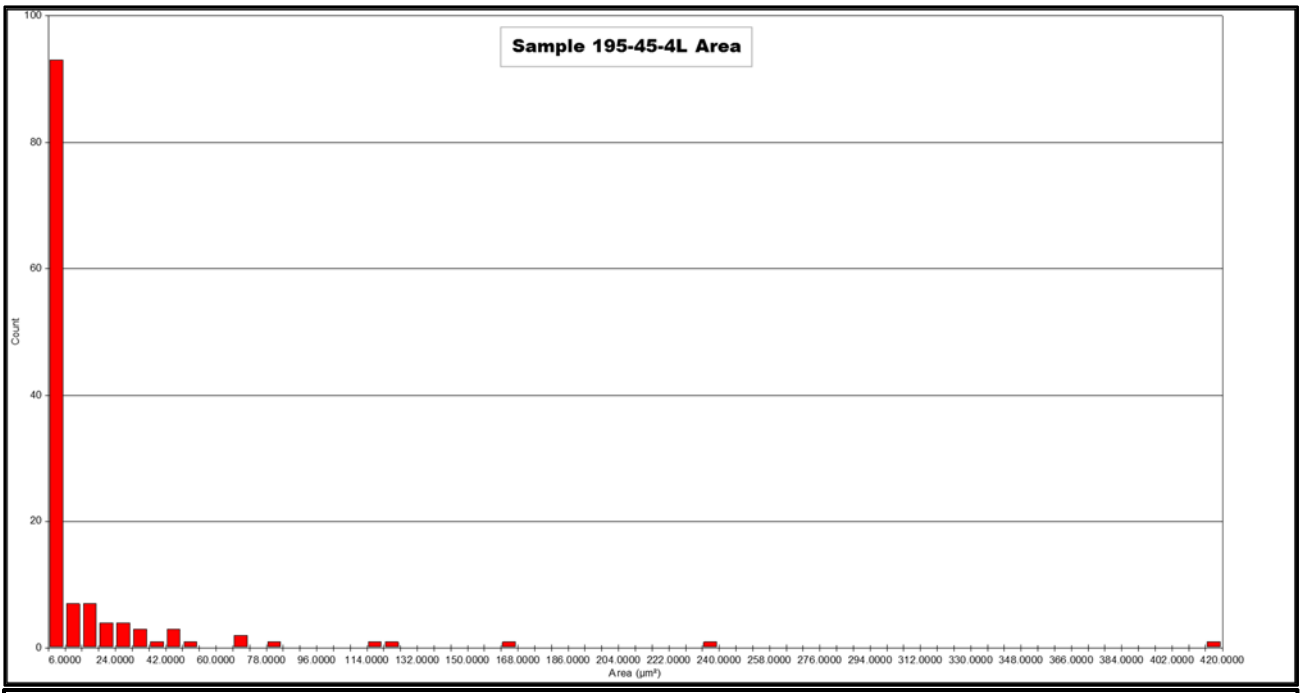
Sample 13234-195-0-3T inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	4	5	5
0.5	1	18	24	29
1	1.5	15	20	49
1.5	2	13	17	66
2	2.5	5	7	72
2.5	3	3	4	76
3	3.5	4	5	82
3.5	4	1	1	83
4	4.5	1	1	84
4.5	5	3	4	88
5	5.5	0	0	88
5.5	6	4	5	93
6	6.5	0	0	93
6.5	7	2	3	96
7	7.5	2	3	99
7.5	8	1	1	100
8	8.5	0	0	100
8.5	9	0	0	100
9	9.5	0	0	100
9.5	10	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	7.59 µm
Mean:	2.20 µm
Std Dev.:	1.93 µm
Sum:	167.32 µm
Count:	76
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Sample 13234-195-0-3T inclusion circular diameter object measurement data.

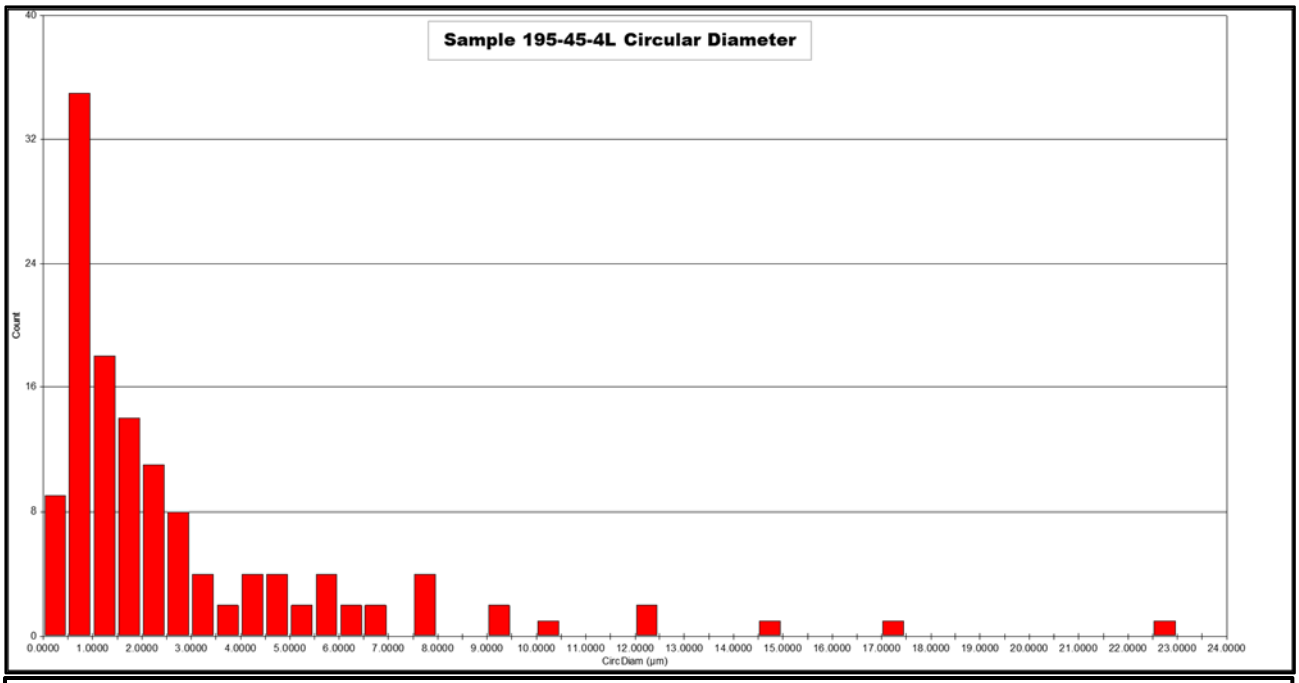


Area (µm²) From	To	Count	%	Cumulative %
0	6	93	71	71
6	12	7	5	76
12	18	7	5	82
18	24	4	3	85
24	30	4	3	88
30	36	3	2	90
36	42	1	1	91
42	48	3	2	93
48	54	1	1	94
54	60	0	0	94
60	66	0	0	94
66	72	2	2	95
72	78	0	0	95
78	84	1	1	96
84	90	0	0	96
90	96	0	0	96
96	102	0	0	96
102	108	0	0	96
108	114	0	0	96
114	120	1	1	97
120	126	1	1	98
126	132	0	0	98
132	138	0	0	98
138	144	0	0	98
144	150	0	0	98
150	156	0	0	98
156	162	0	0	98
162	168	1	1	98
168	174	0	0	98
174	180	0	0	98
180	186	0	0	98
186	192	0	0	98
192	198	0	0	98
198	204	0	0	98
204	210	0	0	98

Area (µm²) From	To	Count	%	Cumulative %
210	216	0	0	98
222	228	0	0	98
228	234	0	0	98
234	240	1	1	99
240	246	0	0	99
246	252	0	0	99
252	258	0	0	99
258	264	0	0	99
264	270	0	0	99
270	276	0	0	99
276	282	0	0	99
282	288	0	0	99
288	294	0	0	99
294	300	0	0	99
300	306	0	0	99
306	312	0	0	99
312	318	0	0	99
318	324	0	0	99
324	330	0	0	99
330	336	0	0	99
336	342	0	0	99
342	348	0	0	99
348	354	0	0	99
354	360	0	0	99
360	366	0	0	99
366	372	0	0	99
372	378	0	0	99
378	384	0	0	99
384	390	0	0	99
390	396	0	0	99
396	402	0	0	99
402	408	0	0	99
408	414	0	0	99
414	420	1	1	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	414.72 µm²
Mean:	15.93 µm²
Std Dev.:	46.95 µm²
Sum:	2086.62 µm²
Count:	131
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Sample 13234-195-45-4L inclusion area object measurement data.

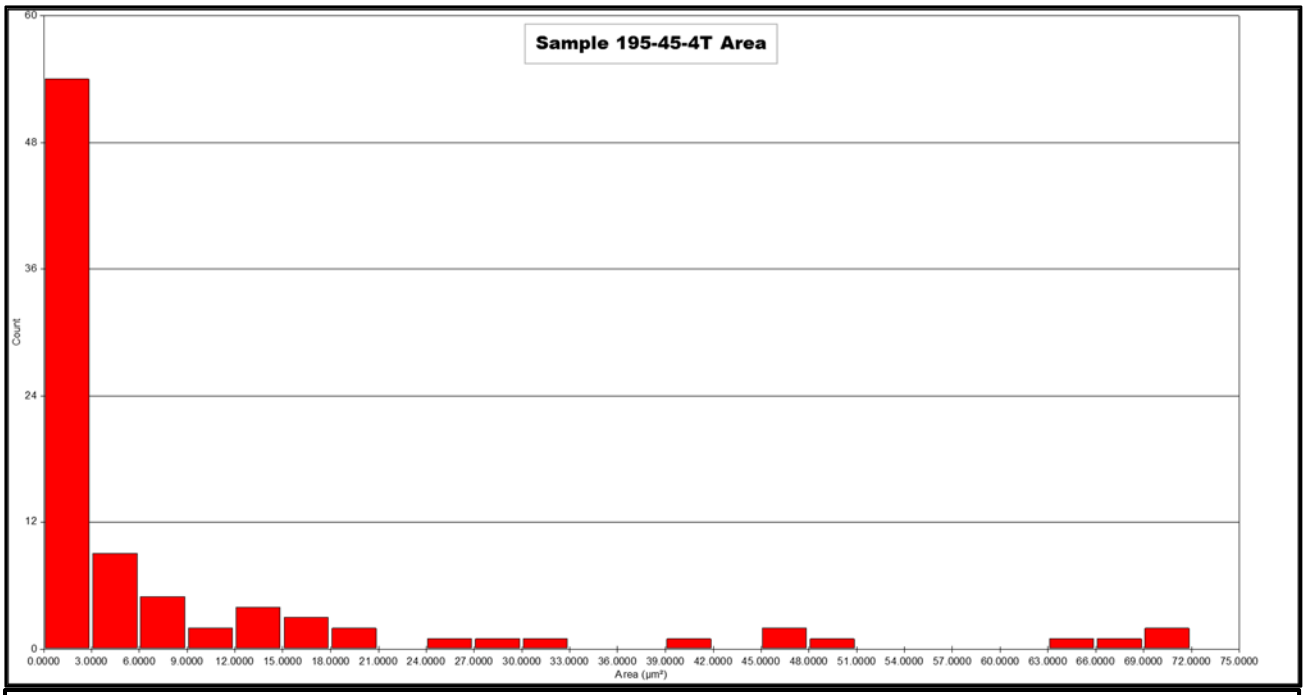


CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	9	7	7
0.5	1	35	27	34
1	1.5	18	14	47
1.5	2	14	11	58
2	2.5	11	8	66
2.5	3	8	6	73
3	3.5	4	3	76
3.5	4	2	2	77
4	4.5	4	3	80
4.5	5	4	3	83
5	5.5	2	2	85
5.5	6	4	3	88
6	6.5	2	2	89
6.5	7	2	2	91
7	7.5	0	0	91
7.5	8	4	3	94
8	8.5	0	0	94
8.5	9	0	0	94
9	9.5	2	2	95
9.5	10	0	0	95
10	10.5	1	1	96
10.5	11	0	0	96
11	11.5	0	0	96
11.5	12	0	0	96

CircDia (µm) From	To	Count	%	Cumulative %
12	12.5	2	2	98
12.5	13	0	0	98
13	13.5	0	0	98
13.5	14	0	0	98
14	14.5	0	0	98
14.5	15	1	1	98
15	15.5	0	0	98
15.5	16	0	0	98
16	16.5	0	0	98
16.5	17	0	0	98
17	17.5	1	1	99
17.5	18	0	0	99
18	18.5	0	0	99
18.5	19	0	0	99
19	19.5	0	0	99
19.5	20	0	0	99
20	20.5	0	0	99
20.5	21	0	0	99
21	21.5	0	0	99
21.5	22	0	0	99
22	22.5	0	0	99
22.5	23	1	1	100
23	23.5	0	0	100
23.5	24	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	22.98 µm
Mean:	2.88 µm
Std Dev.:	3.47 µm
Sum:	377.62 µm
Count:	131
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

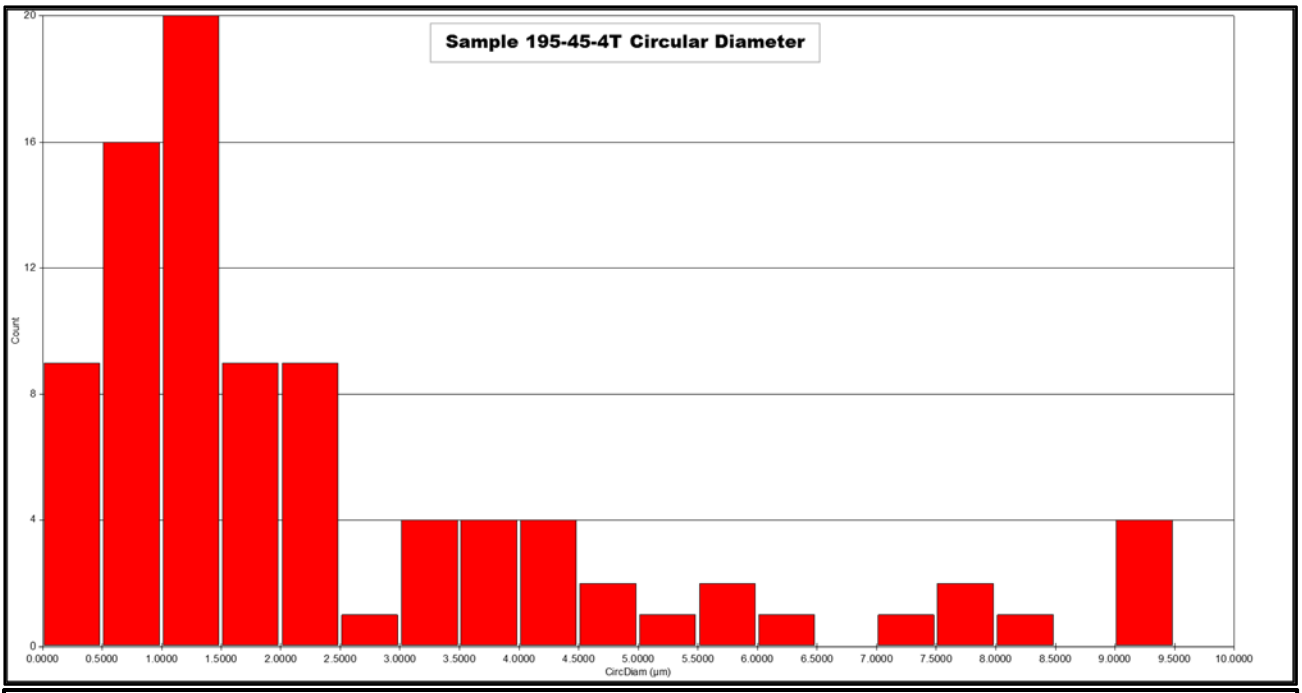
Sample 13234-195-45-4L inclusion circular diameter object measurement data.



Area (µm²) From	To	Count	%	Cumulative %
0	3	54	60	60
3	6	9	10	70
6	9	5	6	76
9	12	2	2	78
12	15	4	4	82
15	18	3	3	86
18	21	2	2	88
21	24	0	0	88
24	27	1	1	89
27	30	1	1	90
30	33	1	1	91
33	36	0	0	91
36	39	0	0	91
39	42	1	1	92
42	45	0	0	92
45	48	2	2	94
48	51	1	1	96
51	54	0	0	96
54	57	0	0	96
57	60	0	0	96
60	63	0	0	96
63	66	1	1	97
66	69	1	1	98
69	72	2	2	100
72	75	0	0	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	70.22 µm²
Mean:	9.20 µm²
Std Dev.:	16.70 µm²
Sum:	827.94 µm²
Count:	90
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

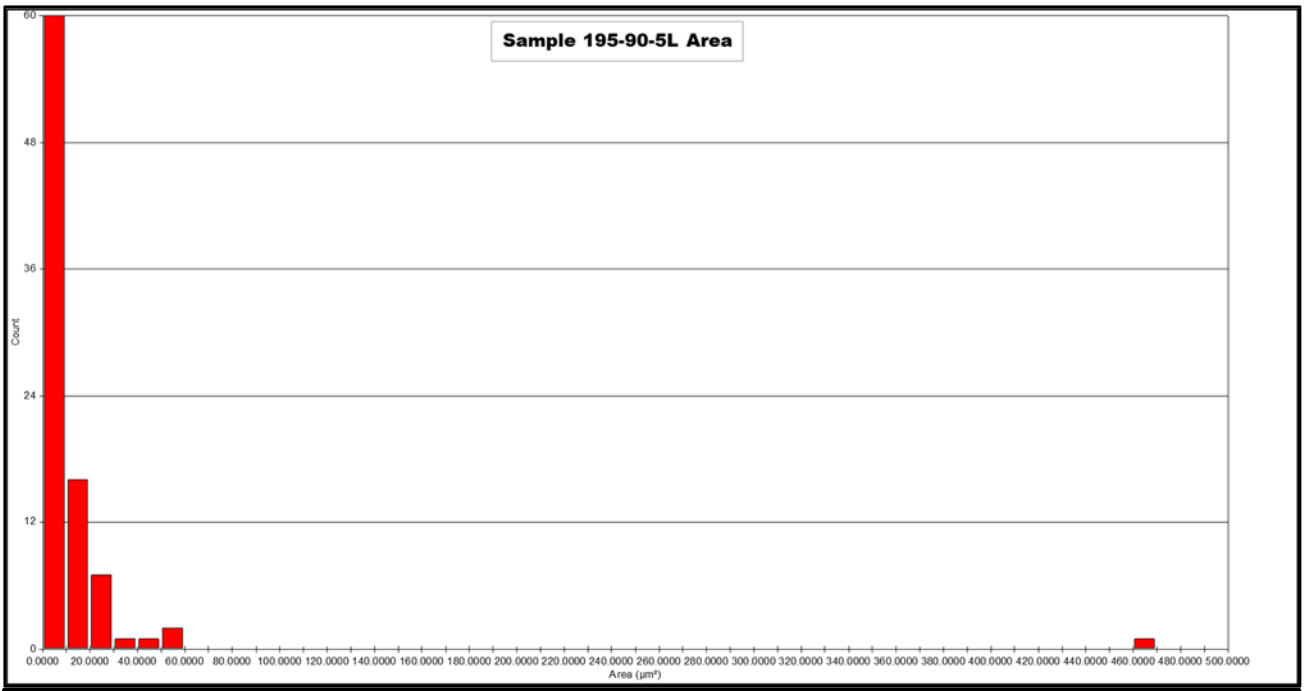
Sample 13234-195-45-4T inclusion area object measurement data.



CircDia (µm)		Count	%	Cumulative %
0	0.5	9	10	10
0.5	1	16	18	28
1	1.5	20	22	50
1.5	2	9	10	60
2	2.5	9	10	70
2.5	3	1	1	71
3	3.5	4	4	76
3.5	4	4	4	80
4	4.5	4	4	84
4.5	5	2	2	87
5	5.5	1	1	88
5.5	6	2	2	90
6	6.5	1	1	91
6.5	7	0	0	91
7	7.5	1	1	92
7.5	8	2	2	94
8	8.5	1	1	96
8.5	9	0	0	96
9	9.5	4	4	100
9.5	10	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	9.46 µm
Mean:	2.49 µm
Std Dev.:	2.36 µm
Sum:	224.19 µm
Count:	90
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Sample 13234-195-45-4T inclusion circular diameter object measurement data.

