OAK RIDGE
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Data Compilation for AGR-2 Baseline Coated Particle Batch G73J-14-93072A

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Data Compilation for AGR-2 Baseline Coated Particle Batch G73J-14-93072A

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Oak Ridge National Laboratory

Coated particle fuel batch G73J-14-93072A 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-14-93072A 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-B7940 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 0.62 ml/m^2. An unusually high SiC soot defect fraction was observed in this sample, mostly due to bands of porosity apparently resulting from a fabrication anomaly in the coating gas delivery system. 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-14-93072A
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)	1.0355	0.0019	10	1.833	mean ≤ 1.045	B = x + ts/√n ≤ 1.045	1.037	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	D = x + ks < 1.06	1.043	pass	
OPyC anisotropy (BAFo equivalent)	1.0242	0.0008	10	1.833	mean ≤ 1.035	B = x + ts/√n ≤ 1.035	1.025	pass	DRF-18
				3.981	dispersion ≤0.01 ≥1.06	D = x + ks < 1.06	1.027	pass	

Comments

John Hunn
QC Supervisor

10-07-08
Date

Accept coated particle composite (Yes or No):	Yes

M. C. Lee
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:	M08082201
Sample ID:	NP-B7940-B01
Sample Description:	From G73J-14-93072A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082701\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0126	0.0027	0.0006	1.0378	0.0081	0.0018
2	4,5	0.0118	0.0025	0.0006	1.0354	0.0075	0.0018
3	4,6	0.0115	0.0027	0.0006	1.0345	0.0081	0.0018
4	5,4	0.0126	0.0028	0.0006	1.0378	0.0084	0.0018
5	5,5	0.0118	0.0025	0.0005	1.0354	0.0075	0.0015
6	5,6	0.0119	0.0026	0.0005	1.0357	0.0078	0.0015
7	6,4	0.0124	0.0029	0.0005	1.0372	0.0087	0.0015
8	6,5	0.0107	0.0023	0.0005	1.0321	0.0069	0.0015
9	6,6	0.0111	0.0022	0.0006	1.0333	0.0066	0.0018
10	5,7	0.0119	0.0023	0.0006	1.0357	0.0069	0.0018
Average		0.0118	0.0026	0.0006	1.0355	0.0077	0.0017

Mean of average BAFo per particle:	1.0355
Standard deviation of average BAFo per particle:	0.0019

Comments

G. E. Jellison
Operator

8/27/08
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:	M08082201
Sample ID:	NP-B7940-B01
Sample Description:	From G73J-14-93072A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082701\

Particle #	Grid Position	Diattenuation			Equivalent BAFo = 1+3N		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0083	0.0019	0.0007	1.0249	0.0057	0.0021
2	4,5	0.0082	0.0017	0.0006	1.0246	0.0051	0.0018
3	4,6	0.0080	0.0018	0.0007	1.0240	0.0054	0.0021
4	5,4	0.0085	0.0023	0.0006	1.0255	0.0069	0.0018
5	5,5	0.0084	0.0019	0.0006	1.0252	0.0057	0.0018
6	5,6	0.0077	0.0021	0.0006	1.0231	0.0063	0.0018
7	6,4	0.0081	0.0021	0.0006	1.0243	0.0063	0.0018
8	6,5	0.0078	0.0021	0.0006	1.0234	0.0063	0.0018
9	6,6	0.0077	0.0020	0.0006	1.0231	0.0060	0.0018
10	5,7	0.0081	0.0022	0.0006	1.0243	0.0066	0.0018
Average		0.0081	0.0020	0.0006	1.0242	0.0060	0.0019

Mean of average BAFo per particle:	1.0242
Standard deviation of average BAFo per particle:	0.0008

Comments

Analyzed particle 4 OPyC using individual points rather than donut to avoid dust particle.

