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Introduction

In 2008 a modified crush testing technique for hemispherical shell SiC specimens was developed. The technique uses a soft metal at the specimen-plunger contact to generate a uniformly stressed area at the inner surface of the shell specimens. The method was applied to a series of hemispherical shell SiC specimens extracted from samples taken from nine historical fuel particle batches. Results of these experiments and test method development were reported in ORNL/TM-2008/167. A list of samples and results for this initial experimental series, labeled Series A, is attached in Appendix A. A major conclusion from this initial experiment was that the microstructure at the inner surface of the SiC layer may strongly affect the whole layer strength.

In 2009 two more series of SiC strength experiments were proposed to expand on the initial work on the historical samples. Series B samples will explore the effect of the bulk SiC microstructure while minimizing the effect of the inner surface microstructure. Open surface porosity in the inner pyrocarbon (IPyC) layer results in roughness on the inner surface of the SiC shell due to infiltration of SiC into the open porosity of the IPyC. For Series B, one batch of IPyC coated substrate material was produced in a single run using the 150 mm coater at Babcock and Wilcox (B&W). The IPyC substrate was produced on a mixed batch of zirconia kernels with two different diameters. All the Series B variants used this IPyC substrate in order to keep the effect of the substrate constant. Sixteen Series B variants were produced using four different coating conditions, 2 different coating times, and the two different substrate particle sizes.

The third experimental series, Series C, involves the production of IPyC substrates of varying porosity subsequently coated with SiC using fixed deposition conditions. The SiC deposition conditions are similar to the Advanced Gas Reactor (AGR) program primary coating variant, which uses an Ar-H mix during SiC deposition. The purpose of this series is to study the effect of the inner surface roughness on the SiC shell strength. Following successful production and testing of Series B and Series C samples, a set of irradiation tests have been planned to study the effects of irradiation on the SiC properties, with emphasis on the strength of the SiC layer.

This report provides the coating and pre-irradiation characterization results for Series B. Based on these results, it is clear that some further work is needed prior to starting the irradiation. Some additional characterization is planned to provide additional data. A few of the samples exhibited low fracture stress due to the SiC being less than 30 μm thick. These variants may need to be redone. Finally, some questions in the analysis of fracture stress need to be addressed by additional sample preparation and testing.

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Coating Conditions

A single coating run was performed using the 150 mm coater at B&W to make a large quantity of IPyC coated ZrO_2. Two ZrO_2 kernel sizes were mixed in a 4:1 ratio of nominally 520 µm diameter and 670 µm diameter kernels. These were then coated using typical AGR IPyC coating conditions. No buffer was deposited prior to the IPyC deposition. Particles from this coating run, G73H-NF-93083, were sent to ORNL for use as the substrate material for the Series B SiC samples.

SiC was chemical vapor deposited in a 50 mm coater using methyl trichlorosilane (MTS), CH_3SiCl_3. Four different coating conditions and two different deposition times were used. Three of the coating conditions used only H mixed with the MTS as the fluidization medium, with coating temperature varied in order to obtain variation in grain size. The forth deposition condition used a 50:50 mix of Ar:H to improve fluidization (lower total gas flow) and allow a further reduction in coating temperature. Table 1 shows the deposition conditions for the 8 coating runs in Series B. Note that the MTS flow also varied slightly because it was delivered using a bubbler through which some of the H was passed, and therefore, the flow rate was not absolutely controlled.

Table 1. Series B deposition conditions

Run #	Coating Temp. (°C)	Run time (min)	H2 flow (sccm)	Ar flow (sccm)	MTS flow (sccm)
AGRBW-1	1450	120	14800		160
AGRBW-2	1500	120	14800		168
AGRBW-3	1550	120	14800		166
AGRBW-4	1425	120	5200	5200	160
AGRBW-5	1450	240	14800		161
AGRBW-6	1500	240	14800		152
AGRBW-7	1550	240	14800		152
AGRBW-8	1425	240	5200	5200	150

Particle Sorting

After coating, particles were sorted using a rollermicrometer to separate the two different kernel sizes. The rollermicrometer uses a v-trough vibrational feeder to drop particles in a single stream onto two nearly parallel, inclined, counter-rotating cylinders. As the particles roll down the 10° incline, they eventually drop through the ever-widening gap between the rollers into 11 receptacle bins underneath. The roller gap is adjusted to the particle size using pin gauges. The roller gap was adjusted for each particle sample to separate the sample into 3 subsamples (A, B, and C). Debris was collected in the first bin and discarded. Subsample A contained particles with small kernels and subsample C contained particles with large kernels. Subsample B was a mixed sample and was set aside. Subsamples A and C were then rolled again after readjusting the roller gap in order to further refine the size distribution into subsamples A1, A2, A3, C1, C2, and C3. Subsamples A2 and C2 were used for strength testing and characterization.

Characterization of Physical Properties

The SiC coatings were characterized to determine average layer thickness, average sink-float density, and typical microstructure. In addition, the open surface porosity of the IPyC layer, which may affect the layer strength, was also measured.

SiC layer thickness

SiC layer thickness was measured by materialographic cross-sectioning and optical imaging. The data report forms for all the analyzed samples are included in Appendix B. Sample preparation and results of the analysis are discussed below.

Samples were mounted in Struers Specifast clear thermoplastic epoxy using a Struers ProntoPress hot press. The lower ram of the press was machined with small holes in a 9 x 9 square array to hold particles in position during mounting. An end mill with a rounded bottom was used to machine the holes so that particles would tend to sit in the center of the hole. Several hole depths and diameters were tried and a 200 µm deep, 1000 µm diameter hole was determined to be best for particles in the 600 - 1000 µm diameter range. The 9 x 9 array of holes were closely spaced (1500 µm on center) to keep particles in the middle of the 1.25" diameter mount. Staying in the middle of the mount and in a tight array keeps the cross sections flatter and reduces the variation in polish down distance across the array. The perimeter of the ram, outside the array, was also milled down 200 µm. This results in a raised perimeter in the final mount, which is at the same height as the tips of the particles. This raised perimeter helps to keep the mount level and flat until the first 200 µm is removed during grinding. The machined ram replaces the previously used procedure, where a plastic mesh was used to position the particles. The plastic mesh could complicate grinding and polishing of difficult samples.

Eighty particles were placed in each mount, with one open position for indexing. The mounted particles were ground to near midplane using a Struers RotoPol 8" rotary platen system. Coarse grinding was done using 9 µm diamond grit on a Struers Allegro cast iron surfaced disc. Note that this would normally be considered a fine grinding step for most materialographic preparations, but coarser grit or fixed grit grinding with SiC paper is much to aggressive for TRISO-coated particles. Our standard coarse grinding procedure had to be modified by reducing the applied force from 30 N down to 5 N, the minimum force available. This was because the ZrO_2 kernels were loosely bound inside of the IPyC layer and kernel rotation had to be avoided. Kernel rotation complicates the grinding and can result in fractured coatings. Finer grinding was performed by stepping down to 6 µm and 3 µm diamond grit on an Allegro disc. The Allegro disc is used even for the fine grinding step because it is very effective at maintaining a planar surface. Coarse polishing was performed using 3 µm diamond grit on a Struers Dac silk cloth surfaced disc. The 3 µm coarse polish results in a sufficient polish for optical imaging. Finer polishing is not advantageous because it results in excessive relief at the pyrocarbon interfaces.

The polished cross sections were imaged using a Leica DMRX optical microscope. The microscope is equipped with a computer controlled stage, which takes advantage of the square array mounting pattern to automate the imaging process. Image analysis was performed using in-house software [1, 2], which identifies up to 720 points on each interface, spaced at half degree increments around the circular cross section. The image analysis determines the mean layer thickness and kernel radius for each particle cross section from which an average and standard deviation are determined for the 80 particle sample [3]. A geometrical correction algorithm is used to account for the fact that particles are imaged at a cross section that is not exactly through the midplane of the particle. The analyzed results are manually inspected to determine if the layer interfaces were properly identified. Defects in the polished cross section can cause an error in the automated image analysis. Every particle may not be included in the reported average as a result of this manual inspection to eliminate data that is not representative of the actual layer thickness. The number of imaged particles included in the final result is reported on the data report form.

The data report forms for all the analyzed samples are included in Appendix B. Table 2 and Table 3 summarize the mean and standard deviations measured for each of the samples in Series B. Note that the mean kernel diameter and mean IPyC thickness should be the same for all particle samples in Series B-A2 and B-C2 because these kernels were all coated in the same 150 mm coater batch at B&W. All the IPyC mean thicknesses were indeed within 1 μm of the average for both series and the standard deviations were all essentially the same. This indicates some reliability in the analysis. Note that the larger kernels in Series B-C2 did have slightly thinner IPyC. This is expected, because the coating rate usually varies inversely with particle size due to the geometrical effect on surface flux. The mean kernel diameter values varied somewhat more than the IPyC, but this is expected due to both the greater standard deviation in the kernel size and the fact that kernel diameter analysis by cross sectioning carries a much larger uncertainty. The size of the uncertainty is also indicative of the accuracy of the analysis. Note that the mean kernel diameter reported for AGRBW-4C2 was the lowest value of the series, but also showed the highest standard deviation. The higher standard deviation usually indicates either a sampling abnormality or an error in the analysis. In fact, this indicator was used to refine the analysis. Samples that showed an above average standard deviation in one of the measured values were reviewed manually to look for analysis errors. In some cases, particles were found that had low report kernel diameters. These turned out to be particles that were not close to the midplane, which was obvious from observation of the thickness of the particle's shadow (difference between the edge of the cross sectioned layer imaged with reflected light and the actual edge of the particle imaged with transmitted light). These particles, which were not at the measured polish down distance used in the midplane correction algorithm, were removed from the data set.

Table 2. Dimensional data for Series B-A2

Sample ID	Kernel diameter		IPyC thickness		SiC thickness	
	mean	st. dev.	mean	st. dev.	mean	st. dev.
AGRBW-1A2	532	13	44	3	31.8	0.8
AGRBW-2A2	529	11	46	3	33.7	0.8
AGRBW-3A2	532	14	46	3	33.2	1.0
AGRBW-4A2	528	11	45	3	33.6	0.8
AGRBW-5A2	536	22	46	3	62.6	1.7
AGRBW-6A2	549	12	45	3	60.1	0.9
AGRBW-7A2	541	13	45	3	61.6	1.5
AGRBW-8A2	541	12	45	3	60.4	1.1
Average	536		45		N/A	

Table 3. Dimensional data for Series B-C2

Sample ID	Kernel diameter		IPyC thickness		SiC thickness	
	mean	st. dev.	mean	st. dev.	mean	st. dev.
AGRBW-1C2	715	11	43	2	27.4	0.6
AGRBW-2C2	711	24	43	3	28.7	0.9
AGRBW-3C2	712	21	43	3	27.8	0.8
AGRBW-4C2	700	35	43	3	33.4	1.4
AGRBW-5C2	718	19	44	3	62.8	1.1
AGRBW-6C2	720	31	42	3	56.1	1.8
AGRBW-7C2	731	22	43	3	57.9	1.4
AGRBW-8C2	709	26	44	3	64.6	1.6
Average	714		43		N/A	

The SiC thickness is expected to vary from sample to sample because each sample had SiC deposited in a different 50 mm coater batch. In general, samples 5 through 8 were about twice as thick as samples 1 through 4, as expected due to the factor of two in coating time. Figure 1 and Figure 2 compare the 120 min and 240 min SiC deposition runs, respectively. In most cases, it can be seen that the SiC layer was thinner on the C samples. Again this is expected due to the higher flux of coating products to the surface of the smaller spheres. In contrast to this expectation are coating runs 4, 5, and 8. The data on these runs will have to be analyzed in more detail to determine the cause of this unexpected result. Runs 4 and 8 are the Ar-H runs, which may explain the difference in the relative coating rates for those two cases. However, Run 5 should show the same characteristics as the other H-only runs.

In analyzing the quality of the data, it is sometimes useful to look at the distribution of the mean values of thickness measured on each particle. It is preferable that this distribution have a normal or Gaussian shape, indicating sufficient sampling of a well-controlled property. Table 5 through Table 8 provide a mosaic of the histograms associated with the dimensional analysis of Series B. Table 4 summarizes the quality of the analyses based on the distributions of the measured values, with a determination to measure more particles for some of the samples and completely redo the analysis of AGRBW-4C2. Note that the coating runs mentioned above that did not show the expected trends are the same that show inadequate analysis in Table 4. For instance, it can be seen that the kernel analysis for AGRBW-5A2 is less well defined than the other Series B-A2 samples, and this non-normality is repeated in the IPyC and SiC analyses. This may indicate a problem in the analysis or inadequate statistical sampling.

Table 4. Summary of analysis quality based on distribution of measured values

Sample ID	Analysis quality based on shape of distribution			Disposition
	Kernel	IPyC	SiC	
AGRBW-1A2	Good	Mediocre	Good	OK
AGRBW-2A2	Good	Good	Good	OK
AGRBW-3A2	Good	Good	Mediocre	OK
AGRBW-4A2	Good	Good	Good	OK
AGRBW-5A2	Mediocre	Mediocre	Mediocre	Add more data
AGRBW-6A2	Good	Good	Good	OK
AGRBW-7A2	Good	Good	Good	OK
AGRBW-8A2	Mediocre	Poor	Mediocre	Add more data
AGRBW-1C2	Good	Good	Good	OK
AGRBW-2C2	Mediocre	Good	Mediocre	OK
AGRBW-3C2	Mediocre	Mediocre	Mediocre	Add more data
AGRBW-4C2	Poor	Good	Poor	Redo
AGRBW-5C2	Good	Good	Good	OK
AGRBW-6C2	Poor	Mediocre	Mediocre	Add more data
AGRBW-7C2	Good	Good	Good	OK
AGRBW-8C2	Good	Good	Good	OK

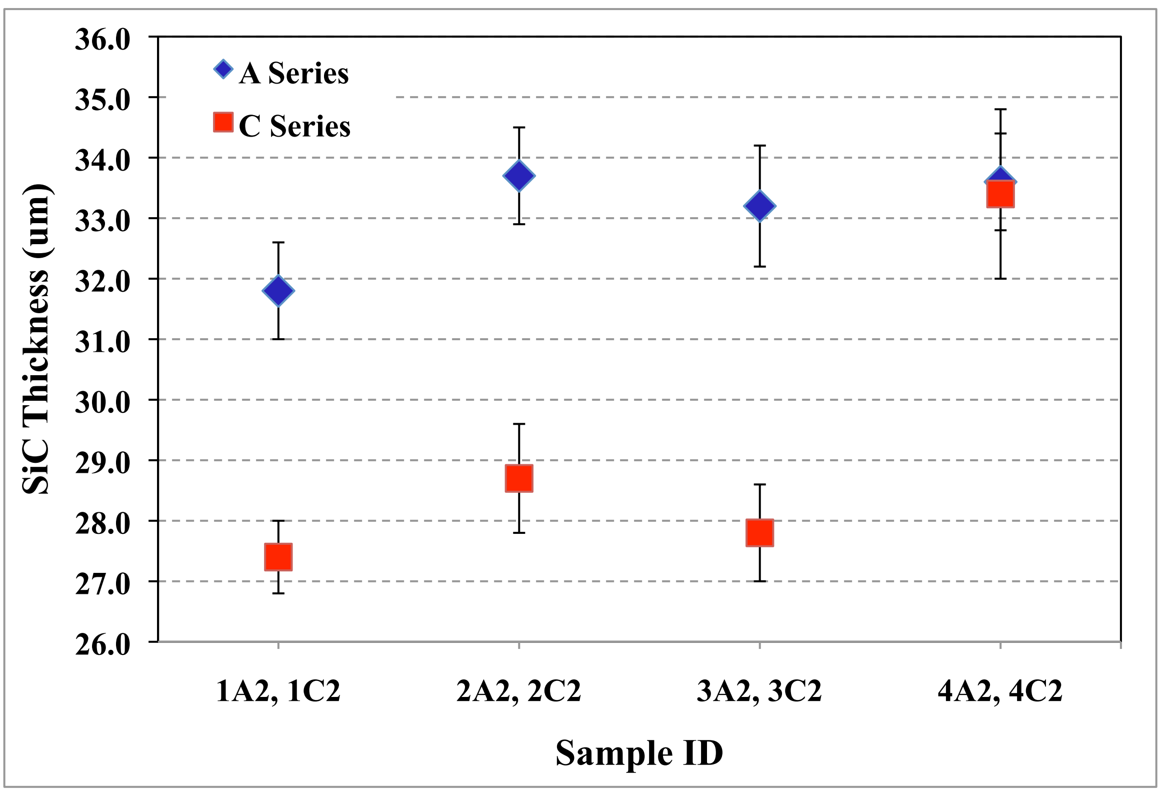


Figure 1. Comparison of 120 min SiC runs.

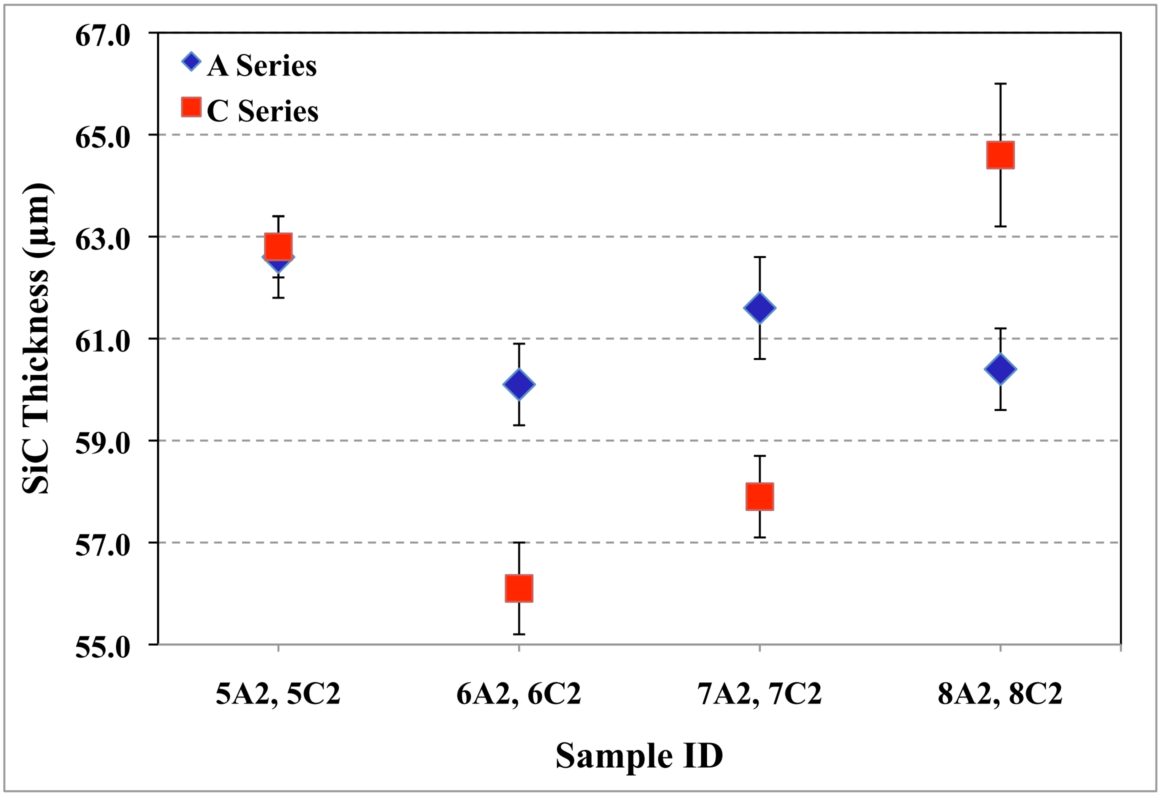


Figure 2. Comparison of 240 min SiC runs.

Table 5. Histograms from optical analysis of coating thickness, Series B-A2 runs 1-4

Table 6. Histograms from optical analysis of coating thickness, Series B-A2 runs 5-8

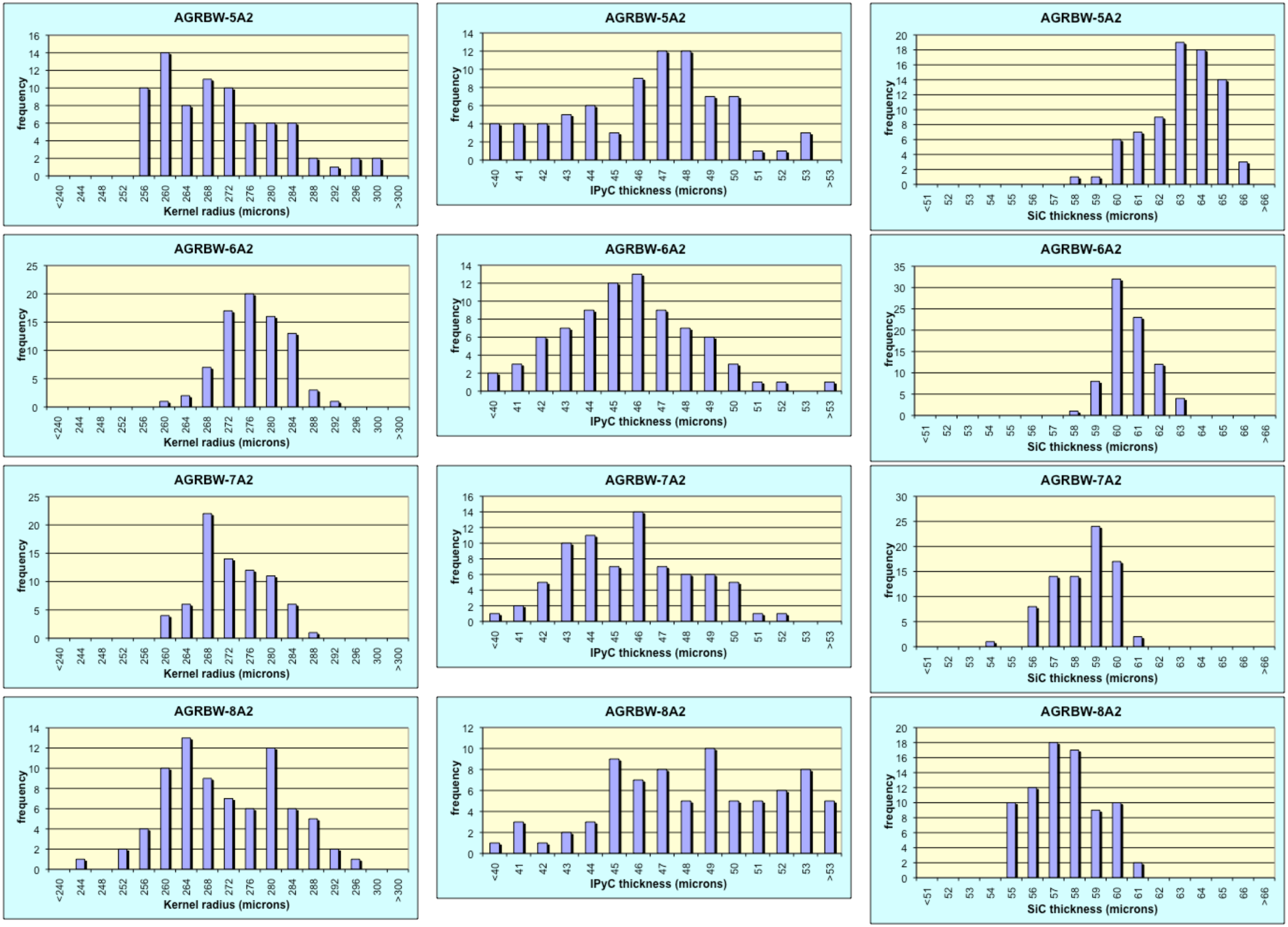


Table 7. Histograms from optical analysis of coating thickness, Series B-C2 runs 1-4

Table 8. Histograms from optical analysis of coating thickness, Series B-C2 runs 5-8

SiC density

Sink-float density of the SiC layers was measured using a liquid gradient density column. All samples in Series B exhibited a mean density above 3.2 g/cm^3, indicating a good SiC layer. Thicker samples had a higher mean density, probably due to a larger average grain size.

A liquid gradient density column was constructed using methylene iodide and bromoform to give a column range from 3.15 g/cm^3 to 3.21 g/cm^3. An initial mix of 38% bromoform and 62% methylene iodide was pumped from Beaker A at a constant rate of 3 ml/min into the bottom of the glass column. A mix of 6% bromoform and 94% methylene iodide was gravity fed from Beaker B into Beaker A at a controlled rate of 1.5 ml/min. Both beakers were constantly stirred to mix the chemicals. When the column was full, the feed tube was clamped off and pumps and stirrers deactivated. The glass density column was maintained at a temperature of 25°C using a recirculating water bath.

SiC fragments were obtained from the coated particles by placing the particles in a bullet press with a few stainless steel pen balls with a diameter larger than the kernel but smaller than the coated particle. The steel balls act to stop the ram after coatings are fractured from the kernel and prior to further fracture of the coatings into smaller pieces. Coating fragments were picked out under a stereo microscope and placed in an alumina boat. The fragments were then heated in air for 2 hours at 850°C to burn of the pyrocarbon layer. Forty to sixty pyrocarbon-free SiC fragments were then injected into the top of the density column using a 38% bromoform and 62% methylene iodide solution.

The SiC fragments were allowed at least 4 hours to settle in the column. Insufficient settle time results in an under-estimate of the sink-float density because zero buoyancy has not yet been reached. Four glass encapsulated density standards, which remain in the column between analyses, were used to calibrate the column prior to measurement of the SiC fragments. The position of the standards and the fragments was measured using a survey scope mounted on a digital height gauge. After each sample was measured, the column was drained and rinsed with alcohol to remove the SiC fragments and prepare the column for the next use.

The data report forms for all the analyzed samples are included in Appendix C. The linear fit obtained from the four calibration standards is shown on these forms. This fit is used to calculate the density of each fragment based on its position in the column. Table 9 lists the mean and standard deviation of each sample of SiC fragments. All samples showed an acceptable mean density above 3.2 g/cm3. This indicates a good SiC layer, without excessive porosity or free silicon. Figure 3 shows the mean density measured on each sample with error bars indicating the 95% confidence interval on the mean value for all the particles in the rollermiked lot. Note that coating runs 5 through 8 show a significantly higher mean density. This is presumably related to the tendency for thicker layers to exhibit a larger average grain size, with grain size continually increasing as a function of distance from the particle center. Layers with larger grain size would be expected to have fewer grain boundaries sites where small pores or defects may be located.

Table 9. Summary of SiC sink-float density for Series B

Coating Run	Series B-A2 SiC density (g/cm^3)		Series B-C2 SiC density (g/cm^3)	
	mean	st. dev.	mean	st. dev.
AGRBW-1	3.2014	0.0028	3.2017	0.0025
AGRBW-2	3.2040	0.0024	3.2017	0.0027
AGRBW-3	3.2038	0.0020	3.2019	0.0023
AGRBW-4	3.2035	0.0019	3.2025	0.0019
AGRBW-5	3.2064	0.0017	3.2064	0.0010
AGRBW-6	3.2079	0.0020	3.2069	0.0016
AGRBW-7	3.2077	0.0011	3.2078	0.0009
AGRBW-8	3.2074	0.0006	3.2069	0.0005

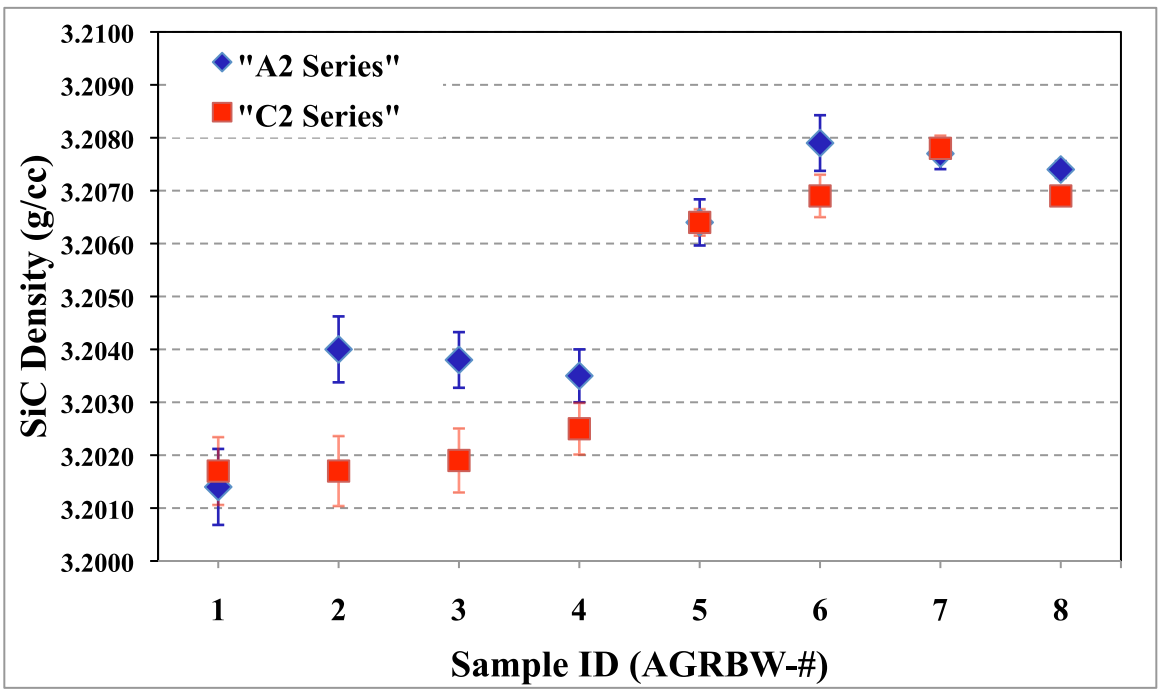


Figure 3. SiC sink-float density for Series B

IPyC open porosity

The open porosity of the IPyC substrate was measured using a Quantachrome Poremaster-60 mercury porosimeter. The data report forms are included in Appendix D. To minimize variation in SiC strength due to substrate effects, all the SiC samples in Series B were deposited on IPyC-coated ZrO_2 particles produced in a single coating run using the B&W 150 mm coater. A sample of this IPyC substrate was analyzed for open porosity. As for the coated particles, the IPyC sample was size separated using the rollermicrometer in order to isolate the two kernel sizes. This was important for the porosity measurement because the surface area of the sample is determined from the measured volume with the assumption that the sample consists of a number of uniform spheres. A bimodal size distribution violates this assumption. The measured open porosity for the small kernel substrate was 0.468 ml/m^2. The measured open porosity for the large kernel substrate was 0.384 ml/m^2. These are relatively low porosities for an IPyC layer, but in line with previously measured IPyC samples from B&W. Typical AGR-1 baseline fuel has an IPyC open porosity of around 1.6 ml/m^2.