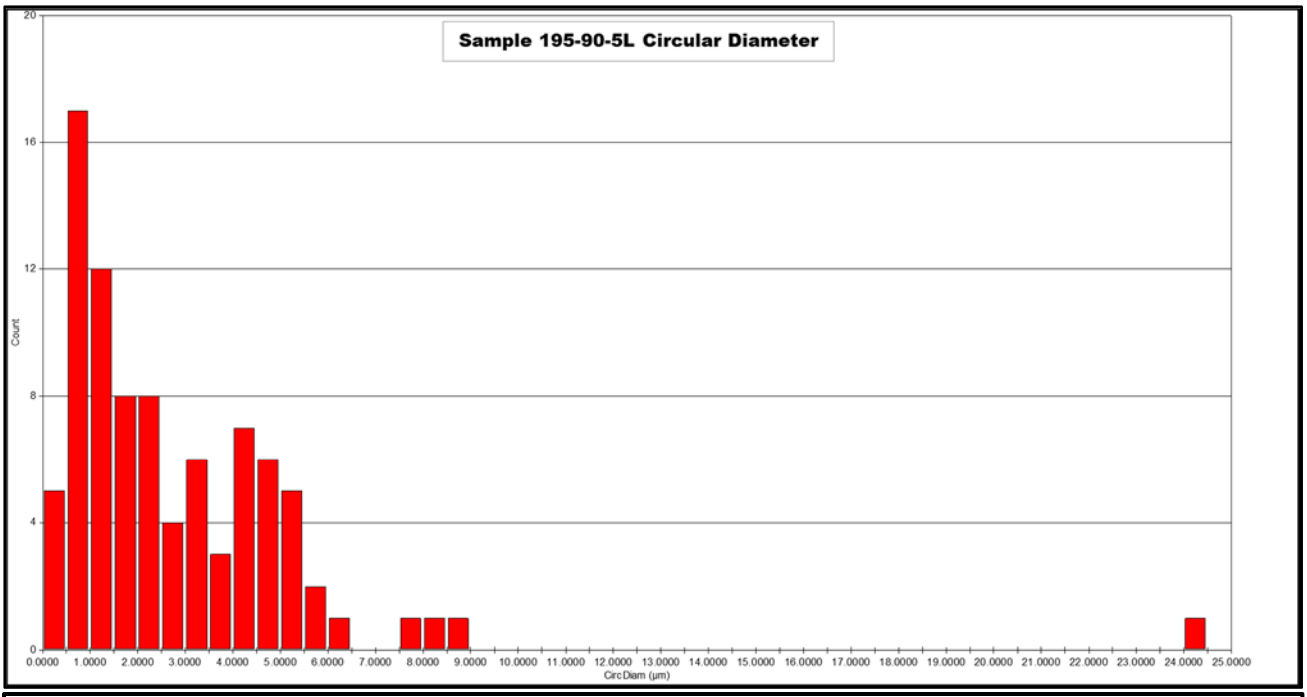


Area (µm²) From	To	Count	%	Cumulative %
0	10	60	68	68
10	20	16	18	86
20	30	7	8	94
30	40	1	1	95
40	50	1	1	97
50	60	2	2	99
60	70	0	0	99
70	80	0	0	99
80	90	0	0	99
90	100	0	0	99
100	110	0	0	99
110	120	0	0	99
120	130	0	0	99
130	140	0	0	99
140	150	0	0	99
150	160	0	0	99
160	170	0	0	99
170	180	0	0	99
180	190	0	0	99
190	200	0	0	99
200	210	0	0	99
210	220	0	0	99
220	230	0	0	99
230	240	0	0	99
240	250	0	0	99

Area (µm²) From	To	Count	%	Cumulative %
250	260	0	0	99
260	270	0	0	99
270	280	0	0	99
280	290	0	0	99
290	300	0	0	99
300	310	0	0	99
310	320	0	0	99
320	330	0	0	99
330	340	0	0	99
340	350	0	0	99
350	360	0	0	99
360	370	0	0	99
370	380	0	0	99
380	390	0	0	99
390	400	0	0	99
400	410	0	0	99
410	420	0	0	99
420	430	0	0	99
430	440	0	0	99
440	450	0	0	99
450	460	0	0	99
460	470	1	1	100
470	480	0	0	100
480	490	0	0	100
490	500	0	0	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	464.17 µm²
Mean:	13.55 µm²
Std Dev.:	49.86 µm²
Sum:	1192.71 µm²
Count:	88
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Sample 13234-195-90-5L inclusion area object measurement data.

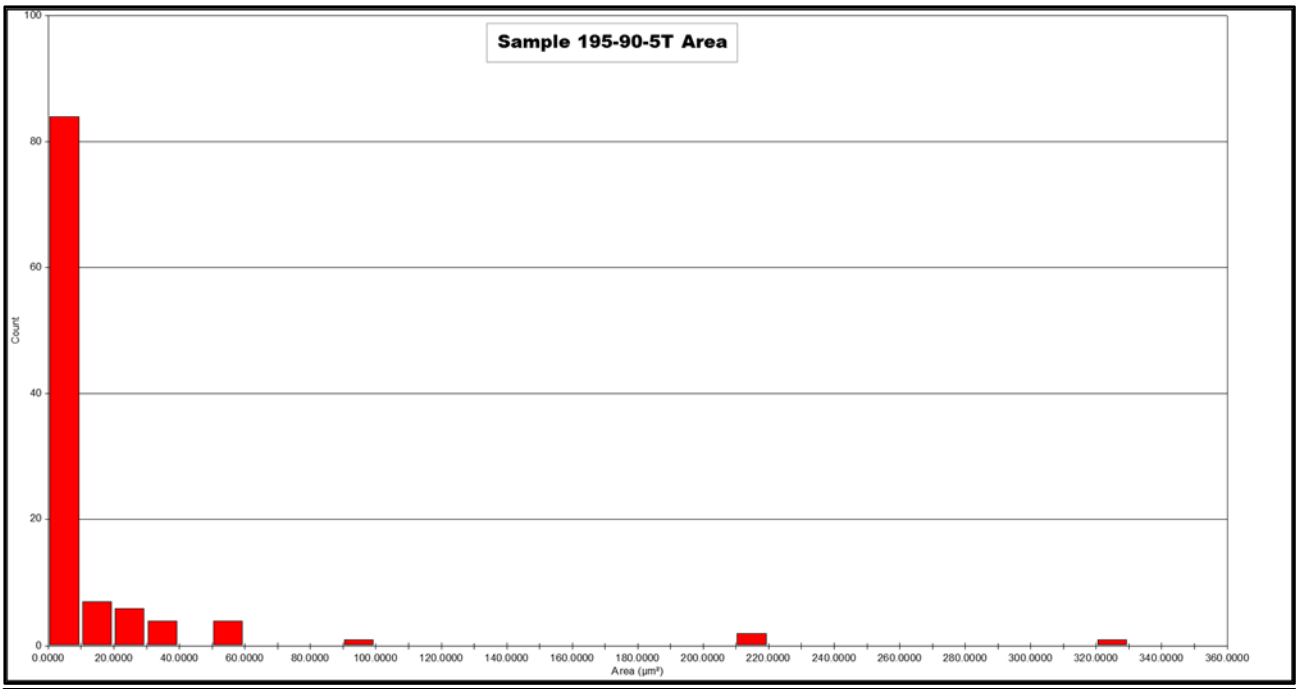


CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	5	6	6
0.5	1	17	19	25
1	1.5	12	14	39
1.5	2	8	9	48
2	2.5	8	9	57
2.5	3	4	5	61
3	3.5	6	7	68
3.5	4	3	3	72
4	4.5	7	8	80
4.5	5	6	7	86
5	5.5	5	6	92
5.5	6	2	2	94
6	6.5	1	1	95
6.5	7	0	0	95
7	7.5	0	0	95
7.5	8	1	1	97
8	8.5	1	1	98
8.5	9	1	1	99
9	9.5	0	0	99
9.5	10	0	0	99
10	10.5	0	0	99
10.5	11	0	0	99
11	11.5	0	0	99
11.5	12	0	0	99
12	12.5	0	0	99

CircDia (µm) From	To	Count	%	Cumulative %
12.5	13	0	0	99
13	13.5	0	0	99
13.5	14	0	0	99
14	14.5	0	0	99
14.5	15	0	0	99
15	15.5	0	0	99
15.5	16	0	0	99
16	16.5	0	0	99
16.5	17	0	0	99
17	17.5	0	0	99
17.5	18	0	0	99
18	18.5	0	0	99
18.5	19	0	0	99
19	19.5	0	0	99
19.5	20	0	0	99
20	20.5	0	0	99
20.5	21	0	0	99
21	21.5	0	0	99
21.5	22	0	0	99
22	22.5	0	0	99
22.5	23	0	0	99
23	23.5	0	0	99
23.5	24	0	0	99
24	24.5	1	1	100
24.5	25	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	24.31 µm
Mean:	2.88 µm
Std Dev.:	3.01 µm
Sum:	253.19 µm
Count:	88
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

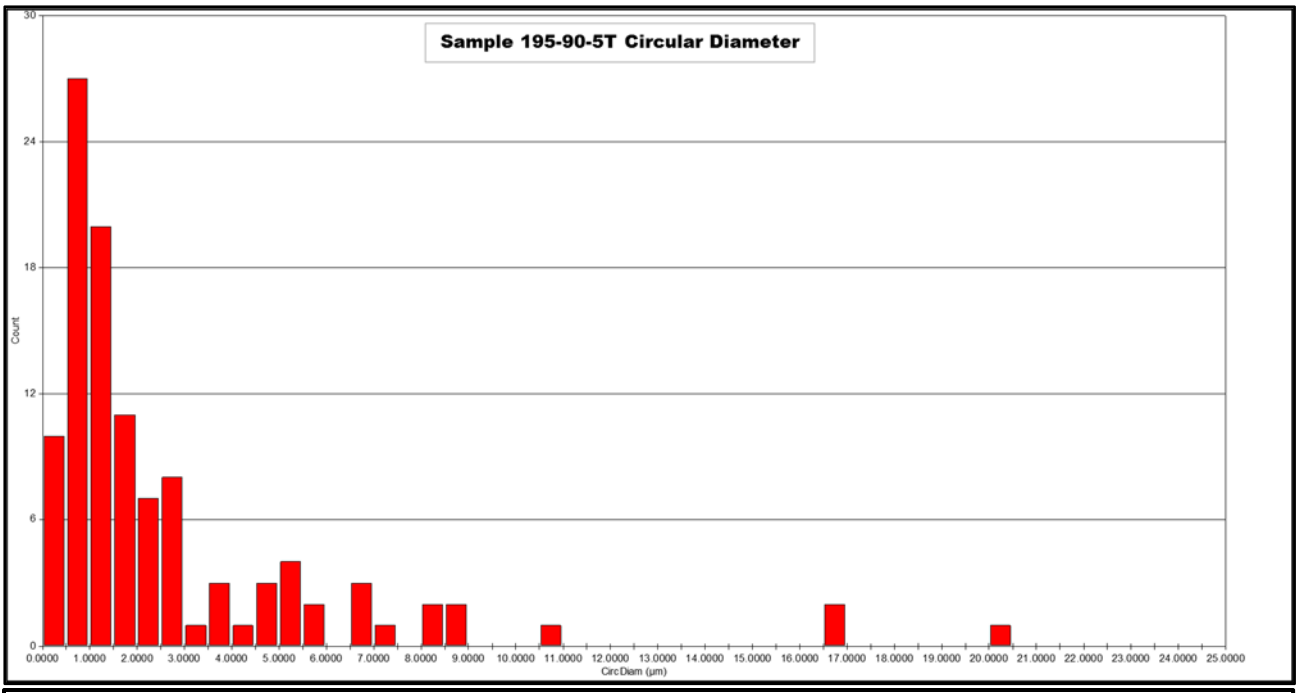
Sample 13234-195-90-5L inclusion circular diameter object measurement data.



Area (µm²) From	To	Count	%	Cumulative %
0	10	84	77	77
10	20	7	6	83
20	30	6	6	89
30	40	4	4	93
40	50	0	0	93
50	60	4	4	96
60	70	0	0	96
70	80	0	0	96
80	90	0	0	96
90	100	1	1	97
100	110	0	0	97
110	120	0	0	97
120	130	0	0	97
130	140	0	0	97
140	150	0	0	97
150	160	0	0	97
160	170	0	0	97
170	180	0	0	97
180	190	0	0	97
190	200	0	0	97
200	210	0	0	97
210	220	2	2	99
220	230	0	0	99
230	240	0	0	99
240	250	0	0	99
250	260	0	0	99
260	270	0	0	99
270	280	0	0	99
280	290	0	0	99
290	300	0	0	99
300	310	0	0	99
310	320	0	0	99
320	330	1	1	100
330	340	0	0	100
340	350	0	0	100
350	360	0	0	100

Statistics:	
Minimum:	0.14 µm²
Maximum:	326.17 µm²
Mean:	14.72 µm²
Std Dev.:	43.89 µm²
Sum:	1604.77 µm²
Count:	109
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

Sample 13234-195-90-5T inclusion area object measurement data.



CircDia (µm) From	To	Count	%	Cumulative %
0	0.5	10	9	9
0.5	1	27	25	34
1	1.5	20	18	52
1.5	2	11	10	62
2	2.5	7	6	69
2.5	3	8	7	76
3	3.5	1	1	77
3.5	4	3	3	80
4	4.5	1	1	81
4.5	5	3	3	83
5	5.5	4	4	87
5.5	6	2	2	89
6	6.5	0	0	89
6.5	7	3	3	92
7	7.5	1	1	93
7.5	8	0	0	93
8	8.5	2	2	95
8.5	9	2	2	96
9	9.5	0	0	96
9.5	10	0	0	96
10	10.5	0	0	96
10.5	11	1	1	97
11	11.5	0	0	97
11.5	12	0	0	97
12	12.5	0	0	97

CircDia (µm) From	To	Count	%	Cumulative %
12.5	13	0	0	97
13	13.5	0	0	97
13.5	14	0	0	97
14	14.5	0	0	97
14.5	15	0	0	97
15	15.5	0	0	97
15.5	16	0	0	97
16	16.5	0	0	97
16.5	17	2	2	99
17	17.5	0	0	99
17.5	18	0	0	99
18	18.5	0	0	99
18.5	19	0	0	99
19	19.5	0	0	99
19.5	20	0	0	99
20	20.5	1	1	100
20.5	21	0	0	100
21	21.5	0	0	100
21.5	22	0	0	100
22	22.5	0	0	100
22.5	23	0	0	100
23	23.5	0	0	100
23.5	24	0	0	100
24	24.5	0	0	100
24.5	25	0	0	100

Statistics:	
Minimum:	0.43 µm
Maximum:	20.38 µm
Mean:	2.70 µm
Std Dev.:	3.40 µm
Sum:	294.08 µm
Count:	109
Under:	0
Over:	0
Accepted:	100 %
Field Count:	7
Field Area:	99075.82 µm²
Total Area:	693530.75 µm²

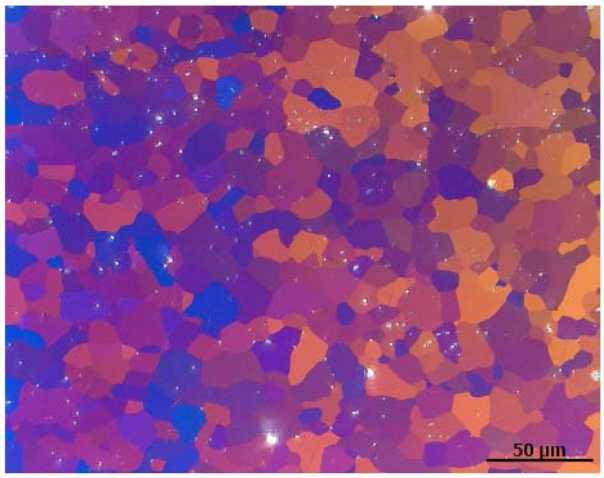
Sample 13234-195-90-5T inclusion circular diameter object measurement data.

Appendix C – Axiovision-Generated Grain Size Data

Sample No:	13234-116-45-1L
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.9

Image - 1

Grain Size Number Ø: 10.00



Original image

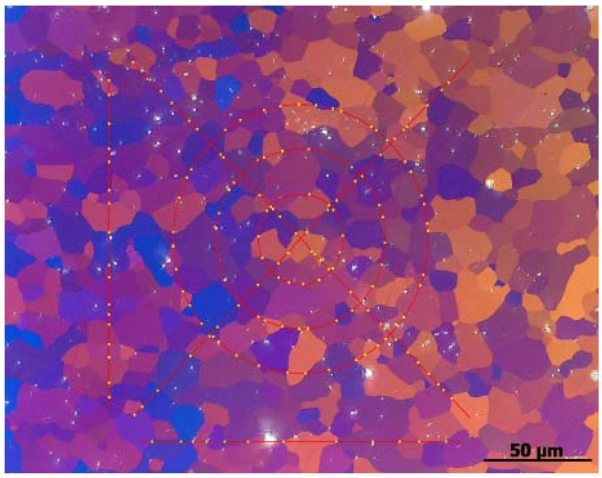
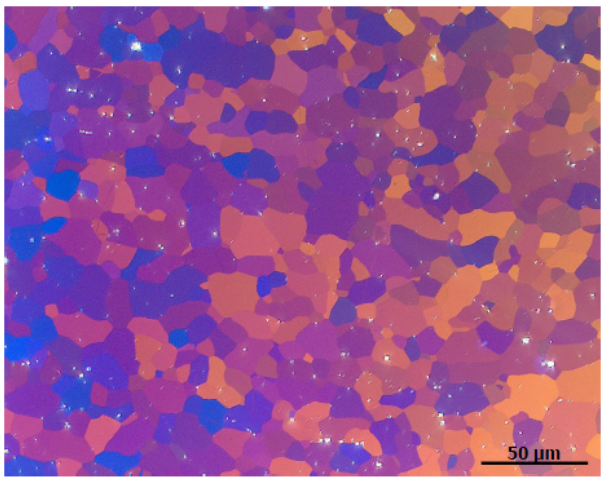


Image with Annotations

Image - 2

Grain Size Number Ø: 10.00



Original image

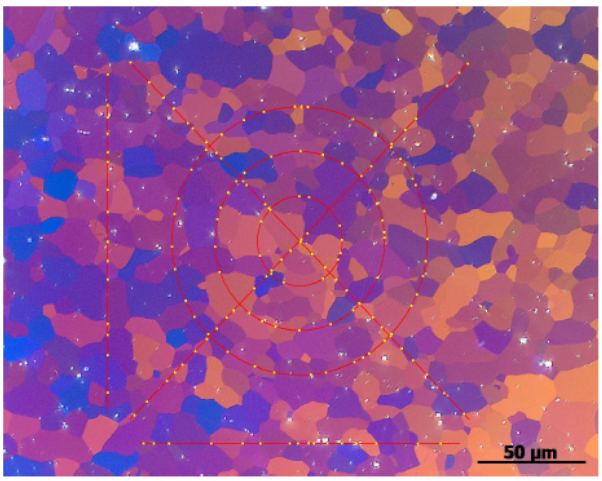
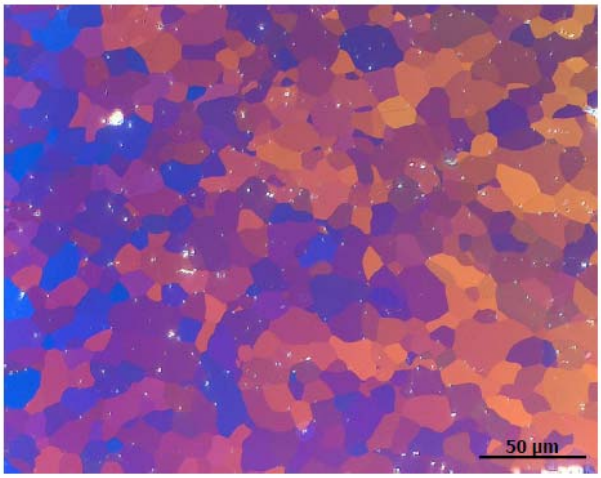


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

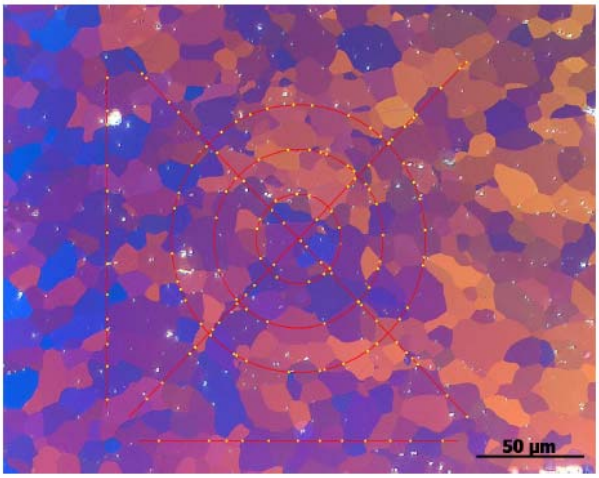
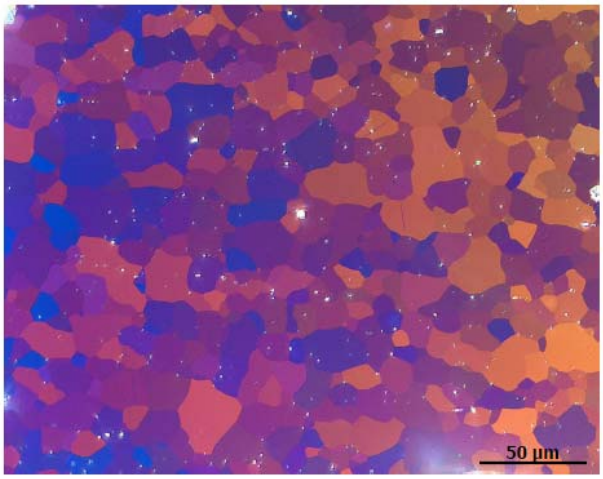