G. E. Jellison
Operator

8/27/08
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:	M08082201
Sample ID:	NP-B7940-B01
Sample Description:	From G73J-14-93072A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082701\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0126	0.0027	0.0006	1.0255	0.0055	0.0012
2	4,5	0.0118	0.0025	0.0006	1.0239	0.0051	0.0012
3	4,6	0.0115	0.0027	0.0006	1.0233	0.0055	0.0012
4	5,4	0.0126	0.0028	0.0006	1.0255	0.0057	0.0012
5	5,5	0.0118	0.0025	0.0005	1.0239	0.0051	0.0010
6	5,6	0.0119	0.0026	0.0005	1.0241	0.0053	0.0010
7	6,4	0.0124	0.0029	0.0005	1.0251	0.0059	0.0010
8	6,5	0.0107	0.0023	0.0005	1.0216	0.0047	0.0010
9	6,6	0.0111	0.0022	0.0006	1.0224	0.0045	0.0012
10	5,7	0.0119	0.0023	0.0006	1.0241	0.0047	0.0012
Average		0.0118	0.0026	0.0006	1.0239	0.0052	0.0011

Mean of average BAFo per particle:	1.0239
Standard deviation of average BAFo per particle:	0.0013

Comments

G. E. Jellison — Operator

08/27/08 — 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:	M08082201
Sample ID:	NP-B7940-B01
Sample Description:	From G73J-14-93072A AGR-2 Baseline batch
Folder containing data:	\\mc-agr\AGR\2-MGEM\R08082701\

Particle #	Grid Position	Diattenuation			True BAFo = (1+N)/(1-N)		
		Average	St. Dev.	Ave. Error	Average	St. Dev.	Ave. Error
1	4,4	0.0083	0.0019	0.0007	1.0167	0.0039	0.0014
2	4,5	0.0082	0.0017	0.0006	1.0165	0.0035	0.0012
3	4,6	0.0080	0.0018	0.0007	1.0161	0.0037	0.0014
4	5,4	0.0085	0.0023	0.0006	1.0171	0.0047	0.0012
5	5,5	0.0084	0.0019	0.0006	1.0169	0.0039	0.0012
6	5,6	0.0077	0.0021	0.0006	1.0155	0.0043	0.0012
7	6,4	0.0081	0.0021	0.0006	1.0163	0.0043	0.0012
8	6,5	0.0078	0.0021	0.0006	1.0157	0.0043	0.0012
9	6,6	0.0077	0.0020	0.0006	1.0155	0.0041	0.0012
10	5,7	0.0081	0.0022	0.0006	1.0163	0.0045	0.0012
Average		0.0081	0.0020	0.0006	1.0163	0.0041	0.0013

Mean of average BAFo per particle:	1.0163
Standard deviation of average BAFo per particle:	0.0006

Comments

G. E. Jellison
Operator

8/27/08
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-B7940-C01
Particle Lot Description:	From G73J-14-93072A AGR-2 Baseline batch
Filename:	\\mc-agr\AGR\ParticleWeight\W08082501_DRF22R1.xls

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of particles (g):	0.1571	0.1493	0.1131	0.1406	0.1534
Number of particles:	155	148	112	140	153
Average weight/particle (g):	1.014E-03	1.009E-03	1.010E-03	1.004E-03	1.003E-03

Mean average weight/particle (g):	1.008E-03
Standard error in mean average weight/particle (g):	1.97E-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-B7940-D01
Batch Description:	From G73J-14-93072A AGR-2 Baseline batch
Thermocouple Expiration Date:	5/15/09
Penetrometer Expiration Date:	7/10/09
Completed DRF Filename:	\\mc-agr\AGR\Porosimeter\S08091602\S08091602__DRF31R1.xls

Mean average weight/particle (g):	1.01E-03
Standard error in mean average weight/particle (g):	1.97E-06

Weight of particles (g):	3.8728
Approximate number of particles:	3842
Uncertainty in number of particles:	8
Total envelope volume of sample (cc):	1.273
Average envelope volume/particle (cc):	3.31E-04
Sample envelope density (g/cc):	3.042

