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Data Compilation for AGR-2 Baseline Coated Particle Batch G73J-14-93071A

John D. Hunn

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Oak Ridge National Laboratory

Coated particle fuel batch G73J-14-93071A was produced by the Babcock and Wilcox Company (B&W) for possible selection as UCO baseline fuel for the Advanced Gas Reactor Fuel Development and Qualification Program's AGR-2 irradiation test. Batch G73J-14-93071A is a single batch of TRISO-coated 425 μm nominal diameter 14% low enrichment uranium oxide/uranium carbide kernels (LEUCO). The TRISO-coatings consist of a ~50% dense carbon buffer layer (100 μm nominal thickness) followed by a dense inner pyrocarbon layer (40 μm nominal thickness) followed by a SiC layer (35 μm nominal thickness) followed by another dense outer pyrocarbon layer (40 μm nominal thickness).

The AGR-2 Fuel Specification (INL SPC-923) provides the requirements necessary for acceptance of the fuel manufactured for the AGR-2 irradiation test. The bulk of the kernels and coated particle acceptance testing was performed at B&W and is not contained in this report. Sample NP-B7927 was sent to ORNL for supplemental characterization. The procedures for the limited characterization and qualification of the particles performed at ORNL are outlined in ORNL product inspection plan AGR-CHAR-PIP-09. The BAFo equivalent optical anisotropies of the inner and outer pyrocarbon layers are reported on Inspection Report Form IRF-09, with a determination as to whether the particle batch satisfied the specified parameters for this property. The batch was found to satisfy the AGR-2 Fuel Specification SPC-923, Rev. 1 for IPyC and OPyC anisotropy.

Also provided in this data package are data on the true BAFo, average particle weight, OPyC open porosity, and SiC soot inclusion defect fraction. True BAFo is calculated as (1+N)/(1-N), where N is the diattenuation. This differs from equivalent BAFo = 1+3N, which is the calculation used by the fuel specification to allow comparison to historical measurements. Average OPyC open porosity was determined using a single sample to be 0.65 ml/m^2. An unusually high SiC soot defect fraction was observed in this sample, apparently due to a fabrication anomaly which resulted in one of the hot sampling cups disturbing the bed fluidization during SiC deposition. This is discussed further in the pages following Data Report Form DRF-32.

Inspection Report Form IRF-09: AGR-2 Coated Particles

Procedure:	AGR-CHAR-PIP-09 Rev. 0
Coated particle composite ID:	G73J-14-93071A
Coated particle composite description:	AGR-2 Baseline particle batch

Property	Measured Data				Specification	Acceptance Criteria	Acceptance Test Value	Pass or fail	Data Records
	Mean (x)	Std. Dev. (s)	# measured (n)	k or t value	INL SPC-923				
IPyC anisotropy (BAFo equivalent)	1.0386	0.0021	10	1.833	mean ≤ 1.045	B = x + ts/√n ≤ 1.045	1.040	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	D = x + ks < 1.06	1.047	pass	
OPyC anisotropy (BAFo equivalent)	1.0262	0.0013	10	1.833	mean ≤ 1.035	B = x + ts/√n ≤ 1.035	1.027	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	D = x + ks < 1.06	1.031	pass	

Comments

John Thom — QC Supervisor

10-06-08 — Date

Accept coated particle composite (Yes or No):	Yes

M. C. Thom — QA Reviewer

10/14/08 — Date

Data Report Form DRF-18A: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - IPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08082501
Sample ID:	NP-B7927-B01
Sample Description:	From G73J-14-93071A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082801\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0127	0.0023	0.0004	1.0381	0.0069	0.0012
2	4,5	0.0116	0.0022	0.0004	1.0348	0.0066	0.0012
3	4,6	0.0130	0.0021	0.0004	1.0390	0.0063	0.0012
4	5,3	0.0141	0.0022	0.0004	1.0423	0.0066	0.0012
5	5,5	0.0133	0.0025	0.0005	1.0399	0.0075	0.0015
6	5,6	0.0123	0.0024	0.0005	1.0369	0.0072	0.0015
7	6,4	0.0131	0.0024	0.0005	1.0393	0.0072	0.0015
8	6,5	0.0131	0.0023	0.0005	1.0393	0.0069	0.0015
9	6,6	0.0132	0.0025	0.0004	1.0396	0.0075	0.0012
10	5,7	0.0121	0.0024	0.0005	1.0363	0.0072	0.0015
Average		0.0129	0.0023	0.0005	1.0386	0.0070	0.0014