As part of the measurement of open porosity, average envelope volume is determined, from which the average particle diameter can be calculated. Average particle diameters were 614 µm and 790 µm. This is in reasonable agreement with the average measured values for the kernels plus IPyC on the polished cross sections, 626 µm and 800 µm.

SiC grain structure

SiC microstructure was examined by scanning electron microscopy (SEM). Backscattered electron imaging was used to distinguish the grain structure. Grain structure was found to vary as expected with the variation in the deposition conditions.

Samples were mounted and ground to midplane, as for optical imaging, with additional fine polishing steps. After the coarse polish using 3 µm diamond on a Struers Dac silk, a fine polish was performed using 1 µm grit diamond on Dac followed by a very fine polish using 1/4 µm diamond on a Struers Plus high nap disc. Graphite powder was added to the Struers Specifast epoxy in order to reduce charging during SEM. Polished cross sections were also coated with a very light evaporated carbon film to further reduce charging effects.

Backscattered electron imaging was used for the SEM. In this mode, the effect of grain orientation on the electron stopping power produces contrast between grains oriented in different directions. This allows one to visualize the grain boundaries and distinguish the grain structure. This methods requires the contrast of the microscope to be increased to maximum and the settings and apertures should be adjusted to get a well columnized, high current beam.

Table 10 through Table 15 are a series of montages that show the typical microstructure of the different coating variants in Series B. Table 10 and Table 11 show the three H+MTS temperature variants for the small kernel particles and large kernel particles, respectively. Grain size increased with coating temperature, as expected. A coating temperature of 1450°C clearly produced a finer grain structure throughout the layer. The difference between 1500°C and 1550°C is less obvious. It is also clear that the grain size increased through the thickness of the layer, becoming larger as the deposition progressed. This grain growth effect appears to be more pronounced as coating temperature increased. Table 12 through Table 14 show the three H+MTS temperature variants for the small kernel particles and large kernel particles at higher magnification. It is interesting to note that the grain size at the IPyC interface along the inner edge of the SiC is fairly similar for all the H+MTS temperature variants (Table 12 and Table 13). This could be significant in terms of how much the average SiC grain size should be expected to affect the SiC strength in these fracture tests, given that fracture initiates at this inner surface. Also in Table 12 and Table 13, the degree of SiC penetration into the IPyC can be seen. The observed stitching is minimal, relative to what is often seen, which agrees with the relatively low open porosity measured for the IPyC substrate. Table 12 and Table 14 show the outer edge of the SiC, where the larger grain growth for the higher deposition temperatures is evident. The 1450°C sample still shows a mix of smaller grains at the outer edge. Table 15 shows the two Ar-H-MTS variants. The grain structure for these samples appears to be much finer, although there may be more porosity. Also note that the circumferential cracking along the inner edge of the SiC in many of these images is often seen and most likely an artifact of the polishing.

Table 10. SiC grain structure of H+MTS temperature variants on small kernels, with a side by side comparison of thin and thick samples

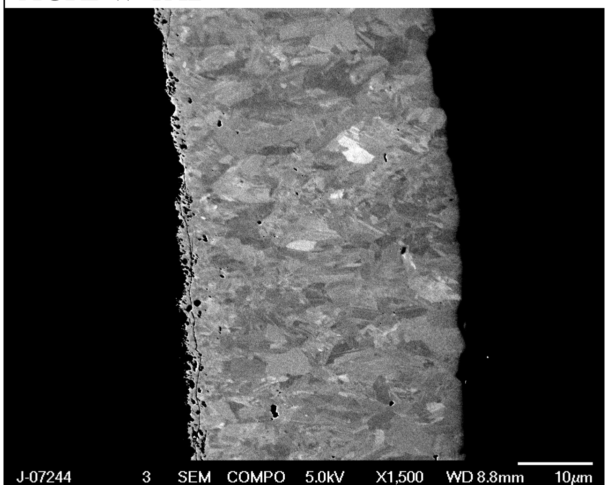
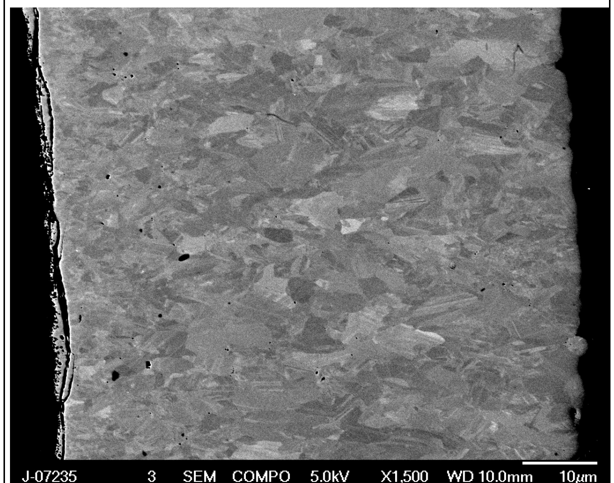
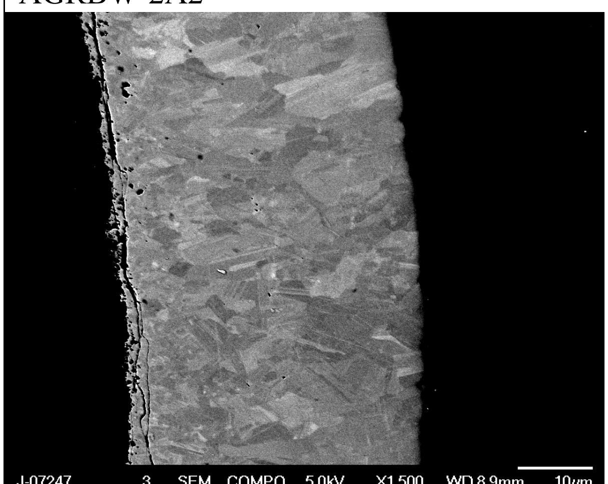
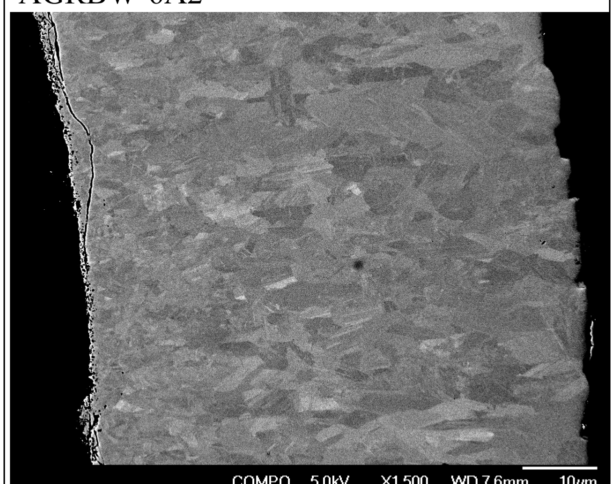
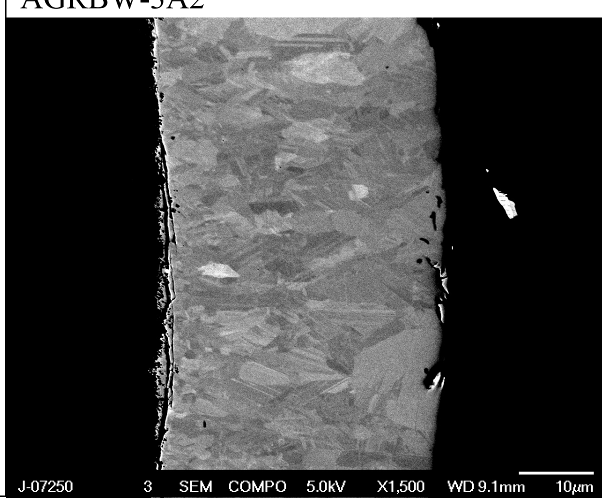
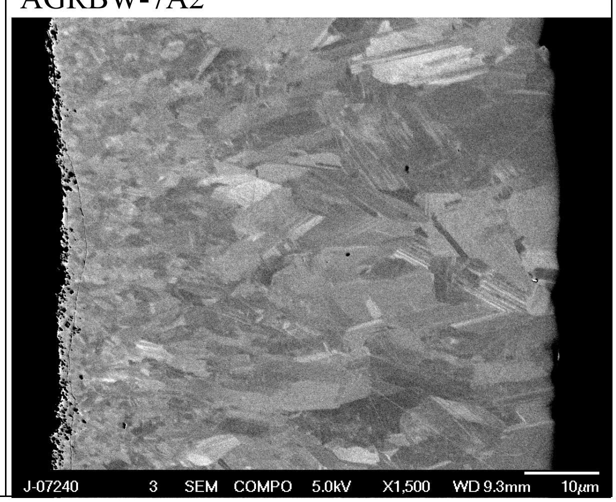
	120 min, small kernel	**240 min, small kernel**
1450°C	AGRBW-1A2 	AGRBW-5A2 
1500°C	AGRBW-2A2 	AGRBW-6A2 
1550°C	AGRBW-3A2 	AGRBW-7A2 

Table 11. SiC grain structure of H+MTS temperature variants on large kernels, with a side by side comparison of thin and thick samples

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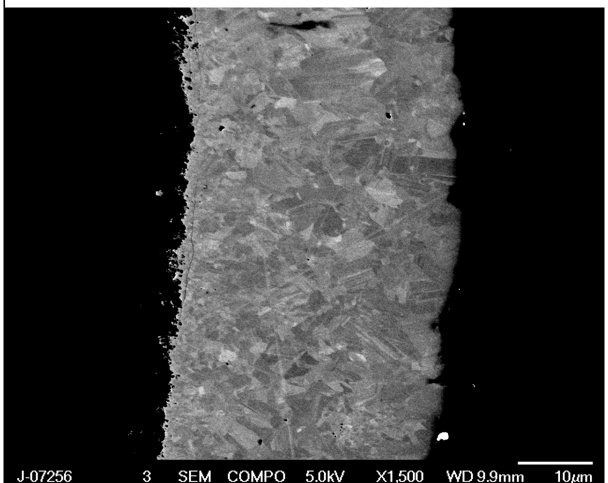
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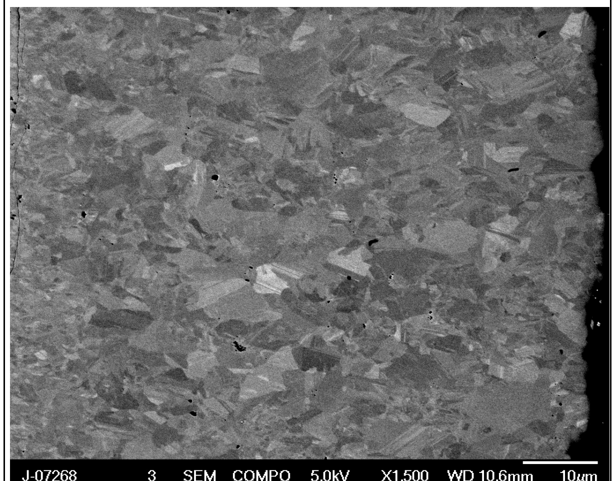
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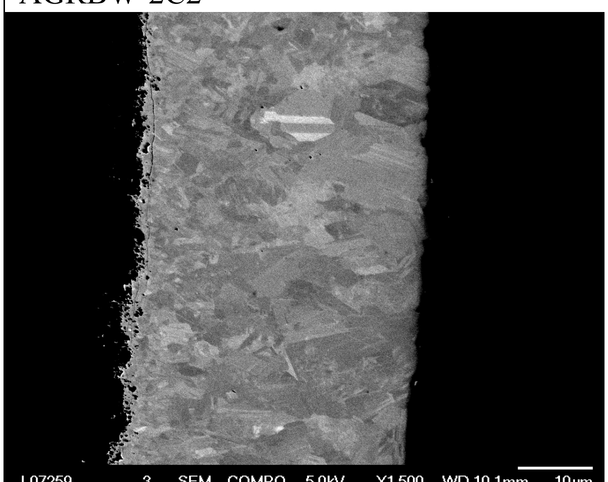
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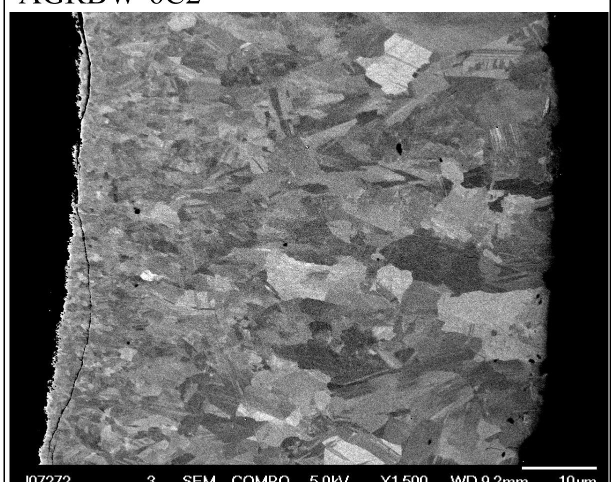
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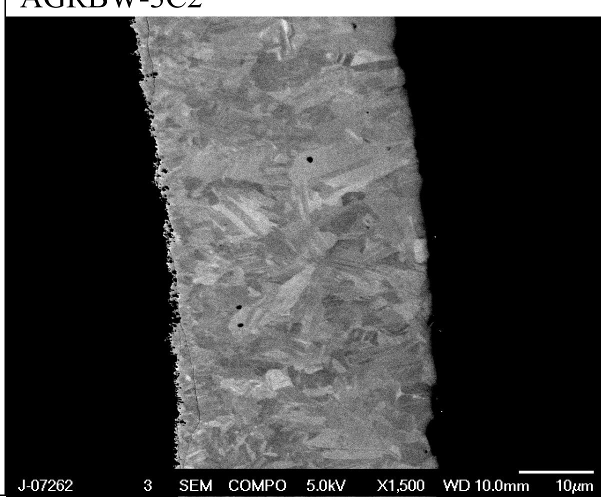
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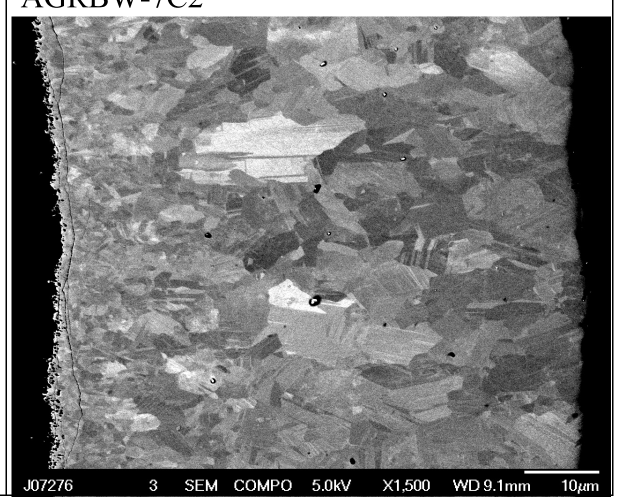
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</table>

Table 12. Higher magnification images of SiC grain structure of H+MTS temperature variants, thin samples with a side by side comparison for small and large kernels

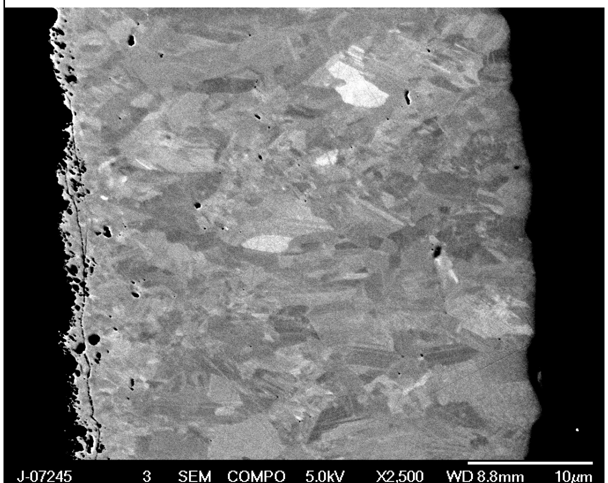
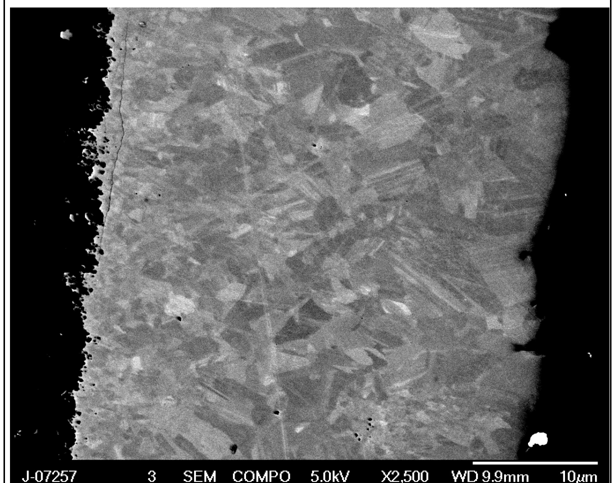
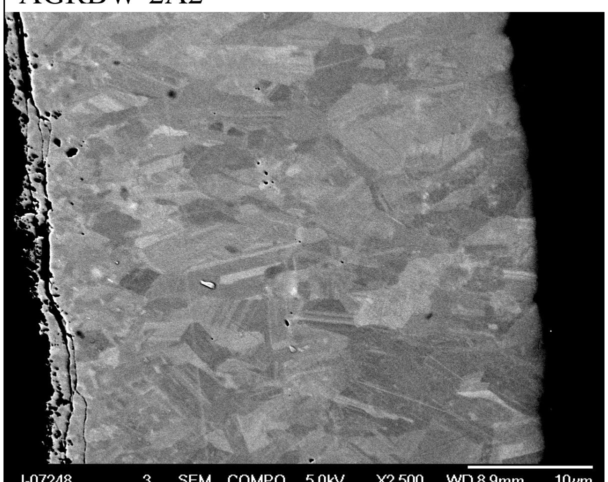
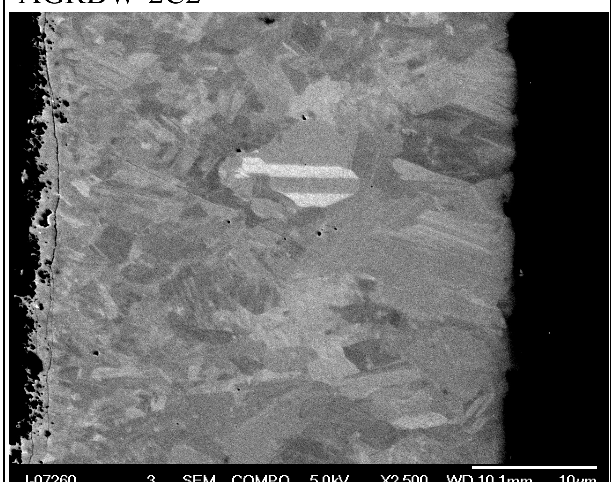
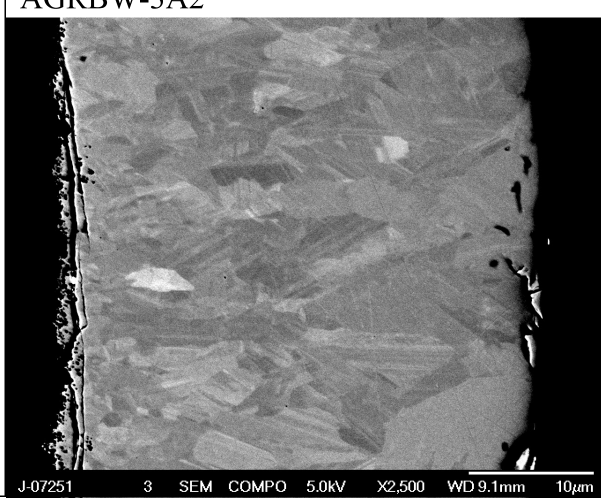
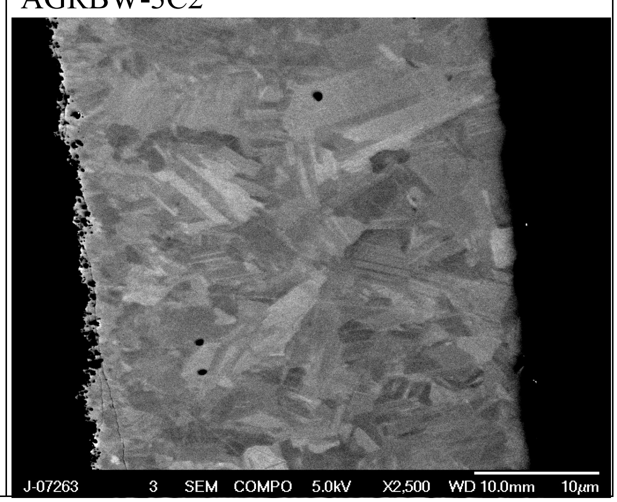
<table>
<tr><th></th><th>120 min, small kernel</th><th>120 min, large kernel</th></tr>
<tr><td>1450°C</td><td>AGRBW-1A2

</td><td>AGRBW-1C2

</td></tr>
<tr><td>1500°C</td><td>AGRBW-2A2

</td><td>AGRBW-2C2

</td></tr>
<tr><td>1550°C</td><td>AGRBW-3A2

</td><td>AGRBW-3C2

</td></tr>
</table>

Table 13. SiC grain structure of H+MTS temperature variants, inner edge of thick samples with a side by side comparison for small and large kernels

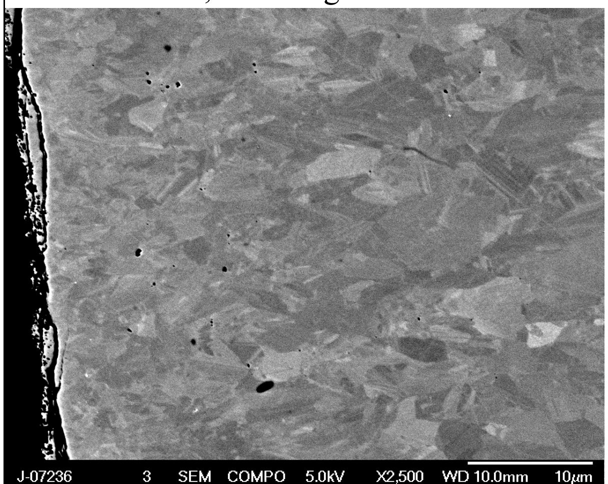
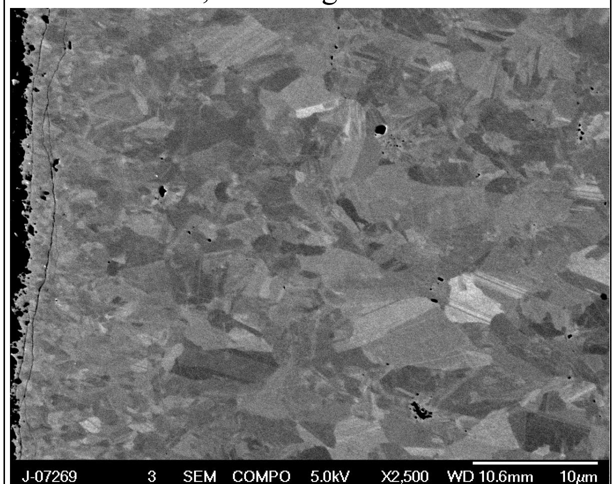
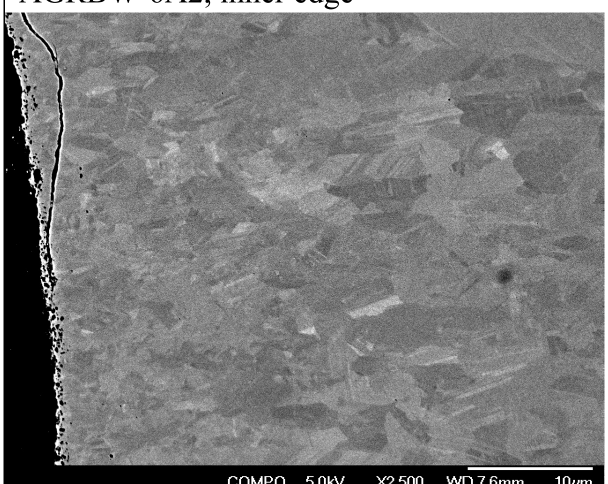
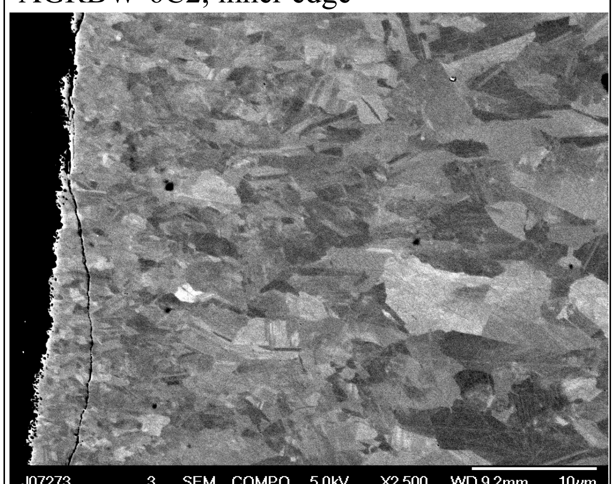
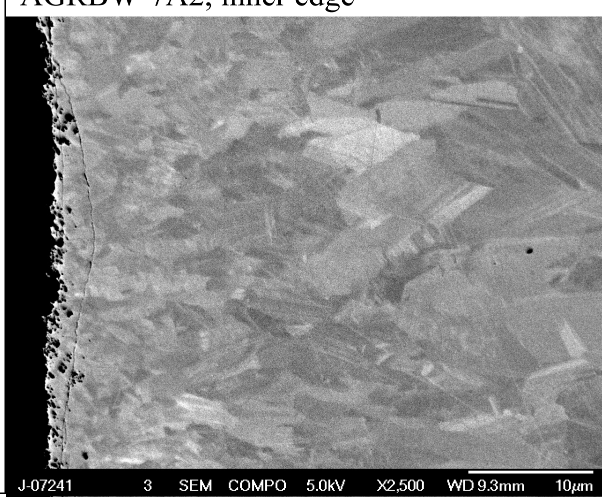
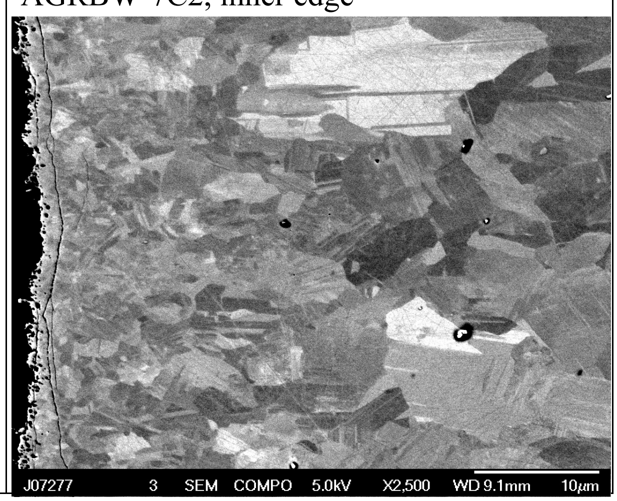
	120 min, small kernel	120 min, large kernel
1450°C	AGRBW-5A2, inner edge  	AGRBW-5C2, inner edge 
1500°C	AGRBW-6A2, inner edge  	AGRBW-6C2, inner edge 
1550°C	AGRBW-7A2, inner edge  	AGRBW-7C2, inner edge 

Table 14. SiC grain structure of H+MTS temperature variants, outer edge of thick samples with a side by side comparison for small and large kernels