Image with Annotations

Image - 4

Grain Size Number Ø: 9.50



Original image

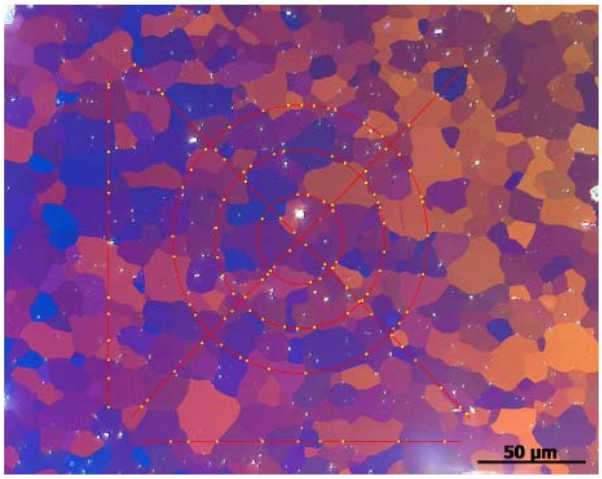
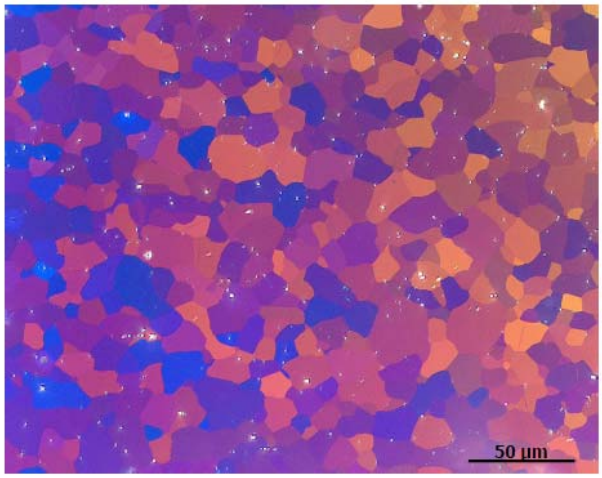


Image with Annotations

Image - 5

Grain Size Number Ø: 10.00



Original image

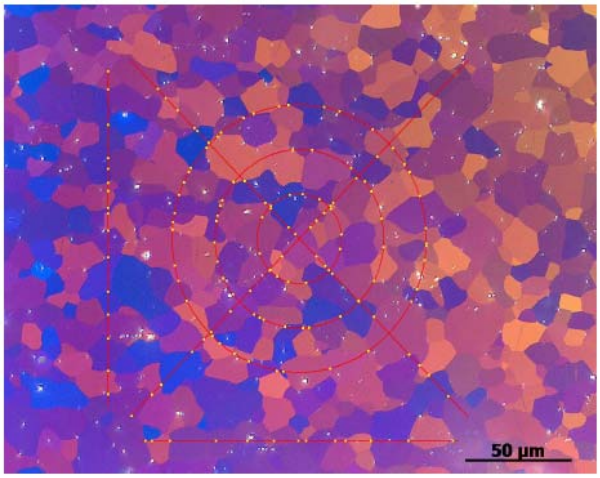
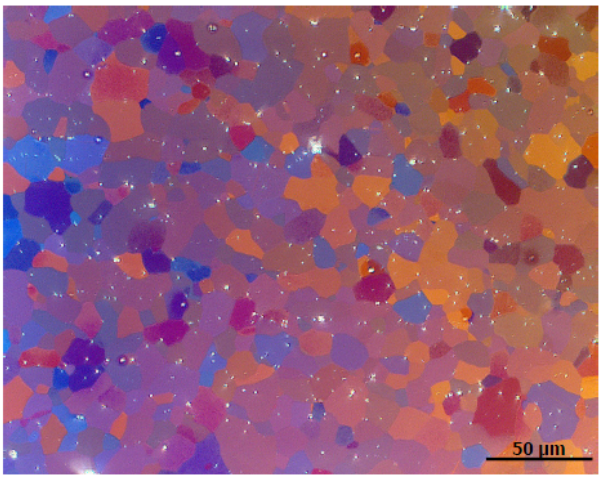


Image with Annotations

Sample No:	13234-116-45-1T
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	10.1

Image - 1

Grain Size Number Ø: 10.50



Original image

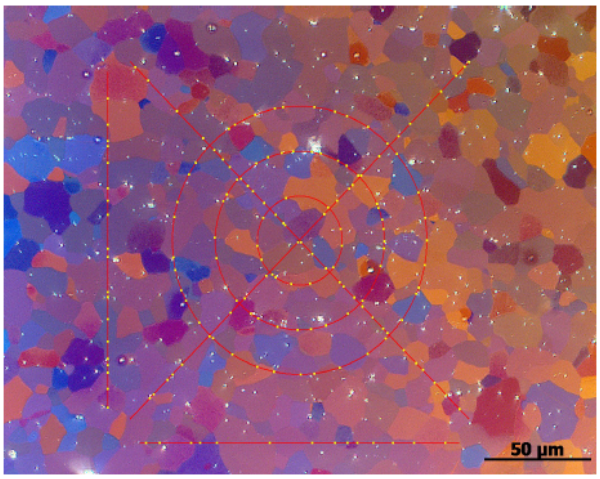
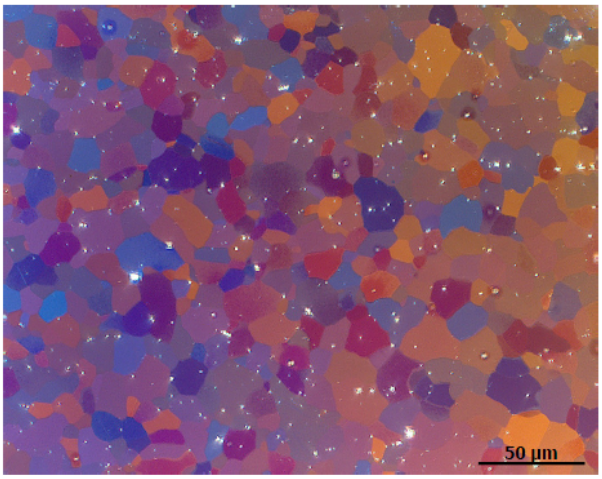


Image with Annotations

Image - 2

Grain Size Number Ø: 10.00



Original image

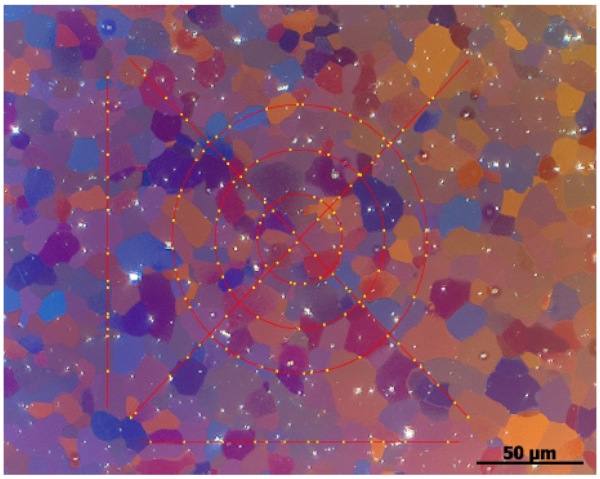
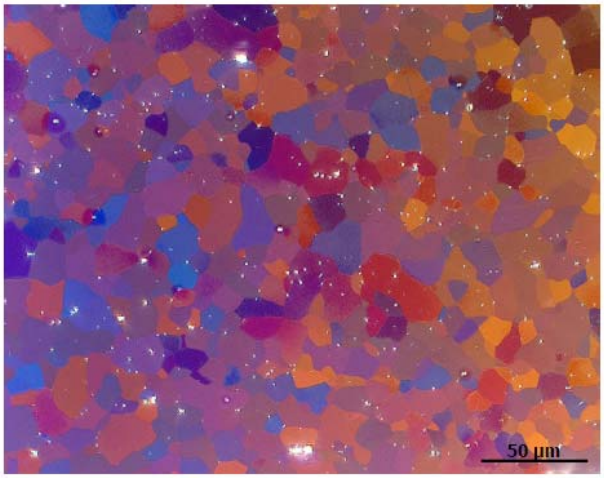


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

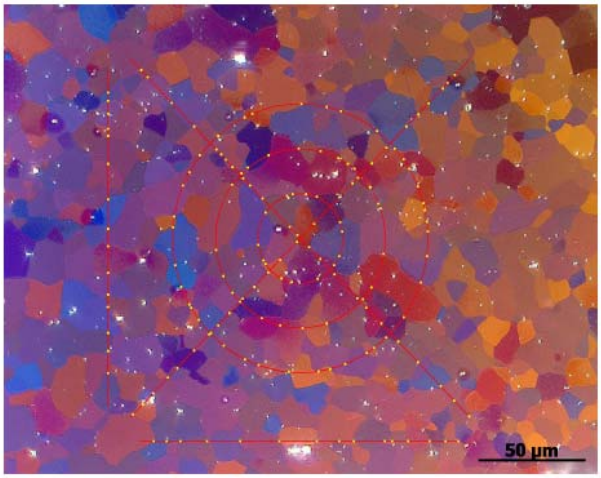
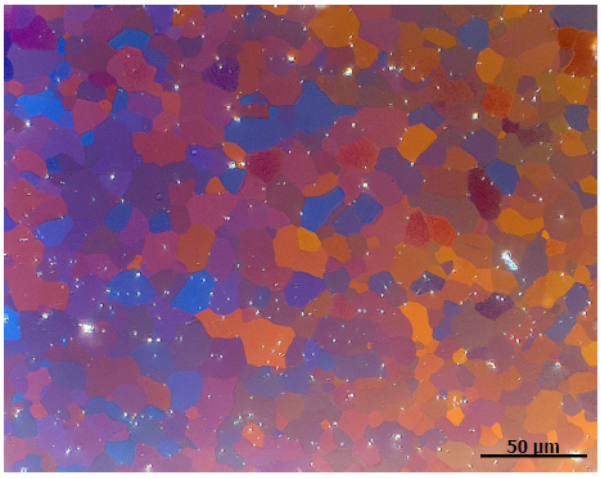


Image with Annotations

Image - 4

Grain Size Number Ø: 10.00



Original image

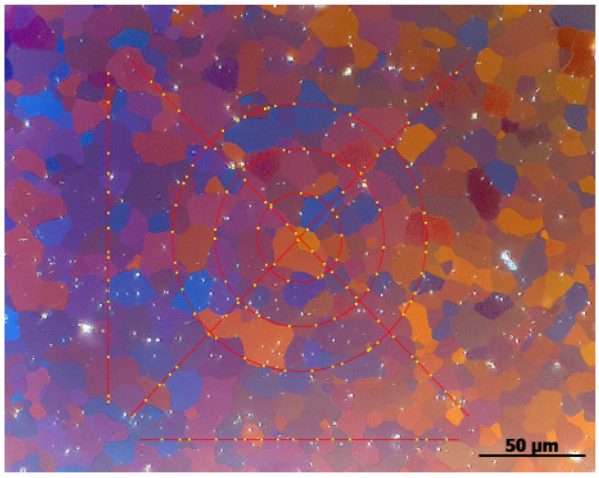
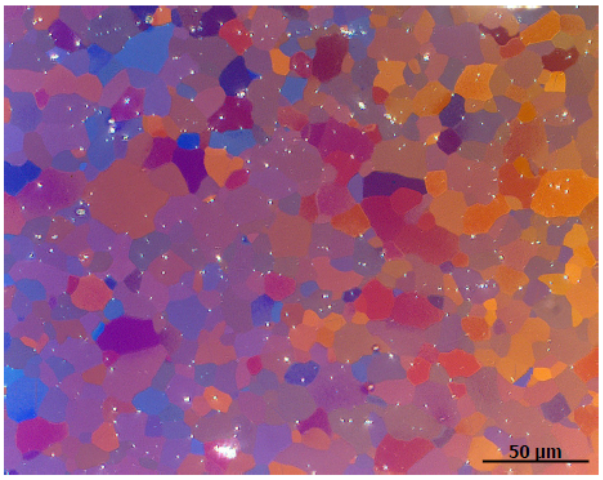


Image with Annotations

Image - 5

Grain Size Number Ø: 10.00



Original image

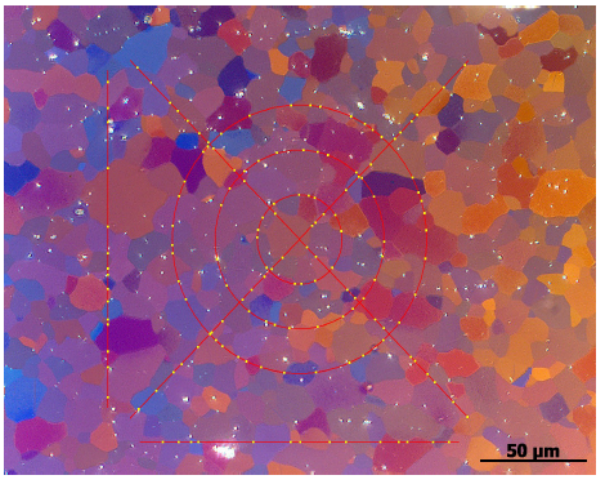
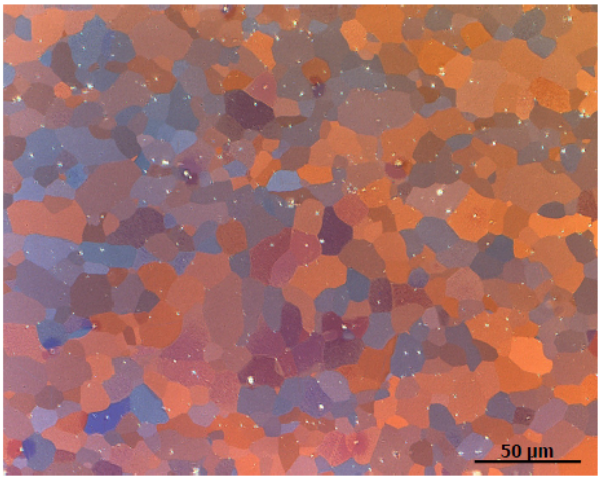


Image with Annotations

Sample No:	13234-116-90-2L
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.8

Image - 1

Grain Size Number Ø: 10.00



Original image

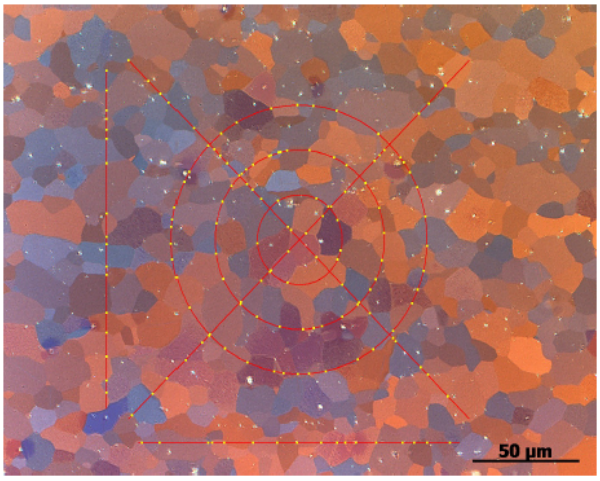
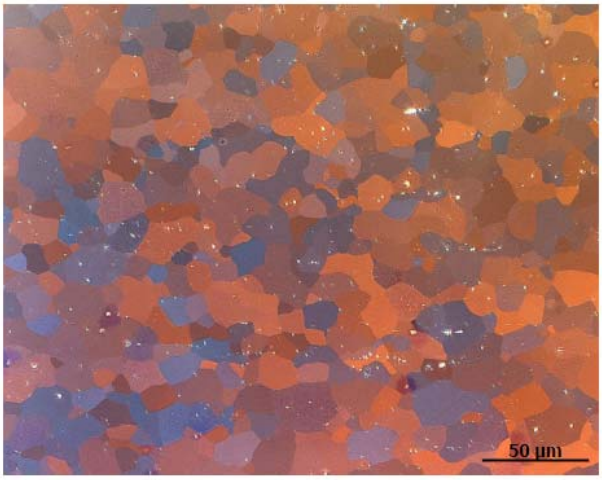


Image with Annotations

Image - 2

Grain Size Number Ø: 10.00



Original image

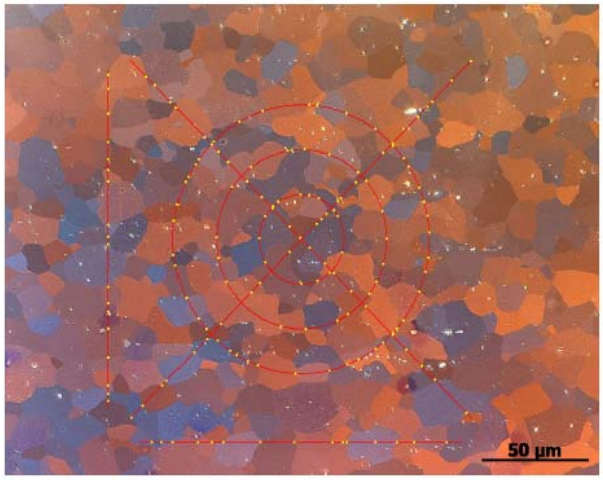
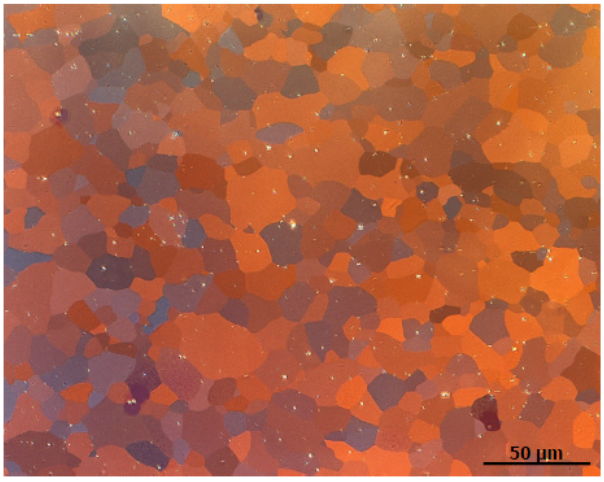


Image with Annotations

Image - 3

Grain Size Number Ø: 9.50



Original image

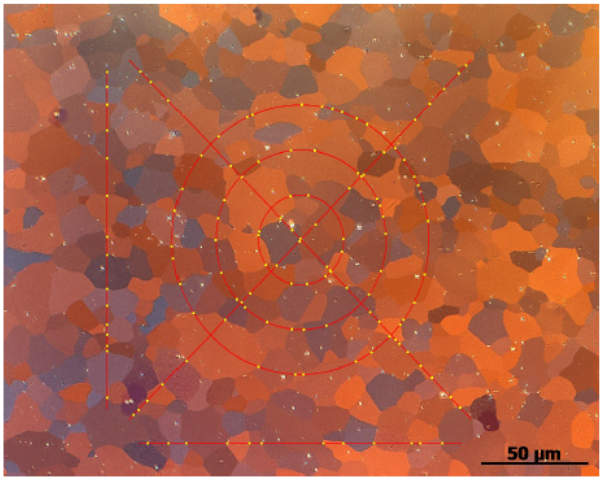
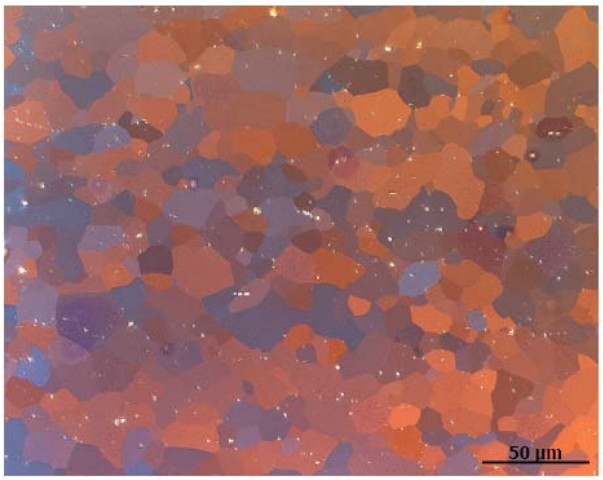


Image with Annotations

Image - 4

Grain Size Number Ø: 9.50



Original image

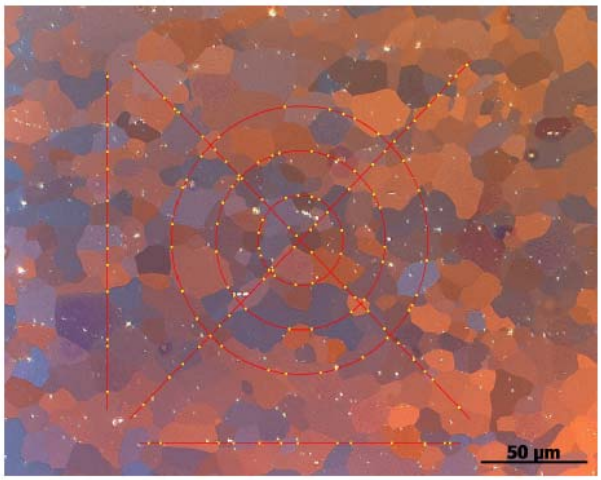
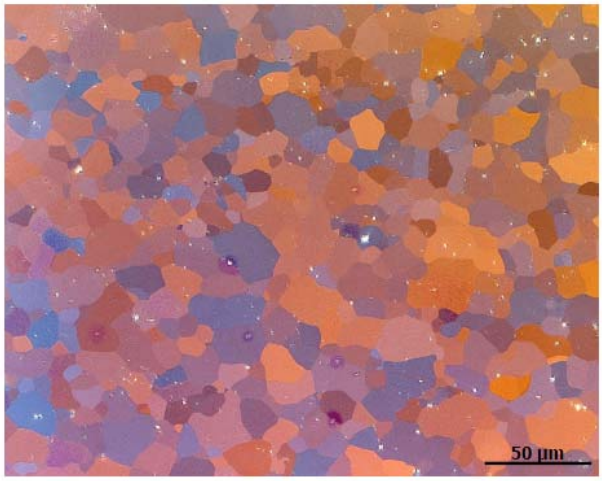