Average particle diameter (microns):	8.59E+02
Average surface area/particle (cm2):	2.32E-02
Total sample surface area (cm2):	8.90E+01
Intruded mercury volume from 250-10,000 psia (cc):	5.50E-03
Open porosity (ml/m2):	6.18E-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-B7940-E01
Sample Description:	From G73J-14-93072A AGR-2 Baseline batch
Folder containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08082901\
DRF filename:	\\mc-agr\AGR\ImageProcessing\Completed_Inclusions\P08082901_DRF32R0.xls

Mean average weight/particle (g):	1.01E-03
Uncertainty in average weight/particle (g):	1.97E-06
Weight of sample of particles (g):	4.953
Approximate number of particles in sample:	4913
Uncertainty in number of particles in sample:	10

Number of particles with SiC soot inclusion defects:	146

Comments

146/4913 corresponds to <3.5E-2 defect fraction at 95% confidence.
3 of the observed defects were related to small diameter soot inclusions thick enough to noticeably deform the SiC. The remaining defects appeared in bright field as lines of spots caused by small pits. These lines were associated with bands of porosity that could be observed using dark field.

Fred C. Montgomery
Operator

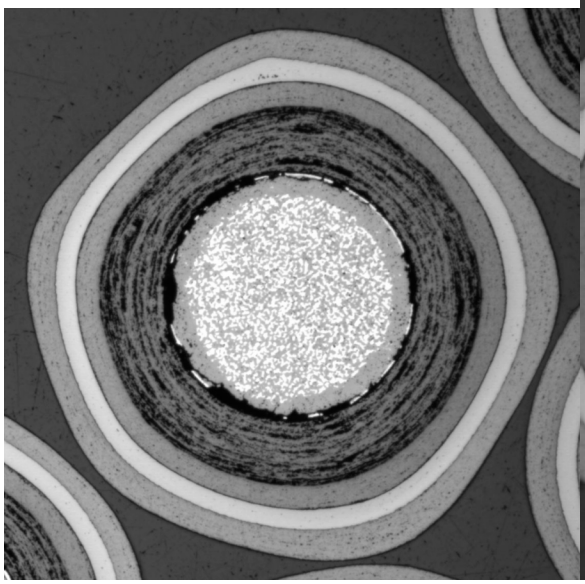
10-14-08
Date

NP-B7940-E01, G73J-14-93072A AGR-2 Baseline batch.

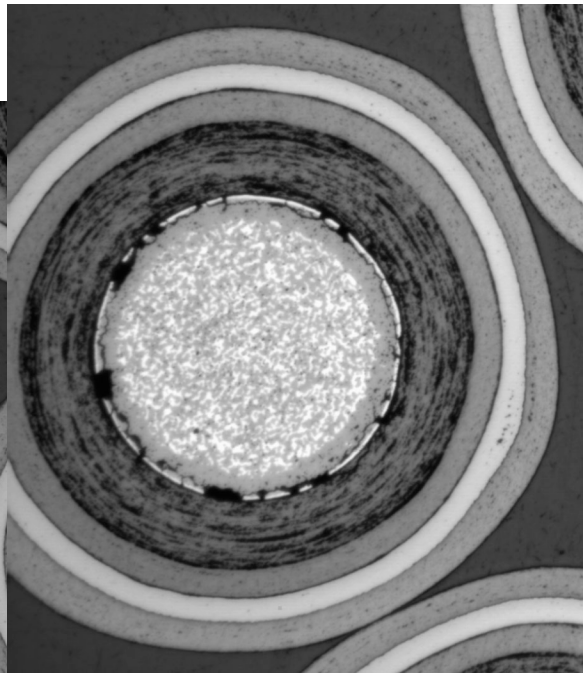
146/4913 corresponds to <3.5E-2 defect fraction at 95% confidence.

3 of the observed defects were related to small diameter soot inclusions thick enough to noticeably deform the SiC. The remaining defects appeared in bright field as often barely discernable lines of spots caused by small pits. These lines were associated with bands of porosity that could be observed using dark field.