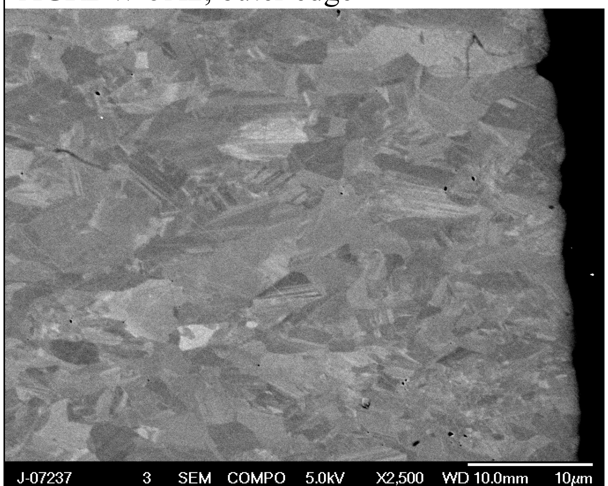
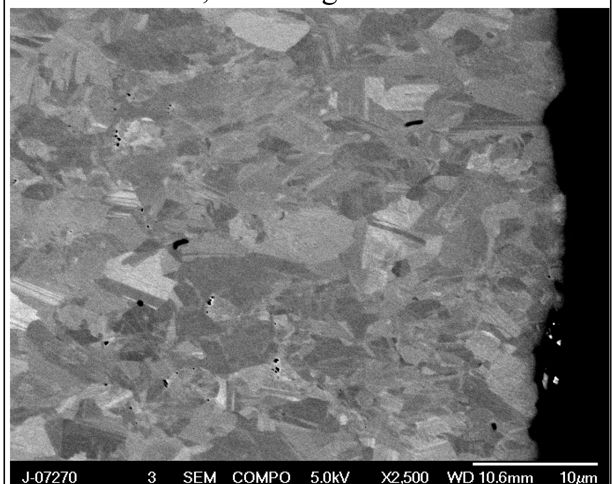
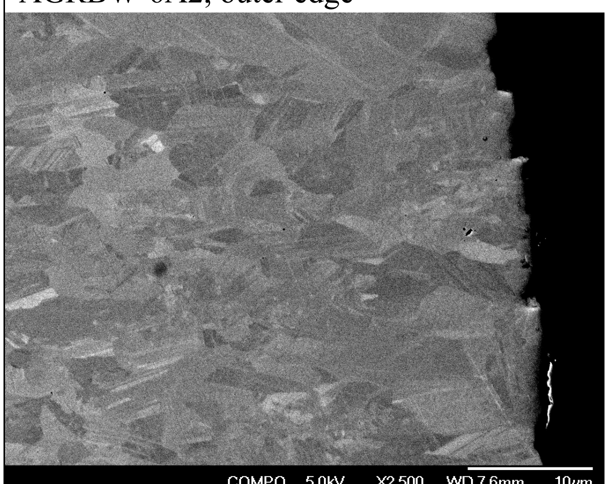
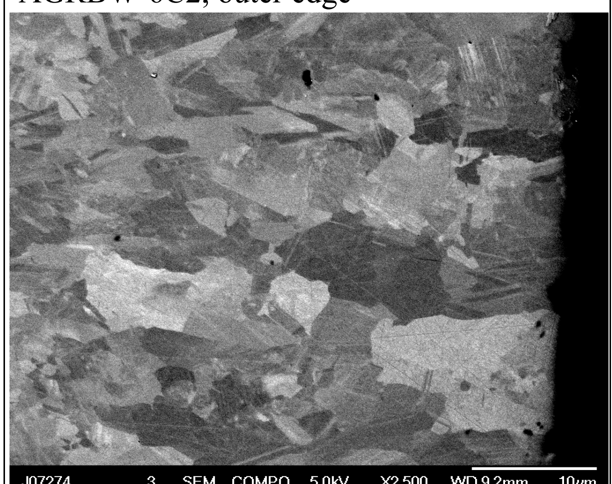
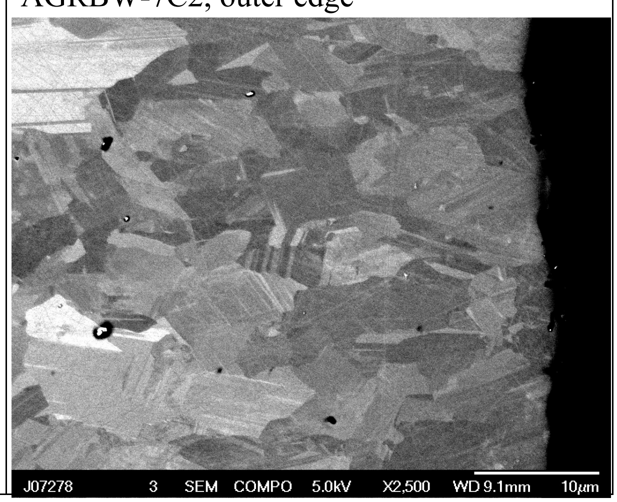
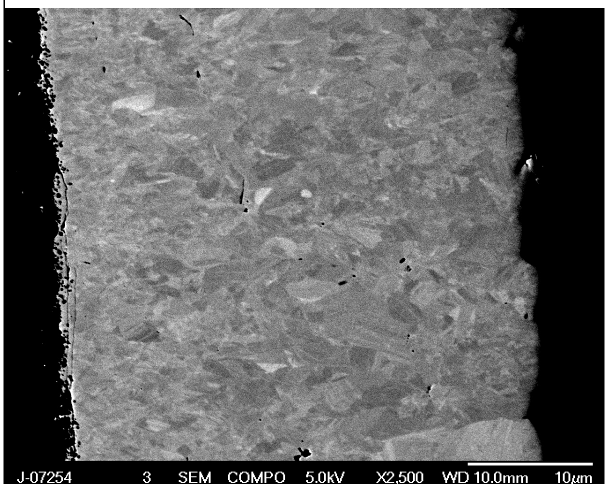
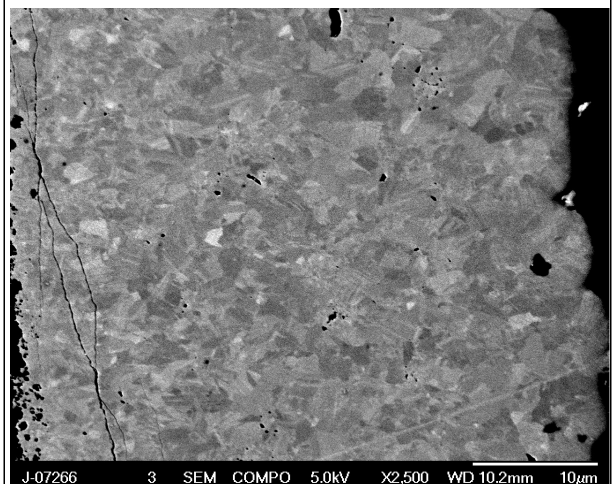
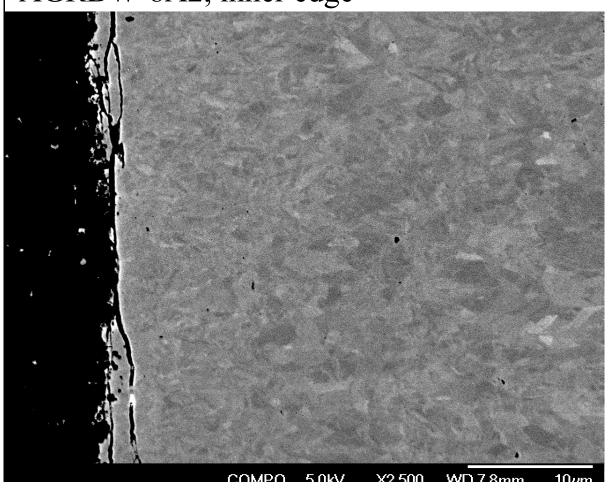
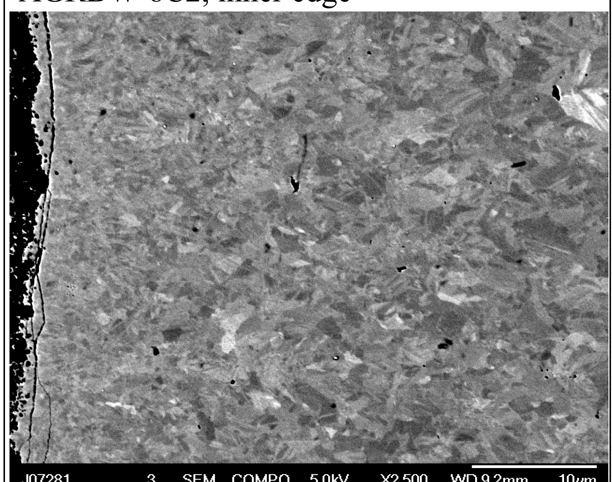
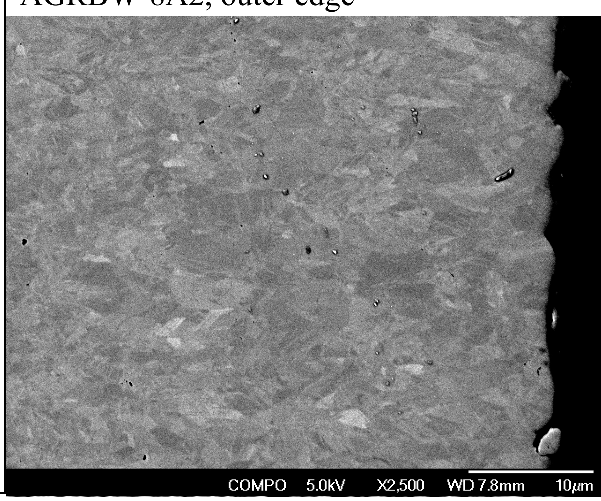
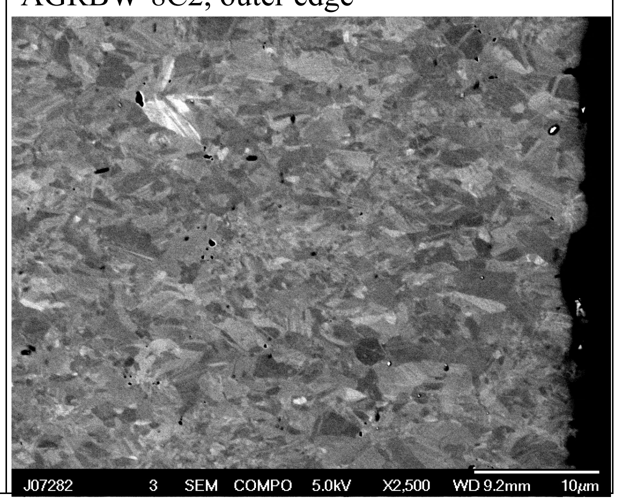
<table>
<tr><th></th><th>120 min, small kernel</th><th>120 min, large kernel</th></tr>
<tr><td>1450°C</td><td>AGRBW-5A2, outer edge
</td><td>AGRBW-5C2, outer edge
</td></tr>
<tr><td>1500°C</td><td>AGRBW-6A2, outer edge
</td><td>AGRBW-6C2, outer edge
</td></tr>
<tr><td>1550°C</td><td>AGRBW-7A2, outer edge
</td><td>AGRBW-7C2, outer edge
</td></tr>
</table>

Table 15. SiC grain structure of Ar+H+MTS variants, with a side by side comparison for small and large kernels

<table>
<tr><th></th><th>1425°C Ar-H, small kernel</th><th>1425°C Ar-H, large kernel</th></tr>
<tr><td>120 min</td><td>AGRBW-4A2

</td><td>AGRBW-4C2

</td></tr>
<tr><td>240 min</td><td>AGRBW-8A2, inner edge

</td><td>AGRBW-8C2, inner edge

</td></tr>
<tr><td>240 min</td><td>AGRBW-8A2, outer edge

</td><td>AGRBW-8C2, outer edge

</td></tr>
</table>

Characterization of SiC Strength

A modified crush testing and evaluation method for hemispherical shell specimens was applied to obtain the fracture stress data for the 16 samples in Series B. For each sample, 24 – 47 hemispherical shell specimens were selected and tested. The data reported here are the measured fracture loads, contact diameters, fracture stress data for loaded areas and full spherical shells, and a summary of Weibull statistical analysis results. Tables of the strength test data for each individual hemisphere are included in Appendix E. The procedure and results are summarized below.

Preparation of SiC hemispherical shells

SiC hemispherical shells were prepared by grinding to near midplane and burning out the IPyC layer. Approximately 200 particles were bonded to an 1.25" diameter aluminum cylinder using Crystalbond-509 mounting adhesive. This adhesive melts at 121°C to allow particles to be mounted in a single layer and sets upon cooling to a hard form suitable for grinding. Enough epoxy was applied to cover the particles, which provided suitable edge support during grinding. The grinding procedure was similar to that described above for preparation of cross sections for optical imaging. Care had to be taken to avoid kernel rotation during grinding, which could result in broken layers. Grinding was stopped close to, but before passing through, the particle midplane. Attempting to grind past the midplane was more likely to result in broken coatings due to kernels becoming loose and even falling out of the mounts. Acetone was used to dissolve the Crystalbond-509 and recover the ground hemispheres. Samples were than placed in a muffle furnace and heated for 3 hours at 750°C. This was sufficient to remove the IPyC layer, leaving the ZrO2 kernel hemispheres free to fall out of the SiC hemispherical shells.

Preparation of IPyC/SiC hemispherical bilayer shells

Early attempts at preparing IPyC/SiC hemispherical bilayer shells were successful but more difficult than simple SiC shells. Leaving the IPyC intact meant that the kernels had to be removed without the burn step described above. This required grinding to very close to the midplane. The midplane must be approached very slowly or kernels will fall out of the mount during grinding, which can result in broken coatings. One set of test samples, AGRBW2-C1, were prepared as both IPyC/SiC hemispherical bilayers and SiC-only hemispherical shells. Strength tests on these shells indicated on about a 10% difference in the strength with no reduction in the measurement spread. It was decided to abandon the bilayer approach in favor of testing only SiC hemispherical shells.

Modified crush test method

Details of the modified crush testing method and its background are described in ORNL/TM-2008/167, and only summarized here. The hemispherical shell specimens of SiC layers obtained from the surrogate fuel particles were diametrically loaded between a bottom base and a plunger with a blanket (insert) metal at its end. Either copper or brass foil was selected for the insert metal, depending on the fracture load level for the sample. The copper insert was selected for relatively fragile samples; while the brass was used for less fragile samples. In testing, larger indentation impressions were formed on softer insert metal, and consequently, higher fracture loads were measured; however, the final results in terms of the fracture stress data, did not show considerable difference.

A screw-driven tensile machine with a cross head speed of about 0.008 mm/sec was used to test the specimens at room temperature. Figure 4 illustrates the crush test setup, which shows a soft metal film inserted between the hemispherical shell specimen and the plunger. The machine was set to catch and display the maximum load, which was taken as the fracture load. The diameters of the loading/contact area were measured in an optical microscope from the impressions formed in the copper or brass foil. This experimental procedure provided the two needed input datasets, fracture load and the impression diameter, for calculation of the fracture stress and Weibull statistical analyses described below.

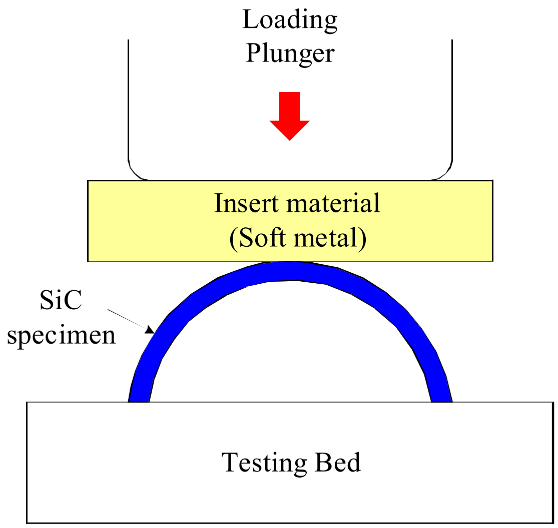


Figure 4. Schematic of the modified crush testing setup. Two insert materials were used, pure copper and a brass, depending on the fracture load level.

Calculation of local fracture stress

When a partial spherical shell is diametrically loaded by an external load, F, concentrated on a small circular area of radius, , the stress components in the thin shell, the maximum membrane stress and bending stress, are given by

$$\sigma_{menbrane} = -C_1 \frac{F\sqrt{1-\upsilon^2}}{t^2}, \tag{1}$$

and

$$\sigma_{bending} = -C_2 \frac{F\sqrt{1+\upsilon}}{t^2}, \tag{2}$$

where ν is Poisson's ratio and t is the thickness of the shell specimen. The coefficients C_1 and C_2 are obtained by fitting the following equations, where R is the outer radius of the shell.

$$C_1 = 0.2205 - 0.04\mu - 0.0115\mu^2, \tag{3}$$

$$C_2 = 1.2044\exp(-1.2703\mu), \tag{4}$$

$$\mu = r_0[12(1-\upsilon^2)/(R^2t^2)]^{1/4}. \tag{5}$$

The maximum tensile stress, which occurs at the inner surface of the shell, is then given by

$$\sigma_{\max} = \sigma_{membrane} + \sigma_{bending}. \tag{6}$$

It is worth noting that the bending stress component at the loaded inner surface of the SiC shells is tensile and usually larger in absolute value than the membrane component, which is compressive. At fracture, the maximum tensile stress at the center of the inner surface becomes the fracture stress for the specimen, which represents the local loading or the size of sampling. Since the fracture stress is dependent on the loaded volume or area and the size effect is significant in the range of the present particle size, this local fracture stress is converted to the value for a full size spherical shell. The Weibull moduli of the local fracture stress datasets were used for the conversion.

Calculation of Weibull parameters

Thus far, the size effect in the SiC crush testing has been described based on the effective area. Using the Weibull's two-parameter distribution, the cumulative probability of failure P is presented by:

$$P = 1 - \exp[-S_E\left(\frac{\sigma_f}{\sigma_0}\right)^m], \tag{7}$$

where σ_f, m, σ_0, and S_E are the fracture stress, the Weibull modulus, the scale parameter, and the effective surface area (or the load weighted surface area), respectively. The Weibull modulus, m, also called the shape parameter, represents the scatter in the fracture strength. The term S_E represents the surface area of a hypothetical specimen subjected to a uniform stress over the whole surface area, which has the same probability of fracture as the test specimen stressed at σ_f. In this analysis the average value of the measured contact areas ($\pi\bar{r}_0^2$) was used for this parameter.

By taking the logarithm twice, Eq. (7) can be rewritten in a linear form:

$$\ln\ln\left(\frac{1}{1-P}\right) = m \cdot \ln\sigma_f + \ln\left(\frac{S_E}{\sigma_0{}^m}\right). \tag{8}$$

The Weibull modulus and scale parameter can be obtained from the slope and intercept terms in Eq. (8), respectively. Since the true value of P_i for each σ_i is not known, a prescribed probability estimator has to be used as the value of P_i. In this calculation a conservative probability estimator was chosen as

$$P_i = \frac{i}{N+1}, \tag{9}$$

where P_i is the probability of failure for the ith-ranked stress datum and N is the sample size.

Size effect and calculation of fracture stress for full spherical shell

Larger specimens or components are likely to be weaker because of their greater chance to have a larger and more severe flaw. For two specimens having different sizes or loading configurations, the ratio between their mean fracture strengths (or characteristic strengths) can be correlated with the ratio of the effective surface areas:

$$\sigma_f^F = \left(\frac{S_E^L}{S_E^F}\right)^{1/m} \sigma_f^L = \left(\frac{\pi r_0^2}{4\pi(R-t)^2}\right)^{1/m} \sigma_f^L. \tag{10}$$

σ_f^L and σ_f^F are the fracture stresses for partially loaded and full spherical shell specimens. S_E^L and S_E^F are the effective surfaces. In the evaluation of the size effect parameter, the measured radius of indentation impression is used for the radius of effective area (r_0).

Results of strength measurements

Table 16 summarizes the measured and calculated average values for key parameters. Data for all individual tests are provided in Appendix E. Note that, in the fracture stress calculations, average values were used for the SiC layer thickness and shell radius for each sample, while the individual impression diameters for each specimen were used for the area under load.

Figure 5 shows the average fracture loads for the 16 samples in Series B. In general, the thicker specimens (5-8) fractured at higher loads, as expected. However, sample AGRBW-8A2 exhibited an anomalously low average fracture load. The cause is currently unknown and will need to be investigated. It is possible that this may be related to hemispherical shell specimen preparation, so sample preparation and testing may need to be repeated.

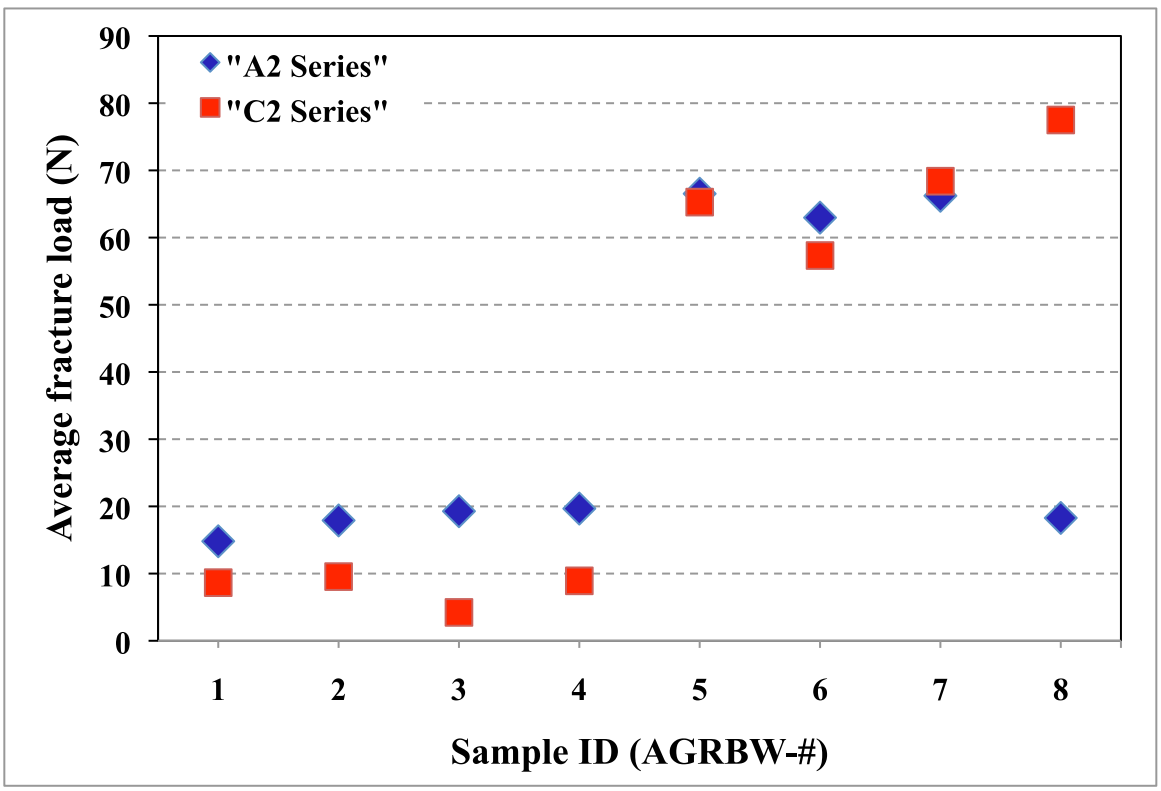


Figure 5. Average load at failure for Series B samples.

Figure 6 and Figure 7 show the average local fracture stress and average mean fracture stress for the 16 samples in Series B. The contribution from the shell wall thickness is accounted for in the calculation of fracture stress, which brings the fracture stress for the thicker specimens (5 - 8) down to the same regime as that measured for the thinner samples, as expected. In fact, since the area under load is larger for the thicker samples, the local fracture stress for these samples is actually a little lower, in general, than that calculated for the thinner samples. This is due to the fact that the larger loaded area increases the probability that a weaker region will be located in the loaded area. There was considerable scatter in the stress data, in general, and it is difficult to extract any significant trends. Further analysis to consider the measurement and sampling uncertainty in the reported fracture stress values is needed to be able to better determine the significance of the observed variation.

There does not seem to be any significant effect of average grain size on the fracture stress. This may indicate that only the microstructure near the inner surface of the SiC is important. As noted in the SEM analysis of the SiC microstructure, little difference can be seen in the first 5 μm of SiC for Series B variants 1&5, 2&6, 3&7. The Ar-H variants 4&8, may have a slightly finer grained microstructure at the IPyC interface.

The mean fracture stress (Figure 7), which was scaled to a full spherical shell from the local fracture stress, varied with test material in the range of 157 – 1035 MPa and the Weibull moduli ranged from 3 to 7.5. However, if the thinnest specimens (<30 μm) are excluded, the mean fracture stress was at least 373 MPa. The thinnest shell samples with wall thicknesses of ~28 μm (AGRBW-1C2, 2C2, and 3C2) failed at very low loads, often at a fraction of a pound-force (see Appendix E). Also, the fracture load data show a clear bimodal distribution. This bimodal distribution feature disappeared in the local fracture stress data since the impression diameter measurements, which also have a bimodal distribution, removed the bimodal behavior in calculation of the true stress. The relatively low fracture loads in these thinnest samples resulted in correspondingly low fracture stresses, whose mean values were in the range 157 – 269 MPa. The Weibull moduli from these low fracture stresses were also relatively low, 3 – 4.1, but not significantly different from those of some of the other samples. Such low strengths may be because the effect from inner surface roughness becomes more influential in the fracture process and weakens the whole SiC shell. The companion samples to these three weakest samples (AGRBW-1A2, 2A2, and 3A2), which were coated in the same run, but were 15 – 20% thicker and ~20% smaller in radius, showed higher fracture strengths.

The size effect parameter, the ratio between the local fracture stress and the fracture stress for a full spherical shell, was also calculated and is listed for individual specimens in Appendix E. The size effect tended to be higher for the thinner walled specimens.

In general, the samples with higher average mean fracture stress also exhibited a higher Weibull modulus. A higher Weibull modulus is calculated when there is greater uniformity in the strength within a given sample. A low modulus indicates a greater probability for failure at stress levels much lower than the average value. Figure 8 shows the Weibull plots for the 16 samples in Series B. In general, these plots appear to be linear, except for the three thinnest and weakest materials (AGRBW-1C2, 2C2, and 3C2). The tendency for these thinner materials to exhibit low strength with larger scatter in the load to failure could be of concern for TRISO coatings with thinner SiC layers. For the purpose of this study, new samples should be coated for these 3 sample conditions in order to get mean layer thickness closer to the 35 μm target, which should produce more consistent strength data.

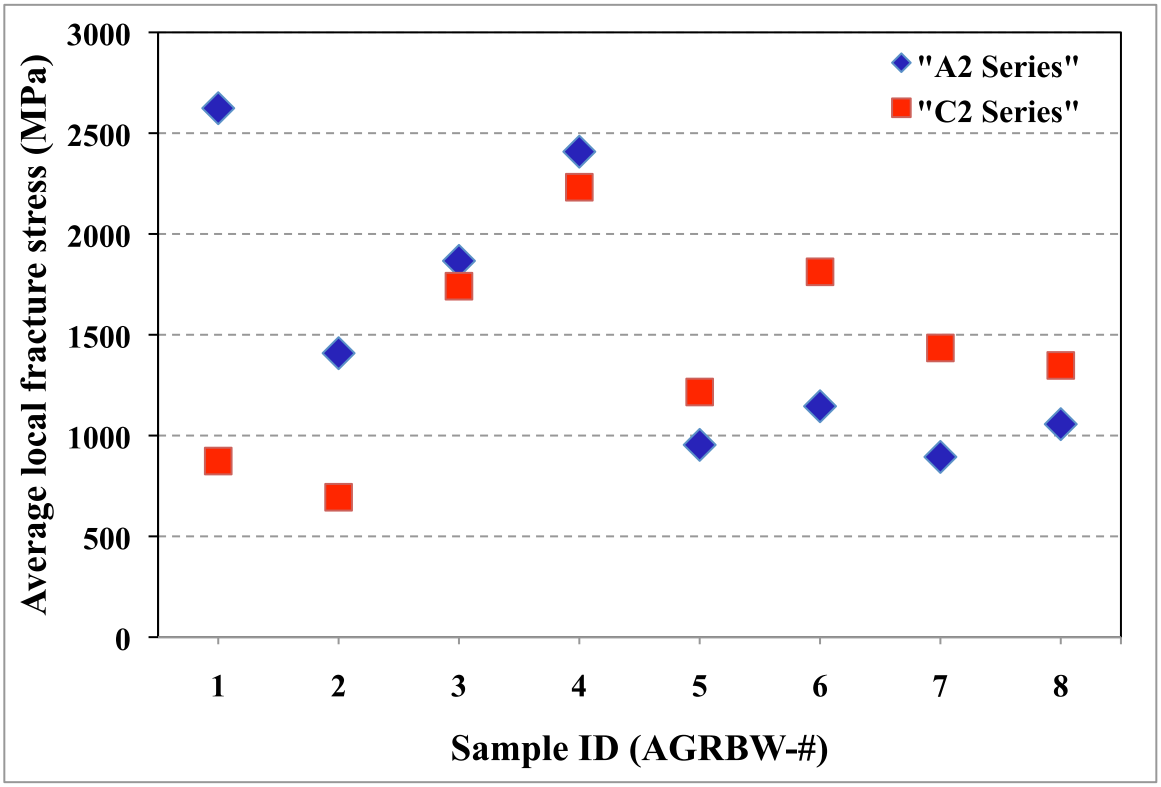


Figure 6. Average local fracture stress for Series B samples.

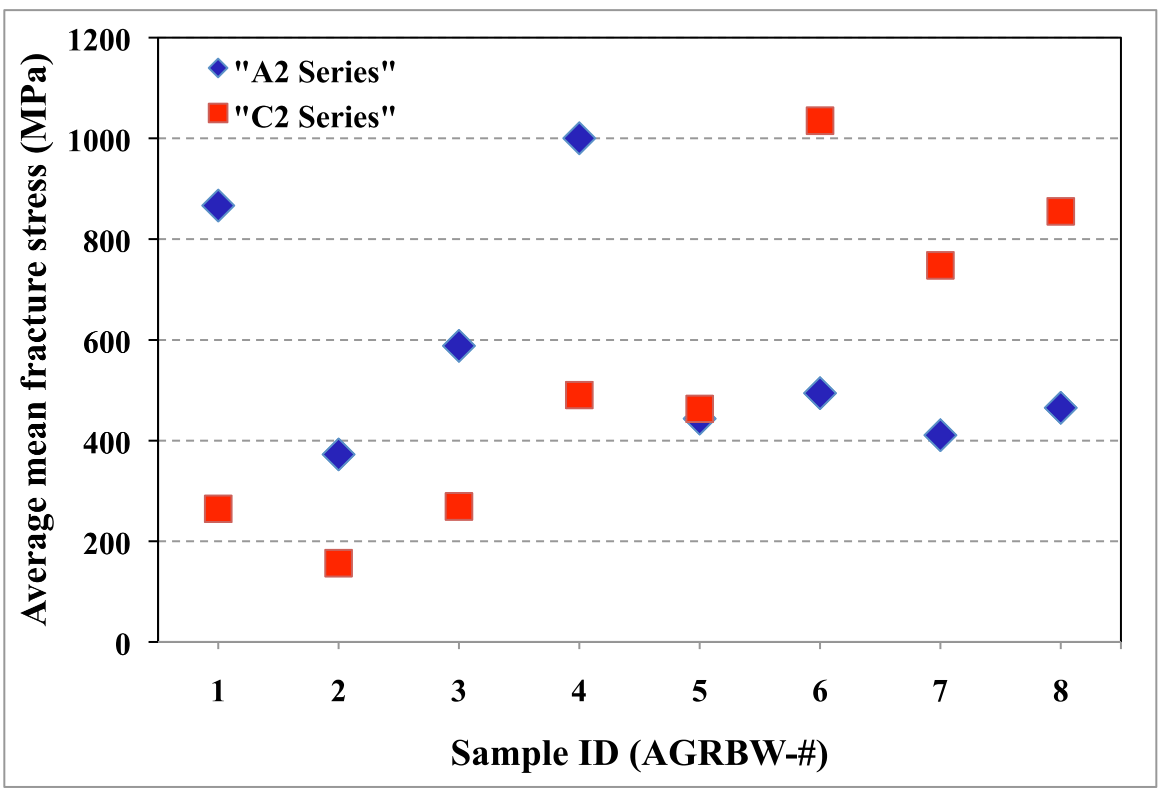


Figure 7. Average mean fracture stress for Series B samples.