Image with Annotations

Image - 5

Grain Size Number Ø: 10.00



Original image

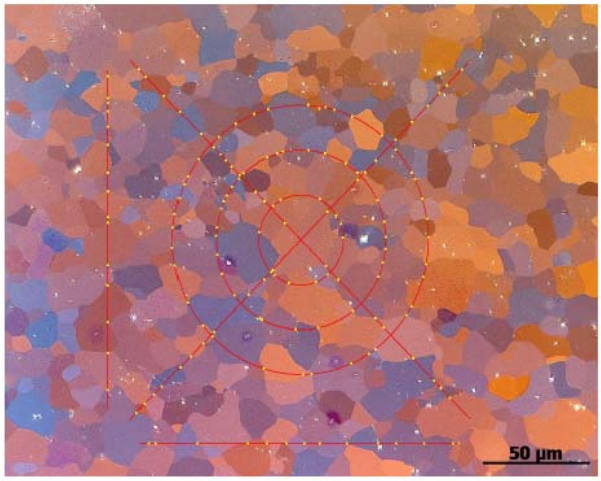
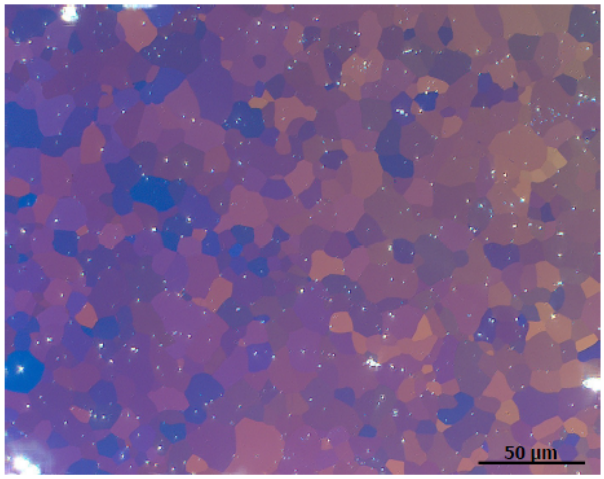


Image with Annotations

Sample No:	13234-116-90-2T
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.9

Image - 1

Grain Size Number Ø: 10.00



Original image

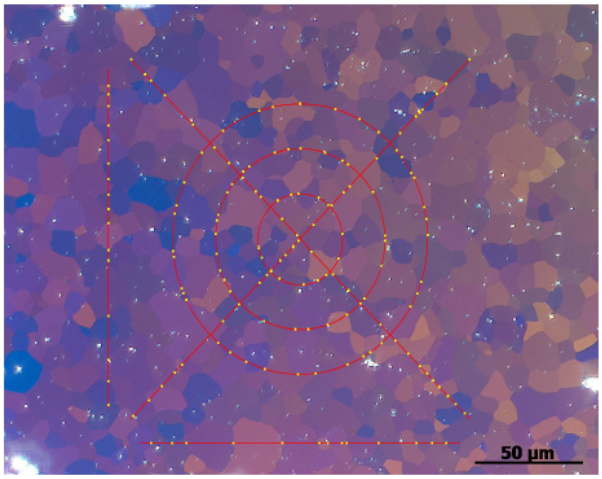
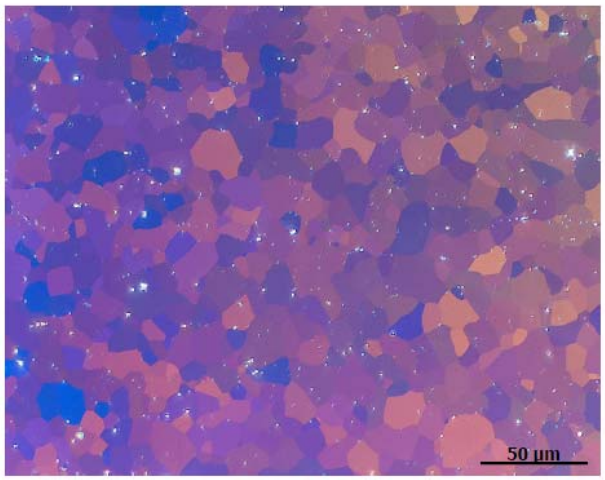


Image with Annotations

Image - 2

Grain Size Number Ø: 10.00



Original image

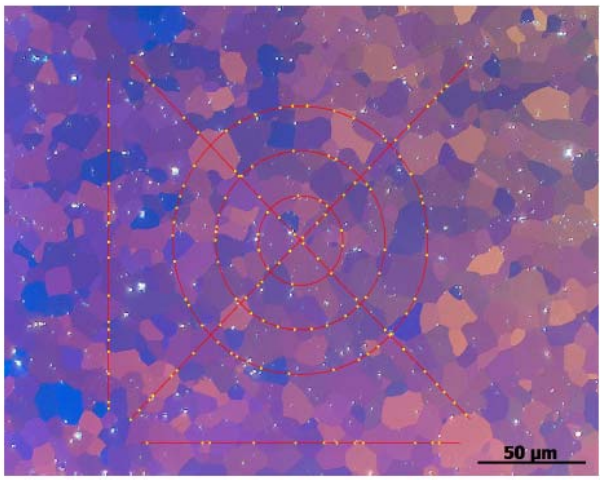
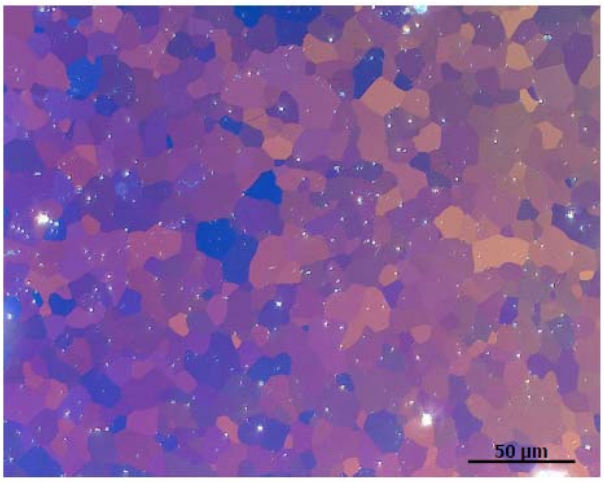


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

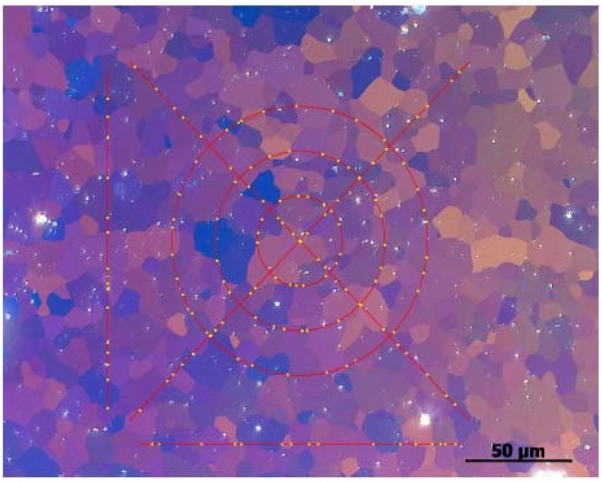
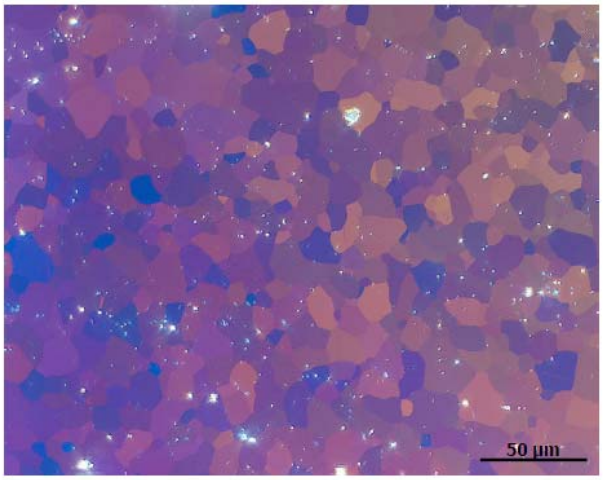


Image with Annotations

Image - 4

Grain Size Number Ø: 10.00



Original image

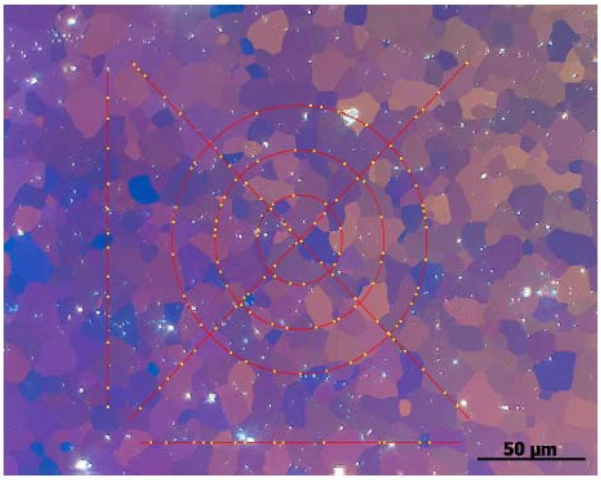
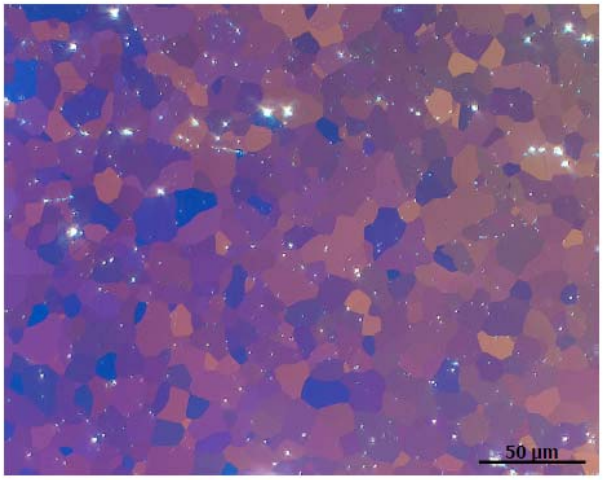


Image with Annotations

Image - 5

Grain Size Number Ø: 9.50



Original image

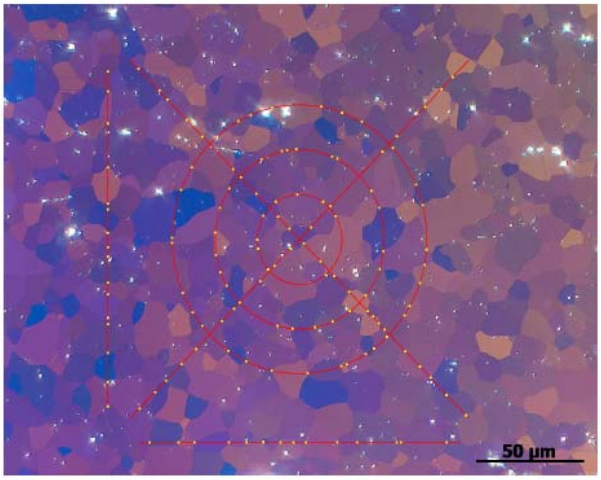
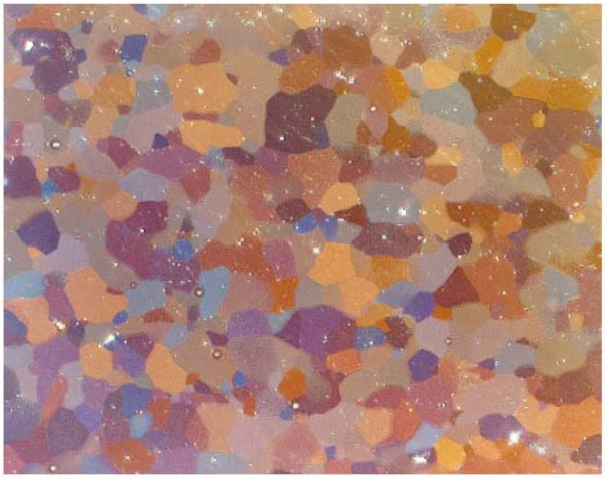


Image with Annotations

Sample No:	13234-195-0-3L
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.5

Image - 1

Grain Size Number Ø: 9.50



Original image

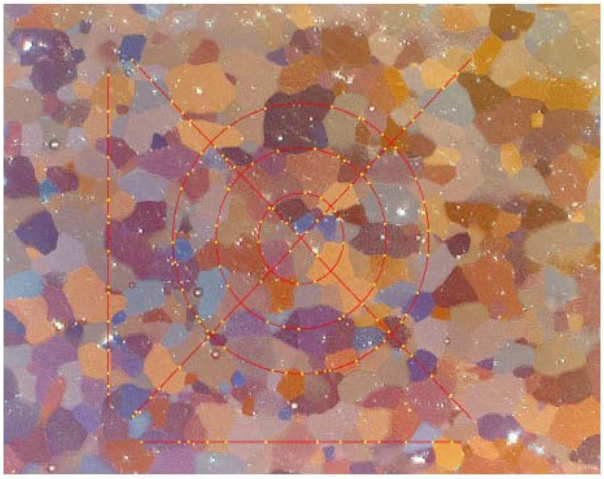
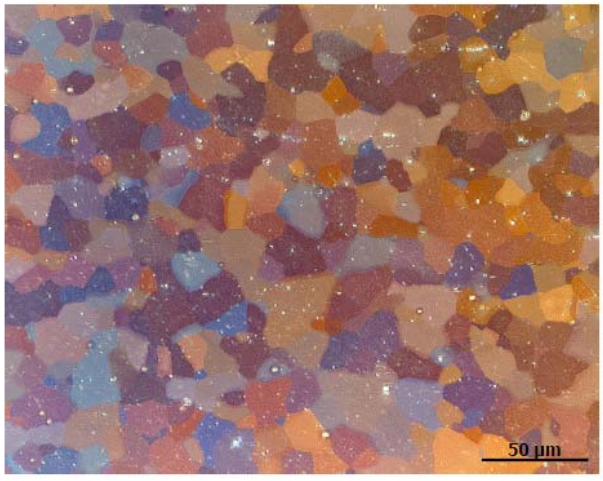


Image with Annotations

Image - 2

Grain Size Number Ø: 9.50



Original image

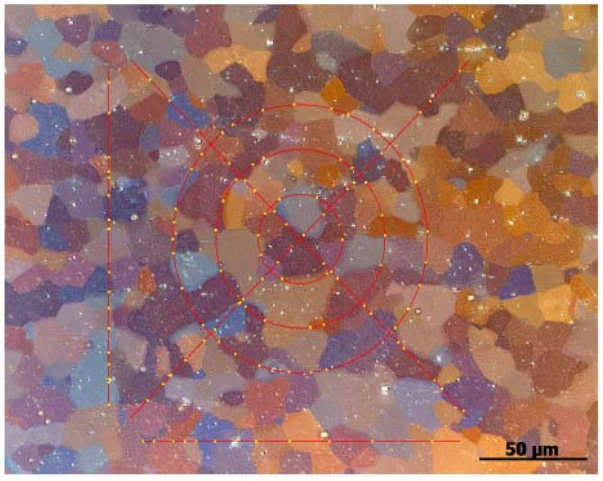
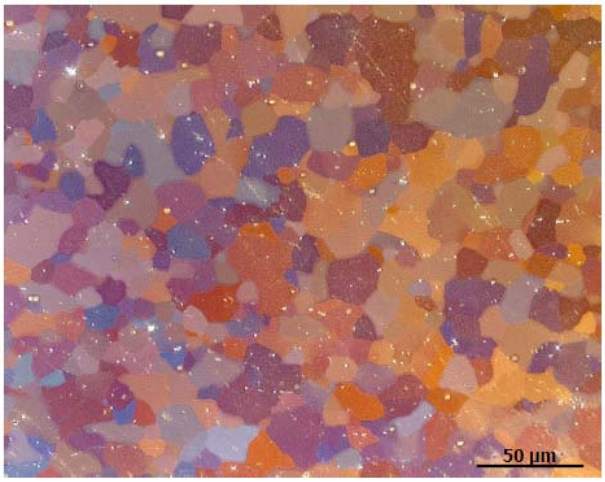


Image with Annotations

Image - 3

Grain Size Number Ø: 9.50



Original image

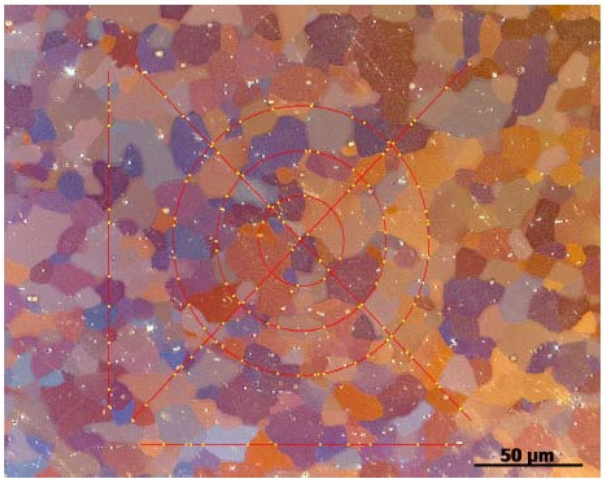
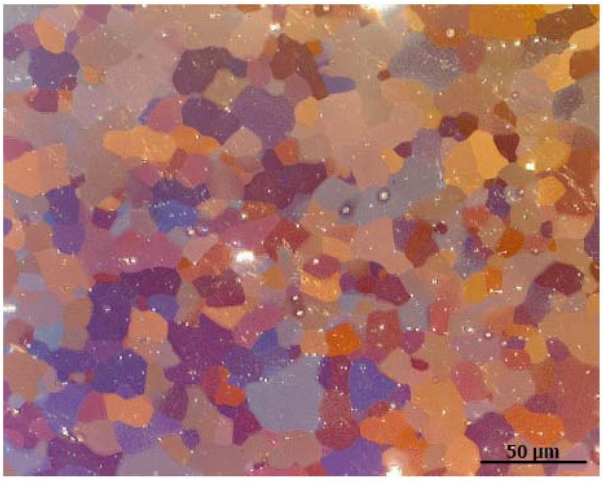


Image with Annotations

Image - 4

Grain Size Number Ø: 9.50



Original image

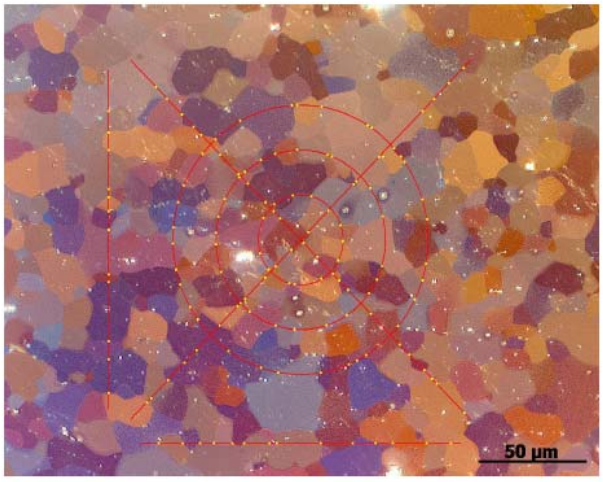
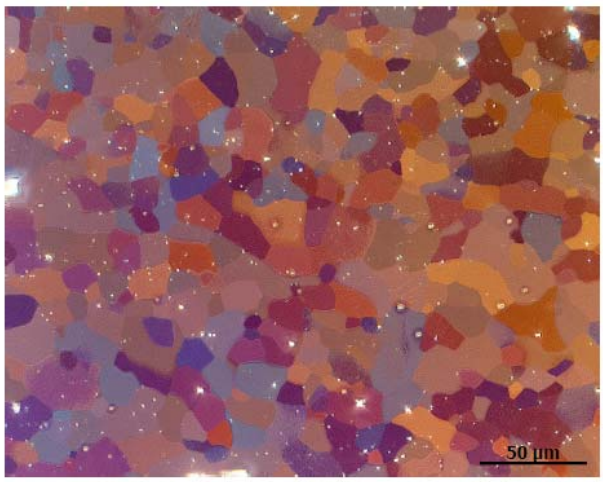


Image with Annotations

Image - 5

Grain Size Number Ø: 9.50



Original image

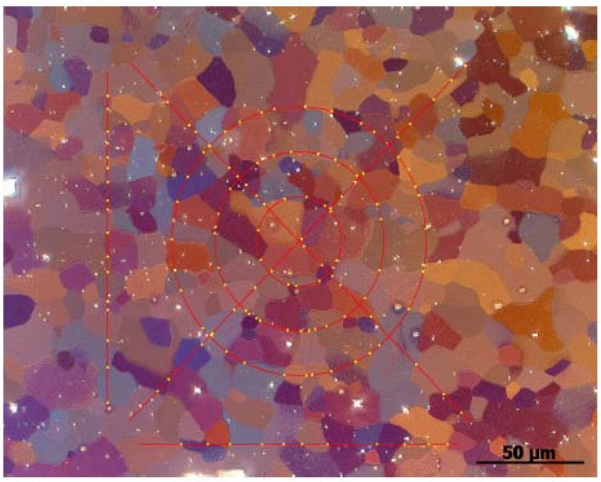
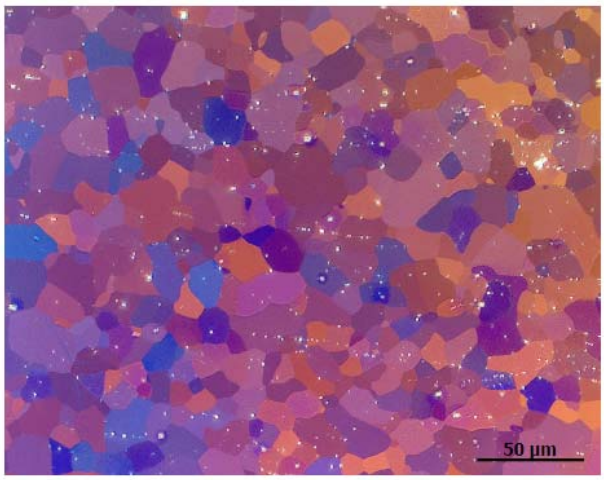