Mean of average BAFo per particle:	1.0386
Standard deviation of average BAFo per particle:	0.0021

Comments

Run stopped after particle 4. Particles 5-10 use file labels 01a-06a

G. E. Jellison
Operator

8/29/08
Date

Data Report Form DRF-18B: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - OPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08082501
Sample ID:	NP-B7927-B01
Sample Description:	From G73J-14-93071A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082801\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0089	0.0021	0.0004	1.0267	0.0063	0.0012
2	4,5	0.0088	0.0020	0.0004	1.0264	0.0060	0.0012
3	4,6	0.0079	0.0020	0.0004	1.0237	0.0060	0.0012
4	5,3	0.0088	0.0020	0.0004	1.0264	0.0060	0.0012
5	5,5	0.0086	0.0023	0.0005	1.0258	0.0069	0.0015
6	5,6	0.0087	0.0022	0.0005	1.0261	0.0066	0.0015
7	6,4	0.0087	0.0027	0.0005	1.0261	0.0081	0.0015
8	6,5	0.0097	0.0021	0.0004	1.0291	0.0063	0.0012
9	6,6	0.0086	0.0021	0.0005	1.0258	0.0063	0.0015
10	5,7	0.0085	0.0020	0.0005	1.0255	0.0060	0.0015
Average		0.0087	0.0022	0.0005	1.0262	0.0065	0.0014

Mean of average BAFo per particle:	1.0262
Standard deviation of average BAFo per particle:	0.0013

Comments

G. E. Jellison
Operator

08/29/08
Date

Data Report Form DRF-18A: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - IPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08082501
Sample ID:	NP-B7927-B01
Sample Description:	From G73J-14-93071A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082801\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0127	0.0023	0.0004	1.0257	0.0047	0.0008
2	4,5	0.0116	0.0022	0.0004	1.0235	0.0045	0.0008
3	4,6	0.0130	0.0021	0.0004	1.0263	0.0043	0.0008
4	5,3	0.0141	0.0022	0.0004	1.0286	0.0045	0.0008
5	5,5	0.0133	0.0025	0.0005	1.0270	0.0051	0.0010
6	5,6	0.0123	0.0024	0.0005	1.0249	0.0049	0.0010
7	6,4	0.0131	0.0024	0.0005	1.0265	0.0049	0.0010
8	6,5	0.0131	0.0023	0.0005	1.0265	0.0047	0.0010
9	6,6	0.0132	0.0025	0.0004	1.0268	0.0051	0.0008
10	5,7	0.0121	0.0024	0.0005	1.0245	0.0049	0.0010
Average		0.0129	0.0023	0.0005	1.0260	0.0048	0.0009

Mean of average BAFo per particle:	1.0260
Standard deviation of average BAFo per particle:	0.0014

Comments

G. E. Jellison
Operator

08/29/08
Date

Data Report Form DRF-18B: Measurement of Pyrocarbon Anisotropy using the 2-MGEM - OPyC

Procedure:	AGR-CHAR-DAM-18 Rev. 1
Operator:	G. E. Jellison
Mount ID:	M08082501
Sample ID:	NP-B7927-B01
Sample Description:	From G73J-14-93071A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082801\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0089	0.0021	0.0004	1.0180	0.0043	0.0008
2	4,5	0.0088	0.0020	0.0004	1.0178	0.0041	0.0008
3	4,6	0.0079	0.0020	0.0004	1.0159	0.0041	0.0008
4	5,3	0.0088	0.0020	0.0004	1.0178	0.0041	0.0008
5	5,5	0.0086	0.0023	0.0005	1.0173	0.0047	0.0010
6	5,6	0.0087	0.0022	0.0005	1.0176	0.0045	0.0010
7	6,4	0.0087	0.0027	0.0005	1.0176	0.0055	0.0010
8	6,5	0.0097	0.0021	0.0004	1.0196	0.0043	0.0008
9	6,6	0.0086	0.0021	0.0005	1.0173	0.0043	0.0010
10	5,7	0.0085	0.0020	0.0005	1.0171	0.0041	0.0010
Average		0.0087	0.0022	0.0005	1.0176	0.0044	0.0009