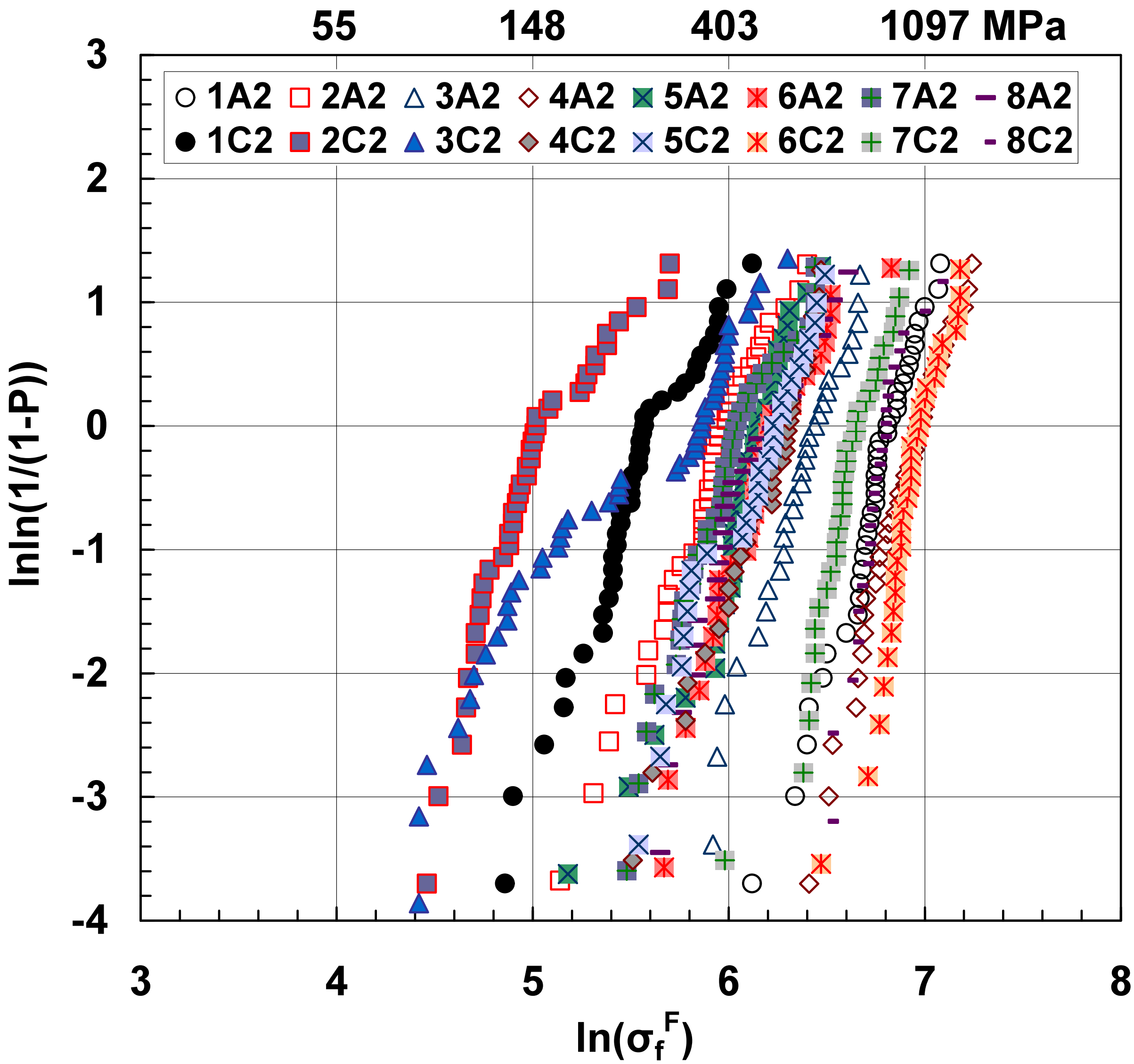


Figure 8. Weibull plots of fracture stress for Series B samples.

Table 16. **Summary of fracture strength test results for Series B.**

Sample ID	Average wall thickness (mm)	Average outer radius (mm)	Average fracture load (N)	Average contact diameter (mm)	Average local fracture stress (MPa)	**Weibull modulus**	**Average mean fracture stress (MPa)**
AGRBW-1A2	0.0318	0.342	14.81	0.124	2623.8	**4.28**	**866.6**
AGRBW-2A2	0.0337	0.344	17.91	0.168	1408.6	**3.11**	**372.5**
AGRBW-3A2	0.0332	0.345	19.28	0.154	1866.5	**3.73**	**588.1**
AGRBW-4A2	0.0336	0.343	19.67	0.142	2408.2	**5.03**	**1000.2**
AGRBW-5A2	0.0626	0.376	66.53	0.279	953.8	**3.97**	**443.6**
AGRBW-6A2	0.0601	0.380	62.97	0.265	1145.4	**3.79**	**494.1**
AGRBW-7A2	0.0616	0.377	66.22	0.284	894.0	**3.89**	**410.7**
AGRBW-8A2	0.0604	0.376	18.28	0.162	1056.6	**5.02**	**465.1**
AGRBW-1C2	0.0274	0.428	8.65	0.150	873.6	**4.09**	**264.5**
AGRBW-2C2	0.0287	0.428	9.55	0.156	694.0	**3.33**	**156.6**
AGRBW-3C2	0.0278	0.427	4.22	0.090	1740.9	**3.01**	**269.2**
AGRBW-4C2	0.0334	0.426	8.92	0.122	2231.9	**3.43**	**490.4**
AGRBW-5C2	0.0628	0.465	65.28	0.292	1216.1	**3.58**	**462.9**
AGRBW-6C2	0.0561	0.458	57.33	0.249	1812.3	**6.70**	**1035.1**
AGRBW-7C2	0.0579	0.467	68.39	0.282	1434.6	**5.43**	**747.9**
AGRBW-8C2	0.0646	0.463	77.50	0.295	1347.8	**7.45**	**855.1**

Conclusions

Sixteen SiC samples were produced for the Series B strength testing experiment. Samples were deposited on an IPyC substrate taken from a single batch of IPyC coated ZrO2 in order to minimize the variation from the effect of the inner surface roughness on the SiC strength. Two kernel sizes were used for the IPyC substrate in order to introduce a variation in the SiC shell diameter. Three SiC deposition variants were produced by varying temperature and one by mixing Ar in with the H fluidization gas. Two different coating thicknesses were produced by changing the total coating time. Coating thickness, density, microstructure, and fracture strength were measured on each of the sixteen samples.

SiC microstructure varied as expected. Layer density was above 3.2 g/cm^3 for all samples, indicating high quality SiC. Most of the coating thickness results showed a tight distribution in the SiC thickness. Those that did not, showed indication of a need for additional analysis, as opposed to a real dispersion in the SiC thickness. Open porosity of the IPyC substrate was low, but within a range typical for AGR-2 TRISO particles. As this may minimize the effect of the inner surface roughness on the SiC strength, the low porosity may be beneficial for this experimental series.

Strength testing was performed on SiC hemispherical shells extracted from the coated particles by grinding to midplane and burning out the IPyC layer. Results were somewhat as expected but no clear trends were evident that could correlate the SiC strength to the bulk microstructure. It is possible that this correlation will not exist due to the fact that fracture occurs at the inner surface and the microstructure in this region does not greatly vary for the samples in Series B.

There were some anomalous results in the measured fracture load and calculated fracture stress. In addition, analysis of the characterization results showed that some additional work is needed to refine some of the data. Prior to proceeding with irradiation testing on these samples, the following issues need to be addressed.

1. Samples AGRBW-1C2, AGRBW-2C2, and AGRBW-3C2 were all less than 30 µm thick. This resulted in SiC fracture at very low load and the fracture stress for these sample cannot be well determined. These variants need to be fabricated again with thicker coatings.

2. Some of the measured values for thickness come from distributions that indicate either too much error was introduced by polishing defects or insufficient sampling occurred. These deficiencies are listed in Table 4. Additional polished cross sections need to be prepared and analyzed to reduce the uncertainty in the measured values for these samples.

3. The uncertainty in the calculated fracture stress needs to be determined in order to allow for conclusions to be drawn as to the significance of the observed differences in fracture stress for the various samples.

4. A question has arisen as to how much affect the SiC hemispherical shell preparation may have had on some of the strength measurements. Some additional SiC shells need to be prepared and tested in order to answer this question. Sample AGRBW-6C2 may be a good candidate to see if the SiC shell geometry (distance from midplane) has an effect. Some of the weaker samples could also be re-prepared and tested.

5. Some of the anomalous strength test results need to be studied. Sample AGRBW-8A2 failed at a much lower fracture load than expected. The fracture stress for AGRBW-1A2 is higher than would fit the apparent trend for the other data.

6. The bimodal distribution in the fracture load for the weaker samples has to be understood and addressed.

6. The Weibull modulus is low for many of the samples. This makes comparison of the fracture stress between the different samples in the series difficult. It also is a concern for future determination of irradiation effects.

7. The shape of the SiC shell needs to be considered. Shadow analysis of the particle shape should be performed. If sphericity is low, samples should be tabled and the strength measured again to determine how shape may affect the Weibull modulus.

Appendix A: Specimen Description and Results for Series A

In 2008 the test method described herein was applied to a series of hemispherical shell SiC specimens extracted from samples taken from nine historical fuel particle batches. These have now been labeled as Series A. Results of these experiments and test method development were reported in ORNL/TM-2008/167. The following tables list the specimens in Series A and the results obtained by those early experiments.

Nine historical sample used in Series A

No.	Sample ID	Mean Thickness (μm)	Mean Outer Diameter (μm)	Mean Density (g/cc)	Remarks
1	DUN500S-14B	~25	~870	3.185±0.005	Mixed Ar/H SiC deposition at 1340°C, very fine grained and porous
2	DUN500S-6B	~30	~886	3.205±0.001	H only SiC deposition at 1510°C, large grain
3	DUN500S-7B	~35	~862	3.206±0.005	Mixed Ar/H SiC deposition at 1440°C, small grain
4	AGR-06	33.9±1.4	850	3.201±0.002	German reference fuel
5	AGR-10	26.8±0.6	718	3.206±0.002	US HRB-21 reference fuel
6	LEU01-46T	35.3±1.3	759	3.2075±0.0032	AGR-1 Baseline
7	LEU01-49T	35.9±2.1	756	3.2046±0.0010	AGR-1 Variant 3 (Ar-H mixed SiC deposition, finer grain structure at lower deposition temperature)
8	B&W-93059	34.3	~797	3.199	B&W AGR-2 Variant Qualification TRISO
9	B&W-93060	36.8	~813	3.195	B&W AGR-2 Baseline Qualification TRISO

Note: ± values give the measured standard deviation and indicate how much variation was observed for that property.

Results of strength testing on nine historical sample in Series A

No.	Sample ID	Contact diameter (mm)	Fracture load, N	Local fracture stress (MPa)	**Weibull modulus**	**Fracture stress (MPa)**	**Scale parameter (MPa)**
1	DUN500S-14B	0.1179*	2.59	997.2	**6.61**	**449.8**	**539.2**
2	DUN500S-6B	0.1245	3.60	1050.5	**5.49**	**409.6**	**509.7**
3	DUN500S-7B	0.1421	5.32	1001.0	**7.25**	**514.7**	**602.0**
4	AGR-06	0.1472	5.84	1016.3	**6.22**	**475.4**	**567.8**
5	AGR-10	0.1131	4.20	1232.0	**6.40**	**570.7**	**645.1**
6	LEU01-46T	0.1533	11.36	1203.3	**3.98**	**399.1**	**490.4**
7	LEU01-49T	0.1405	8.64	1324.2	**6.35**	**646.5**	**737.1**
8	B&W-93059	0.1514	6.47	923.1	**6.58**	**463.9**	**537.4**
9	B&W-93060	0.1668	6.97	769.5	**5.15**	**329.9**	**398.0**

*Calculated from the load versus contact diameter data of the case no. 2.

Appendix B: SiC Layer Thickness Data Reports

SiC layer thickness was measured using data acquisition methods developed for the AGR program: AGR-DAM-CHAR-08, AGR-DAM-CHAR-11, and AGR-DAM-CHAR-14. The attached data report forms give the mean kernel diameter, IPyC thickness, and SiC thickness for each sample and show histograms of the measured values for each parameter. The mean values are also summarized in the table below.

Dimensional data for Series B-A2

Sample ID	Kernel diameter		IPyC thickness		SiC thickness	
	mean	st. dev.	mean	st. dev.	mean	st. dev.
AGRBW-1A2	532	13	44	3	31.8	0.8
AGRBW-2A2	529	11	46	3	33.7	0.8
AGRBW-3A2	532	14	46	3	33.2	1.0
AGRBW-4A2	528	11	45	3	33.6	0.8
AGRBW-5A2	536	22	46	3	62.6	1.7
AGRBW-6A2	549	12	45	3	60.1	0.9
AGRBW-7A2	541	13	45	3	61.6	1.5
AGRBW-8A2	541	12	45	3	60.4	1.1
Average	536		45		N/A	

Dimensional data for Series B-C2

Sample ID	Kernel diameter		IPyC thickness		SiC thickness	
	mean	st. dev.	mean	st. dev.	mean	st. dev.
AGRBW-1C2	715	11	43	2	27.4	0.6
AGRBW-2C2	711	24	43	3	28.7	0.9
AGRBW-3C2	712	21	43	3	27.8	0.8
AGRBW-4C2	700	35	43	3	33.4	1.4
AGRBW-5C2	718	19	44	3	62.8	1.1
AGRBW-6C2	720	31	42	3	56.1	1.8
AGRBW-7C2	731	22	43	3	57.9	1.4
AGRBW-8C2	709	26	44	3	64.6	1.6
Average	714		43		N/A	

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-1A2
Sample description:	SiC Strength Test Sample: 1450 C, 120 min, 520 um ZrO2
Mount ID number:	M09101901
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09102201

DMR calibration expiration date:	10/28/09
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.0

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
298	282	304	294

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
266		39	33	

G.W. Chinthaka — Operator

11/25/09 — Date

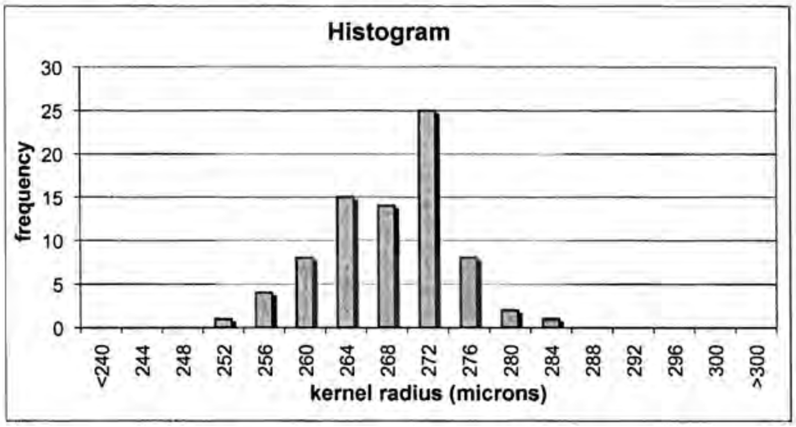
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102201
Sample ID:	AGRBW-1A2
Sample Description:	SiC Strength Test Sample: 1450 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102201_output

Number of kernels analyzed:	78
Mean of the average kernel diameter of each particle (µm):	531.9
Standard deviation in the average kernel diameter of each particle (µm):	12.8

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	0
252	1
256	4
260	8
264	15
268	14
272	25
276	8
280	2
284	1
288	0
292	0
296	0
300	0
>300	0



G. W. Chinthaka

Operator

11/25/09

Date

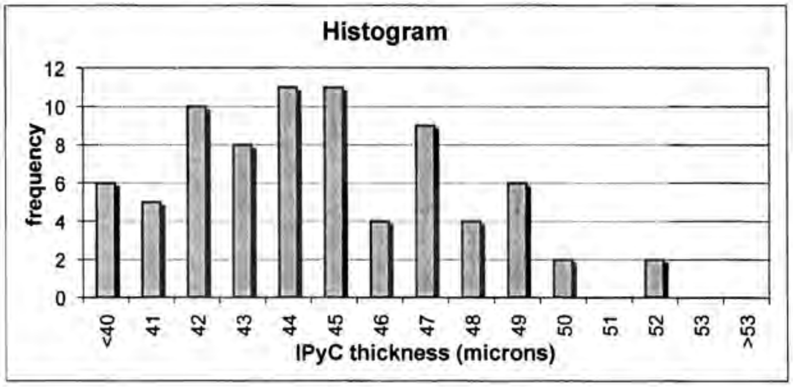
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102201
Sample ID:	AGRBW-1A2
Sample Description:	SiC Strength Test Sample: 1450 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102201_output

Number of inner pyrocarbon layers analyzed:	78
Mean of the average IPyC thickness of each particle (μm):	44.1
Standard deviation in the average IPyC thickness of each particle (μm):	3.1

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<40	6
41	5
42	10
43	8
44	11
45	11
46	4
47	9
48	4
49	6
50	2
51	0
52	2
53	0
>53	0



G. W. Chinthaka

Operator

11/25/09

Date

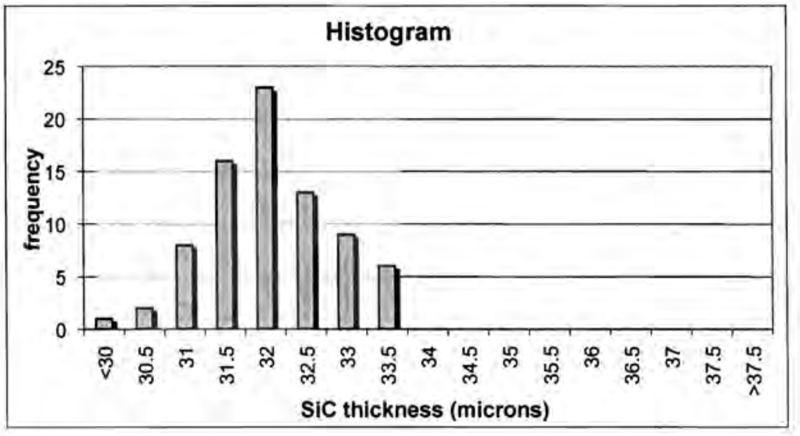
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102201
Sample ID:	AGRBW-1A2
Sample Description:	SiC Strength Test Sample: 1450 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102201_output

Number of silicon carbide layers analyzed:	78
Mean of the average SiC thickness of each particle (μm):	31.8
Standard deviation in the average SiC thickness of each particle (μm):	0.8

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<30	1
30.5	2
31	8
31.5	16
32	23
32.5	13
33	9
33.5	6
34	0
34.5	0
35	0
35.5	0
36	0
36.5	0
37	0
37.5	0
>37.5	0



G.W. Chinthaka

Operator

11/25/09

Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva/ Andrew K. Kercher
Sample ID:	AGRBW-2A2
Sample description:	SiC Strength Test Sample: 1500 C, 120 min, 520 um ZrO2
Mount ID number:	M09101601
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09102101

DMR calibration expiration date:	10/28/09
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.0

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
297	315	321	316

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
267		40	36	

G. W. Chinthaka
Operator

11/25/09
Date

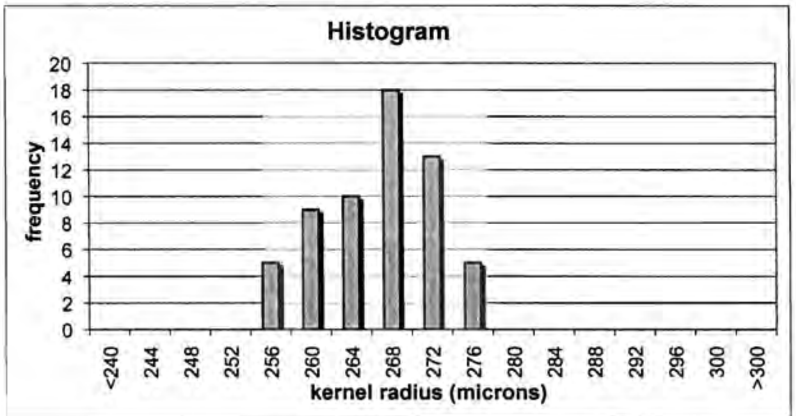
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102101
Sample ID:	AGRBW-2A2
Sample Description:	SiC Strength Test Sample: 1500 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102101_output

Number of kernels analyzed:	60
Mean of the average kernel diameter of each particle (μm):	529.3
Standard deviation in the average kernel diameter of each particle (μm):	10.9

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	0
252	0
256	5
260	9
264	10
268	18
272	13
276	5
280	0
284	0
288	0
292	0
296	0
300	0
>300	0



G. W. Chinthaka

Operator

11/25/09

Date

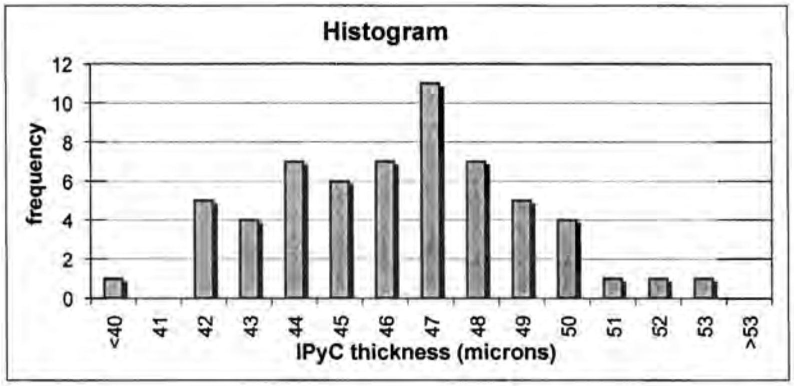
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102101
Sample ID:	AGRBW-2A2
Sample Description:	SiC Strength Test Sample: 1500 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102101_output

Number of inner pyrocarbon layers analyzed:	60
Mean of the average IPyC thickness of each particle (µm):	45.7
Standard deviation in the average IPyC thickness of each particle (µm):	2.8

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (µm)	*Frequency*
<40	1
41	0
42	5
43	4
44	7
45	6
46	7
47	11
48	7
49	5
50	4
51	1
52	1
53	1
>53	0



G.W. Chinthaka
Operator

11/25/09
Date

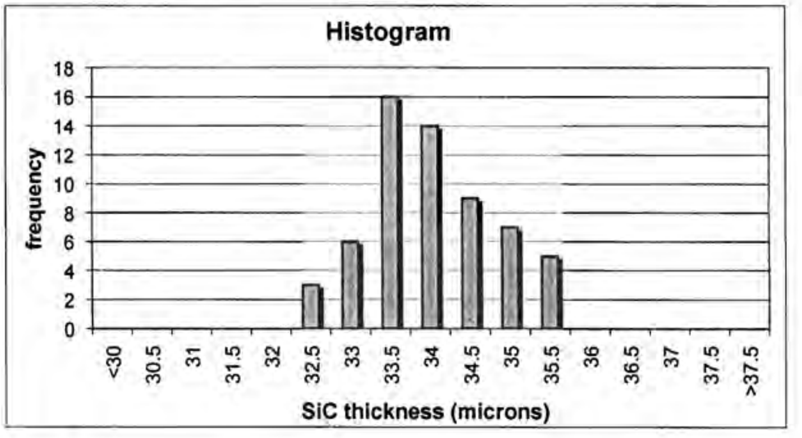
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102101
Sample ID:	AGRBW-2A2
Sample Description:	SiC Strength Test Sample: 1500 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102101_output

Number of silicon carbide layers analyzed:	60
Mean of the average SiC thickness of each particle (μm):	33.7
Standard deviation in the average SiC thickness of each particle (μm):	0.8

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<30	0
30.5	0
31	0
31.5	0
32	0
32.5	3
33	6
33.5	16
34	14
34.5	9
35	7
35.5	5
36	0
36.5	0
37	0
37.5	0
>37.5	0



G.W. Chinthaka
Operator

11/25/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-3A2
Sample description:	SiC Strength Test Sample: 1550 C, 120 min, 520 um ZrO2
Mount ID number:	M09102001
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09102202

DMR calibration expiration date:	10/28/09
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.0

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
297	275	305	289

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
266		36	35	

G W. Chinthaka — Operator

11/25/09 — Date

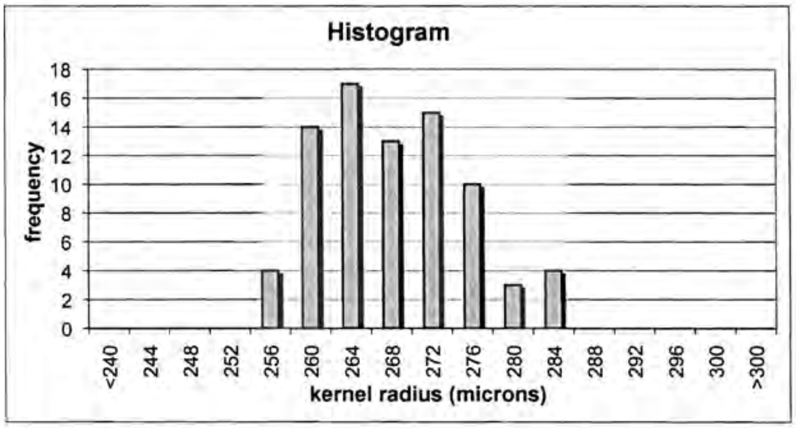
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102202
Sample ID:	AGRBW-3A2
Sample Description:	SiC Strength Test Sample: 1550 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102202_output

Number of kernels analyzed:	80
Mean of the average kernel diameter of each particle (µm):	532.2
Standard deviation in the average kernel diameter of each particle (µm):	14.4

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	0
252	0
256	4
260	14
264	17
268	13
272	15
276	10
280	3
284	4
288	0
292	0
296	0
300	0
>300	0



[signature] 11/25/09

Operator Date

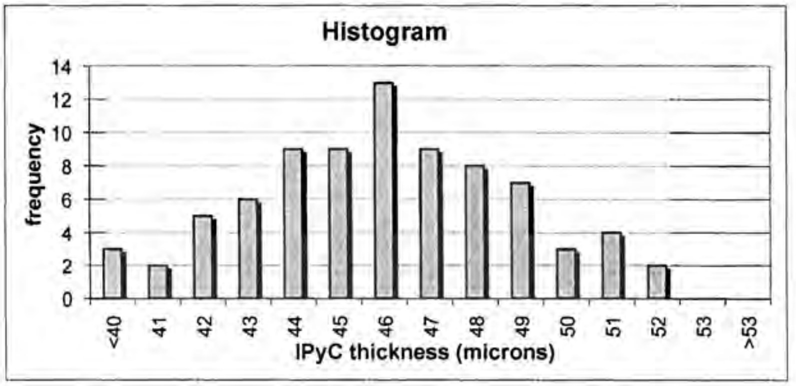
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102202
Sample ID:	AGRBW-3A2
Sample Description:	SiC Strength Test Sample: 1550 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102202_output

Number of inner pyrocarbon layers analyzed:	80
Mean of the average IPyC thickness of each particle (µm):	45.5
Standard deviation in the average IPyC thickness of each particle (µm):	2.9

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (µm)	*Frequency*
<40	3
41	2
42	5
43	6
44	9
45	9
46	13
47	9
48	8
49	7
50	3
51	4
52	2
53	0
>53	0



Ea W. C. Windham 11/25/09

Operator Date

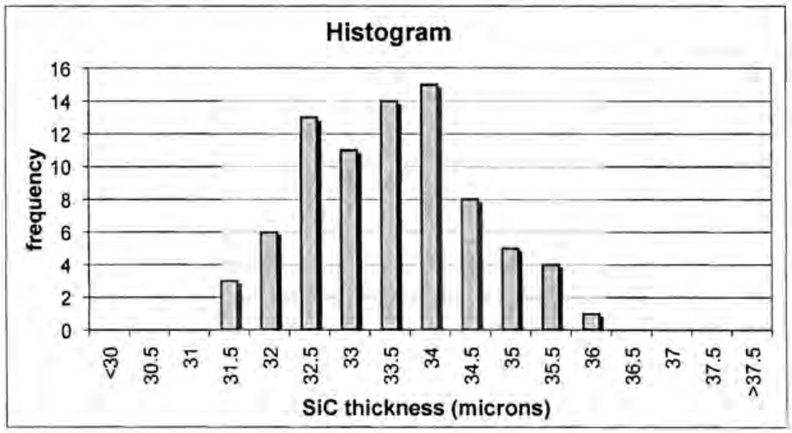
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102202
Sample ID:	AGRBW-3A2
Sample Description:	SiC Strength Test Sample: 1550 C, 120 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102202_output

Number of silicon carbide layers analyzed:	80
Mean of the average SiC thickness of each particle (µm):	33.2
Standard deviation in the average SiC thickness of each particle (µm):	1.0

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (µm)	*Frequency*
<30	0
30.5	0
31	0
31.5	3
32	6
32.5	13
33	11
33.5	14
34	15
34.5	8
35	5
35.5	4
36	1
36.5	0
37	0
37.5	0
>37.5	0



G W Chinthaka

Operator

11/25/09

Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-4A2
Sample description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 520 um ZrO2
Mount ID number:	M09102101
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09110301