Image with Annotations

Sample No:	13234-195-0-3T
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.8

Image - 1

Grain Size Number Ø: 10.00



Original image

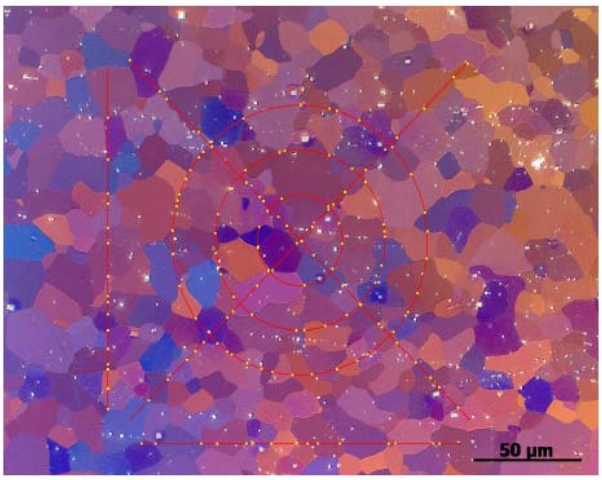
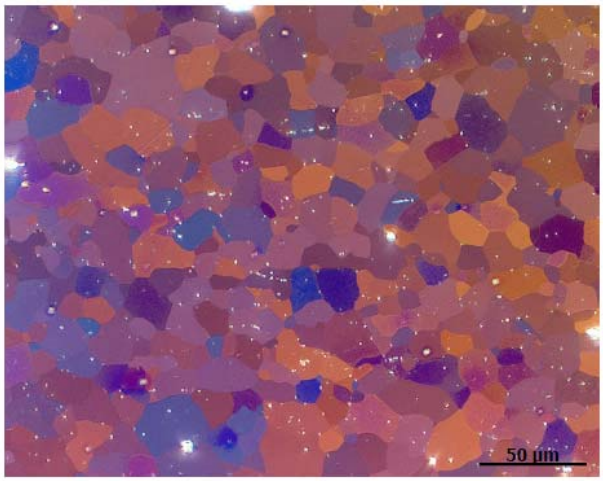


Image with Annotations

Image - 2

Grain Size Number Ø: 10.00



Original image

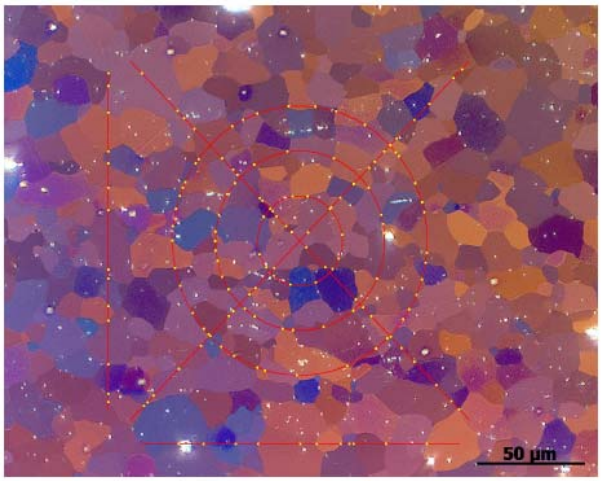
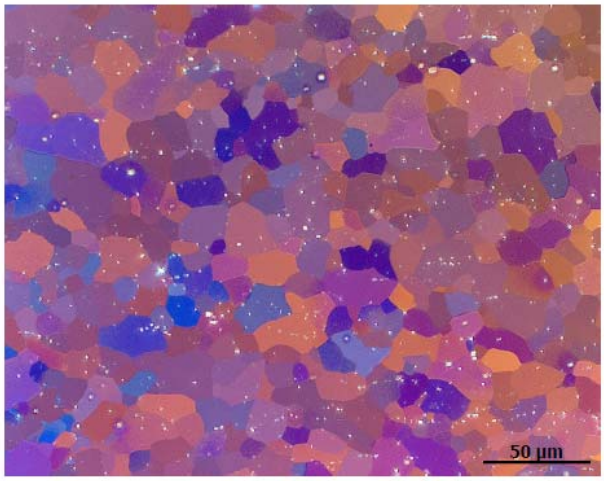


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

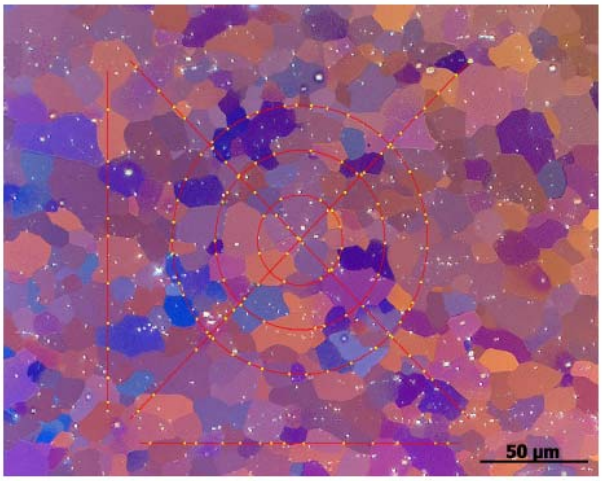
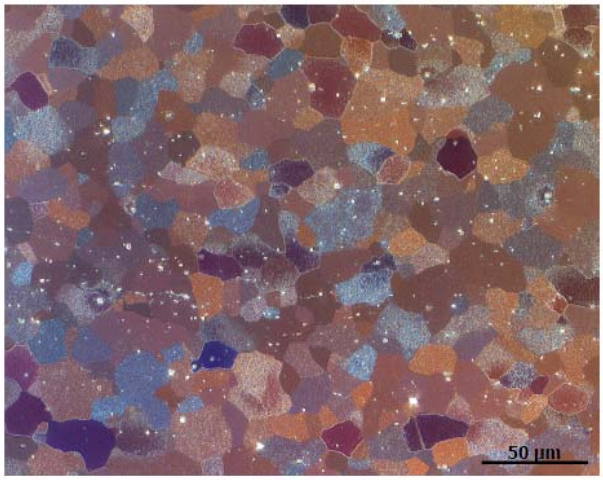


Image with Annotations

Image - 4

Grain Size Number Ø: 9.50



Original image

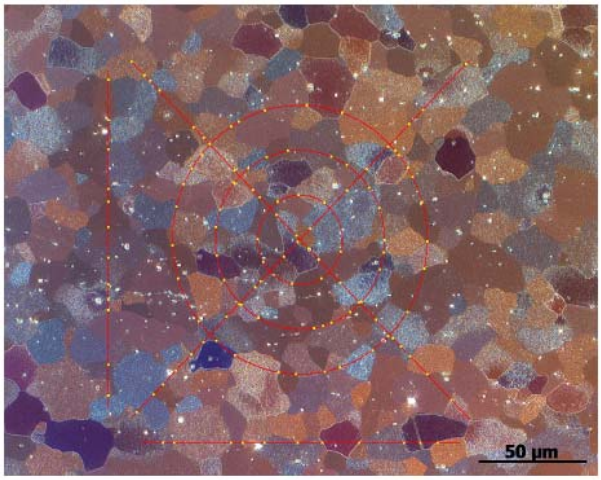
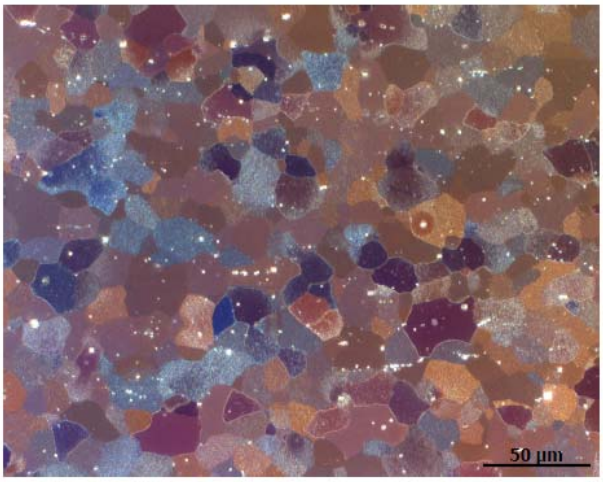


Image with Annotations

Image - 5

Grain Size Number Ø: 9.50



Original image

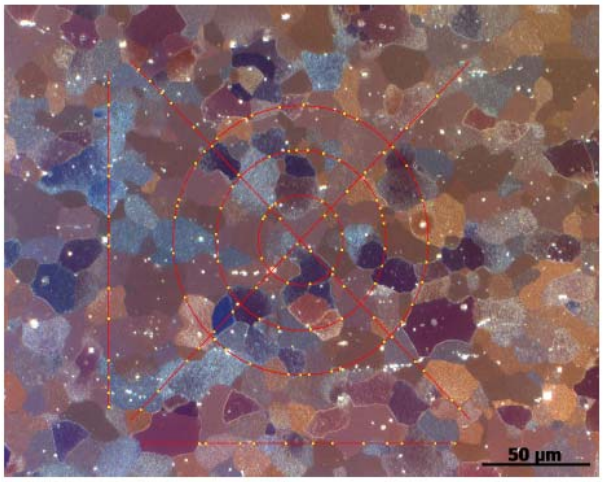
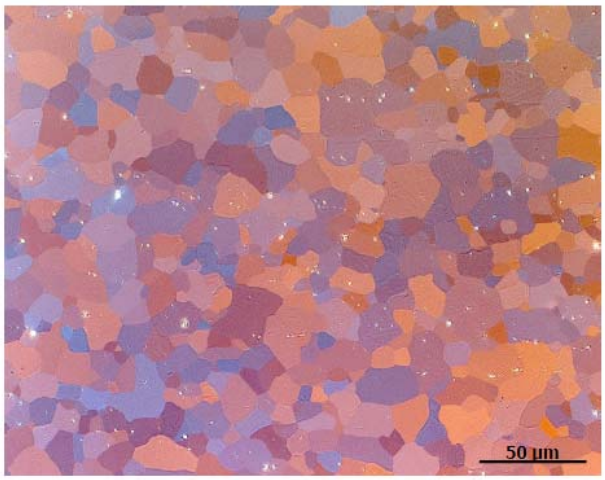


Image with Annotations

Sample No:	13234-195-45-4L
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.9

Image - 1

Grain Size Number Ø: 10.00



Original image

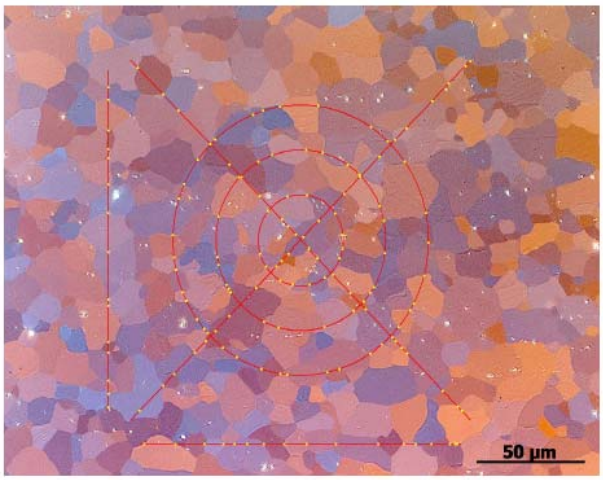
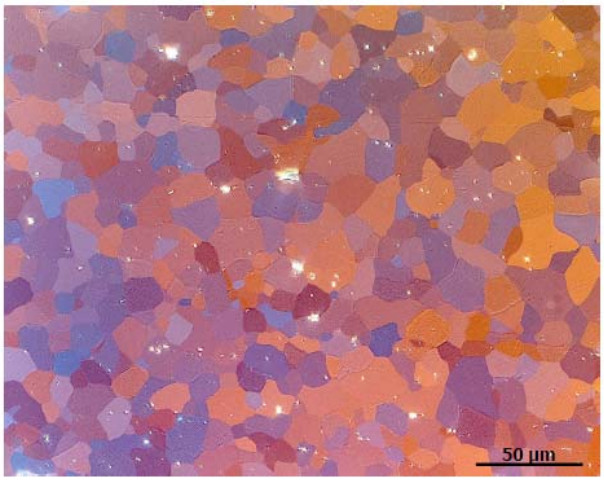


Image with Annotations

Image - 2

Grain Size Number Ø: 9.50



Original image

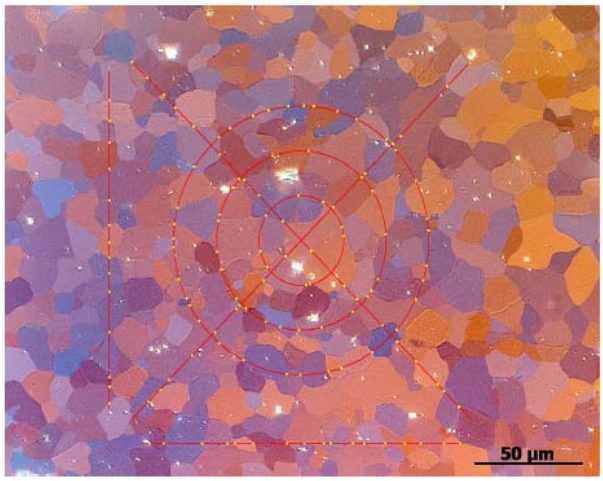
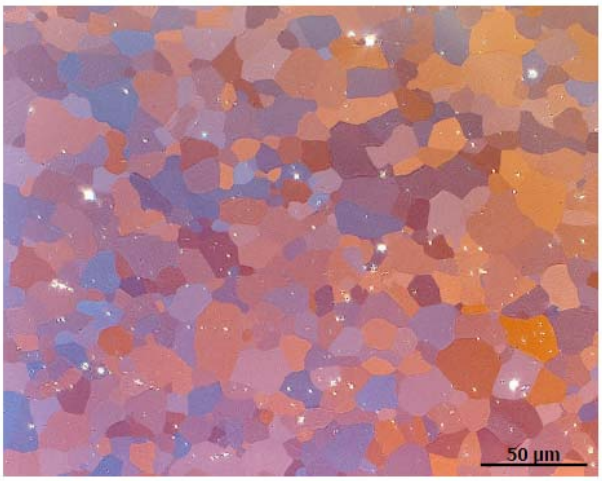


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

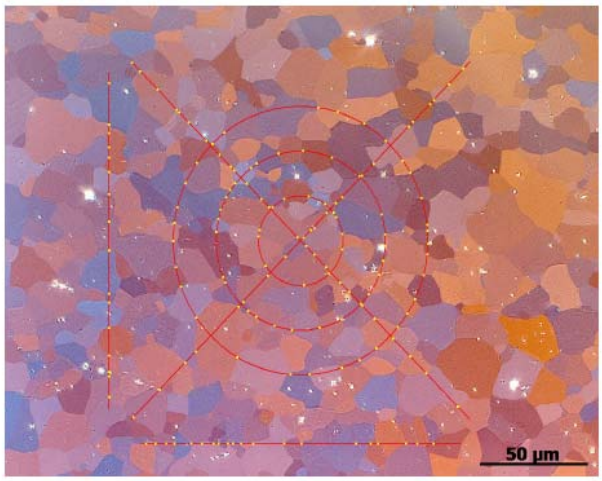
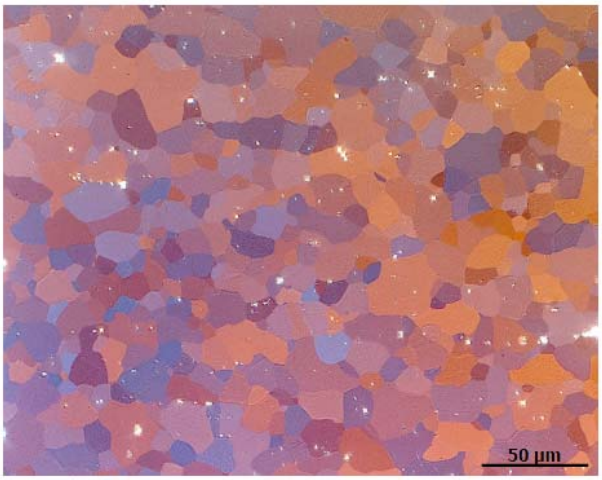


Image with Annotations

Image - 4

Grain Size Number Ø: 10.00



Original image

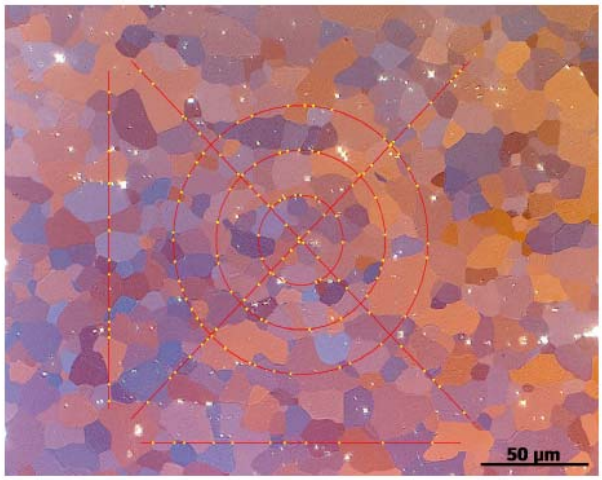
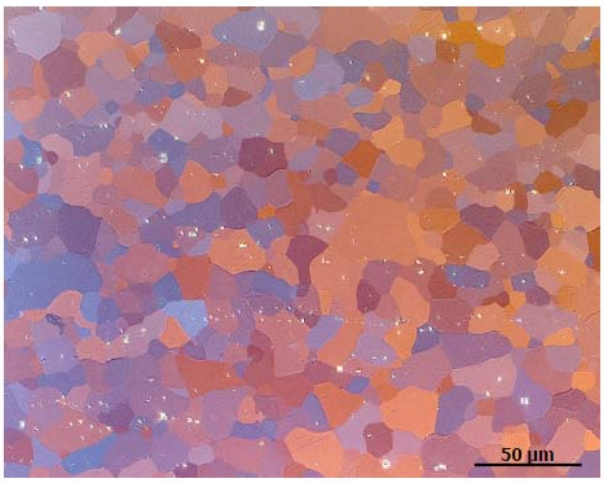


Image with Annotations

Image - 5

Grain Size Number Ø: 10.00



Original image

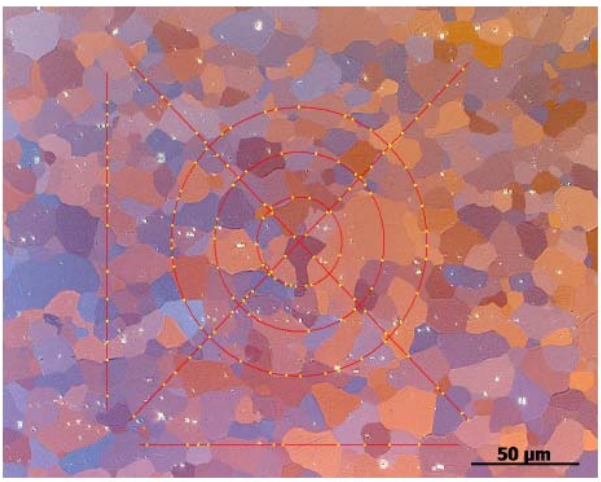
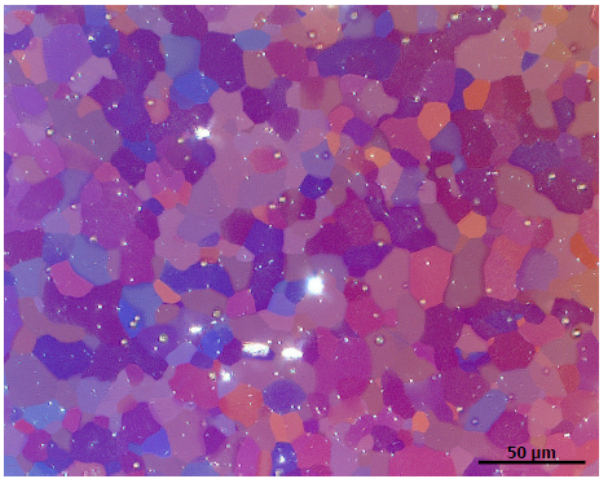


Image with Annotations

Sample No:	13234-195-45-4T
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	9.9