Examples of small diameter thick inclusions (3 observed)

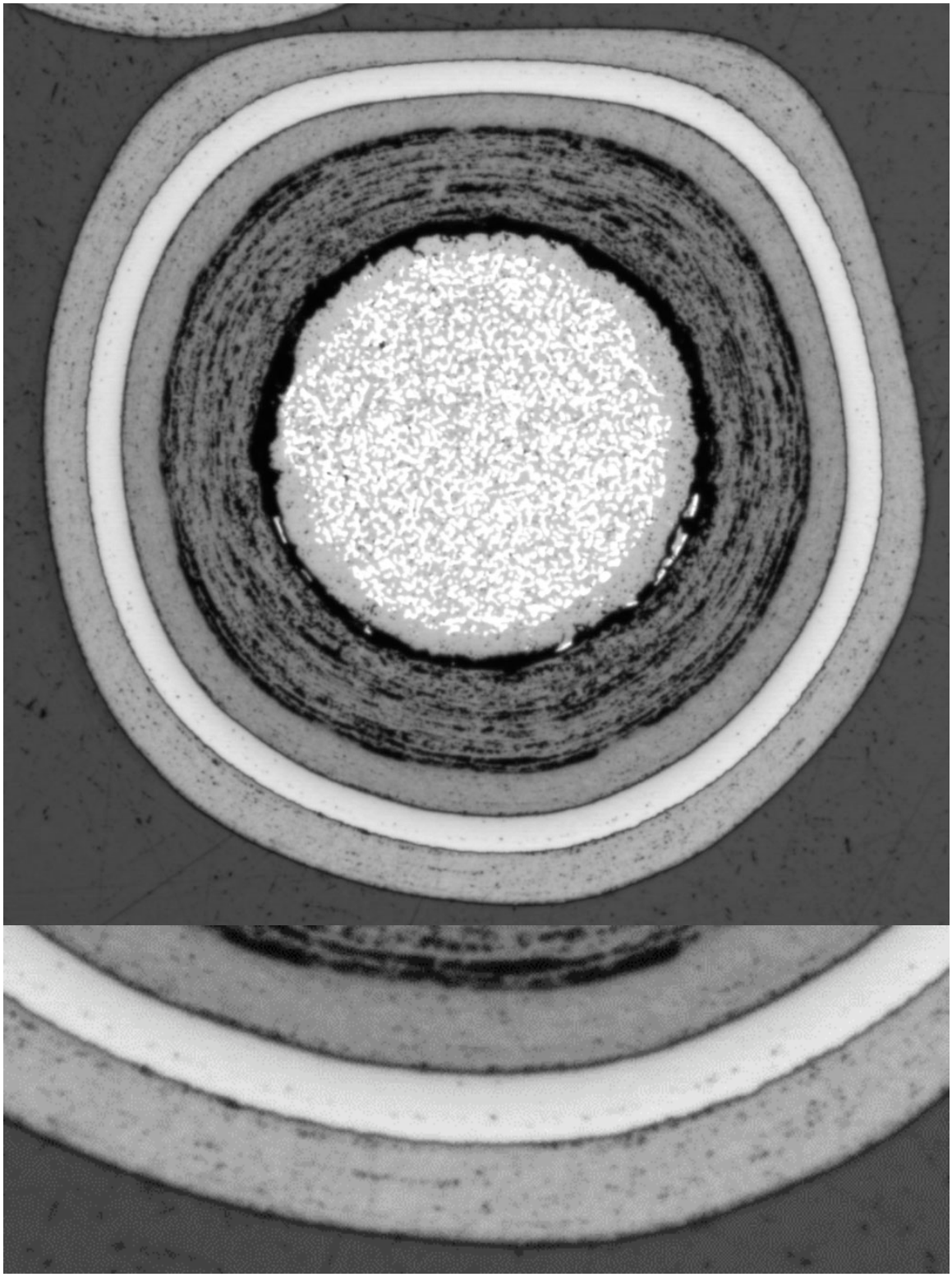


P0808290102 XYF056



P0808290104 XYF064

Example of line of pits caused by porosity



P08082903 XYF037