Mean of average BAFo per particle:	1.0176
Standard deviation of average BAFo per particle:	0.0009

Comments

G. E. Jellison
Operator

08/29/08
Date

Data Report Form DRF-22: Estimation of Average Particle Weight

Procedure:	AGR-CHAR-DAM-22 Rev. 1
Operator:	Dixie Barker
Particle Lot ID:	NP-B7927-C01
Particle Lot Description:	From G73J-14-93071A AGR-2 Baseline Batch
Filename:	\\mc-agr\AGR\ParticleWeight\W08082502_DRF22R1.xls

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of particles (g):	0.1732	0.1652	0.1393	0.1606	0.1433
Number of particles:	172	163	138	159	142
Average weight/particle (g):	1.007E-03	1.013E-03	1.009E-03	1.010E-03	1.009E-03

Mean average weight/particle (g):	1.010E-03
Standard error in mean average weight/particle (g):	1.06E-06

Dixie Barker
Operator

8-25-08
Date

Data Report Form DRF-31: Measurement of Open Porosity using a Mercury Porosimeter

Procedure:	AGR-CHAR-DAM-31 Rev. 1
Operator:	S. D. Nunn
Coated particle batch ID:	NP-B7927-D01
Batch Description:	From G73J-14-93071A AGR-2 Baseline batch
Thermocouple Expiration Date:	5/15/09
Penetrometer Expiration Date:	7/10/09
Completed DRF Filename:	\\mc-agr\AGR\Porosimeter\S08091601\S08091601_DRF31R1.xls

Mean average weight/particle (g):	1.01E-03
Standard error in mean average weight/particle (g):	1.06E-06

Weight of particles (g):	3.8896
Approximate number of particles:	3851
Uncertainty in number of particles:	4
Total envelope volume of sample (cc):	1.284
Average envelope volume/particle (cc):	3.33E-04
Sample envelope density (g/cc):	3.029

Average particle diameter (microns):	8.60E+02
Average surface area/particle (cm2):	2.33E-02
Total sample surface area (cm2):	8.96E+01
Intruded mercury volume from 250-10,000 psia (cc):	5.80E-03
Open porosity (ml/m2):	6.48E-01

Comments

S. D. Nunn
Operator

9/16/08
Date

Data Report Form DRF-32: Counting of Particles with SiC Soot Inclusion Defects by Visual Inspection

Procedure:	AGR-CHAR-DAM-32 Rev. 0
Operator:	Fred Montgomery
Sample ID:	NP-B7927-E01
Sample Description:	from G73J-14-93071A AGR-2 Baseline batch
Folder containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08090402\
DRF filename:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08090402_DRF32R0.xls

Mean average weight/particle (g):	1.01E-03
Uncertainty in average weight/particle (g):	1.06E-06
Weight of sample of particles (g):	4.941
Approximate number of particles in sample:	4892
Uncertainty in number of particles in sample:	5

Number of particles with SiC soot inclusion defects:	25

Comments

25/4892 corresponds to <7.2E-3 defect fraction at 95% confidence.
Many of the defects were marginal and possibly related to porosity bands. Dark field rings were much more prevalent in this sample than in the qualification batches, indicating a change in the SiC coating conditions.
There are 9 particles in this population that have sufficiently large inclusions in the SiC that it changes the radius of curvature and forms a bulge in the SiC. These are of greater concern and represent a defect population of <3.3E-3 at 95% confidence.
The most serious defect is a particle missing a portion of the IPyC layer. This could represent a defect population as high as 9.7E-4.