Image - 1

Grain Size Number Ø: 10.00



Original image

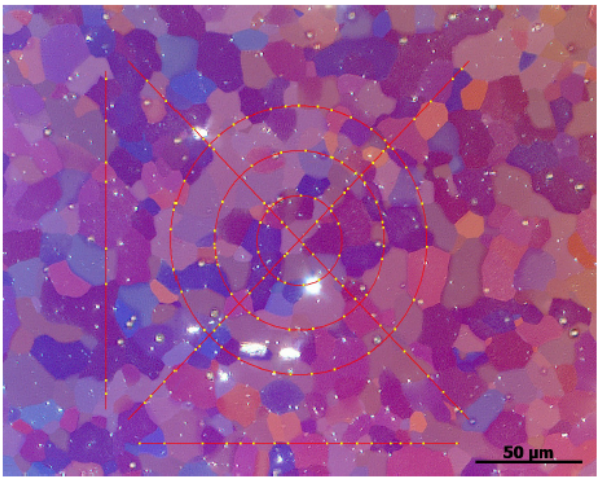
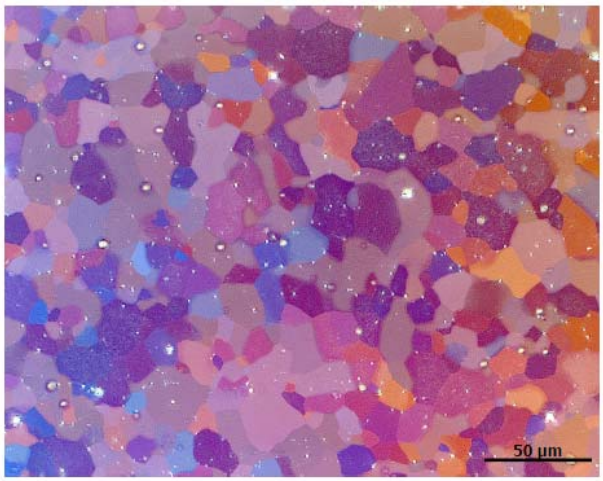


Image with Annotations

Image - 2

Grain Size Number Ø: 9.50



Original image

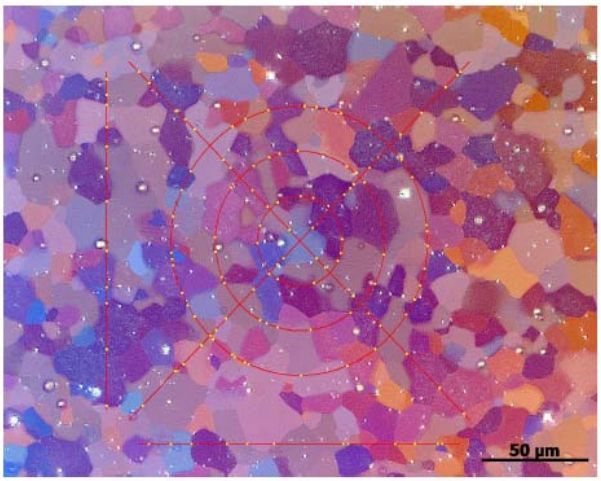
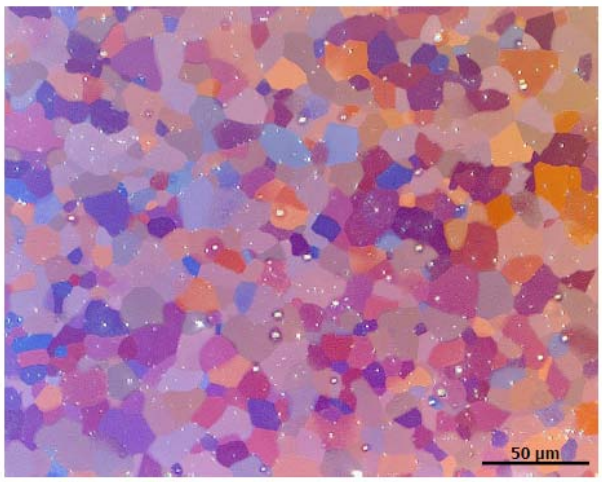


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

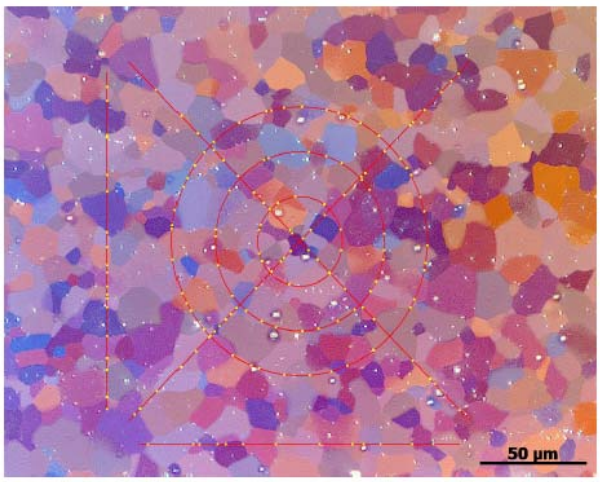
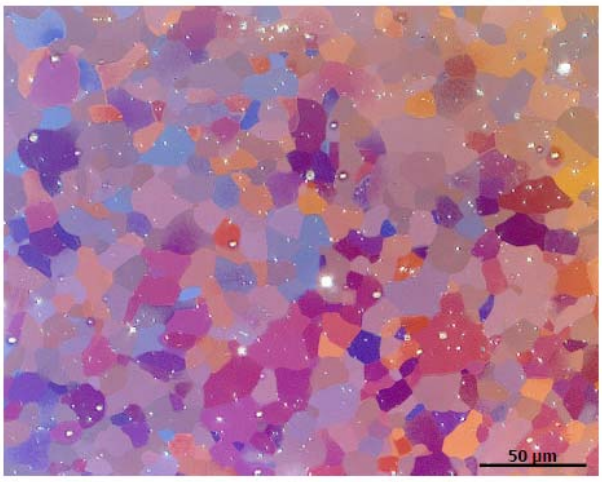


Image with Annotations

Image - 4

Grain Size Number Ø: 10.50



Original image

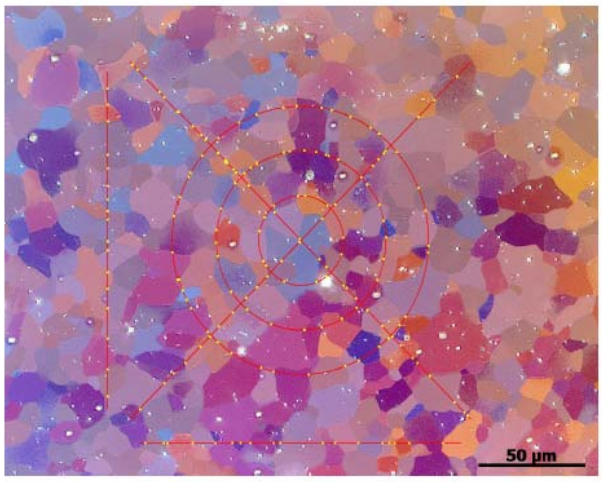
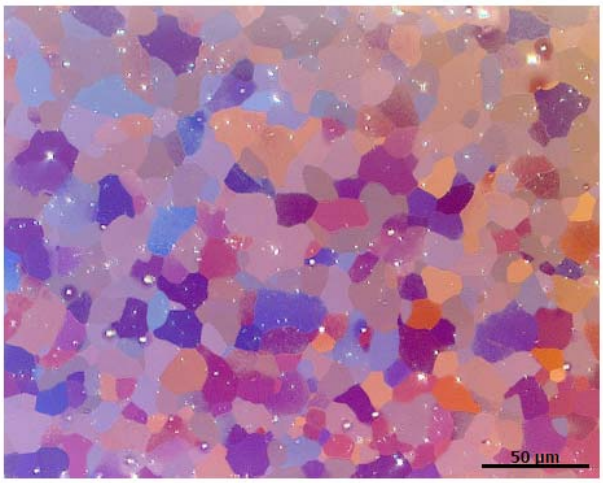


Image with Annotations

Image - 5

Grain Size Number Ø: 9.50



Original image

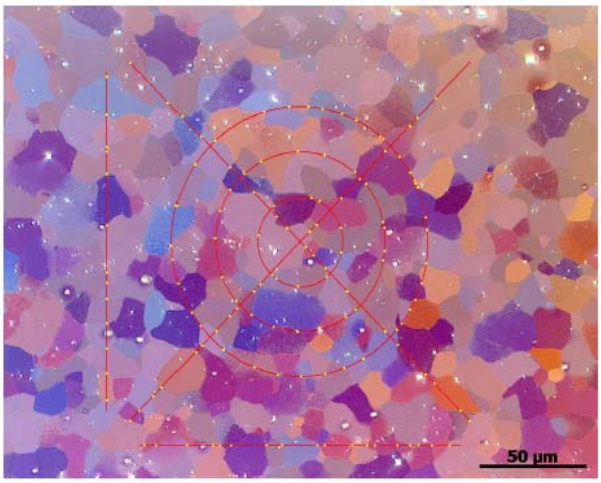
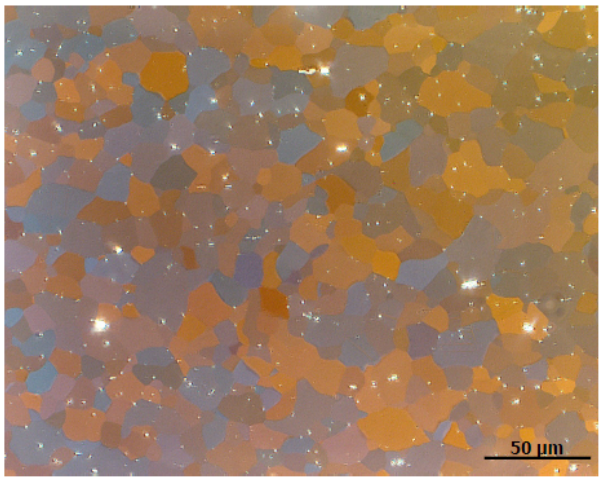


Image with Annotations

Sample No: 13234-195-90-5L
Standard: ASTM E 112
Method: Intercept
Chord Pattern: Combined Chord
Material: Wrought DU
No of images: 5
Mean Grain Size Number: 9.8

Image - 1

Grain Size Number Ø: 10.00



Original image

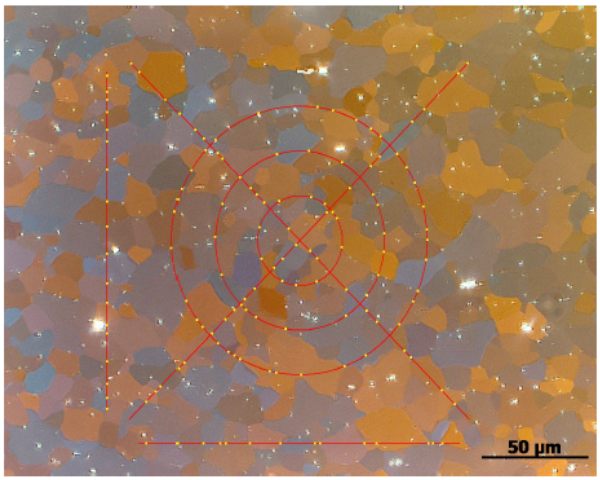
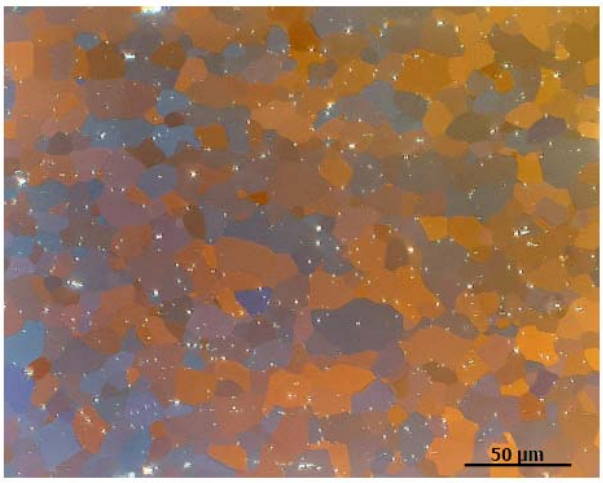


Image with Annotations

Image - 2

Grain Size Number Ø: 9.50



Original image

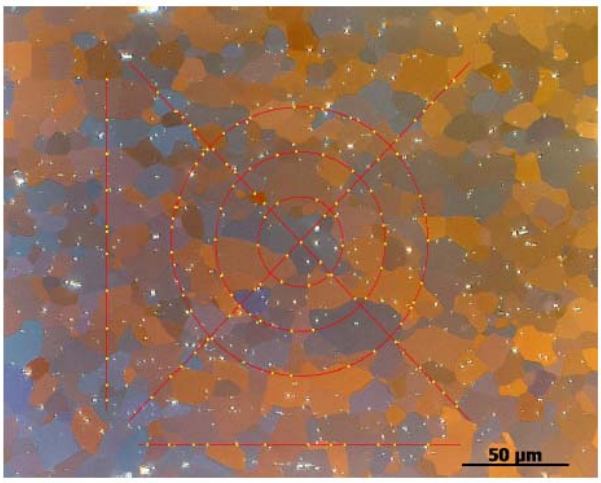
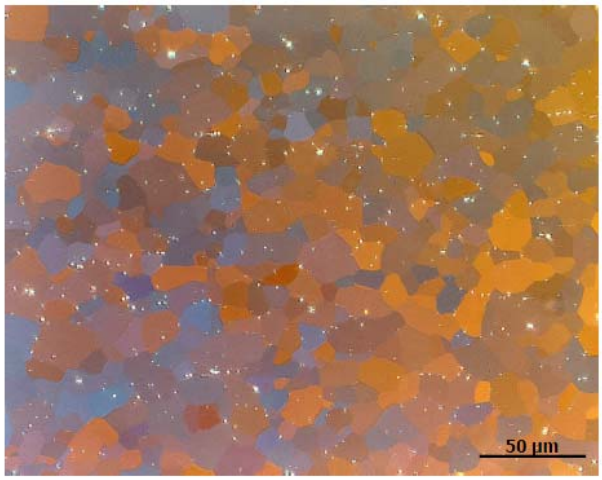


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

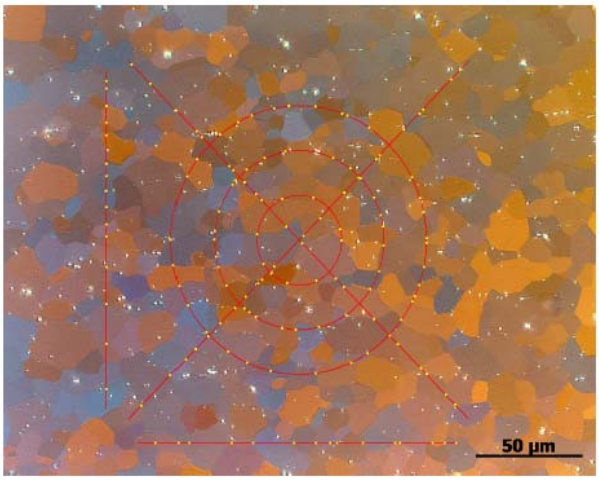
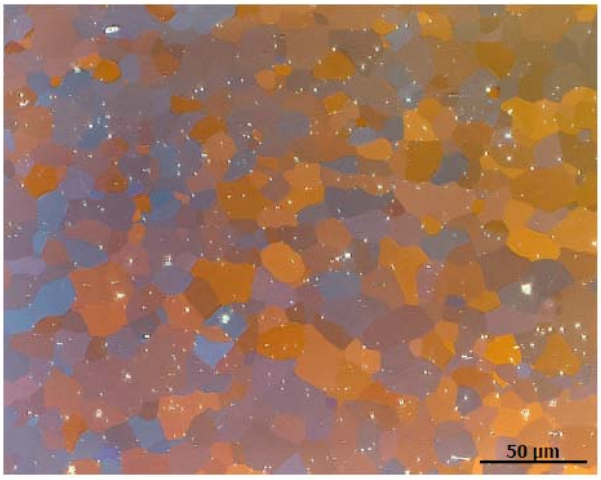


Image with Annotations

Image - 4

Grain Size Number Ø: 10.00



Original image

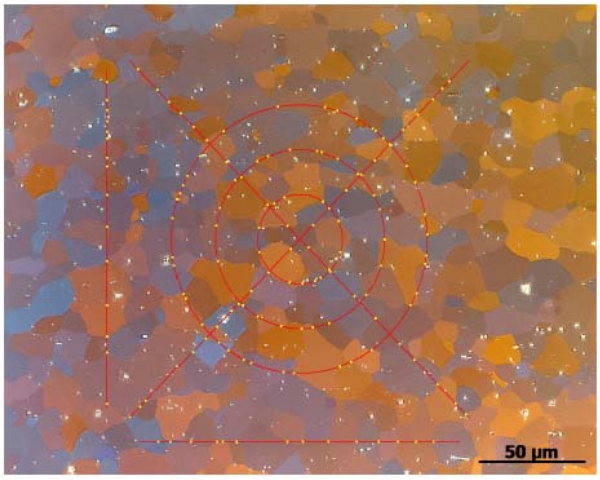
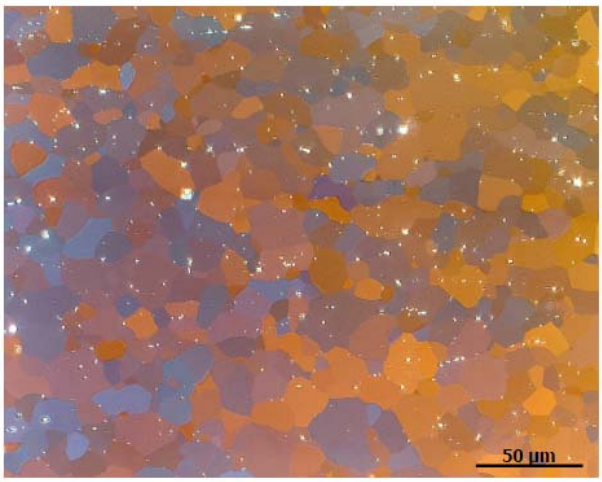


Image with Annotations

Image - 5

Grain Size Number Ø: 9.50



Original image

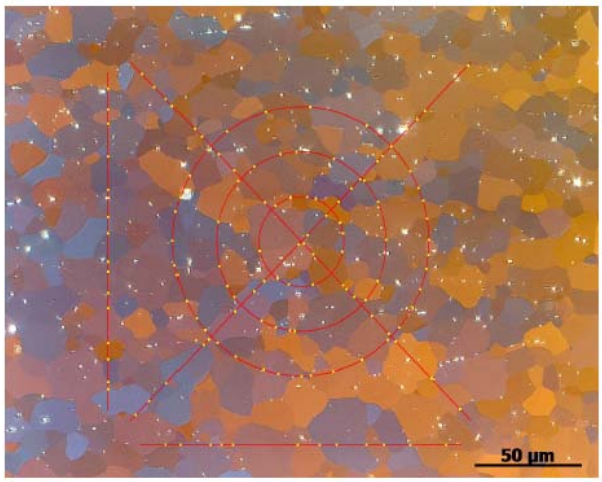
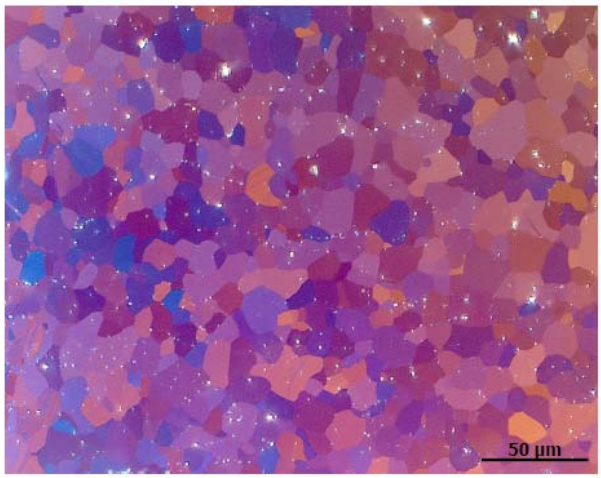


Image with Annotations

Sample No:	13234-195-90-5T
Standard:	ASTM E 112
Method:	Intercept
Chord Pattern:	Combined Chord
Material:	Wrought DU
No of images:	5
Mean Grain Size Number:	10.0

Image - 1

Grain Size Number Ø: 10.00



Original image

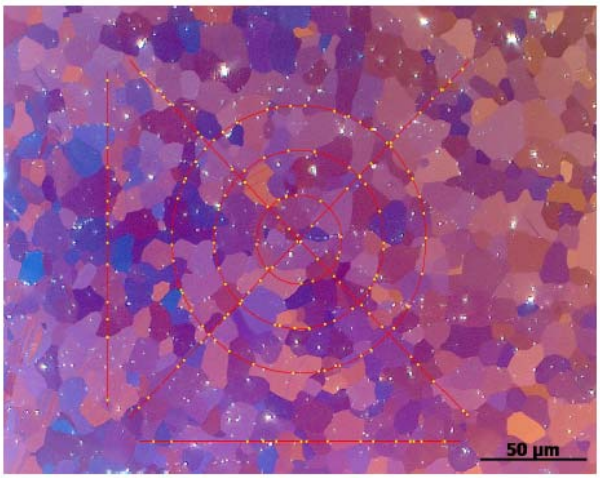
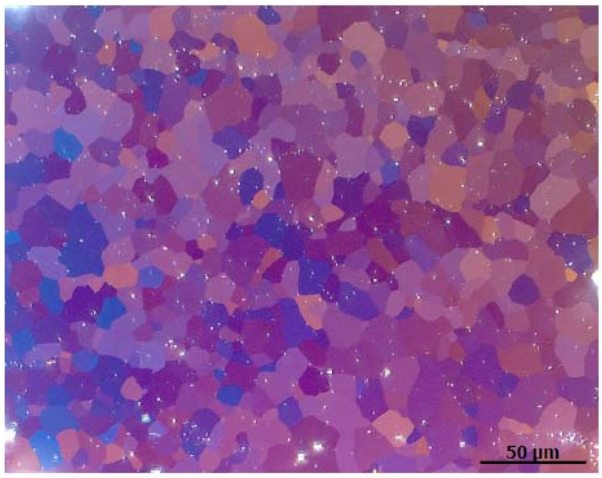