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.7

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
307	291	297	293

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
260		41	36	

G.W. Chinthaka
Operator

11/25/09
Date

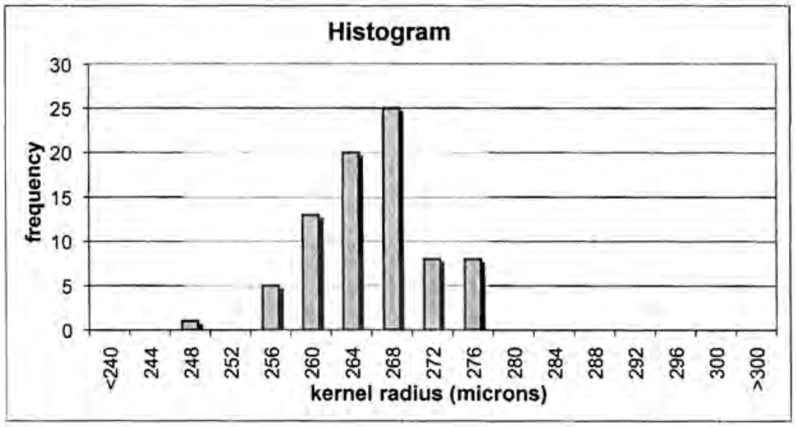
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110301
Sample ID:	AGRBW-4A2
Sample Description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110301_output

Number of kernels analyzed:	80
Mean of the average kernel diameter of each particle (μm):	528.2
Standard deviation in the average kernel diameter of each particle (μm):	11.1

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	1
252	0
256	5
260	13
264	20
268	25
272	8
276	8
280	0
284	0
288	0
292	0
296	0
300	0
>300	0



G W Chandhaha

Operator

11/25/09

Date

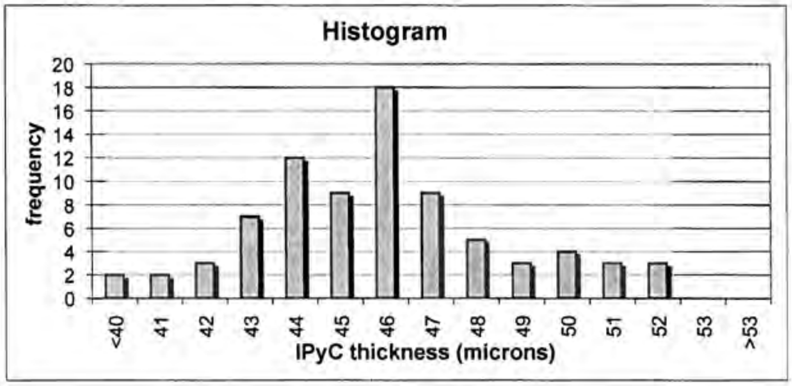
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110301
Sample ID:	AGRBW-4A2
Sample Description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110301_output

Number of inner pyrocarbon layers analyzed:	80
Mean of the average IPyC thickness of each particle (μm):	45.3
Standard deviation in the average IPyC thickness of each particle (μm):	2.7

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<40	2
41	2
42	3
43	7
44	12
45	9
46	18
47	9
48	5
49	3
50	4
51	3
52	3
53	0
>53	0



G.W. Chinthaka

Operator

11/23/09

Date

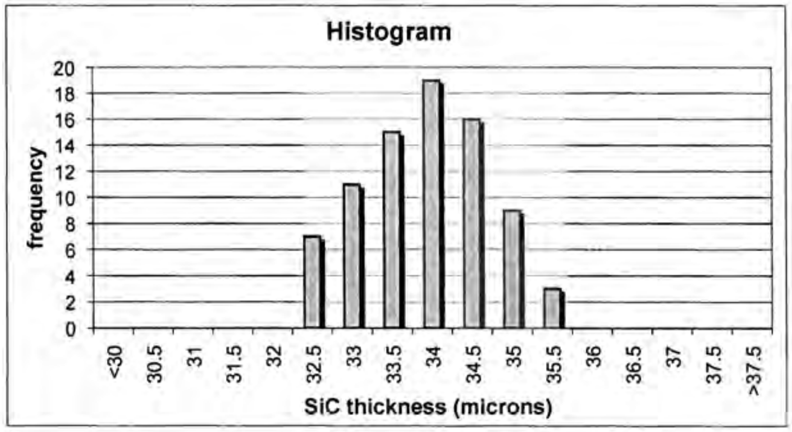
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110301
Sample ID:	AGRBW-4A2
Sample Description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110301_output

Number of silicon carbide layers analyzed:	80
Mean of the average SiC thickness of each particle (µm):	33.6
Standard deviation in the average SiC thickness of each particle (µm):	0.8

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (µm)	*Frequency*
<30	0
30.5	0
31	0
31.5	0
32	0
32.5	7
33	11
33.5	15
34	19
34.5	16
35	9
35.5	3
36	0
36.5	0
37	0
37.5	0
>37.5	0



G W Chinthaka

Operator

11/20/09

Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-5A2
Sample description:	SiC Strength Test Sample: 1450 C, 240 min, 520 um ZrO2
Mount ID number:	M09102601
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09110302

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.7

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
287	321	296	343

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
269		38	65	

G. W. Chinthaka
Operator

11/25/09
Date

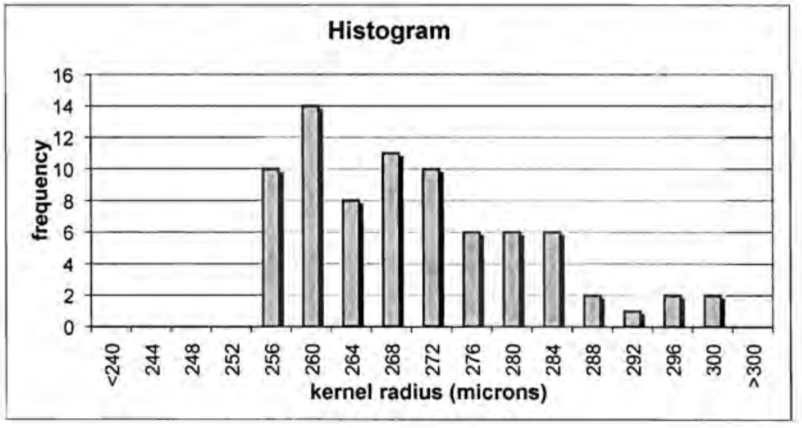
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110302
Sample ID:	AGRBW-5A2
Sample Description:	SiC Strength Test Sample: 1450 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110302_output

Number of kernels analyzed:	78
Mean of the average kernel diameter of each particle (μm):	536.1
Standard deviation in the average kernel diameter of each particle (μm):	22.4

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	0
252	0
256	10
260	14
264	8
268	11
272	10
276	6
280	6
284	6
288	2
292	1
296	2
300	2
>300	0



G W Chinthaka

Operator

11/25/09

Date

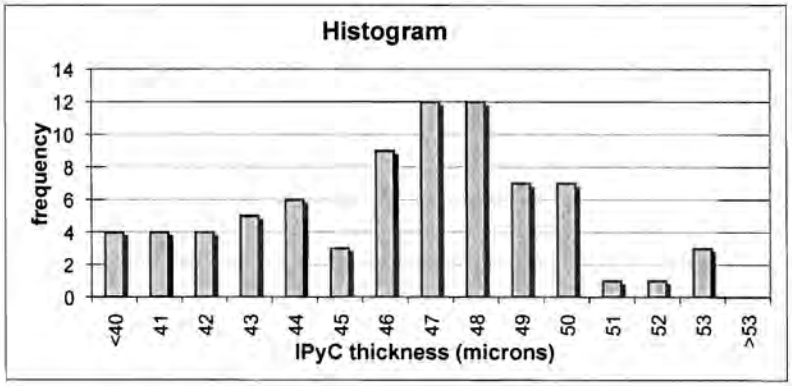
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110302
Sample ID:	AGRBW-5A2
Sample Description:	SiC Strength Test Sample: 1450 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110302_output

Number of inner pyrocarbon layers analyzed:	78
Mean of the average IPyC thickness of each particle (μm):	45.9
Standard deviation in the average IPyC thickness of each particle (μm):	3.4

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<40	4
41	4
42	4
43	5
44	6
45	3
46	9
47	12
48	12
49	7
50	7
51	1
52	1
53	3
>53	0



G. W. Chinthaka

Operator

11/25/09

Date

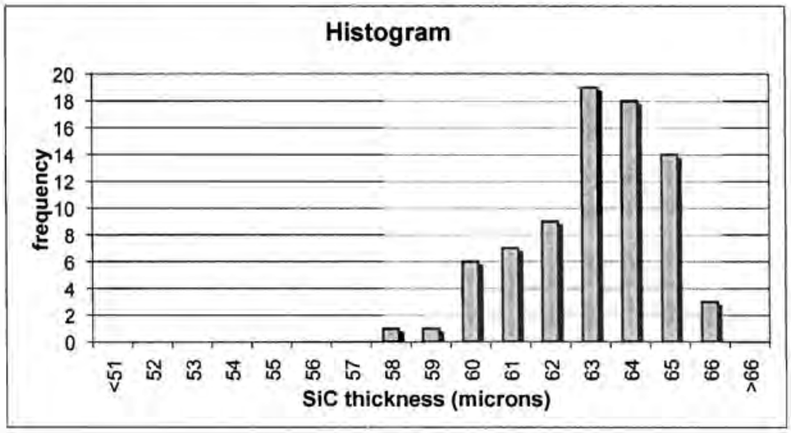
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110302
Sample ID:	AGRBW-5A2
Sample Description:	SiC Strength Test Sample: 1450 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110302_output

Number of silicon carbide layers analyzed:	78
Mean of the average SiC thickness of each particle (µm):	62.6
Standard deviation in the average SiC thickness of each particle (µm):	1.7

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (µm)	*Frequency*
<51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	1
59	1
60	6
61	7
62	9
63	19
64	18
65	14
66	3
>66	0



G.W. Chinthaka
Operator

11/25/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-6A2
Sample description:	SiC Strength Test Sample: 1500 C, 240 min, 520 um ZrO2
Mount ID number:	M09102701
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09110401

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.7

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
304	333	318	269

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
270		39	62	

G.W. Chinthaka
Operator

11/25/09
Date

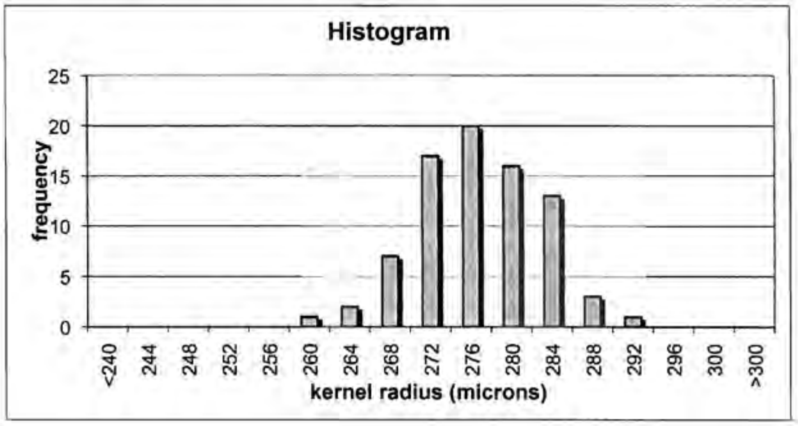
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110401
Sample ID:	AGRBW-6A2
Sample Description:	SiC Strength Test Sample: 1500 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110401_output

Number of kernels analyzed:	80
Mean of the average kernel diameter of each particle (μm):	549.2
Standard deviation in the average kernel diameter of each particle (μm):	11.6

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	0
252	0
256	0
260	1
264	2
268	7
272	17
276	20
280	16
284	13
288	3
292	1
296	0
300	0
>300	0



G. W. Chinthaka 11/25/09

Operator Date

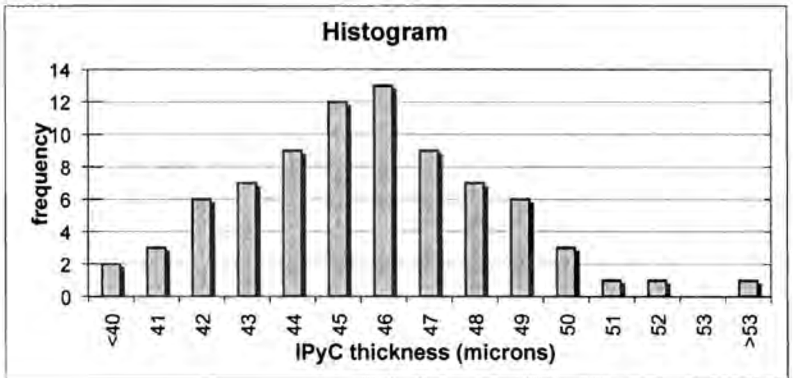
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110401
Sample ID:	AGRBW-6A2
Sample Description:	SiC Strength Test Sample: 1500 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110401_output

Number of inner pyrocarbon layers analyzed:	80
Mean of the average IPyC thickness of each particle (μm):	45.1
Standard deviation in the average IPyC thickness of each particle (μm):	2.8

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<40	2
41	3
42	6
43	7
44	9
45	12
46	13
47	9
48	7
49	6
50	3
51	1
52	1
53	0
>53	1



G.W. Chinthaka — Operator

11/25/09 — Date

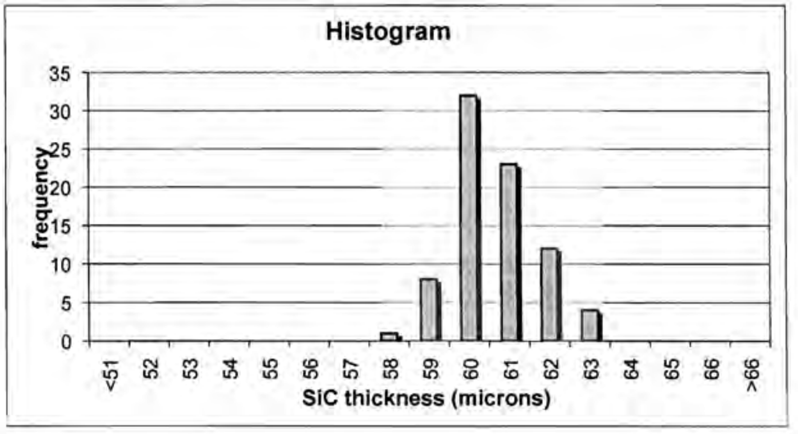
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110401
Sample ID:	AGRBW-6A2
Sample Description:	SiC Strength Test Sample: 1500 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09110401_output

Number of silicon carbide layers analyzed:	80
Mean of the average SiC thickness of each particle (μm):	60.1
Standard deviation in the average SiC thickness of each particle (μm):	0.9

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	1
59	8
60	32
61	23
62	12
63	4
64	0
65	0
66	0
>66	0



G. W. Chinthaka

Operator

11/25/09

Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-7A2
Sample description:	SiC Strength Test Sample: 1550 C, 240 min, 520 um ZrO2
Mount ID number:	M09102802
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09121601

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.7

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
330	360	318	356

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
261		40	61	

G.W. Chinthaka

Operator

12/17/09

Date

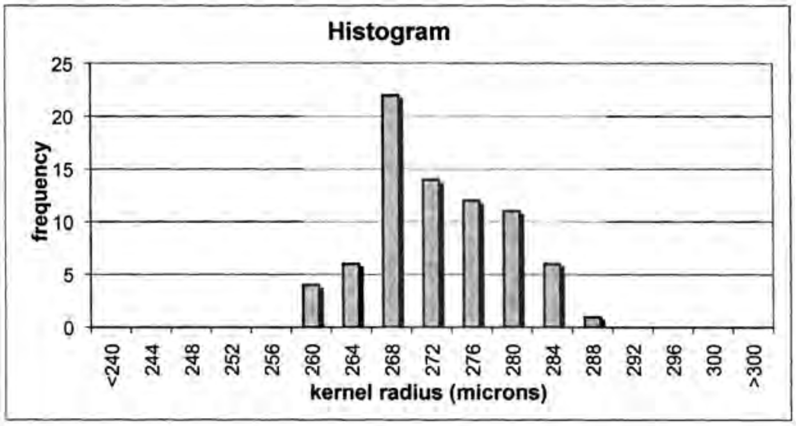
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121601
Sample ID:	AGRBW-7A2
Sample Description:	SiC Strength Test Sample: 1550 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121601_output

Number of kernels analyzed:	76
Mean of the average kernel diameter of each particle (μm):	541.2
Standard deviation in the average kernel diameter of each particle (μm):	12.9

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	0
248	0
252	0
256	0
260	4
264	6
268	22
272	14
276	12
280	11
284	6
288	1
292	0
296	0
300	0
>300	0



G.W. Chinthaka
Operator

12/17/09
Date

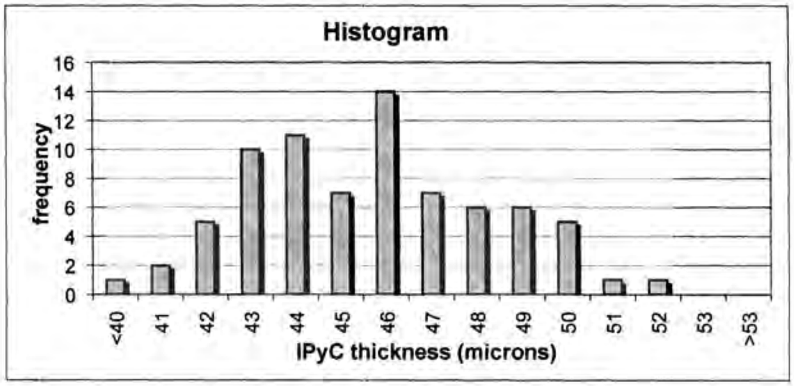
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121601
Sample ID:	AGRBW-7A2
Sample Description:	SiC Strength Test Sample: 1550 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121601_output

Number of inner pyrocarbon layers analyzed:	76
Mean of the average IPyC thickness of each particle (μm):	45.2
Standard deviation in the average IPyC thickness of each particle (μm):	2.6

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<40	1
41	2
42	5
43	10
44	11
45	7
46	14
47	7
48	6
49	6
50	5
51	1
52	1
53	0
>53	0



G. W. Chinthaka

Operator

12/17/09

Date

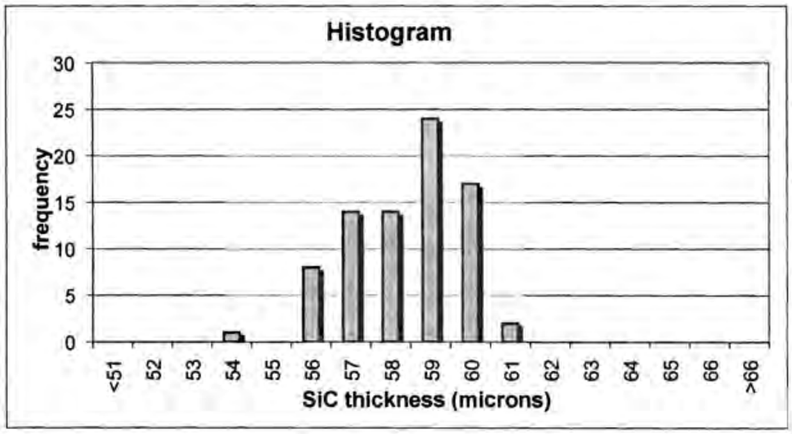
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121601
Sample ID:	AGRBW-7A2
Sample Description:	SiC Strength Test Sample: 1550 C, 240 min, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121601_output

Number of silicon carbide layers analyzed:	76
Mean of the average SiC thickness of each particle (μm):	61.6
Standard deviation in the average SiC thickness of each particle (μm):	1.5

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<51	0
52	0
53	0
54	1
55	0
56	8
57	14
58	14
59	24
60	17
61	2
62	0
63	0
64	0
65	0
66	0
>66	0



G. W. Chinthaka
Operator

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-8A2
Sample description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 520 um ZrO2
Mount ID number:	M09110201
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09121602

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.7

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
319	347	327	329

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
268		41	60	

G. W. Chinthaka

Operator

12/17/09

Date

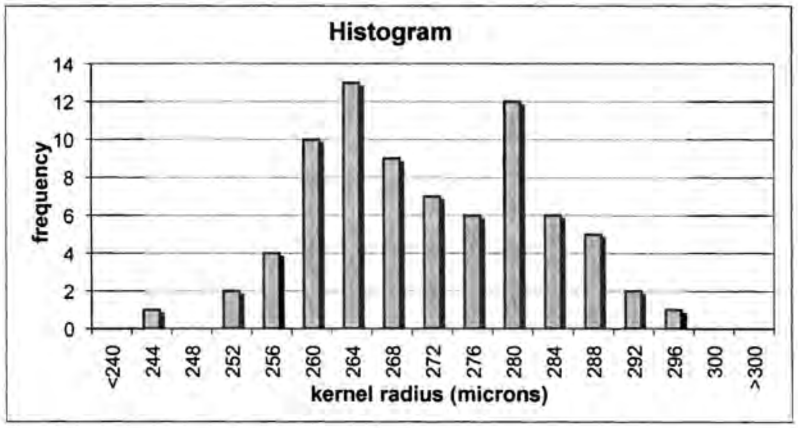
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121602
Sample ID:	AGRBW-8A2
Sample Description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121602_output

Number of kernels analyzed:	79
Mean of the average kernel diameter of each particle (µm):	541.0
Standard deviation in the average kernel diameter of each particle (µm):	12.4

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<240	0
244	1
248	0
252	2
256	4
260	10
264	13
268	9
272	7
276	6
280	12
284	6
288	5
292	2
296	1
300	0
>300	0



G.W. Chinthaka
Operator

12/17/09
Date

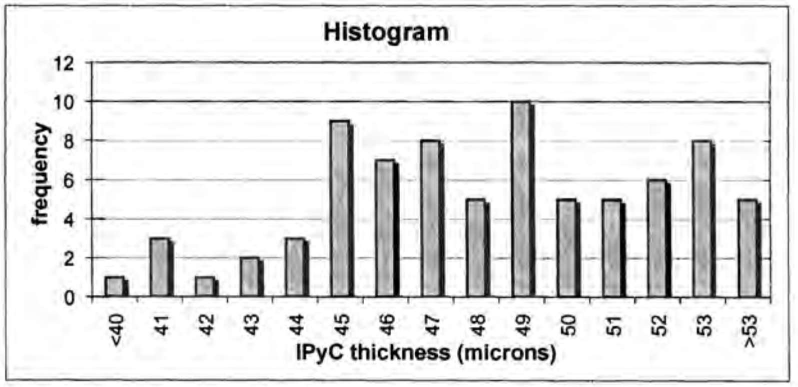
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121602
Sample ID:	AGRBW-8A2
Sample Description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121602_output

Number of inner pyrocarbon layers analyzed:	79
Mean of the average IPyC thickness of each particle (μm):	45.1
Standard deviation in the average IPyC thickness of each particle (μm):	3.1

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<40	1
41	3
42	1
43	2
44	3
45	9
46	7
47	8
48	5
49	10
50	5
51	5
52	6
53	8
>53	5



G. W. Chinthaka
Operator

12/17/09
Date

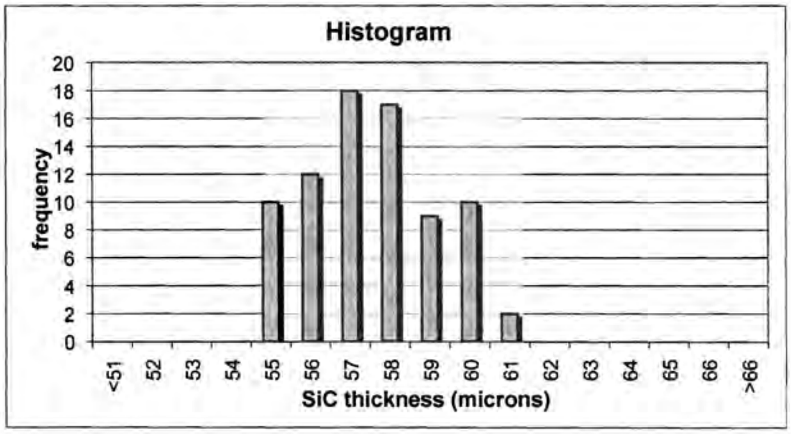
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121602
Sample ID:	AGRBW-8A2
Sample Description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 520 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121602_output

Number of silicon carbide layers analyzed:	79
Mean of the average SiC thickness of each particle (μm):	60.4
Standard deviation in the average SiC thickness of each particle (μm):	1.1

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<51	0
52	0
53	0
54	0
55	10
56	12
57	18
58	17
59	9
60	10
61	2
62	0
63	0
64	0
65	0
66	0
>66	0



G W. Chinthaka
Operator

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	Andrew K. Kercher / Chinthaka Silva
Sample ID:	AGRBW-1C2
Sample description:	SiC Strength Test Sample: 1450 C, 120 min, 670 um ZrO2
Mount ID number:	M09101501
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09102001

DMR calibration expiration date:	10/28/09
Calibrated pixels/micron:	2.8280
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.0

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
417	403	424	376

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
357		39	29	

G. W. Chinthaka

Operator

11/25/09

Date

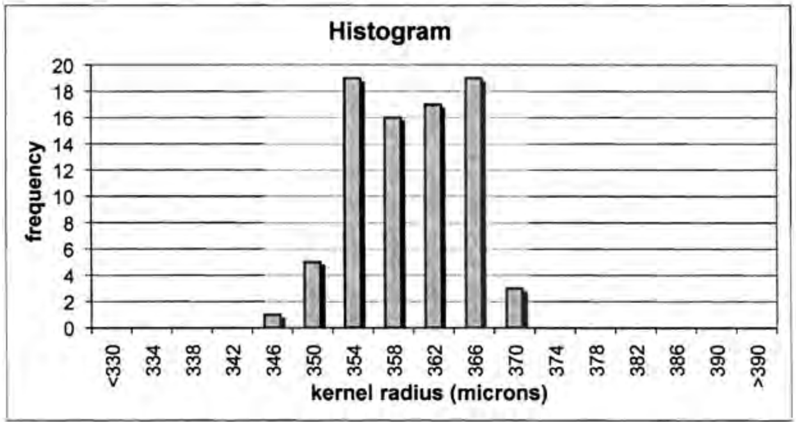
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102001
Sample ID:	AGRBW-1C2
Sample Description:	SiC Strength Test Sample: 1450 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102001_output

Number of kernels analyzed:	80
Mean of the average kernel diameter of each particle (μm):	715.2
Standard deviation in the average kernel diameter of each particle (μm):	11.1

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	0
334	0
338	0
342	0
346	1
350	5
354	19
358	16
362	17
366	19
370	3
374	0
378	0
382	0
386	0
390	0
>390	0



G.W. Chinthaka
Operator

12/17/09
Date

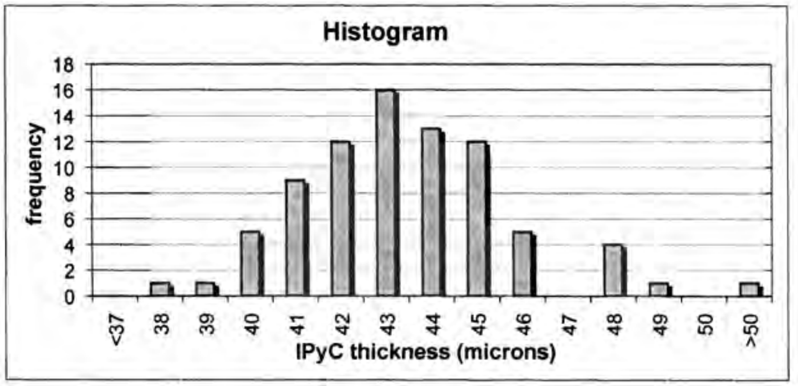
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102001
Sample ID:	AGRBW-1C2
Sample Description:	SiC Strength Test Sample: 1450 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102001_output

Number of inner pyrocarbon layers analyzed:	80
Mean of the average IPyC thickness of each particle (μm):	42.9
Standard deviation in the average IPyC thickness of each particle (μm):	2.4

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<37	0
38	1
39	1
40	5
41	9
42	12
43	16
44	13
45	12
46	5
47	0
48	4
49	1
50	0
>50	1



G.W. Chinthaka

Operator

12/17/09

Date

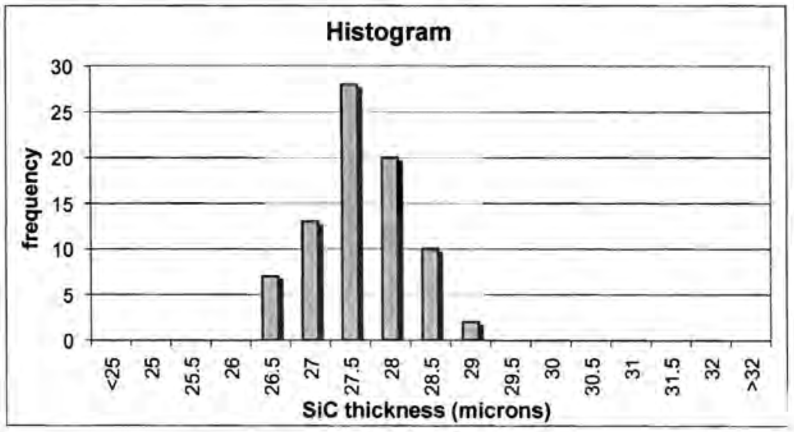
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102001
Sample ID:	AGRBW-1C2
Sample Description:	SiC Strength Test Sample: 1450 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09102001_output

Number of silicon carbide layers analyzed:	80
Mean of the average SiC thickness of each particle (μm):	27.4
Standard deviation in the average SiC thickness of each particle (μm):	0.6

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<25	0
25	0
25.5	0
26	0
26.5	7
27	13
27.5	28
28	20
28.5	10
29	2
29.5	0
30	0
30.5	0
31	0
31.5	0
32	0
>32	0



G.W. Chinthal
Operator

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-2C2
Sample description:	SiC Strength Test Sample: 1500 C, 120 min, 670 um ZrO2
Mount ID number:	M09111101
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09111901