Fred C. Montgomery
Operator

10-14-08
Date

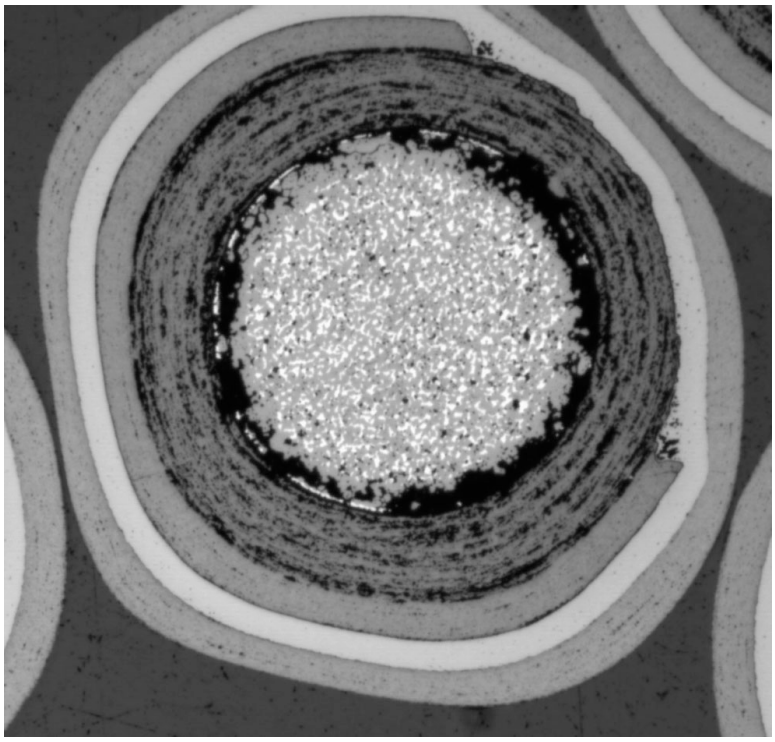
NP-B7927-E01, G73J-14-93071A AGR-2 Baseline batch.

The observed defect fraction was 25/4892, this corresponds to <7.2E-3 defect fraction at 95% confidence. Many of the defects were marginal and possibly related to porosity bands. Dark field rings were much more prevalent in this sample than in the qualification batches, indicating a change in the SiC coating conditions.

There were 9 particles in this population that had sufficiently large inclusions in the SiC that it changed the radius of curvature and formed a bulge in the SiC. These are of greater concern and represent a defect population of <3.3E-3 at 95% confidence. Images are provided below.

A major issue with the soot inclusions observed is that over half only cover small arcs. This contradicts the assumption that a single polish plane is sufficient to do this analysis and means that the defect fraction may be higher than 3.3E-3, which was calculated by a simple binomial distribution. The single polish plane assumption was based on observations of earlier batches that had larger inclusions, but this particular batch is showing a different fluidization problem, probably related to the presence of the hot sample cup in the bed.

The most serious defect is a particle missing a portion of the IPyC layer, possibly broken off when the cup dropped or due to subsequent collision with the cup. This could represent a defect population as high as 9.7E-4. Notice that it also appears in the image below that the kernel surface may have suffered attack by chlorine.