Image with Annotations

Image - 2

Grain Size Number Ø: 10.00



Original image

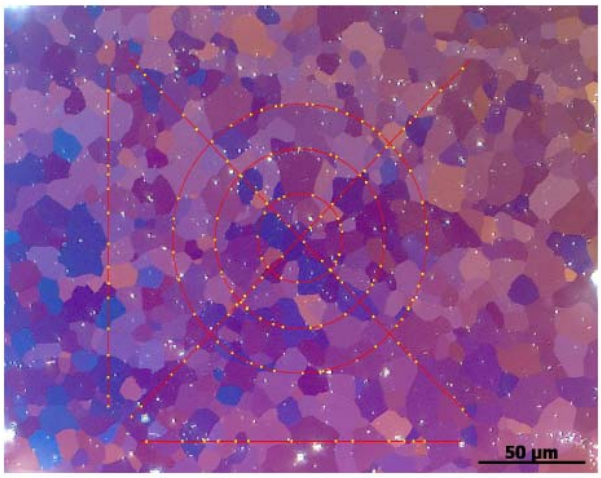
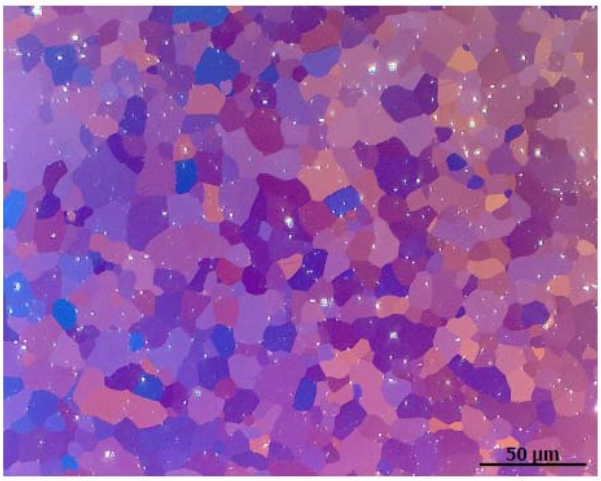


Image with Annotations

Image - 3

Grain Size Number Ø: 10.00



Original image

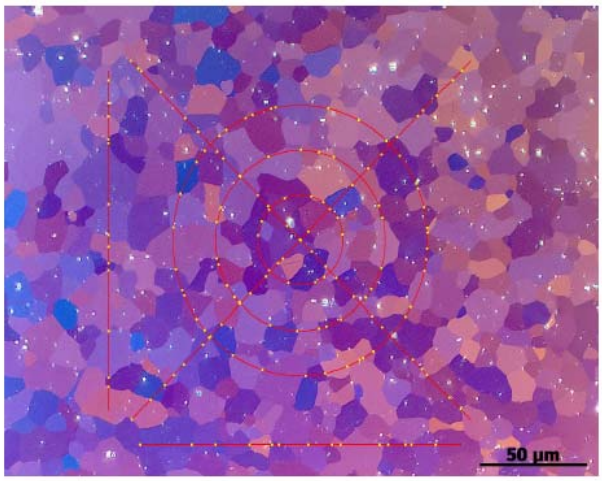
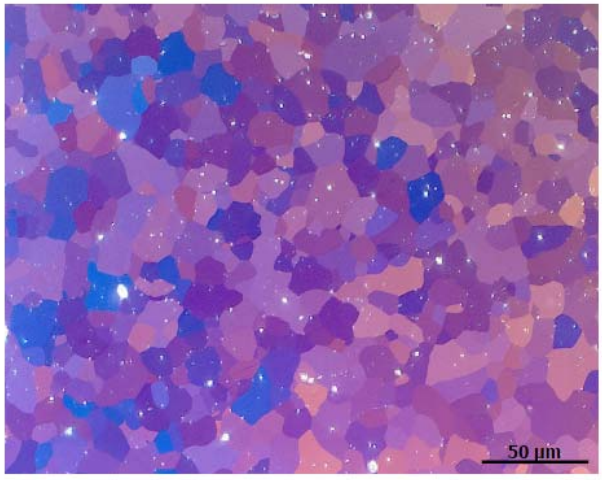


Image with Annotations

Image - 4

Grain Size Number Ø: 10.00



Original image

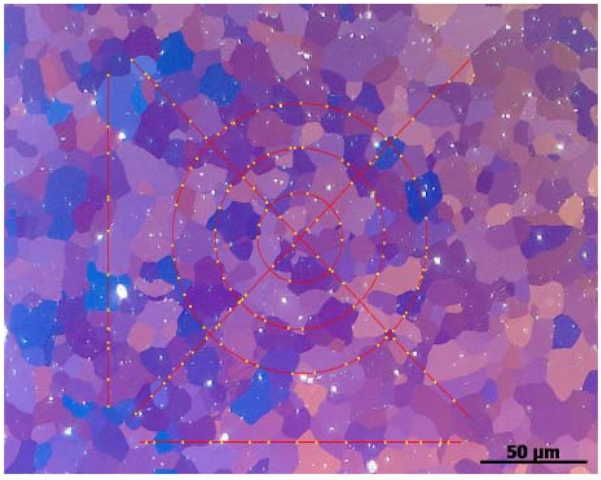
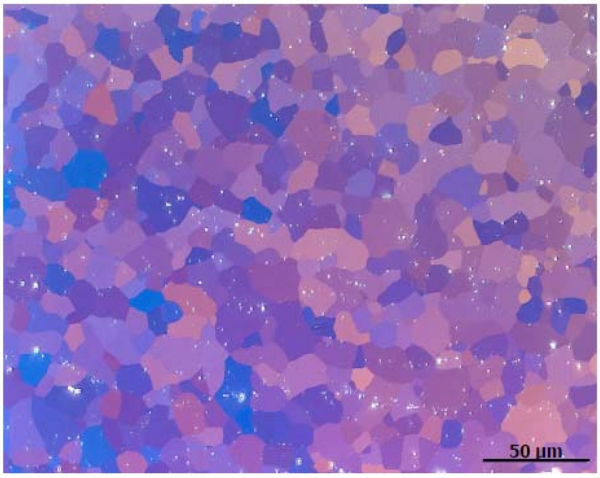


Image with Annotations

Image - 5

Grain Size Number Ø: 10.00



Original image

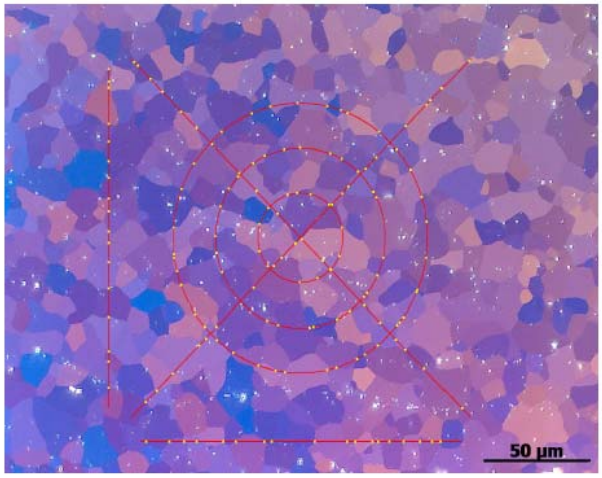
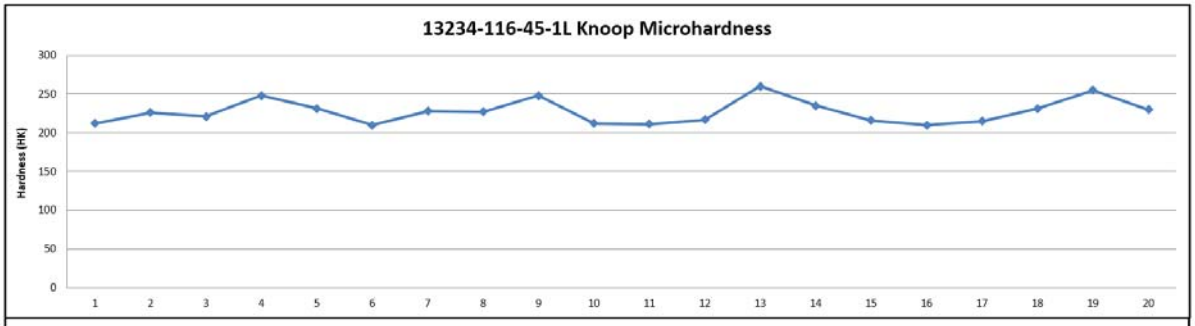


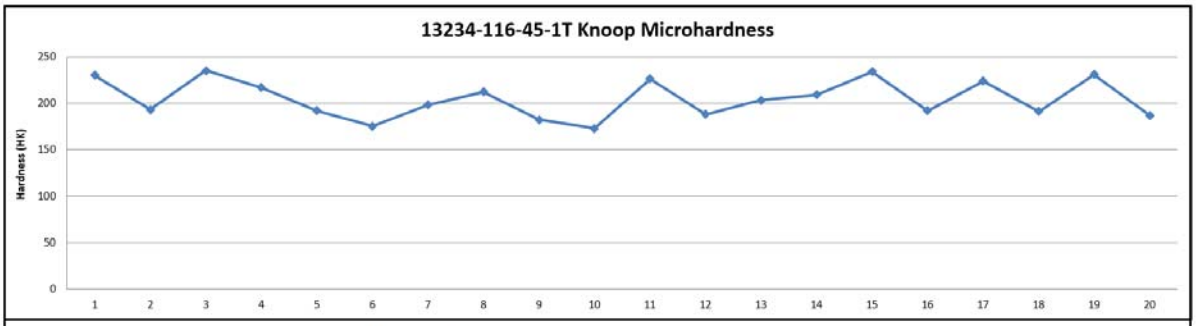
Image with Annotations

Appendix D – Knoop Microhardness Data



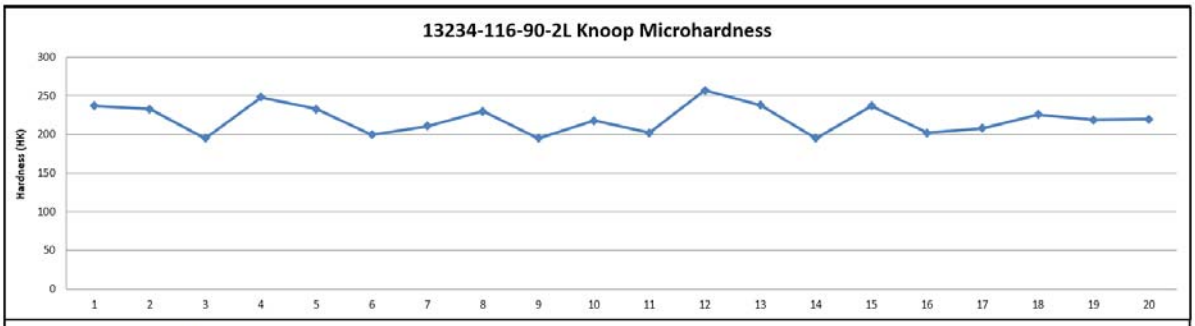
Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-116-45-1L	Knoop	1	Knoop	HK 0,1	Auto60x	212	81.942	81.942	26.871	OK	Measured
		2	Knoop	HK 0,1	Auto60x	226	79.302	79.302	23.504	OK	Measured
		3	Knoop	HK 0,1	60x	221	80.324	80.324	43.782	OK	Indent has been Remeasured Manually
		4	Knoop	HK 0,1	Auto60x	248	75.724	75.724	24.585	OK	Measured
		5	Knoop	HK 0,1	Auto60x	231	78.535	78.535	23.235	OK	Measured
		6	Knoop	HK 0,1	Auto60x	210	82.37	82.37	17.635	OK	Measured
		7	Knoop	HK 0,1	Auto60x	228	79.046	79.046	24.925	OK	Measured
		8	Knoop	HK 0,1	Auto60x	227	79.131	79.131	32.222	OK	Measured
		9	Knoop	HK 0,1	Auto60x	248	75.81	75.81	18.312	OK	Measured
		10	Knoop	HK 0,1	Auto60x	212	81.942	81.942	29.923	OK	Measured
		11	Knoop	HK 0,1	60x	211	82.112	82.112	23.935	OK	Indent has been Remeasured Manually
		12	Knoop	HK 0,1	Auto60x	217	80.92	80.92	30.3	OK	Measured
		13	Knoop	HK 0,1	60x	260	73.935	73.935	43.782	OK	Indent has been Remeasured Manually
		14	Knoop	HK 0,1	60x	235	77.853	77.853	43.782	OK	Indent has been Remeasured Manually
		15	Knoop	HK 0,1	60x	216	81.175	81.175	18.058	OK	Indent has been Remeasured Manually
		16	Knoop	HK 0,1	60x	210	82.368	82.368	29.302	OK	Indent has been Remeasured Manually
		17	Knoop	HK 0,1	60x	215	81.431	81.431	43.782	OK	Indent has been Remeasured Manually
		18	Knoop	HK 0,1	60x	231	78.535	78.535	34.753	OK	Indent has been Remeasured Manually
		19	Knoop	HK 0,1	60x	255	74.702	74.702	22.572	OK	Indent has been Remeasured Manually
		20	Knoop	HK 0,1	Auto60x	230	78.621	78.621	29.483	OK	Measured

Maximum:	260
Minimum:	210
Range:	50
Average:	227.2
Standard Deviation:	15.5



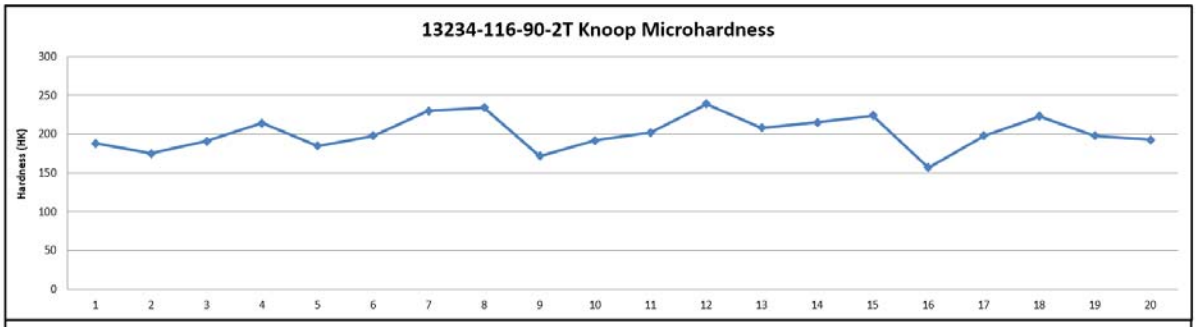
Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-116-45-1T	Knoop	1	Knoop	HK 0,1	Auto60x	230	78.62	78.62	29.575	OK	Measured
		2	Knoop	HK 0,1	60x	193	85.945	85.945	20.613	OK	Indent has been Remeasured Manually
		3	Knoop	HK 0,1	Auto60x	235	77.769	77.769	18.334	OK	Measured
		4	Knoop	HK 0,1	Auto60x	217	80.92	80.92	17.622	OK	Measured
		5	Knoop	HK 0,1	60x	192	86.116	86.116	27.257	OK	Indent has been Remeasured Manually
		6	Knoop	HK 0,1	60x	175	90.204	90.204	20.358	OK	Indent has been Remeasured Manually
		7	Knoop	HK 0,1	60x	198	84.668	84.668	21.21	OK	Indent has been Remeasured Manually
		8	Knoop	HK 0,1	Auto60x	212	81.942	81.942	17.008	OK	Measured
		9	Knoop	HK 0,1	Auto60x	182	88.416	88.416	35.588	OK	Measured
		10	Knoop	HK 0,1	60x	173	90.801	90.801	26.15	OK	Indent has been Remeasured Manually
		11	Knoop	HK 0,1	Auto60x	226	79.302	79.302	15.851	OK	Measured
		12	Knoop	HK 0,1	60x	188	87.053	87.053	17.206	OK	Indent has been Remeasured Manually
		13	Knoop	HK 0,1	Auto60x	203	83.731	83.731	26.219	OK	Measured
		14	Knoop	HK 0,1	Auto60x	209	82.538	82.538	21.205	OK	Measured
		15	Knoop	HK 0,1	Auto60x	234	77.94	77.94	21.095	OK	Measured
		16	Knoop	HK 0,1	Auto60x	192	86.116	86.116	22.919	OK	Measured
		17	Knoop	HK 0,1	60x	224	79.642	79.642	18.058	OK	Indent has been Remeasured Manually
		18	Knoop	HK 0,1	60x	191	86.201	86.201	19.421	OK	Indent has been Remeasured Manually
		19	Knoop	HK 0,1	Auto60x	231	78.535	78.535	22.172	OK	Measured
		20	Knoop	HK 0,1	60x	187	87.223	87.223	18.058	OK	Indent has been Remeasured Manually

Maximum:	235
Minimum:	173
Range:	62
Average:	204.6
Standard Deviation:	20.3



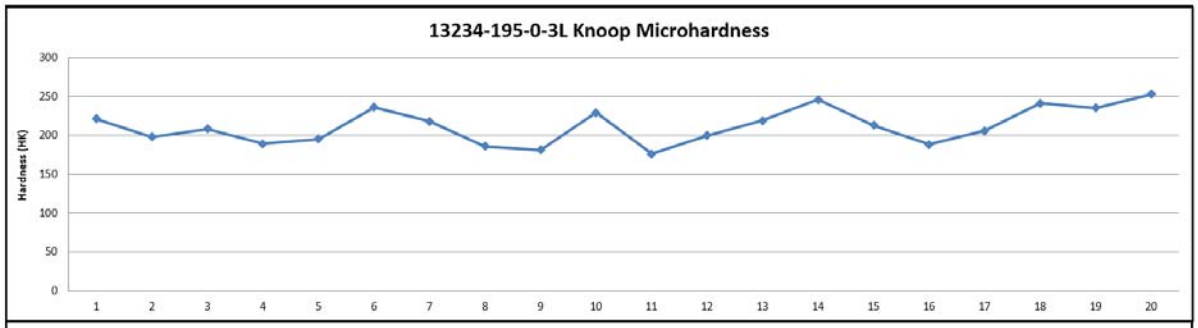
Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-116-90-2L	Knoop	1	Knoop	HK 0,1	Auto60x	237	77.428	77.428	21.718	OK	Measured
		2	Knoop	HK 0,1	Auto60x	233	78.194	78.194	40.878	OK	Measured
		3	Knoop	HK 0,1	Auto60x	195	85.438	85.438	59.457	OK	Measured
		4	Knoop	HK 0,1	60x	248	75.724	75.724	40.034	OK	Indent has been Remeasured Manually
		5	Knoop	HK 0,1	Auto60x	233	78.109	78.109	42.066	OK	Measured
		6	Knoop	HK 0,1	Auto60x	200	84.418	84.418	41.074	OK	Measured
		7	Knoop	HK 0,1	60x	211	82.198	82.198	43.782	OK	Indent has been Remeasured Manually
		8	Knoop	HK 0,1	Auto60x	230	78.706	78.706	26.349	OK	Measured
		9	Knoop	HK 0,1	60x	195	85.434	85.434	38.245	OK	Indent has been Remeasured Manually
		10	Knoop	HK 0,1	60x	218	80.835	80.835	66.014	OK	Indent has been Remeasured Manually
		11	Knoop	HK 0,1	60x	202	83.901	83.901	43.782	OK	Indent has been Remeasured Manually
		12	Knoop	HK 0,1	60x	257	74.361	74.361	43.782	OK	Indent has been Remeasured Manually
		13	Knoop	HK 0,1	60x	238	77.342	77.342	18.399	OK	Indent has been Remeasured Manually
		14	Knoop	HK 0,1	Auto60x	195	85.435	85.435	18.74	OK	Measured
		15	Knoop	HK 0,1	60x	237	77.513	77.513	30.664	OK	Indent has been Remeasured Manually
		16	Knoop	HK 0,1	60x	202	83.901	83.901	43.782	OK	Indent has been Remeasured Manually
		17	Knoop	HK 0,1	60x	208	82.794	82.794	19.506	OK	Indent has been Remeasured Manually
		18	Knoop	HK 0,1	Auto60x	226	79.387	79.387	49.615	OK	Measured
		19	Knoop	HK 0,1	Auto60x	219	80.58	80.58	39.647	OK	Measured
		20	Knoop	HK 0,1	60x	220	80.494	80.494	34.753	OK	Indent has been Remeasured Manually