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.0

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
322	362	317	349

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
345		39	31	

G. W. Chinthaka

Operator

11/25/09

Date

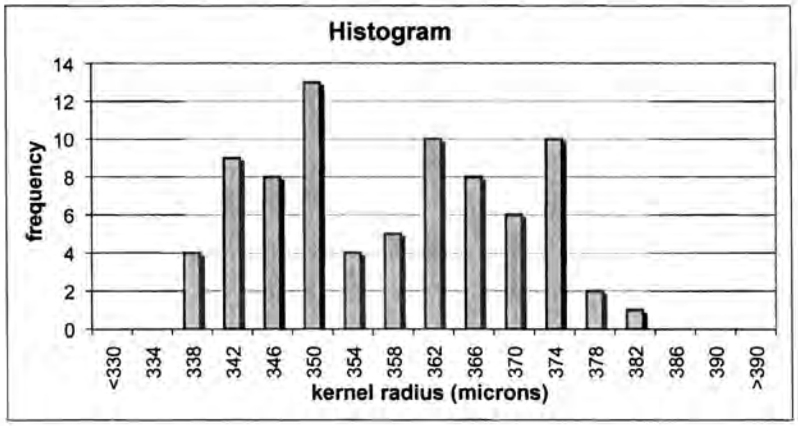
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111901
Sample ID:	AGRBW-2C2
Sample Description:	SiC Strength Test Sample: 1500 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111901_output

Number of kernels analyzed:	80
Mean of the average kernel diameter of each particle (μm):	711.4
Standard deviation in the average kernel diameter of each particle (μm):	24.0

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	0
334	0
338	4
342	9
346	8
350	13
354	4
358	5
362	10
366	8
370	6
374	10
378	2
382	1
386	0
390	0
>390	0



G.W. Chinthaka
Operator

12/17/09
Date

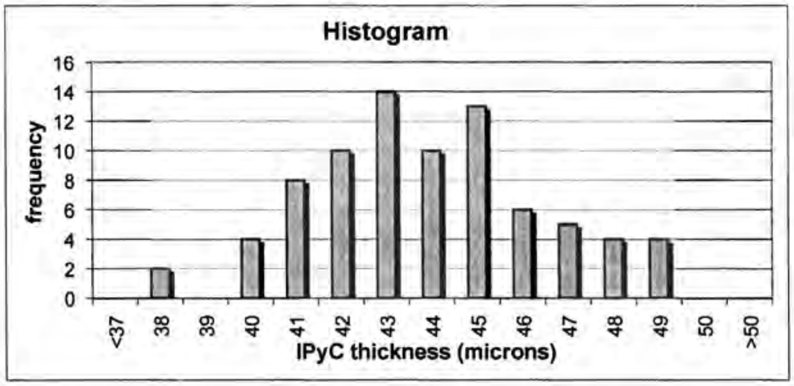
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111901
Sample ID:	AGRBW-2C2
Sample Description:	SiC Strength Test Sample: 1500 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111901_output

Number of inner pyrocarbon layers analyzed:	80
Mean of the average IPyC thickness of each particle (μm):	43.4
Standard deviation in the average IPyC thickness of each particle (μm):	2.5

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<37	0
38	2
39	0
40	4
41	8
42	10
43	14
44	10
45	13
46	6
47	5
48	4
49	4
50	0
>50	0



G.W. Chinthaka

Operator

12/17/09

Date

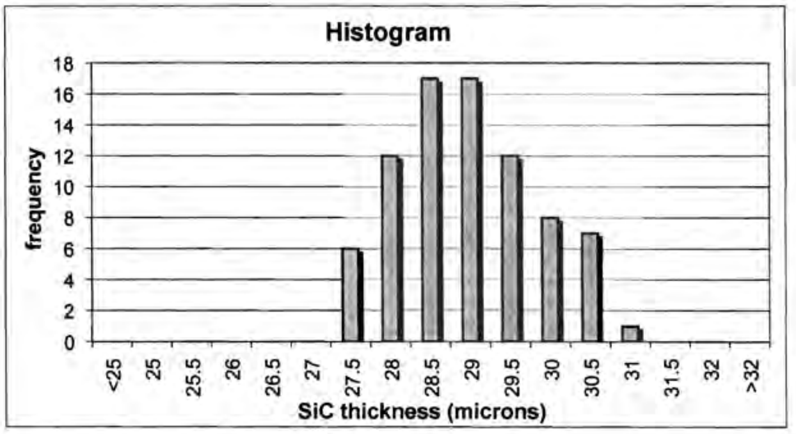
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111901
Sample ID:	AGRBW-2C2
Sample Description:	SiC Strength Test Sample: 1500 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111901_output

Number of silicon carbide layers analyzed:	80
Mean of the average SiC thickness of each particle (μm):	28.7
Standard deviation in the average SiC thickness of each particle (μm):	0.9

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<25	0
25	0
25.5	0
26	0
26.5	0
27	0
27.5	6
28	12
28.5	17
29	17
29.5	12
30	8
30.5	7
31	1
31.5	0
32	0
>32	0



G W. Chinthaka
Operator

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-3C2
Sample description:	SiC Strength Test Sample: 1550 C, 120 min, 670 um ZrO2
Mount ID number:	M09111102
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09111902

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.0

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
299	318	295	324

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
339		39	39	

G.W. Chinthaka — Operator

11/25/09 — Date

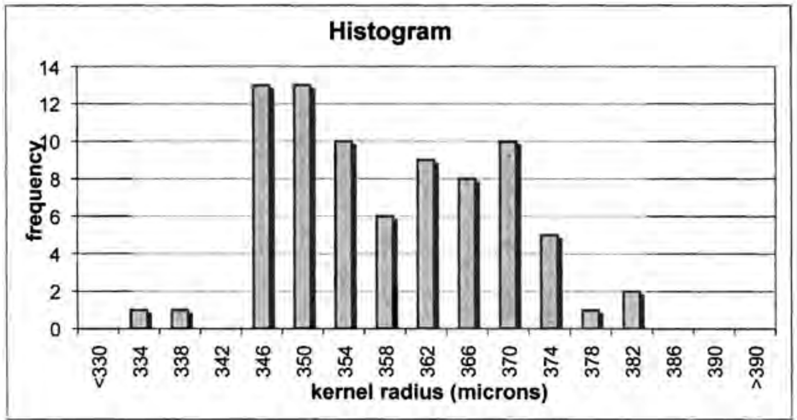
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111902
Sample ID:	AGRBW-3C2
Sample Description:	SiC Strength Test Sample: 1550 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111902_output

Number of kernels analyzed:	79
Mean of the average kernel diameter of each particle (µm):	712.4
Standard deviation in the average kernel diameter of each particle (µm):	20.5

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	0
334	1
338	1
342	0
346	13
350	13
354	10
358	6
362	9
366	8
370	10
374	5
378	1
382	2
386	0
390	0
>390	0



G.W. Chinthaka
Operator

12/17/09
Date

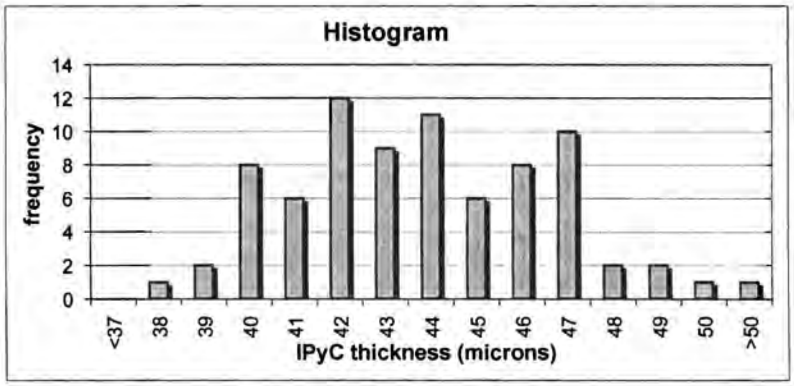
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111902
Sample ID:	AGRBW-3C2
Sample Description:	SiC Strength Test Sample: 1550 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111902_output

Number of inner pyrocarbon layers analyzed:	79
Mean of the average IPyC thickness of each particle (μm):	43.3
Standard deviation in the average IPyC thickness of each particle (μm):	2.9

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<37	0
38	1
39	2
40	8
41	6
42	12
43	9
44	11
45	6
46	8
47	10
48	2
49	2
50	1
>50	1



G.W. Chinthaka

Operator

G.W. 12/17/09

Date

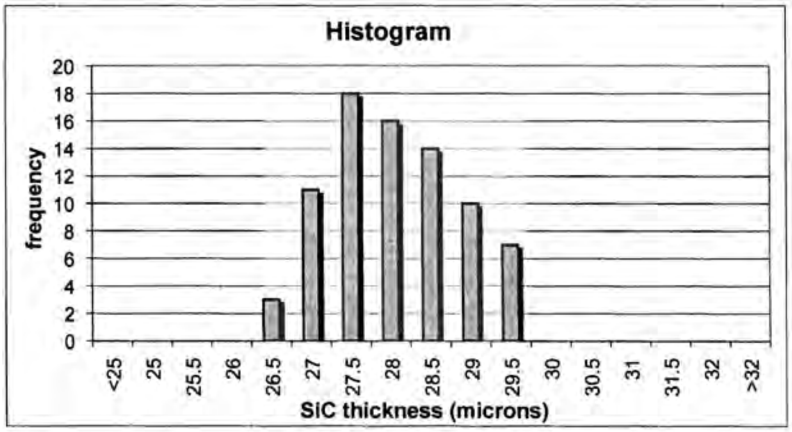
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111902
Sample ID:	AGRBW-3C2
Sample Description:	SiC Strength Test Sample: 1550 C, 120 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09111902_output

Number of silicon carbide layers analyzed:	79
Mean of the average SiC thickness of each particle (µm):	27.8
Standard deviation in the average SiC thickness of each particle (µm):	0.8

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (µm)	*Frequency*
<25	0
25	0
25.5	0
26	0
26.5	3
27	11
27.5	18
28	16
28.5	14
29	10
29.5	7
30	0
30.5	0
31	0
31.5	0
32	0
>32	0



G.W. Chinthaka

Operator

12/17/09

Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-4C2
Sample description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 670 um ZrO2
Mount ID number:	M09120201
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09120402

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.7

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
311	361	317	374

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
341		38	35	

G. W. Chinthaka

Operator

12/15/09

Date

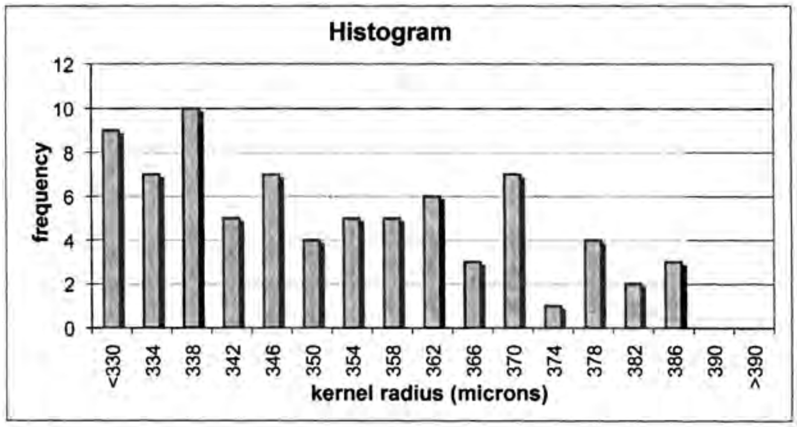
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120402
Sample ID:	AGRBW-4C2
Sample Description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120402_output

Number of kernels analyzed:	78
Mean of the average kernel diameter of each particle (μm):	699.7
Standard deviation in the average kernel diameter of each particle (μm):	34.6

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	9
334	7
338	10
342	5
346	7
350	4
354	5
358	5
362	6
366	3
370	7
374	1
378	4
382	2
386	3
390	0
>390	0



G W. Chinthaka
Operator

12/17/09
Date

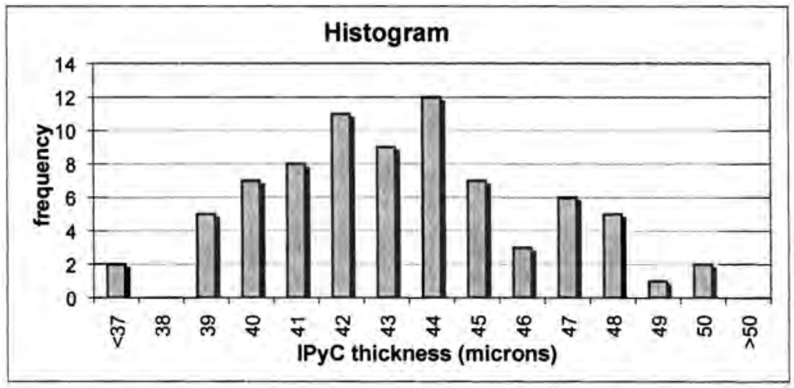
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120402
Sample ID:	AGRBW-4C2
Sample Description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120402_output

Number of inner pyrocarbon layers analyzed:	78
Mean of the average IPyC thickness of each particle (µm):	42.8
Standard deviation in the average IPyC thickness of each particle (µm):	2.9

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (µm)	*Frequency*
<37	2
38	0
39	5
40	7
41	8
42	11
43	9
44	12
45	7
46	3
47	6
48	5
49	1
50	2
>50	0



G.W. Chinthaka

Operator

12/17/09

Date

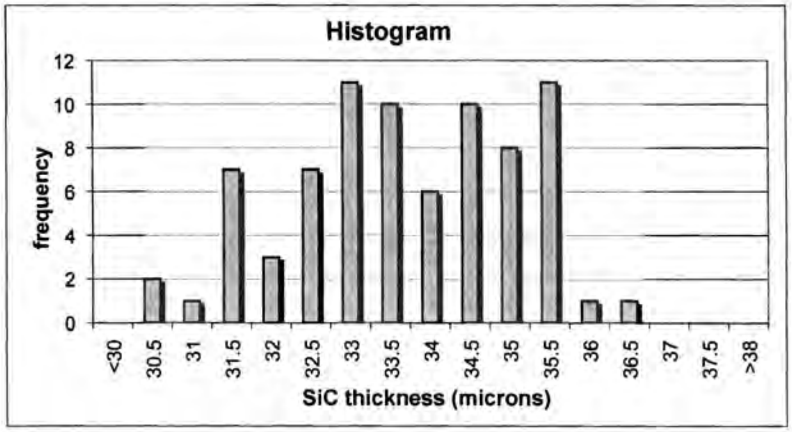
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120402
Sample ID:	AGRBW-4C2
Sample Description:	SiC Strength Test Sample: 1425 C, 120 min, Ar-H, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120402_output

Number of silicon carbide layers analyzed:	78
Mean of the average SiC thickness of each particle (μm):	33.4
Standard deviation in the average SiC thickness of each particle (μm):	1.4

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<30	0
30.5	2
31	1
31.5	7
32	3
32.5	7
33	11
33.5	10
34	6
34.5	10
35	8
35.5	11
36	1
36.5	1
37	0
37.5	0
>38	0



G.W. Chinthaka

Operator

12/17/09

Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-5C2
Sample description:	SiC Strength Test Sample: 1450 C, 240 min, 670 um ZrO2
Mount ID number:	M09113003
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09120401

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.7

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
339	343	340	350

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
345		42	66	

G.W. Chinthaka

Operator

12/15/09

Date

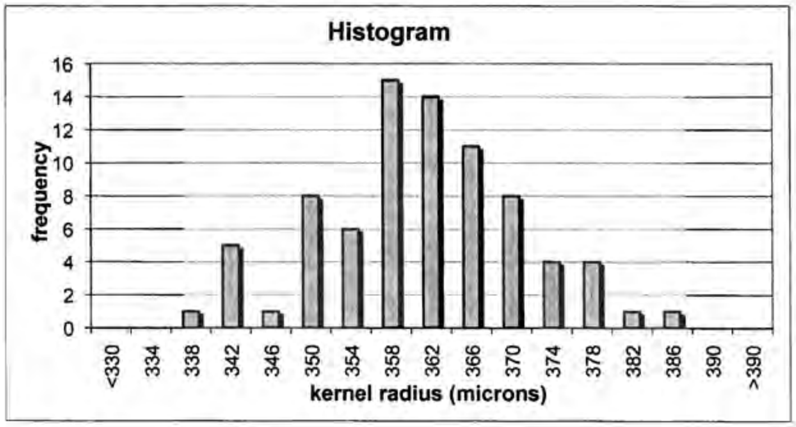
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120401
Sample ID:	AGRBW-5C2
Sample Description:	SiC Strength Test Sample: 1450 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120401_output

Number of kernels analyzed:	79
Mean of the average kernel diameter of each particle (μm):	718.0
Standard deviation in the average kernel diameter of each particle (μm):	19.4

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	0
334	0
338	1
342	5
346	1
350	8
354	6
358	15
362	14
366	11
370	8
374	4
378	4
382	1
386	1
390	0
>390	0



G.W. Chinthaka
Operator

12/17/09
Date

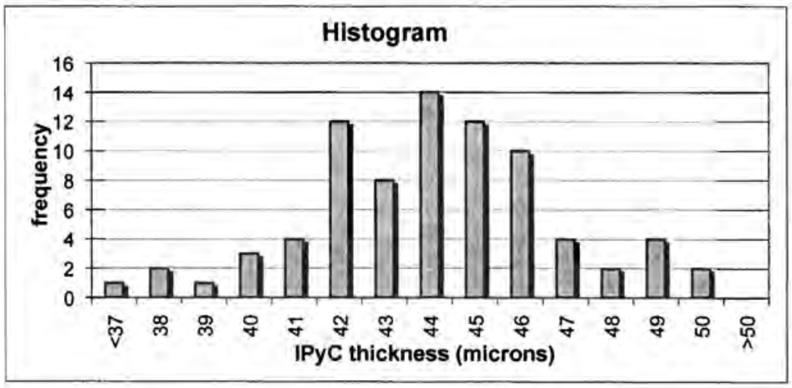
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120401
Sample ID:	AGRBW-5C2
Sample Description:	SiC Strength Test Sample: 1450 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120401_output

Number of inner pyrocarbon layers analyzed:	79
Mean of the average IPyC thickness of each particle (µm):	43.5
Standard deviation in the average IPyC thickness of each particle (µm):	2.7

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (µm)	*Frequency*
<37	1
38	2
39	1
40	3
41	4
42	12
43	8
44	14
45	12
46	10
47	4
48	2
49	4
50	2
>50	0



G.W. Chinthaka

Operator

12/17/09

Date

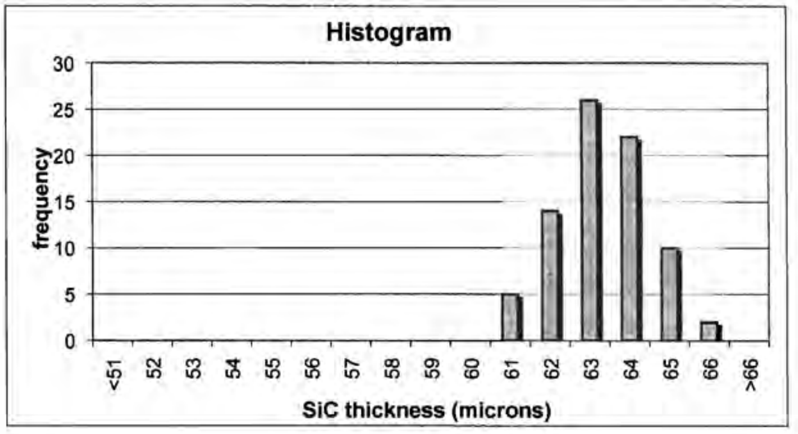
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120401
Sample ID:	AGRBW-5C2
Sample Description:	SiC Strength Test Sample: 1450 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120401_output

Number of silicon carbide layers analyzed:	79
Mean of the average SiC thickness of each particle (μm):	62.8
Standard deviation in the average SiC thickness of each particle (μm):	1.1

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<51	0
52	0
53	0
54	0
55	0
56	0
57	0
58	0
59	0
60	0
61	5
62	14
63	26
64	22
65	10
66	2
>66	0



G.W. Chinthaka
Operator

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-6C2
Sample description:	SiC Strength Test Sample: 1500 C, 240 min, 670 um ZrO2
Mount ID number:	M09120401
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09120901

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 μm in stage micrometer image (μm):	500.4

Polish-down distance n,m (μm)			
2,2	2,8	8,2	8,8
320	335	305	341

Approximate layer width in polish plane (μm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
335		34	57	

G.W. Chinthaka
Operator

12/15/09
Date

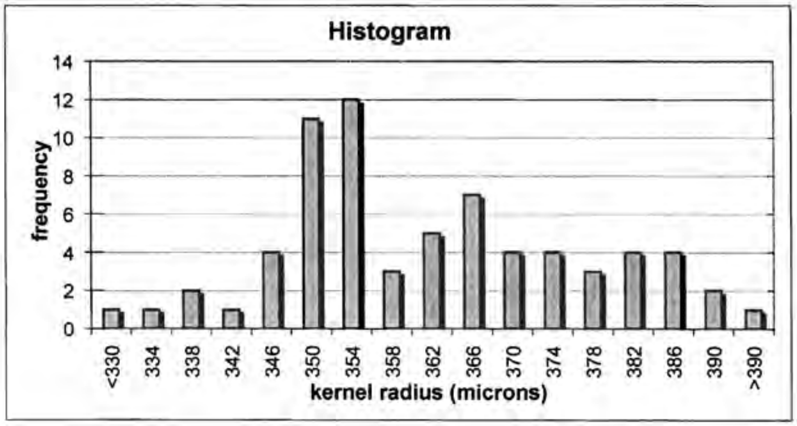
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120901
Sample ID:	AGRBW-6C2
Sample Description:	SiC Strength Test Sample: 1500 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120901_output

Number of kernels analyzed:	69
Mean of the average kernel diameter of each particle (μm):	719.6
Standard deviation in the average kernel diameter of each particle (μm):	30.1

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	1
334	1
338	2
342	1
346	4
350	11
354	12
358	3
362	5
366	7
370	4
374	4
378	3
382	4
386	4
390	2
>390	1



G.W. Chinthaka

Operator

12/17/09

Date

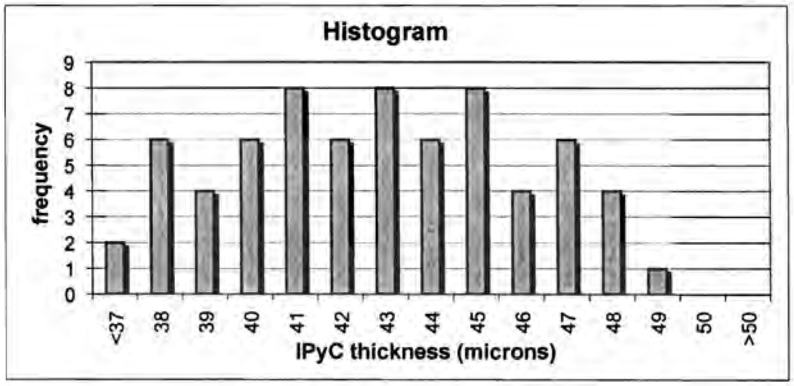
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120901
Sample ID:	AGRBW-6C2
Sample Description:	SiC Strength Test Sample: 1500 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120901_output

Number of inner pyrocarbon layers analyzed:	69
Mean of the average IPyC thickness of each particle (μm):	42.3
Standard deviation in the average IPyC thickness of each particle (μm):	3.2

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<37	2
38	6
39	4
40	6
41	8
42	6
43	8
44	6
45	8
46	4
47	6
48	4
49	1
50	0
>50	0



G.W. Chinthaka

Operator

12/17/09

Date

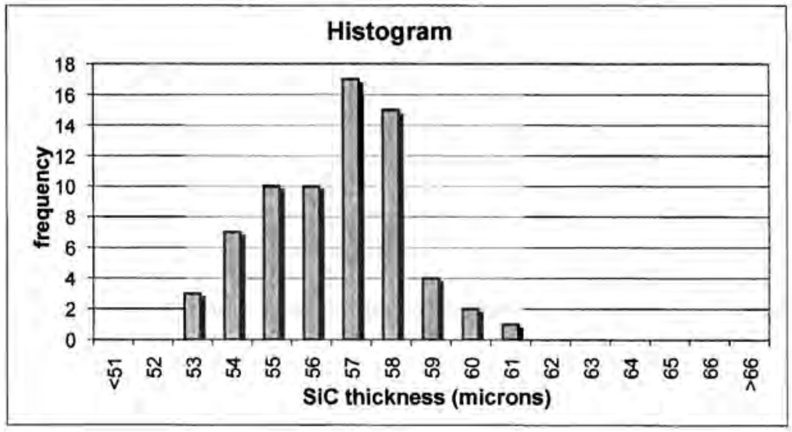
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120901
Sample ID:	AGRBW-6C2
Sample Description:	SiC Strength Test Sample: 1500 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120901_output

Number of silicon carbide layers analyzed:	69
Mean of the average SiC thickness of each particle (μm):	56.1
Standard deviation in the average SiC thickness of each particle (μm):	1.8

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<51	0
52	0
53	3
54	7
55	10
56	10
57	17
58	15
59	4
60	2
61	1
62	0
63	0
64	0
65	0
66	0
>66	0



G.W. Chinthaka
~~Operator~~

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-7C2
Sample description:	SiC Strength Test Sample: 1550 C, 240 min, 670 um ZrO2
Mount ID number:	M09120402
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09120902

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.4

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
333	332	300	325

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
337		37	60	

G.W. Chinthaka

Operator

12/15/09

Date

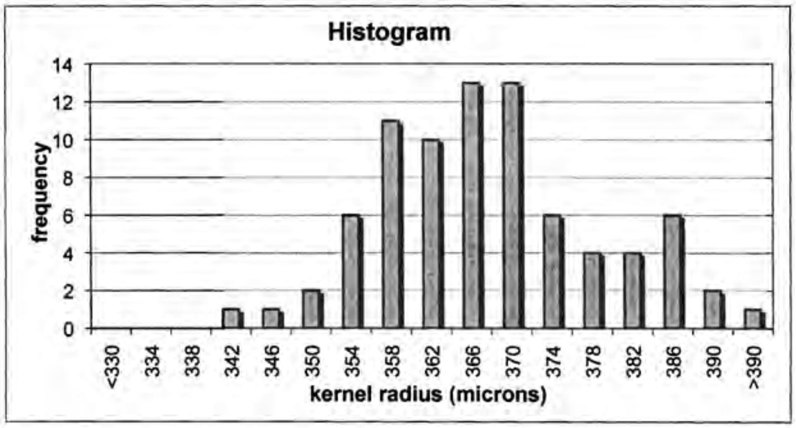
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120902
Sample ID:	AGRBW-7C2
Sample Description:	SiC Strength Test Sample: 1550 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120902_output

Number of kernels analyzed:	80
Mean of the average kernel diameter of each particle (μm):	730.6
Standard deviation in the average kernel diameter of each particle (μm):	21.7

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	0
334	0
338	0
342	1
346	1
350	2
354	6
358	11
362	10
366	13
370	13
374	6
378	4
382	4
386	6
390	2
>390	1



G.W. Chinthaka
Operator

12/17/09
Date

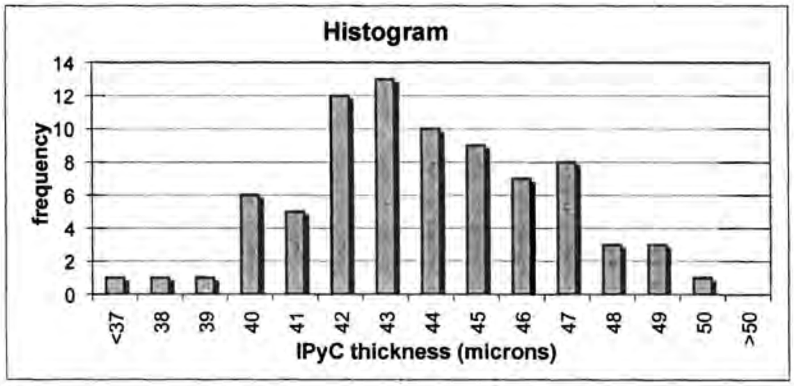
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120902
Sample ID:	AGRBW-7C2
Sample Description:	SiC Strength Test Sample: 1550 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120902_output

Number of inner pyrocarbon layers analyzed:	80
Mean of the average IPyC thickness of each particle (μm):	43.3
Standard deviation in the average IPyC thickness of each particle (μm):	2.7

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (μm)	*Frequency*
<37	1
38	1
39	1
40	6
41	5
42	12
43	13
44	10
45	9
46	7
47	8
48	3
49	3
50	1
>50	0



G.W. Chinthaka
Operator

12/17/09
Date

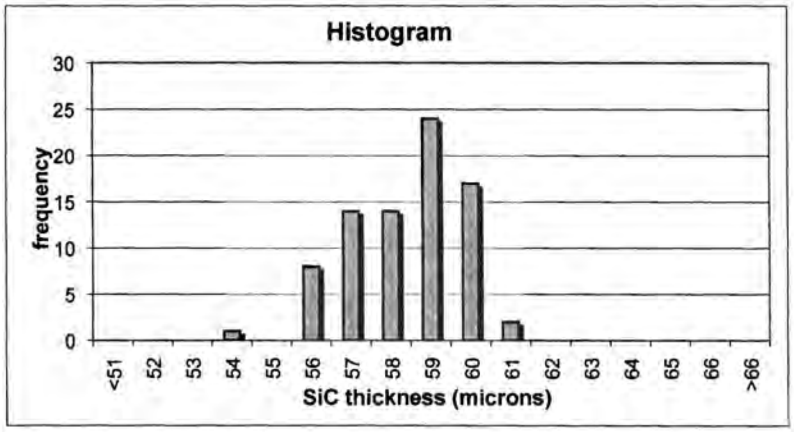
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120902
Sample ID:	AGRBW-7C2
Sample Description:	SiC Strength Test Sample: 1550 C, 240 min, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09120902_output

Number of silicon carbide layers analyzed:	80
Mean of the average SiC thickness of each particle (μm):	57.9
Standard deviation in the average SiC thickness of each particle (μm):	1.4

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (μm)	*Frequency*
<51	0
52	0
53	0
54	1
55	0
56	8
57	14
58	14
59	24
60	17
61	2
62	0
63	0
64	0
65	0
66	0
>66	0