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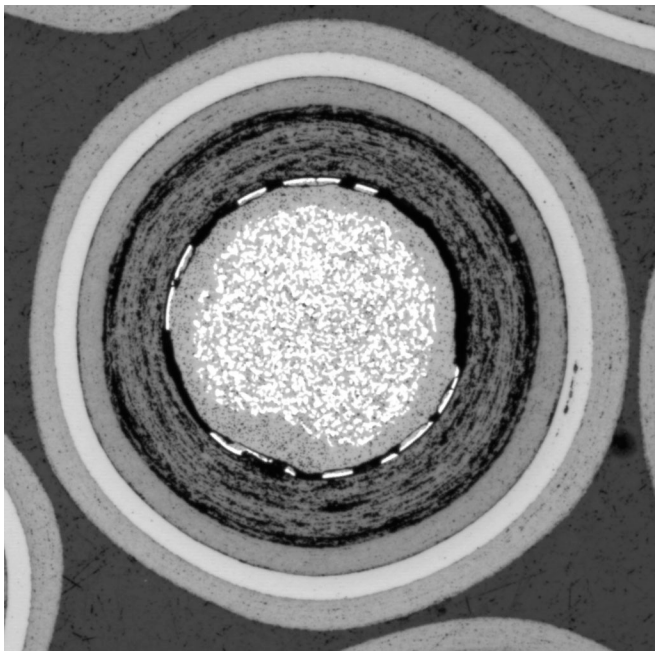
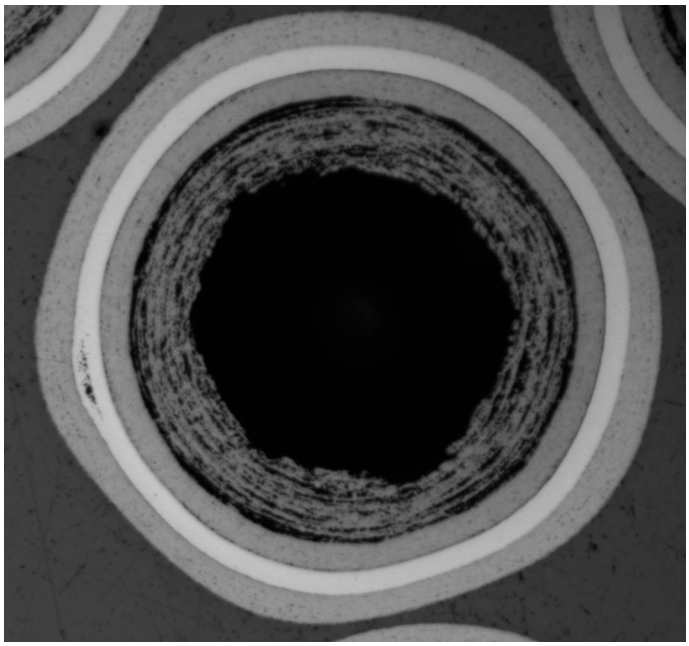


P0809040201 XYF083



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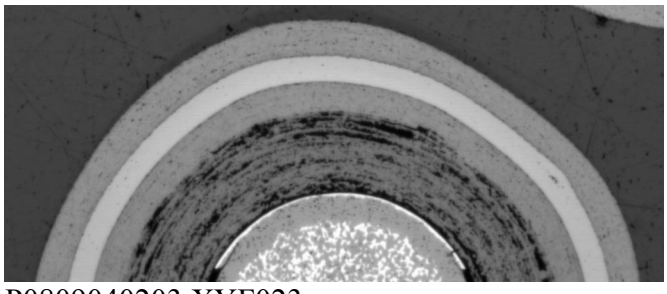

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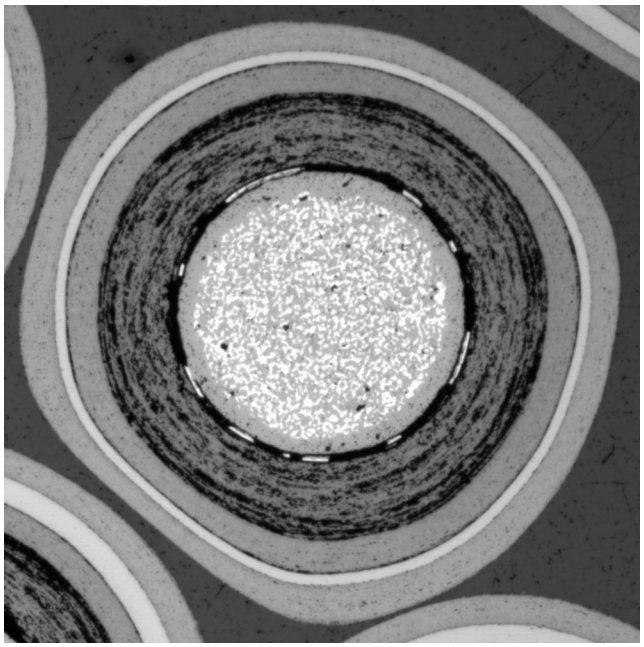

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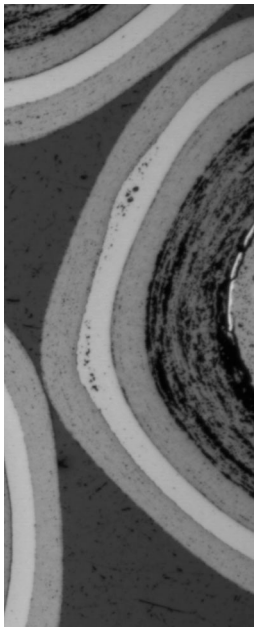