Maximum:	257
Minimum:	195
Range:	62
Average:	220.2
Standard Deviation:	18.8



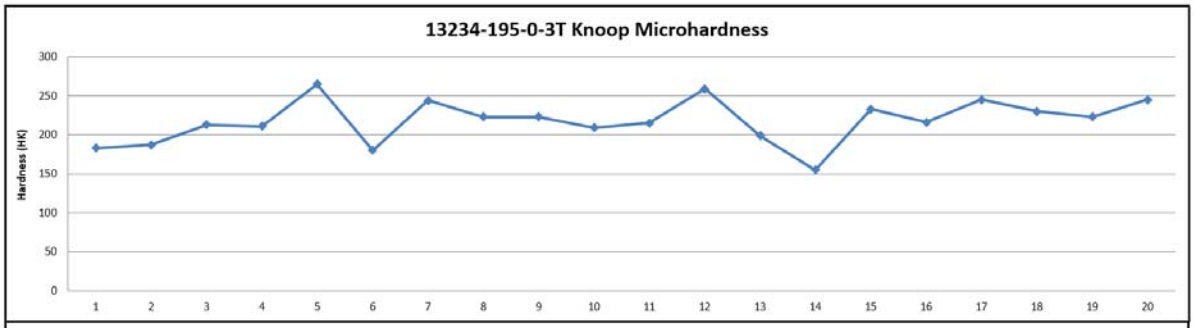
Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-116-90-2T	Knoop	1	Knoop	HK 0,1	60x	188	87.053	87.053	43.782	OK	Indent has been Remeasured Manually
		2	Knoop	HK 0,1	Auto60x	175	90.204	90.204	56.494	OK	Measured
		3	Knoop	HK 0,1	Auto60x	191	86.201	86.201	23.925	OK	Measured
		4	Knoop	HK 0,1	Auto60x	214	81.516	81.516	21.736	OK	Measured
		5	Knoop	HK 0,1	Auto60x	185	87.649	87.649	20.173	OK	Measured
		6	Knoop	HK 0,1	Auto60x	198	84.668	84.668	23.908	OK	Measured
		7	Knoop	HK 0,1	Auto60x	230	78.621	78.621	17.947	OK	Measured
		8	Knoop	HK 0,1	Auto60x	234	77.939	77.939	19.07	OK	Measured
		9	Knoop	HK 0,1	60x	172	90.886	90.886	25.128	OK	Indent has been Remeasured Manually
		10	Knoop	HK 0,1	Auto60x	192	86.116	86.116	16.042	OK	Measured
		11	Knoop	HK 0,1	Auto60x	202	83.903	83.903	14.63	OK	Measured
		12	Knoop	HK 0,1	Auto60x	239	77.173	77.173	20.07	OK	Measured
		13	Knoop	HK 0,1	Auto60x	208	82.709	82.709	15.855	OK	Measured
		14	Knoop	HK 0,1	60x	215	81.431	81.431	24.446	OK	Indent has been Remeasured Manually
		15	Knoop	HK 0,1	Auto60x	224	79.642	79.642	36.473	OK	Measured
		16	Knoop	HK 0,1	60x	157	95.145	95.145	30.75	OK	Indent has been Remeasured Manually
		17	Knoop	HK 0,1	60x	198	84.838	84.838	21.039	OK	Indent has been Remeasured Manually
		18	Knoop	HK 0,1	Auto60x	223	79.898	79.898	26.747	OK	Measured
		19	Knoop	HK 0,1	60x	198	84.668	84.668	30.409	OK	Indent has been Remeasured Manually
		20	Knoop	HK 0,1	Auto60x	193	85.946	85.946	34.941	OK	Measured

Maximum:	239
Minimum:	157
Range:	82
Average:	201.8
Standard Deviation:	21.7



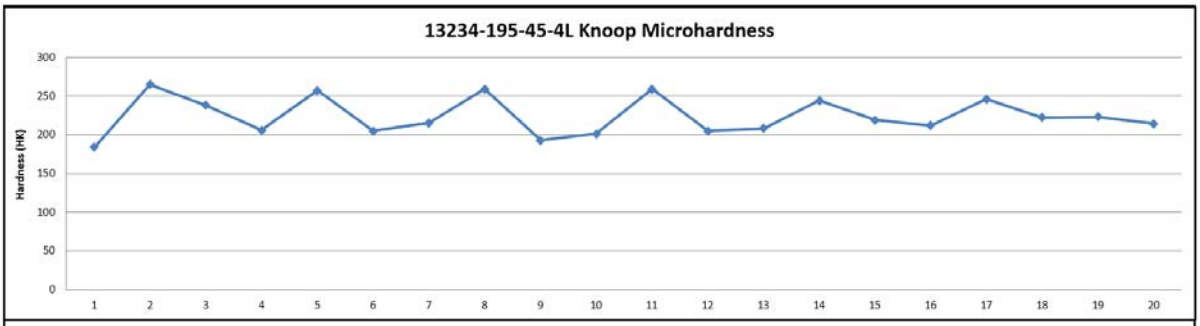
Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-195-0-3L	Knoop	1	Knoop	HK 0,1	Auto60x	221	80.239	80.239	19.941	OK	Measured
		2	Knoop	HK 0,1	Auto60x	198	84.668	84.668	20.83	OK	Measured
		3	Knoop	HK 0,1	Auto60x	208	82.797	82.797	21.131	OK	Measured
		4	Knoop	HK 0,1	Auto60x	189	86.712	86.712	32.922	OK	Measured
		5	Knoop	HK 0,1	60x	195	85.52	85.52	43.782	OK	Indent has been Remeasured Manually
		6	Knoop	HK 0,1	Auto60x	236	77.598	77.598	27.83	OK	Measured
		7	Knoop	HK 0,1	Auto60x	218	80.835	80.835	30.493	OK	Measured
		8	Knoop	HK 0,1	Auto60x	186	87.394	87.394	33.032	OK	Measured
		9	Knoop	HK 0,1	60x	181	88.671	88.671	17.376	OK	Indent has been Remeasured Manually
		10	Knoop	HK 0,1	60x	229	78.79	78.79	31.175	OK	Indent has been Remeasured Manually
		11	Knoop	HK 0,1	60x	176	90.034	90.034	36.659	OK	Indent has been Remeasured
		12	Knoop	HK 0,1	60x	200	84.327	84.327	15.843	OK	Indent has been Remeasured Manually
		13	Knoop	HK 0,1	60x	219	80.664	80.664	43.782	OK	Indent has been Remeasured Manually
		14	Knoop	HK 0,1	60x	246	76.065	76.065	19.932	OK	Indent has been Remeasured Manually
		15	Knoop	HK 0,1	Auto60x	213	81.774	81.774	24.197	OK	Measured
		16	Knoop	HK 0,1	60x	188	86.882	86.882	43.782	OK	Indent has been Remeasured Manually
		17	Knoop	HK 0,1	Auto60x	206	83.135	83.135	19.601	OK	Measured
		18	Knoop	HK 0,1	60x	241	76.917	76.917	21.976	OK	Indent has been Remeasured Manually
		19	Knoop	HK 0,1	Auto60x	235	77.853	77.853	35.028	OK	Measured
		20	Knoop	HK 0,1	Auto60x	253	75.043	75.043	16.235	OK	Measured

Maximum:	253
Minimum:	176
Range:	77
Average:	211.9
Standard Deviation:	22.9



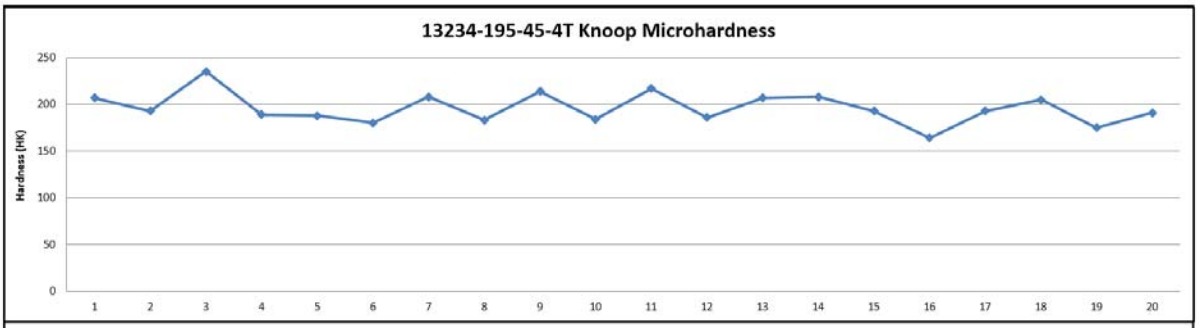
Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-195-0-3T	Knoop	1	Knoop	HK 0,1	60x	183	88.161	88.161	32.337	OK	Indent has been Remeasured
		2	Knoop	HK 0,1	Auto60x	187	87.141	87.141	32.722	OK	Measured
		3	Knoop	HK 0,1	Auto60x	213	81.772	81.772	32.964	OK	Measured
		4	Knoop	HK 0,1	60x	211	82.198	82.198	27.768	OK	Indent has been Remeasured Manually
		5	Knoop	HK 0,1	Auto60x	265	73.339	73.339	22.053	OK	Measured
		6	Knoop	HK 0,1	Auto60x	180	88.842	88.842	33.109	OK	Measured
		7	Knoop	HK 0,1	Auto60x	244	76.406	76.406	18.29	OK	Measured
		8	Knoop	HK 0,1	Auto60x	223	79.902	79.902	24.624	OK	Measured
		9	Knoop	HK 0,1	Auto60x	223	79.905	79.905	24.577	OK	Measured
		10	Knoop	HK 0,1	Auto60x	209	82.455	82.455	29.869	OK	Measured
		11	Knoop	HK 0,1	Auto60x	215	81.346	81.346	28.42	OK	Measured
		12	Knoop	HK 0,1	60x	259	74.191	74.191	12.692	OK	Indent has been Remeasured Manually
		13	Knoop	HK 0,1	Auto60x	199	84.508	84.508	24.64	OK	Measured
		14	Knoop	HK 0,1	60x	155	95.753	95.753	27.882	OK	Indent has been Remeasured
		15	Knoop	HK 0,1	Auto60x	233	78.11	78.11	28.361	OK	Measured
		16	Knoop	HK 0,1	Auto60x	216	81.176	81.176	15.511	OK	Measured
		17	Knoop	HK 0,1	Auto60x	245	76.24	76.24	45.197	OK	Measured
		18	Knoop	HK 0,1	Auto60x	230	78.707	78.707	25.578	OK	Measured
		19	Knoop	HK 0,1	Auto60x	223	79.813	79.813	19.115	OK	Measured
		20	Knoop	HK 0,1	Auto60x	245	76.236	76.236	17.541	OK	Measured

Maximum:	265
Minimum:	155
Range:	110
Average:	217.9
Standard Deviation:	27.7



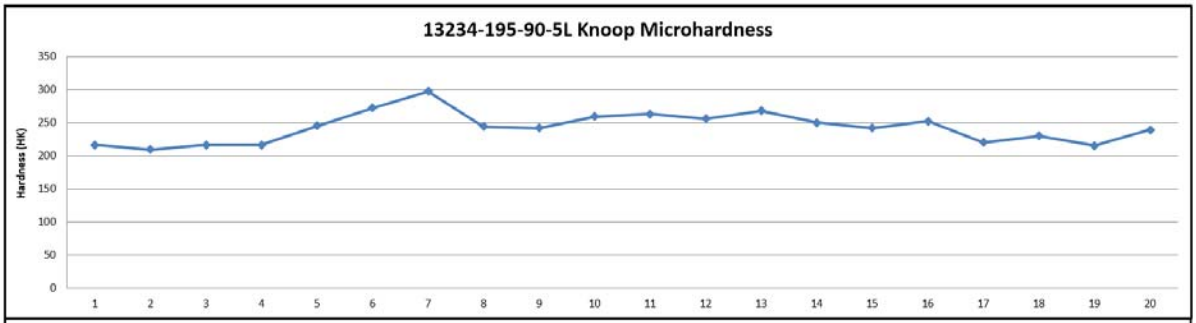
Specimen	Row	Test Point	Measurement Type	Method	Objective I	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-195-45-4L	Knoop	1	Knoop	HK 0,1	60x	184	87.905	87.905	28.336	OK	Indent has been Remeasured
		2	Knoop	HK 0,1	Auto60x	265	73.339	73.339	27.767	OK	Measured
		3	Knoop	HK 0,1	60x	238	77.342	77.342	23.765	OK	Indent has been Remeasured Manually
		4	Knoop	HK 0,1	60x	206	83.135	83.135	31.005	OK	Indent has been Remeasured Manually
		5	Knoop	HK 0,1	60x	257	74.446	74.446	32.964	OK	Indent has been Remeasured Manually
		6	Knoop	HK 0,1	Auto60x	205	83.39	83.39	27.479	OK	Measured
		7	Knoop	HK 0,1	60x	215	81.346	81.346	24.617	OK	Indent has been Remeasured Manually
		8	Knoop	HK 0,1	Auto60x	259	74.191	74.191	32.628	OK	Measured
		9	Knoop	HK 0,1	Auto60x	193	85.776	85.776	28.238	OK	Measured
		10	Knoop	HK 0,1	Auto60x	201	84.157	84.157	17.512	OK	Measured
		11	Knoop	HK 0,1	Auto60x	259	74.192	74.192	44.334	OK	Measured
		12	Knoop	HK 0,1	Auto60x	205	83.22	83.22	34.79	OK	Measured
		13	Knoop	HK 0,1	Auto60x	208	82.624	82.624	26.651	OK	Measured
		14	Knoop	HK 0,1	Auto60x	244	76.32	76.32	16.242	OK	Measured
		15	Knoop	HK 0,1	60x	219	80.579	80.579	16.695	OK	Indent has been Remeasured Manually
		16	Knoop	HK 0,1	60x	212	81.942	81.942	43.782	OK	Indent has been Remeasured Manually
		17	Knoop	HK 0,1	Auto60x	246	76.066	76.066	25.611	OK	Measured
		18	Knoop	HK 0,1	Auto60x	222	79.993	79.993	31.166	OK	Measured
		19	Knoop	HK 0,1	60x	223	79.898	79.898	18.825	OK	Indent has been Remeasured Manually
		20	Knoop	HK 0,1	Auto60x	214	81.518	81.518	16.751	OK	Measured

Maximum:	265
Minimum:	184
Range:	81
Average:	223.8
Standard Deviation:	24.1



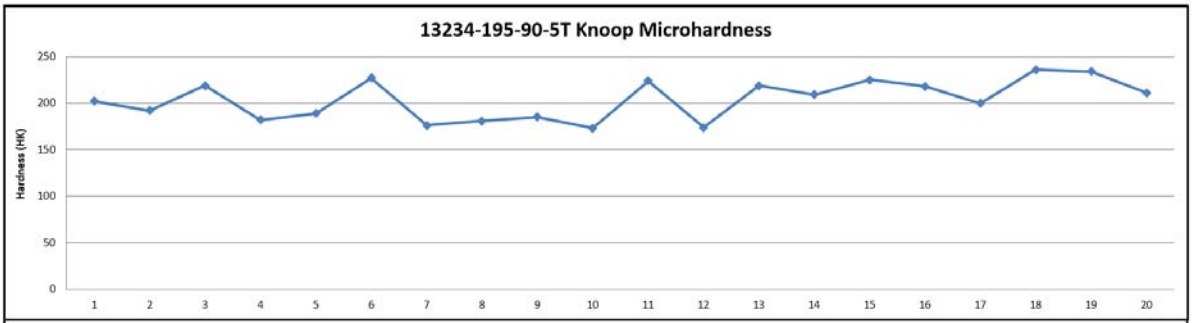
Specimen	Row	Test Point	Measurement Type	Method	Objective I	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-195-45-4T	Knoop	1	Knoop	HK 0,1	Auto60x	207	82.964	82.964	15.656	OK	Measured
		2	Knoop	HK 0,1	Auto60x	193	85.946	85.946	26.32	OK	Measured
		3	Knoop	HK 0,1	Auto60x	235	77.854	77.854	13.318	OK	Measured
		4	Knoop	HK 0,1	Auto60x	189	86.797	86.797	26.94	OK	Measured
		5	Knoop	HK 0,1	60x	188	86.968	86.968	43.782	OK	Indent has been Remeasured Manually
		6	Knoop	HK 0,1	Auto60x	180	88.844	88.844	28.155	OK	Measured
		7	Knoop	HK 0,1	Auto60x	208	82.794	82.794	28.673	OK	Measured
		8	Knoop	HK 0,1	Auto60x	183	88.161	88.161	22.085	OK	Measured
		9	Knoop	HK 0,1	60x	214	81.601	81.601	24.02	OK	Indent has been Remeasured Manually
		10	Knoop	HK 0,1	60x	184	87.991	87.991	20.019	OK	Indent has been Remeasured
		11	Knoop	HK 0,1	Auto60x	217	81.008	81.008	32.859	OK	Measured
		12	Knoop	HK 0,1	60x	186	87.564	87.564	24.191	OK	Indent has been Remeasured Manually
		13	Knoop	HK 0,1	60x	207	82.879	82.879	23.083	OK	Indent has been Remeasured Manually
		14	Knoop	HK 0,1	60x	208	82.709	82.709	24.532	OK	Indent has been Remeasured Manually
		15	Knoop	HK 0,1	Auto60x	193	85.861	85.861	17.855	OK	Measured
		16	Knoop	HK 0,1	Auto60x	164	93.101	93.101	31.587	OK	Measured
		17	Knoop	HK 0,1	Auto60x	193	85.775	85.775	17.331	OK	Measured
		18	Knoop	HK 0,1	Auto60x	205	83.305	83.305	14.659	OK	Measured
		19	Knoop	HK 0,1	Auto60x	175	90.205	90.205	20.564	OK	Measured
		20	Knoop	HK 0,1	Auto60x	191	86.287	86.287	20.776	OK	Measured

Maximum:	235
Minimum:	164
Range:	71
Average:	196.0
Standard Deviation:	16.5



Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-195-90-5L	Knoop	1	Knoop	HK 0,1	Auto60x	216	81.176	81.176	17.411	OK	Measured
		2	Knoop	HK 0,1	60x	209	82.538	82.538	13.969	OK	Indent has been Remeasured Manually
		3	Knoop	HK 0,1	Auto60x	216	81.092	81.092	23.27	OK	Measured
		4	Knoop	HK 0,1	Auto60x	216	81.09	81.09	25.589	OK	Measured
		5	Knoop	HK 0,1	Auto60x	245	76.15	76.15	24.742	OK	Measured
		6	Knoop	HK 0,1	Auto60x	272	72.317	72.317	28.081	OK	Measured
		7	Knoop	HK 0,1	60x	297	69.25	69.25	27.428	OK	Indent has been Remeasured Manually
		8	Knoop	HK 0,1	60x	244	76.405	76.405	18.739	OK	Indent has been Remeasured Manually
		9	Knoop	HK 0,1	Auto60x	242	76.661	76.661	26.275	OK	Measured
		10	Knoop	HK 0,1	Auto60x	259	74.191	74.191	16.954	OK	Measured
		11	Knoop	HK 0,1	60x	263	73.509	73.509	22.572	OK	Indent has been Remeasured Manually
		12	Knoop	HK 0,1	Auto60x	256	74.617	74.617	14.497	OK	Measured
		13	Knoop	HK 0,1	Auto60x	268	72.913	72.913	28.777	OK	Measured
		14	Knoop	HK 0,1	60x	250	75.468	75.468	24.957	OK	Indent has been Remeasured Manually
		15	Knoop	HK 0,1	60x	242	76.746	76.746	26.405	OK	Indent has been Remeasured Manually
		16	Knoop	HK 0,1	Auto60x	252	75.213	75.213	16.44	OK	Measured
		17	Knoop	HK 0,1	60x	220	80.409	80.409	15.417	OK	Indent has been Remeasured Manually
		18	Knoop	HK 0,1	60x	230	78.705	78.705	31.857	OK	Indent has been Remeasured Manually
		19	Knoop	HK 0,1	Auto60x	215	81.261	81.261	35.725	OK	Measured
		20	Knoop	HK 0,1	60x	239	77.087	77.087	15.843	OK	Indent has been Remeasured Manually

Maximum:	297
Minimum:	209
Range:	88
Average:	242.6
Standard Deviation:	23.1



Specimen	Row	Test Point	Measurement Type	Method	Objective	Hardness (HK)	Diagonal (Avg. µm)	Diagonal 1 (µm)	Diagonal 2 (µm)	Info	Status
13234-195-90-5T	Knoop	1	Knoop	HK 0,1	Auto60x	202	83.901	83.901	23.935	OK	Measured
		2	Knoop	HK 0,1	Auto60x	192	86.031	86.031	18.423	OK	Measured
		3	Knoop	HK 0,1	Auto60x	219	80.58	80.58	25.953	OK	Measured
		4	Knoop	HK 0,1	Auto60x	182	88.501	88.501	30.221	OK	Measured
		5	Knoop	HK 0,1	Auto60x	189	86.712	86.712	18.755	OK	Measured
		6	Knoop	HK 0,1	Auto60x	227	79.132	79.132	23.273	OK	Measured
		7	Knoop	HK 0,1	Auto60x	176	89.959	89.959	17.412	OK	Measured
		8	Knoop	HK 0,1	Auto60x	181	88.586	88.586	20.701	OK	Measured
		9	Knoop	HK 0,1	Auto60x	185	87.734	87.734	26.499	OK	Measured
		10	Knoop	HK 0,1	Auto60x	173	90.631	90.631	18.087	OK	Measured
		11	Knoop	HK 0,1	Auto60x	224	79.728	79.728	22.772	OK	Measured
		12	Knoop	HK 0,1	Auto60x	174	90.377	90.377	25.936	OK	Measured
		13	Knoop	HK 0,1	Auto60x	219	80.666	80.666	22.676	OK	Measured
		14	Knoop	HK 0,1	60x	209	82.538	82.538	19.421	OK	Indent has been Remeasured Manually
		15	Knoop	HK 0,1	60x	225	79.472	79.472	21.635	OK	Indent has been Remeasured Manually
		16	Knoop	HK 0,1	60x	218	80.75	80.75	15.758	OK	Indent has been Remeasured Manually
		17	Knoop	HK 0,1	Auto60x	200	84.242	84.242	21.467	OK	Measured
		18	Knoop	HK 0,1	Auto60x	236	77.598	77.598	23.218	OK	Measured
		19	Knoop	HK 0,1	Auto60x	234	77.939	77.939	22.787	OK	Measured
		20	Knoop	HK 0,1	Auto60x	211	82.112	82.112	19.273	OK	Measured

Maximum:	236
Minimum:	173
Range:	63
Average:	203.8
Standard Deviation:	21.1