G.W. Chinthaka
Operator

12/17/09
Date

Data Report Form DRF-08: Imaging of Coated Particle Cross-sections Using an Optical Microscope System

Procedure:	AGR-CHAR-DAM-08 Rev. 2
Operator:	C. Silva
Sample ID:	AGRBW-8C2
Sample description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 670 um ZrO2
Mount ID number:	M09120801
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\P09121603

DMR calibration expiration date:	11/2/10
Calibrated pixels/micron:	2.8260
Stage micrometer calibration expiration date:	2/10/14
Measured value for 500 µm in stage micrometer image (µm):	500.7

Polish-down distance n,m (µm)			
2,2	2,8	8,2	8,8
318	346	344	362

Approximate layer width in polish plane (µm)				
Kernel radius	Buffer	IPyC	SiC	OPyC
330		36	68	

G. W. Chinthaka

Operator

12/17/09

Date

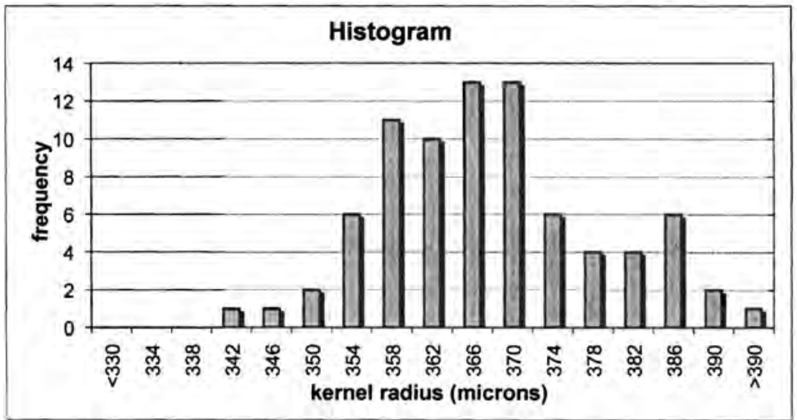
Measurement of Kernel Diameter

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121603
Sample ID:	AGRBW-8C2
Sample Description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121603_output

Number of kernels analyzed:	78
Mean of the average kernel diameter of each particle (µm):	708.6
Standard deviation in the average kernel diameter of each particle (µm):	26.4

Distribution of the average kernel diameter (top binned)

Kernel Radius	*Frequency*
<330	0
334	0
338	0
342	1
346	1
350	2
354	6
358	11
362	10
366	13
370	13
374	6
378	4
382	4
386	6
390	2
>390	1



G.W. Chinthaka
Operator

12/17/09
Date

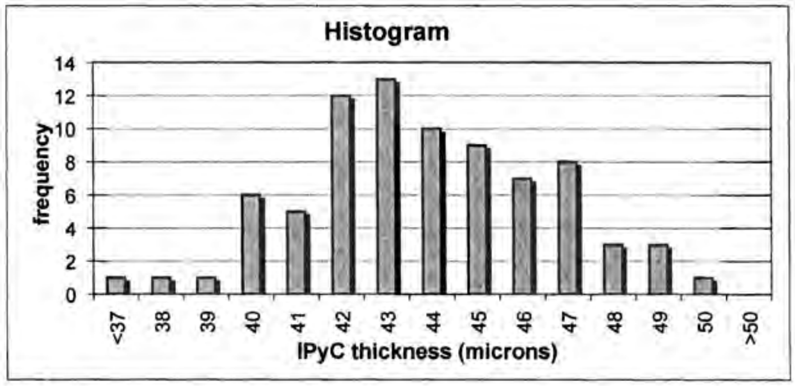
Data Report Form DRF-11B: Measurement of Inner Pyrocarbon Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121603
Sample ID:	AGRBW-8C2
Sample Description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121603_output

Number of inner pyrocarbon layers analyzed:	78
Mean of the average IPyC thickness of each particle (µm):	44.0
Standard deviation in the average IPyC thickness of each particle (µm):	2.7

Distribution of the average IPyC layer thickness (top binned)

IPyC Thickness (µm)	*Frequency*
<37	1
38	1
39	1
40	6
41	5
42	12
43	13
44	10
45	9
46	7
47	8
48	3
49	3
50	1
>50	0



G.W. Chinthak
Operator

12/17/09
Date

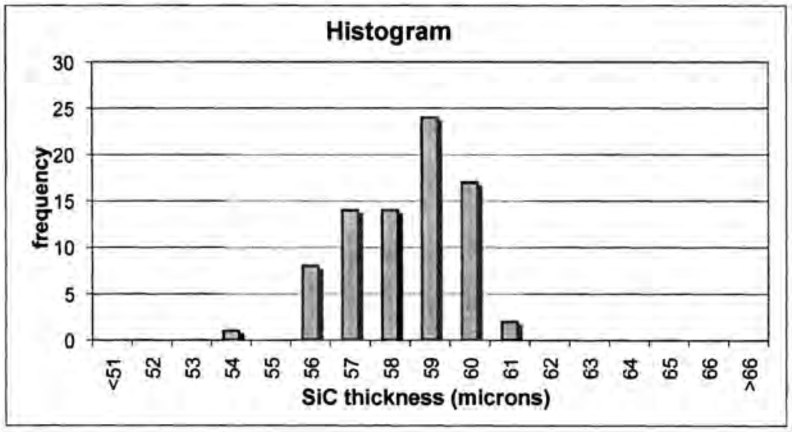
Data Report Form DRF-11C: Measurement of Silicon Carbide Layer Thickness

Procedure:	AGR-CHAR-DAM-11 Rev. 2
Operator:	C. Silva
Folder name containing images:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121603
Sample ID:	AGRBW-8C2
Sample Description:	SiC Strength Test Sample: 1425 C, 240 min, Ar-H, 670 um ZrO2
Folder name containing processed data:	\\mc-agr\AGR\ImageProcessing\Completed_Layers\P09121603_output

Number of silicon carbide layers analyzed:	78
Mean of the average SiC thickness of each particle (µm):	64.6
Standard deviation in the average SiC thickness of each particle (µm):	1.6

Distribution of the average SiC layer thickness (top binned)

SiC Thickness (µm)	*Frequency*
<51	0
52	0
53	0
54	1
55	0
56	8
57	14
58	14
59	24
60	17
61	2
62	0
63	0
64	0
65	0
66	0
>66	0



G.W. Chinthak
Operator

12/17/09
Date

Appendix C: SiC Density Data Reports

SiC sink-float density was measured using data acquisition methods developed for the AGR program: AGR-DAM-CHAR-02 and AGR-DAM-CHAR-04. The attached data report forms show the linear fit to the calibration standards and the individual and average density for the fragments measured. The average values are also summarized in the table below.

Summary of SiC sink-float density for Series B

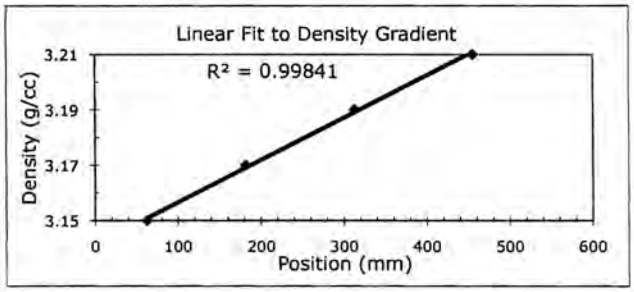
Coating Run	Series B-A2 SiC density (g/cm^3)		Series B-C2 SiC density (g/cm^3)	
	mean	st. dev.	mean	st. dev.
AGRBW-1	3.2014	0.0028	3.2017	0.0025
AGRBW-2	3.2040	0.0024	3.2017	0.0027
AGRBW-3	3.2038	0.0020	3.2019	0.0023
AGRBW-4	3.2035	0.0019	3.2025	0.0019
AGRBW-5	3.2064	0.0017	3.2064	0.0010
AGRBW-6	3.2079	0.0020	3.2069	0.0016
AGRBW-7	3.2077	0.0011	3.2078	0.0009
AGRBW-8	3.2074	0.0006	3.2069	0.0005

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D009081101_DRF02R4.xls
Sample ID:	AGRBW-1A2
Sample description:	SiC Strength Test Sample: 1450 C, 120 min, 520 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.6 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	49.49	69.40	62.76
3.170	165.66	189.71	181.69
3.190	297.96	320.32	312.87
3.210	440.07	462.63	455.11

Linear Fit			
slope	StDev	intercept	StDev
1.53E-04	2.72E-06	3.14E+00	6.68E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	331.68	3.1920	26	396.80	3.2020	51		
2	354.78	3.1955	27	399.28	3.2023	52		
3	356.15	3.1958	28	403.30	3.2030	53		
4	357.71	3.1960	29	403.30	3.2030	54		
5	370.38	3.1979	30	404.55	3.2032	55		
6	381.27	3.1996	31	405.59	3.2033	56		
7	382.66	3.1998	32	405.59	3.2033	57		
8	375.26	3.1987	33	405.59	3.2033	58		
9	382.58	3.1998	34	409.47	3.2039	59		
10	384.76	3.2001	35	410.93	3.2041	60		
11	385.72	3.2003	36	411.49	3.2042	61		
12	386.66	3.2004	37	415.26	3.2048	62		
13	388.21	3.2007	38	415.26	3.2048	63		
14	388.21	3.2007	39	415.26	3.2048	64		
15	385.86	3.2003	40	416.59	3.2050	65		
16	391.76	3.2012	41	420.48	3.2056	66		
17	388.57	3.2007	42	409.92	3.2040	67		
18	390.67	3.2010	43	409.98	3.2040	68		
19	392.00	3.2012	44			69		
20	393.49	3.2015	45			70		
21	393.49	3.2015	46			71		
22	394.22	3.2016	47			72		
23	394.63	3.2016	48			73		
24	395.77	3.2018	49			74		
25	396.80	3.2020	50			75		

Average density of SiC fragments:	3.2014
Standard deviation in density of SiC fragments:	0.0028
Uncertainty in calculated density of SiC fragments:	0.0013

Dixie Barker
Operator

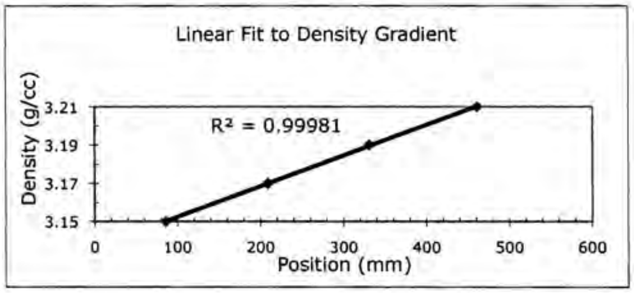
8-11-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09082501_DRF02R4.xls
Sample ID:	AGRBW-2A2
Sample description:	SiC Strength Test Sample 1500C, 120 min, 520 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.8 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	72.06	92.69	85.81
3.170	193.76	216.67	209.03
3.190	316.39	338.52	331.14
3.210	445.08	469.03	461.05

Linear Fit			
slope	StDev	intercept	StDev
1.60E-04	2.95E-06	3.14E+00	8.01E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	368.86	3.1956	26	430.29	3.2054	51		
2	393.97	3.1996	27	431.01	3.2055	52		
3	395.57	3.1998	28	431.99	3.2057	53		
4	396.25	3.1999	29	433.32	3.2059	54		
5	402.87	3.2010	30	434.08	3.2060	55		
6	404.86	3.2013	31	435.48	3.2062	56		
7	408.54	3.2019	32	438.25	3.2067	57		
8	412.11	3.2025	33	441.77	3.2072	58		
9	412.77	3.2026	34	445.64	3.2079	59		
10	414.36	3.2029	35	437.53	3.2066	60		
11	416.54	3.2032	36	434.25	3.2060	61		
12	418.12	3.2035	37	432.38	3.2057	62		
13	418.62	3.2035	38	430.85	3.2055	63		
14	419.44	3.2037	39	428.92	3.2052	64		
15	419.44	3.2037	40	431.47	3.2056	65		
16	420.66	3.2039	41	428.30	3.2051	66		
17	419.92	3.2037	42	427.42	3.2049	67		
18	421.09	3.2039	43			68		
19	421.86	3.2041	44			69		
20	424.57	3.2045	45			70		
21	424.99	3.2046	46			71		
22	425.57	3.2046	47			72		
23	426.27	3.2048	48			73		
24	427.47	3.2050	49			74		
25	428.45	3.2051	50			75		

Average density of SiC fragments:	3.2040
Standard deviation in density of SiC fragments:	0.0024
Uncertainty in calculated density of SiC fragments:	0.0015

Dixie Barker
Operator

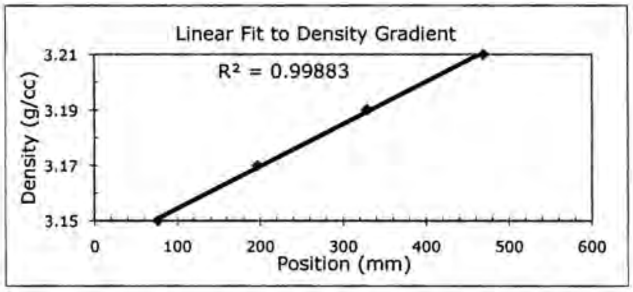
8-25-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09082701_DRF02R4.xls
Sample ID:	AGRBW-3A2
Sample description:	SiC Strength Test Sample: 1550C, 120 min, 520 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.7 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	63.07	83.19	76.48
3.170	181.13	204.86	196.95
3.190	313.90	336.04	328.66
3.210	453.85	476.79	469.14

Linear Fit			
slope	StDev	intercept	StDev
1.53E-04	2.70E-06	3.14E+00	7.06E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	390.86	3.1988	26	432.40	3.2051	51		
2	392.25	3.1990	27	433.16	3.2052	52		
3	394.84	3.1994	28	434.01	3.2054	53		
4	403.24	3.2007	29	435.85	3.2056	54		
5	403.27	3.2007	30	437.68	3.2059	55		
6	406.15	3.2011	31	438.26	3.2060	56		
7	409.03	3.2015	32	446.07	3.2072	57		
8	410.29	3.2017	33	433.28	3.2052	58		
9	412.68	3.2021	34	431.98	3.2050	59		
10	413.34	3.2022	35	428.56	3.2045	60		
11	416.93	3.2027	36	430.31	3.2048	61		
12	418.89	3.2030	37	427.71	3.2044	62		
13	421.19	3.2034	38	428.30	3.2045	63		
14	425.54	3.2041	39	437.74	3.2059	64		
15	425.31	3.2040	40	438.42	3.2060	65		
16	426.46	3.2042	41	431.76	3.2050	66		
17	426.74	3.2042	42			67		
18	426.44	3.2042	43			68		
19	428.41	3.2045	44			69		
20	430.49	3.2048	45			70		
21	431.82	3.2050	46			71		
22	430.39	3.2048	47			72		
23	431.66	3.2050	48			73		
24	432.63	3.2051	49			74		
25	431.36	3.2049	50			75		

Average density of SiC fragments:	3.2038
Standard deviation in density of SiC fragments:	0.0020
Uncertainty in calculated density of SiC fragments:	0.0014

Dixie Barker
Operator

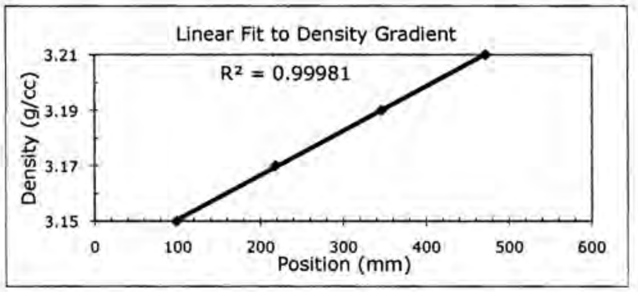
8-27-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09082801_DRF02R4.xls
Sample ID:	AGRBW-4A2
Sample description:	SiC Strength Test Sample: 1425C, 120 min, 520 um ZrO2, Ar-H
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.9 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	85.15	105.45	98.68
3.170	202.38	226.34	218.35
3.190	331.13	353.74	346.20
3.210	456.63	479.56	471.92

Linear Fit			
slope	StDev	intercept	StDev
1.60E-04	2.94E-06	3.13E+00	8.36E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	401.25	3.1988	26	438.08	3.2047	51		
2	406.62	3.1997	27	439.18	3.2049	52		
3	412.74	3.2007	28	447.42	3.2062	53		
4	417.59	3.2014	29	449.12	3.2065	54		
5	419.67	3.2018	30	449.64	3.2066	55		
6	419.67	3.2018	31	447.48	3.2062	56		
7	419.67	3.2018	32	448.77	3.2064	57		
8	420.43	3.2019	33	464.82	3.2090	58		
9	421.95	3.2021	34	434.15	3.2041	59		
10	421.45	3.2021	35	430.16	3.2035	60		
11	426.31	3.2028	36	427.88	3.2031	61		
12	426.31	3.2028	37	426.89	3.2029	62		
13	427.28	3.2030	38	427.77	3.2031	63		
14	427.50	3.2030	39	426.56	3.2029	64		
15	427.46	3.2030	40	426.56	3.2029	65		
16	430.64	3.2035	41	427.94	3.2031	66		
17	430.70	3.2035	42			67		
18	431.57	3.2037	43			68		
19	432.67	3.2039	44			69		
20	433.37	3.2040	45			70		
21	434.11	3.2041	46			71		
22	434.91	3.2042	47			72		
23	434.22	3.2041	48			73		
24	434.51	3.2042	49			74		
25	435.07	3.2042	50			75		

Average density of SiC fragments:	3.2035
Standard deviation in density of SiC fragments:	0.0019
Uncertainty in calculated density of SiC fragments:	0.0016

Dixie Barker
Operator

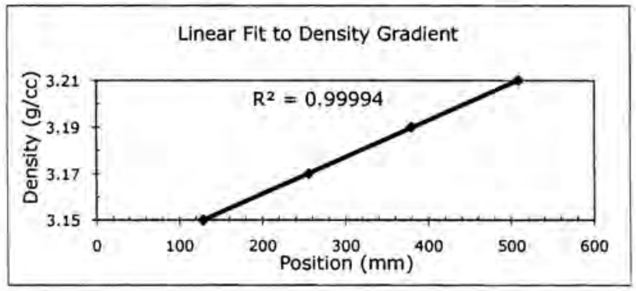
8-28-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09090201_DRF02R4.xls
Sample ID:	AGRBW-5A2
Sample description:	SiC Strength Test Sample: 1450C, 240 min, 520um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	23.2 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	115.48	134.96	128.47
3.170	239.87	264.00	255.96
3.190	364.58	387.13	379.61
3.210	492.80	516.73	508.75

Linear Fit			
slope	StDev	intercept	StDev
1.58E-04	2.84E-06	3.13E+00	9.55E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	440.76	3.1994	26	490.53	3.2073	51		
2	467.09	3.2035	27	490.66	3.2073	52		
3	468.42	3.2038	28	490.66	3.2073	53		
4	467.21	3.2036	29	490.10	3.2072	54		
5	469.26	3.2039	30	490.92	3.2073	55		
6	477.66	3.2052	31	491.92	3.2075	56		
7	476.15	3.2050	32	492.89	3.2076	57		
8	479.63	3.2055	33	494.50	3.2079	58		
9	481.90	3.2059	34	493.96	3.2078	59		
10	481.90	3.2059	35	495.76	3.2081	60		
11	481.73	3.2059	36	496.59	3.2082	61		
12	482.45	3.2060	37	498.75	3.2086	62		
13	483.45	3.2061	38	499.93	3.2087	63		
14	484.28	3.2063	39	495.85	3.2081	64		
15	480.61	3.2057	40	491.47	3.2074	65		
16	483.18	3.2061	41	490.62	3.2073	66		
17	484.31	3.2063	42	489.86	3.2071	67		
18	485.75	3.2065	43	488.41	3.2069	68		
19	487.10	3.2067	44			69		
20	485.00	3.2064	45			70		
21	486.25	3.2066	46			71		
22	486.25	3.2066	47			72		
23	487.86	3.2068	48			73		
24	488.88	3.2070	49			74		
25	489.47	3.2071	50			75		

Average density of SiC fragments:	3.2064
Standard deviation in density of SiC fragments:	0.0017
Uncertainty in calculated density of SiC fragments:	0.0017

Dixie Barker
Operator

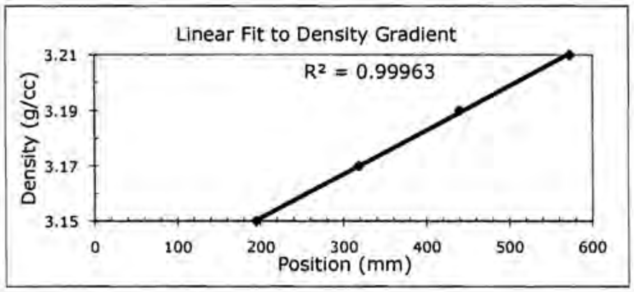
9-2-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09102301_DRF02R4.xls
Sample ID:	AGRBW-6A2
Sample description:	SiC Strength Test Sample: 1500C, 240 min, 520 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	09/2010
Bath temperature:	23.2 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	180.98	201.30	194.53
3.170	302.50	326.56	318.54
3.190	430.09	445.08	440.08
3.210	558.79	580.07	572.98

Linear Fit			
slope	StDev	intercept	StDev
1.59E-04	2.86E-06	3.12E+00	1.12E-03



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	499.42	3.1988	26	585.22	3.2124	51		
2	544.34	3.2059	27	556.10	3.2078	52		
3	544.34	3.2059	28	560.85	3.2085	53		
4	548.72	3.2066	29	556.01	3.2078	54		
5	550.42	3.2069	30	552.93	3.2073	55		
6	552.48	3.2072	31	558.00	3.2081	56		
7	552.48	3.2072	32	561.65	3.2087	57		
8	554.22	3.2075	33	568.94	3.2098	58		
9	552.54	3.2072	34	570.81	3.2101	59		
10	552.54	3.2072	35	565.01	3.2092	60		
11	555.71	3.2077	36	558.43	3.2081	61		
12	556.58	3.2078	37	557.46	3.2080	62		
13	557.39	3.2080	38	550.09	3.2068	63		
14	558.75	3.2082	39	548.58	3.2066	64		
15	558.28	3.2081	40	544.47	3.2059	65		
16	561.84	3.2087	41	544.47	3.2059	66		
17	562.25	3.2087	42			67		
18	561.07	3.2086	43			68		
19	563.69	3.2090	44			69		
20	565.19	3.2092	45			70		
21	568.19	3.2097	46			71		
22	570.75	3.2101	47			72		
23	568.81	3.2098	48			73		
24	565.72	3.2093	49			74		
25	564.64	3.2091	50			75		

Average density of SiC fragments:	3.2079
Standard deviation in density of SiC fragments:	0.0020
Uncertainty in calculated density of SiC fragments:	0.0020

Dixie Barker
Operator

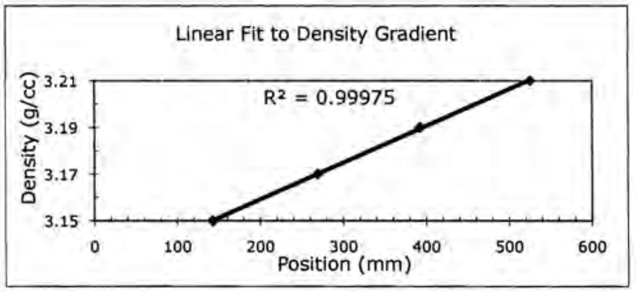
10-23-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09091001_DRF02R4.xls
Sample ID:	AGRBW-7A2
Sample description:	SiC Strength Test Sample: 1550C, 240 min, 520 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.8 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	129.34	149.46	142.75
3.170	253.65	277.36	269.46
3.190	377.46	399.85	392.39
3.210	509.41	533.52	525.48

Linear Fit			
slope	StDev	intercept	StDev
1.57E-04	2.87E-06	3.13E+00	9.55E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	496.77	3.2058	26	516.59	3.2090	51		
2	499.44	3.2063	27	514.85	3.2087	52		
3	500.54	3.2064	28	506.43	3.2074	53		
4	501.75	3.2066	29	504.81	3.2071	54		
5	503.36	3.2069	30	504.07	3.2070	55		
6	504.36	3.2070	31	506.97	3.2074	56		
7	504.67	3.2071	32	504.68	3.2071	57		
8	504.47	3.2070	33	509.48	3.2078	58		
9	504.31	3.2070	34	513.46	3.2085	59		
10	504.31	3.2070	35	513.46	3.2085	60		
11	506.35	3.2073	36	516.19	3.2089	61		
12	507.13	3.2075	37	528.96	3.2109	62		
13	507.13	3.2075	38	506.53	3.2074	63		
14	507.89	3.2076	39	501.86	3.2066	64		
15	508.83	3.2077	40	497.70	3.2060	65		
16	509.58	3.2079	41			66		
17	510.55	3.2080	42			67		
18	510.94	3.2081	43			68		
19	512.22	3.2083	44			69		
20	513.43	3.2085	45			70		
21	514.37	3.2086	46			71		
22	515.31	3.2088	47			72		
23	516.12	3.2089	48			73		
24	520.19	3.2095	49			74		
25	521.28	3.2097	50			75		

Average density of SiC fragments:	3.2077
Standard deviation in density of SiC fragments:	0.0011
Uncertainty in calculated density of SiC fragments:	0.0018

Dixie Barker
Operator

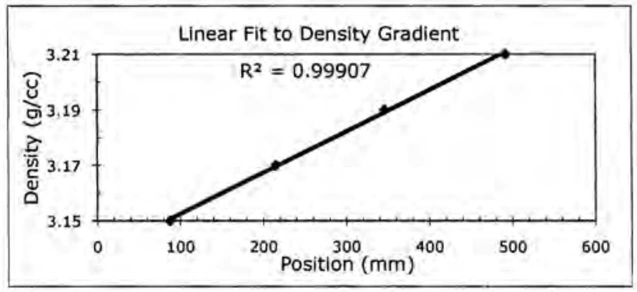
9-10-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09092401_DRF02R4.xls
Sample ID:	AGRBW-8A2
Sample description:	SiC Strength Test Sample: 1425C, 240 min, Ar-H, 520 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.9 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	73.60	94.14	87.29
3.170	199.51	223.18	215.29
3.190	331.41	353.59	346.20
3.210	475.93	499.62	491.72

Linear Fit			
slope	StDev	intercept	StDev
1.49E-04	2.59E-06	3.14E+00	7.18E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	461.82	3.2063	26	472.63	3.2079	51		
2	463.08	3.2065	27	472.63	3.2079	52		
3	464.06	3.2066	28	473.55	3.2080	53		
4	464.67	3.2067	29	474.35	3.2081	54		
5	465.66	3.2068	30	483.54	3.2095	55		
6	464.81	3.2067	31	474.09	3.2081	56		
7	465.61	3.2068	32	472.71	3.2079	57		
8	466.36	3.2069	33	472.07	3.2078	58		
9	466.85	3.2070	34	471.44	3.2077	59		
10	467.58	3.2071	35	469.77	3.2074	60		
11	467.58	3.2071	36	466.20	3.2069	61		
12	468.31	3.2072	37	466.80	3.2070	62		
13	468.31	3.2072	38	466.02	3.2069	63		
14	468.60	3.2073	39	469.45	3.2074	64		
15	469.87	3.2075	40	466.91	3.2070	65		
16	468.19	3.2072	41	465.82	3.2069	66		
17	468.19	3.2072	42			67		
18	469.08	3.2073	43			68		
19	470.27	3.2075	44			69		
20	470.27	3.2075	45			70		
21	469.31	3.2074	46			71		
22	471.63	3.2077	47			72		
23	471.63	3.2077	48			73		
24	471.63	3.2077	49			74		
25	472.58	3.2079	50			75		

Average density of SiC fragments:	3.2074
Standard deviation in density of SiC fragments:	0.0006
Uncertainty in calculated density of SiC fragments:	0.0014

Dixie Barker
Operator

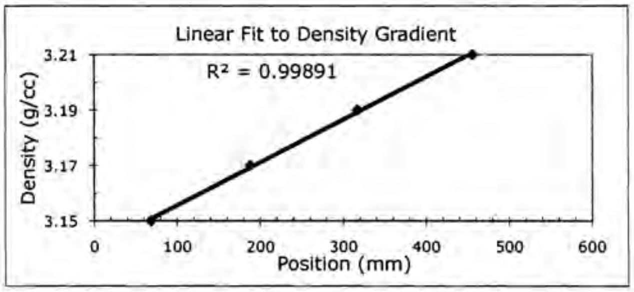
9-24-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09081201_DRF02R4.xls
Sample ID:	AGRBW-1C2
Sample description:	SiC Strength Test Sample: 1450 C, 120 min, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.8 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	54.91	75.27	68.48
3.170	172.15	196.20	188.18
3.190	302.31	324.61	317.18
3.210	440.36	463.75	455.95

Linear Fit			
slope	StDev	intercept	StDev
1.55E-04	2.77E-06	3.14E+00	6.97E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	344.21	3.1934	26	403.50	3.2026	51		
2	368.46	3.1972	27	403.50	3.2026	52		
3	370.10	3.1974	28	404.07	3.2027	53		
4	374.68	3.1981	29	404.81	3.2028	54		
5	378.56	3.1987	30	406.25	3.2030	55		
6	379.44	3.1989	31	407.14	3.2032	56		
7	380.57	3.1990	32	408.01	3.2033	57		
8	380.57	3.1990	33	408.85	3.2034	58		
9	384.49	3.1997	34	410.51	3.2037	59		
10	385.41	3.1998	35	411.51	3.2038	60		
11	386.80	3.2000	36	412.28	3.2040	61		
12	390.13	3.2005	37	413.54	3.2041	62		
13	392.51	3.2009	38	415.98	3.2045	63		
14	393.05	3.2010	39	416.96	3.2047	64		
15	394.29	3.2012	40	416.96	3.2047	65		
16	394.04	3.2011	41	419.34	3.2050	66		
17	396.23	3.2015	42	418.15	3.2049	67		
18	398.26	3.2018	43	417.41	3.2047	68		
19	399.18	3.2019	44			69		
20	399.89	3.2020	45			70		
21	399.41	3.2020	46			71		
22	401.43	3.2023	47			72		
23	402.08	3.2024	48			73		
24	403.04	3.2025	49			74		
25	401.64	3.2023	50			75		