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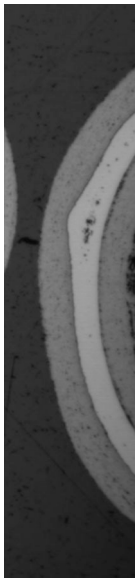

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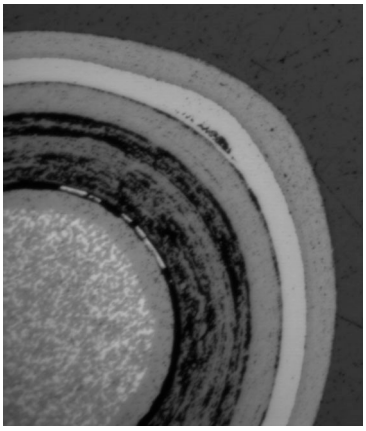

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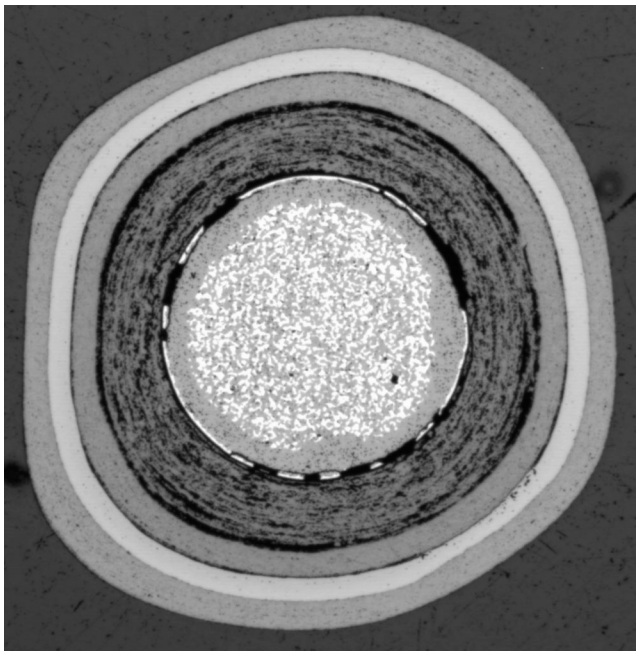

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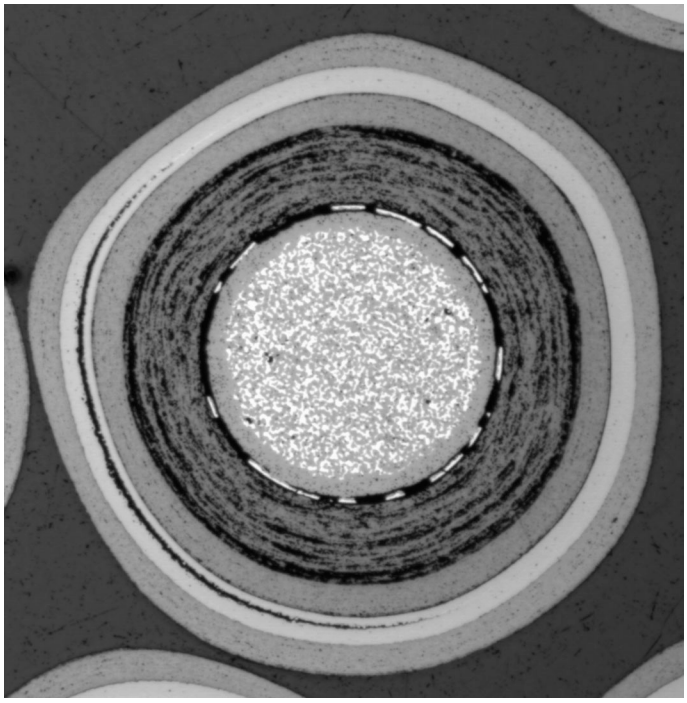

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