Average density of SiC fragments:	3.2017
Standard deviation in density of SiC fragments:	0.0025
Uncertainty in calculated density of SiC fragments:	0.0014

Dixie Barker
Operator

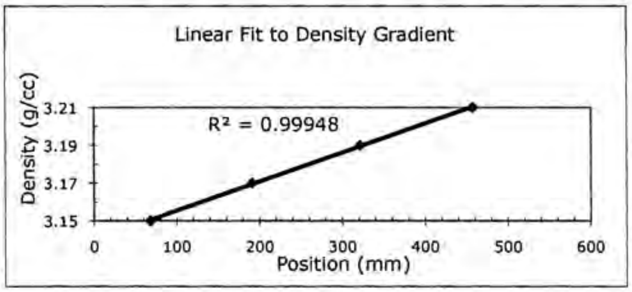
8-12-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09082601_DRF02R4.xls
Sample ID:	AGRBW-2C2
Sample description:	SiC Strength Test Sample: 1500C, 120 min, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.5 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	54.68	75.42	68.51
3.170	175.29	199.26	191.27
3.190	306.38	328.75	321.29
3.210	441.92	465.03	457.33

Linear Fit			
slope	StDev	intercept	StDev
1.54E-04	2.74E-06	3.14E+00	6.92E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	364.24	3.1961	26	405.39	3.2025	51		
2	368.94	3.1969	27	405.41	3.2025	52		
3	369.87	3.1970	28	407.31	3.2028	53		
4	374.43	3.1977	29	408.10	3.2029	54		
5	375.64	3.1979	30	408.90	3.2030	55		
6	377.62	3.1982	31	409.50	3.2031	56		
7	377.55	3.1982	32	411.23	3.2034	57		
8	379.46	3.1985	33	412.39	3.2036	58		
9	380.12	3.1986	34	413.00	3.2037	59		
10	380.12	3.1986	35	413.00	3.2037	60		
11	383.39	3.1991	36	414.18	3.2038	61		
12	383.37	3.1991	37	415.19	3.2040	62		
13	385.37	3.1994	38	416.95	3.2043	63		
14	386.80	3.1996	39	416.95	3.2043	64		
15	390.56	3.2002	40	418.08	3.2044	65		
16	393.66	3.2007	41	419.41	3.2046	66		
17	394.90	3.2009	42	420.38	3.2048	67		
18	398.17	3.2014	43	421.93	3.2050	68		
19	400.01	3.2016	44	423.60	3.2053	69		
20	401.71	3.2019	45	423.43	3.2053	70		
21	402.15	3.2020	46	426.48	3.2057	71		
22	402.15	3.2020	47	427.96	3.2060	72		
23	403.80	3.2022	48			73		
24	403.80	3.2022	49			74		
25	404.32	3.2023	50			75		

Average density of SiC fragments:	3.2017
Standard deviation in density of SiC fragments:	0.0027
Uncertainty in calculated density of SiC fragments:	0.0014

Dixie Barker
Operator

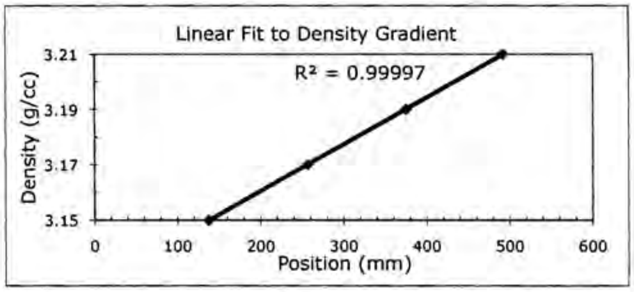
8-26-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09083101_DRF02R4.xls
Sample ID:	AGRBW-3C2
Sample description:	SiC Strength Test Sample: 1550C, 120 min, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.9 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	124.03	144.55	137.71
3.170	240.81	264.65	256.70
3.190	360.04	382.90	375.28
3.210	475.77	499.66	491.70

Linear Fit			
slope	StDev	intercept	StDev
1.69E-04	3.19E-06	3.13E+00	1.03E-03



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	419.43	3.1976	26	452.32	3.2032	51		
2	419.43	3.1976	27	454.08	3.2035	52		
3	422.24	3.1981	28	455.14	3.2037	53		
4	424.33	3.1985	29	455.44	3.2037	54		
5	429.30	3.1993	30	458.75	3.2043	55		
6	430.86	3.1996	31	461.25	3.2047	56		
7	429.19	3.1993	32	461.39	3.2047	57		
8	431.03	3.1996	33	465.32	3.2054	58		
9	433.03	3.1999	34	466.43	3.2056	59		
10	436.49	3.2005	35	469.81	3.2062	60		
11	438.41	3.2008	36	470.93	3.2064	61		
12	436.10	3.2005	37	438.48	3.2009	62		
13	438.23	3.2008	38	442.24	3.2015	63		
14	438.35	3.2008	39	441.31	3.2013	64		
15	440.79	3.2013	40	451.58	3.2031	65		
16	441.94	3.2014	41	444.05	3.2018	66		
17	443.94	3.2018	42			67		
18	443.75	3.2018	43			68		
19	446.46	3.2022	44			69		
20	447.63	3.2024	45			70		
21	448.14	3.2025	46			71		
22	451.39	3.2030	47			72		
23	451.39	3.2030	48			73		
24	452.58	3.2032	49			74		
25	451.77	3.2031	50			75		

Average density of SiC fragments:	3.2019
Standard deviation in density of SiC fragments:	0.0023
Uncertainty in calculated density of SiC fragments:	0.0018

Dixie Barker
Operator

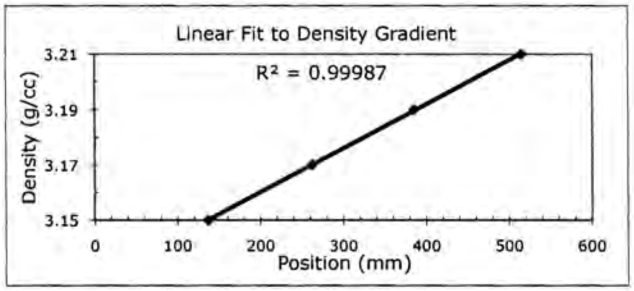
8-31-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09090101_DRF02R4.xls
Sample ID:	AGRBW-4C2
Sample description:	SiC Strength Test Sample: 1425C, 120 min, 670 um ZrO2, Ar-H
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.8 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	123.77	143.47	136.90
3.170	246.33	270.41	262.38
3.190	370.02	392.52	385.02
3.210	499.80	522.79	515.13

Linear Fit			
slope	StDev	intercept	StDev
1.59E-04	2.90E-06	3.13E+00	9.42E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	418.35	3.1949	26	470.26	3.2031	51		
2	442.25	3.1987	27	470.26	3.2031	52		
3	452.97	3.2004	28	472.23	3.2034	53		
4	454.96	3.2007	29	471.97	3.2034	54		
5	456.55	3.2009	30	473.46	3.2036	55		
6	451.16	3.2001	31	474.47	3.2038	56		
7	453.23	3.2004	32	475.11	3.2039	57		
8	458.98	3.2013	33	475.11	3.2039	58		
9	460.58	3.2016	34	474.94	3.2039	59		
10	462.41	3.2019	35	477.54	3.2043	60		
11	462.41	3.2019	36	478.67	3.2045	61		
12	461.37	3.2017	37	479.86	3.2047	62		
13	463.24	3.2020	38	480.33	3.2047	63		
14	464.40	3.2022	39	494.77	3.2070	64		
15	465.25	3.2023	40	474.26	3.2038	65		
16	466.59	3.2025	41	473.20	3.2036	66		
17	466.38	3.2025	42	470.49	3.2032	67		
18	466.87	3.2026	43	466.40	3.2025	68		
19	466.87	3.2026	44			69		
20	467.83	3.2027	45			70		
21	467.85	3.2027	46			71		
22	468.65	3.2029	47			72		
23	469.98	3.2031	48			73		
24	469.98	3.2031	49			74		
25	471.00	3.2032	50			75		

Average density of SiC fragments:	3.2025
Standard deviation in density of SiC fragments:	0.0019
Uncertainty in calculated density of SiC fragments:	0.0017

Dixie Barker
Operator

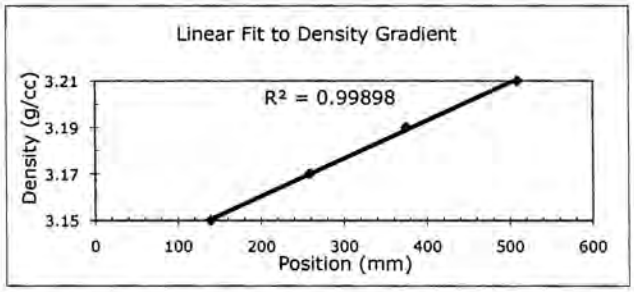
9-1-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09090301_DRF02R4.xls
Sample ID:	AGRBW-5C2
Sample description:	SiC Strength Test Sample: 1450C, 240 min, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	23.3 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	125.80	145.67	139.05
3.170	242.29	266.37	258.34
3.190	360.00	382.39	374.93
3.210	493.38	517.14	509.22

Linear Fit			
slope	StDev	intercept	StDev
1.63E-04	3.02E-06	3.13E+00	9.45E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	460.93	3.2029	26	484.99	3.2068	51		
2	467.85	3.2040	27	484.99	3.2068	52		
3	472.42	3.2048	28	485.63	3.2069	53		
4	475.63	3.2053	29	485.68	3.2069	54		
5	478.04	3.2057	30	486.68	3.2071	55		
6	478.57	3.2058	31	486.72	3.2071	56		
7	478.99	3.2058	32	488.18	3.2073	57		
8	478.48	3.2057	33	488.18	3.2073	58		
9	478.93	3.2058	34	488.18	3.2073	59		
10	480.35	3.2060	35	488.63	3.2074	60		
11	480.35	3.2060	36	489.90	3.2076	61		
12	480.35	3.2060	37	490.47	3.2077	62		
13	480.88	3.2061	38	490.94	3.2078	63		
14	480.88	3.2061	39	492.63	3.2080	64		
15	480.88	3.2061	40	487.54	3.2072	65		
16	480.67	3.2061	41	486.43	3.2070	66		
17	481.33	3.2062	42	484.25	3.2067	67		
18	481.33	3.2062	43	481.22	3.2062	68		
19	481.98	3.2063	44	480.22	3.2060	69		
20	482.82	3.2064	45	478.61	3.2058	70		
21	482.82	3.2064	46			71		
22	482.82	3.2064	47			72		
23	483.78	3.2066	48			73		
24	484.28	3.2067	49			74		
25	484.99	3.2068	50			75		

Average density of SiC fragments:	3.2064
Standard deviation in density of SiC fragments:	0.0010
Uncertainty in calculated density of SiC fragments:	0.0018

Dixie Barker

Operator

9-3-09

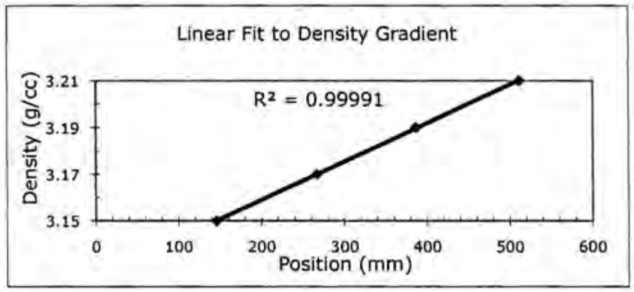
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09090901_DRF02R4.xls
Sample ID:	AGRBW-6C2
Sample description:	SiC Strength Test Sample: 1500C, 240 min, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	23.2 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	132.56	152.87	146.10
3.170	251.20	275.27	267.25
3.190	371.53	393.88	386.43
3.210	495.44	519.50	511.48

Linear Fit			
slope	StDev	intercept	StDev
1.65E-04	3.04E-06	3.13E+00	1.02E-03



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	467.12	3.2029	26	493.71	3.2073	51		
2	473.19	3.2039	27	494.18	3.2074	52		
3	475.07	3.2042	28	495.09	3.2075	53		
4	481.27	3.2053	29	495.09	3.2075	54		
5	481.96	3.2054	30	495.09	3.2075	55		
6	482.75	3.2055	31	495.93	3.2077	56		
7	480.87	3.2052	32	496.74	3.2078	57		
8	480.69	3.2052	33	497.28	3.2079	58		
9	480.68	3.2052	34	498.85	3.2081	59		
10	483.96	3.2057	35	498.85	3.2081	60		
11	480.96	3.2052	36	497.17	3.2079	61		
12	482.96	3.2055	37	498.73	3.2081	62		
13	484.11	3.2057	38	498.73	3.2081	63		
14	486.44	3.2061	39	499.74	3.2083	64		
15	486.68	3.2061	40	501.02	3.2085	65		
16	487.66	3.2063	41	503.84	3.2090	66		
17	488.32	3.2064	42	509.41	3.2099	67		
18	489.70	3.2066	43	510.65	3.2101	68		
19	489.80	3.2067	44	510.65	3.2101	69		
20	489.80	3.2067	45	511.92	3.2103	70		
21	490.84	3.2068	46			71		
22	491.40	3.2069	47			72		
23	490.85	3.2068	48			73		
24	491.34	3.2069	49			74		
25	492.06	3.2070	50			75		

Average density of SiC fragments:	3.2069
Standard deviation in density of SiC fragments:	0.0016
Uncertainty in calculated density of SiC fragments:	0.0019

Dixie Barker
Operator

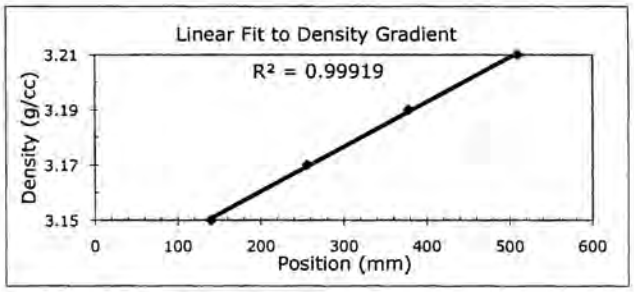
9-9-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09091101_DRF02R4.xls
Sample ID:	AGRBW-7C2
Sample description:	SiC Strength Test Sample: 1550C, 240 min, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	23.2 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	125.95	146.61	139.72
3.170	240.04	263.91	255.95
3.190	362.93	385.91	378.25
3.210	494.16	518.13	510.14

Linear Fit			
slope	StDev	intercept	StDev
1.62E-04	2.92E-06	3.13E+00	9.39E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	482.59	3.2062	26	489.54	3.2073	51		
2	483.67	3.2063	27	487.79	3.2070	52		
3	487.79	3.2070	28	489.10	3.2072	53		
4	488.16	3.2071	29	483.95	3.2064	54		
5	488.86	3.2072	30	492.28	3.2077	55		
6	491.06	3.2075	31	494.22	3.2081	56		
7	491.92	3.2077	32	497.05	3.2085	57		
8	492.82	3.2078	33	501.81	3.2093	58		
9	491.97	3.2077	34	482.40	3.2061	59		
10	492.21	3.2077	35	483.56	3.2063	60		
11	493.00	3.2079	36	490.20	3.2074	61		
12	494.12	3.2080	37	492.96	3.2079	62		
13	492.87	3.2078	38	496.82	3.2085	63		
14	492.35	3.2078	39	499.44	3.2089	64		
15	494.23	3.2081	40	501.11	3.2092	65		
16	496.62	3.2084	41			66		
17	497.98	3.2087	42			67		
18	501.96	3.2093	43			68		
19	501.44	3.2092	44			69		
20	501.42	3.2092	45			70		
21	501.92	3.2093	46			71		
22	497.69	3.2086	47			72		
23	493.17	3.2079	48			73		
24	492.40	3.2078	49			74		
25	491.82	3.2077	50			75		

Average density of SiC fragments:	3.2078
Standard deviation in density of SiC fragments:	0.0009
Uncertainty in calculated density of SiC fragments:	0.0017

Dixie Barker
Operator

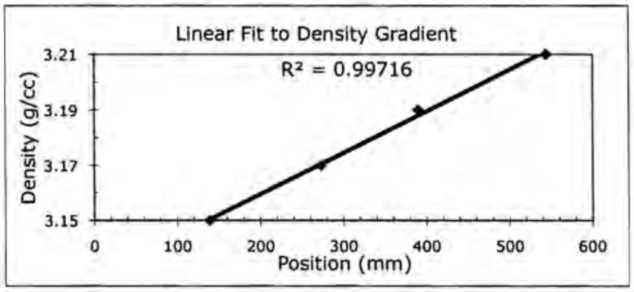
9-11-09
Date

Data Report Form DRF-02: Measurement of SiC Density using a Density Gradient Column

Procedure:	AGR-CHAR-DAM-02 Rev. 4
Operator:	Dixie Barker
Filename:	\\mc-agr\AGR\DensityColumn\D09092901_DRF02R4.xls
Sample ID:	AGRBW-8C2
Sample description:	SiC Strength Test Sample: 1425C, 240 min, Ar-H, 670 um ZrO2
Float expiration date:	01/2014
Gauge expiration date:	10/2009
Bath temperature:	22.9 °C

Calibrated Floats			
Density	Top of Float	Bottom of Float	Center of Mass
3.150	125.39	145.96	139.10
3.170	257.20	281.06	273.11
3.190	374.38	397.48	389.78
3.210	528.34	551.77	543.96

Linear Fit			
slope	StDev	intercept	StDev
1.50E-04	2.65E-06	3.13E+00	9.17E-04



Sample Density								
Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density	Fragment Number	Fragment Position	Calculated Density
1	507.39	3.2056	26	519.81	3.2075	51		
2	507.50	3.2057	27	519.81	3.2075	52		
3	510.46	3.2061	28	520.14	3.2076	53		
4	510.75	3.2061	29	529.17	3.2089	54		
5	511.55	3.2063	30	518.18	3.2073	55		
6	512.59	3.2064	31	519.18	3.2074	56		
7	513.27	3.2065	32	515.62	3.2069	57		
8	513.92	3.2066	33	514.75	3.2067	58		
9	514.57	3.2067	34	518.90	3.2074	59		
10	514.24	3.2067	35	518.71	3.2073	60		
11	513.74	3.2066	36	514.35	3.2067	61		
12	514.57	3.2067	37	514.35	3.2067	62		
13	514.06	3.2066	38	512.90	3.2065	63		
14	515.97	3.2069	39	517.97	3.2072	64		
15	515.97	3.2069	40	516.09	3.2069	65		
16	515.93	3.2069	41	517.18	3.2071	66		
17	516.05	3.2069	42	517.53	3.2072	67		
18	516.05	3.2069	43	519.86	3.2075	68		
19	516.05	3.2069	44			69		
20	516.05	3.2069	45			70		
21	516.05	3.2069	46			71		
22	516.05	3.2069	47			72		
23	516.87	3.2071	48			73		
24	517.68	3.2072	49			74		
25	518.58	3.2073	50			75		

Average density of SiC fragments:	3.2069
Standard deviation in density of SiC fragments:	0.0005
Uncertainty in calculated density of SiC fragments:	0.0017

Dixie Barker
Operator

9-29-09
Date

Appendix D: Inner Pyrocarbon Open Porosity Data Reports

Inner pyrocarbon open porosity was measured using data acquisition methods developed for the AGR program: AGR-DAM-CHAR-22 and AGR-DAM-CHAR-31. The attached data report forms give the average particle weight (used to calculate the number of particles in the porosimetry sample) and the results of the porosimetry measurement. Porosity was determined independently for the IPyC on the two different kernel sizes. The measured open porosity for the small kernel substrate was 0.468 ml/m^2. The measured open porosity for the large kernel substrate was 0.384 ml/m^2.

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

Procedure:	AGR-CHAR-DAM-31 Rev. 1
Operator:	S.Voit
Coated particle batch ID:	NP-B8238-A2 from G73H-NF-93083
Batch Description:	IPyC on ZrO2 substrate for SiC strength test, small kernels
Thermocouple Expiration Date:	4/2/10
Penetrometer Expiration Date:	7/30/10
Completed DRF Filename:	\\mc-agr\AGR\Porosimeter\S09123001\S09123001_DRF31R1.xls

Mean average weight/particle (g):	5.598E-04
Standard error in mean average weight/particle (g):	1.50E-06

Weight of particles (g):	6.4574
Approximate number of particles:	11535
Uncertainty in number of particles:	31
Total envelope volume of sample (cc):	1.398
Average envelope volume/particle (cc):	1.21E-04
Sample envelope density (g/cc):	4.618

Average particle diameter (microns):	6.14E+02
Average surface area/particle (cm2):	1.18E-02
Total sample surface area (cm2):	1.37E+02
Intruded mercury volume from 250-10,000 psia (cc):	6.40E-03
Open porosity (ml/m2):	4.68E-01

Comments

[signature]
Operator

12/30/09
Date

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

Procedure:	AGR-CHAR-DAM-22 Rev. 1
Operator:	Dixie Barker
Particle Lot ID:	B8238-A2 from G73H-NF-93083
Particle Lot Description:	IPyC/ZrO2 substrate for SiC strength test, small kernels
Filename:	\\mc-agr\AGR\ParticleWeight\W09123002_DRF22R1.xls

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of particles (g):	0.0867	0.1032	0.1001	0.1096	0.1233
Number of particles:	155	184	180	194	221
Average weight/particle (g):	5.594E-04	5.609E-04	5.561E-04	5.649E-04	5.579E-04

Mean average weight/particle (g):	5.598E-04
Standard error in mean average weight/particle (g):	1.50E-06

Dixie Barker
Operator

12-30-09
Date

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

Procedure:	AGR-CHAR-DAM-31 Rev. 1
Operator:	S.Voit
Coated particle batch ID:	NP-B8238-C2 from G73H-NF-93083
Batch Description:	IPyC on ZrO2 substrate for SiC strength test, large kernels
Thermocouple Expiration Date:	4/2/10
Penetrometer Expiration Date:	7/30/10
Completed DRF Filename:	\\mc-agr\AGR\Porosimeter\S09123002\S09123002_DRF31R1.xls

Mean average weight/particle (g):	1.264E-03
Standard error in mean average weight/particle (g):	2.19E-06

Weight of particles (g):	6.5474
Approximate number of particles:	5180
Uncertainty in number of particles:	9
Total envelope volume of sample (cc):	1.336
Average envelope volume/particle (cc):	2.58E-04
Sample envelope density (g/cc):	4.901

Average particle diameter (microns):	7.90E+02
Average surface area/particle (cm2):	1.96E-02
Total sample surface area (cm2):	1.01E+02
Intruded mercury volume from 250-10,000 psia (cc):	3.90E-03
Open porosity (ml/m2):	3.84E-01

Comments

[signature] 12/30/09

Operator Date

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

Procedure:	AGR-CHAR-DAM-22 Rev. 1
Operator:	Dixie Barker
Particle Lot ID:	B8238-C2 from G73H-NF-93083
Particle Lot Description:	IPyC/ZrO2 substrate for SiC strength test, large kernels
Filename:	\\mc-agr\AGR\ParticleWeight\W09123001_DRF22R1.xls

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Weight of particles (g):	0.1677	0.1802	0.1770	0.2003	0.1496
Number of particles:	133	142	140	158	119
Average weight/particle (g):	1.261E-03	1.269E-03	1.264E-03	1.268E-03	1.257E-03

Mean average weight/particle (g):	1.264E-03
Standard error in mean average weight/particle (g):	2.19E-06

Dixie Barker
Operator

12-30-09
Date

Appendix E: SiC Strength Measurements

A modified crush testing and evaluation method for hemispherical shell specimens was applied to obtain the fracture stress data for the 16 samples in Series B. For each sample, 24 – 47 hemispherical shell specimens were selected and tested. The data reported here are the measured fracture loads and contact diameters. Average wall thickness and average outer radius are taken from the optical measurements on polished cross sections. Local fracture stress is calculated for the loaded areas and reduced to the mean fracture stress for full spherical shells. The size effect parameter, the ratio between the local fracture stress and the fracture stress for a full spherical shell, was also calculated and is listed for individual specimens. Weibull modulus and scale parameter were obtained from the slope and intercept of the Weibull plots

AGRBW-1A2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0318	0.342	0.077	7.03	2995.3	3.67	4.28	817.2	2028.2
2	0.0318	0.342	0.107	7.85	2100.9	3.14	4.28	668.4	1406.8
3	0.0318	0.342	0.095	8.04	2605.2	3.32	4.28	784.1	1496.5
4	0.0318	0.342	0.091	8.38	2890.4	3.39	4.28	852.6	1516.9
5	0.0318	0.342	0.125	8.41	1664.6	2.92	4.28	569.5	958.8
6	0.0318	0.342	0.141	8.43	1254.8	2.76	4.28	454.2	730.3
7	0.0318	0.342	0.099	8.59	2611.5	3.26	4.28	801.3	1238.8
8	0.0318	0.342	0.098	8.65	2673.7	3.28	4.28	816.5	1219.4
9	0.0318	0.342	0.102	8.81	2554.4	3.21	4.28	794.7	1150.8
10	0.0318	0.342	0.090	8.83	3091.0	3.41	4.28	907.1	1277.0
11	0.0318	0.342	0.086	8.94	3327.8	3.48	4.28	956.0	1311.5
12	0.0318	0.342	0.110	8.96	2284.0	3.10	4.28	736.1	985.8
13	0.0318	0.342	0.098	9.03	2790.5	3.28	4.28	852.1	1115.7
14	0.0318	0.342	0.097	9.07	2848.8	3.29	4.28	865.8	1109.7
15	0.0318	0.342	0.100	9.34	2796.8	3.24	4.28	862.2	1082.9
16	0.0318	0.342	0.101	9.52	2805.1	3.23	4.28	868.8	1070.4
17	0.0318	0.342	0.079	9.59	3965.4	3.62	4.28	1094.9	1324.2
18	0.0318	0.342	0.092	9.79	3321.6	3.37	4.28	984.8	1170.0
19	0.0318	0.342	0.100	9.83	2943.3	3.24	4.28	907.3	1059.4
20	0.0318	0.342	0.092	10.16	3449.9	3.37	4.28	1022.8	1174.4
21	0.0318	0.342	0.110	10.21	2601.4	3.10	4.28	838.4	947.0
22	0.0318	0.342	0.096	10.30	3283.9	3.31	4.28	993.2	1103.8
23	0.0318	0.342	0.106	11.79	3205.9	3.16	4.28	1015.5	1110.9
24	0.0318	0.342	0.120	11.85	2556.9	2.98	4.28	858.3	924.2
25	0.0318	0.342	0.127	12.63	2415.9	2.90	4.28	832.8	882.9
26	0.0318	0.342	0.126	14.28	2778.6	2.91	4.28	954.2	996.1
27	0.0318	0.342	0.126	15.99	3111.8	2.91	4.28	1068.7	1098.4
28	0.0318	0.342	0.124	17.37	3499.0	2.93	4.28	1192.7	1206.9
29	0.0318	0.342	0.127	17.84	3411.2	2.90	4.28	1175.8	1171.3
30	0.0318	0.342	0.147	21.31	2835.9	2.71	4.28	1046.7	1026.1
31	0.0318	0.342	0.151	22.60	2786.9	2.68	4.28	1041.6	1004.6
32	0.0318	0.342	0.162	24.15	2398.4	2.59	4.28	926.3	878.5
33	0.0318	0.342	0.166	24.20	2214.6	2.56	4.28	865.1	806.2
34	0.0318	0.342	0.177	26.91	1951.9	2.48	4.28	785.7	718.9
35	0.0318	0.342	0.167	27.25	2442.5	2.55	4.28	956.8	858.6
36	0.0318	0.342	0.180	28.56	1939.8	2.47	4.28	787.0	691.4
37	0.0318	0.342	0.190	28.85	1564.1	2.40	4.28	650.8	558.4
38	0.0318	0.342	0.195	29.54	1425.3	2.37	4.28	600.3	501.2
39	0.0318	0.342	0.178	29.78	2113.5	2.48	4.28	853.0	688.7
40	0.0318	0.342	0.195	29.85	1440.4	2.37	4.28	606.6	466.7

AGRBW-2A2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0337	0.344	0.126	8.96	1662.6	4.35	3.11	381.9	1323.8
2	0.0337	0.344	0.151	9.34	1122.7	3.88	3.11	289.7	800.3
3	0.0337	0.344	0.133	9.45	1559.2	4.21	3.11	370.8	895.3
4	0.0337	0.344	0.132	9.67	1623.2	4.23	3.11	384.1	841.9
5	0.0337	0.344	0.087	9.76	3322.2	5.53	3.11	601.3	1221.3
6	0.0337	0.344	0.173	9.88	779.1	3.55	3.11	219.4	418.3
7	0.0337	0.344	0.140	9.90	1447.3	4.07	3.11	355.7	642.4
8	0.0337	0.344	0.144	10.34	1409.7	4.00	3.11	352.8	607.5
9	0.0337	0.344	0.142	10.39	1466.6	4.03	3.11	363.8	600.1
10	0.0337	0.344	0.148	10.41	1320.9	3.93	3.11	336.5	533.9
11	0.0337	0.344	0.143	10.79	1496.6	4.01	3.11	372.9	570.8
12	0.0337	0.344	0.148	10.99	1394.3	3.93	3.11	355.2	525.9
13	0.0337	0.344	0.178	11.03	786.3	3.49	3.11	225.5	323.7
14	0.0337	0.344	0.125	11.03	2080.4	4.38	3.11	475.4	662.5
15	0.0337	0.344	0.140	11.28	1649.0	4.07	3.11	405.3	549.2
16	0.0337	0.344	0.117	11.45	2460.4	4.57	3.11	538.8	710.8
17	0.0337	0.344	0.132	11.70	1962.8	4.23	3.11	464.5	597.2
18	0.0337	0.344	0.151	11.74	1411.4	3.88	3.11	364.2	456.8
19	0.0337	0.344	0.144	11.77	1603.7	4.00	3.11	401.4	491.4
20	0.0337	0.344	0.155	12.72	1420.6	3.81	3.11	372.8	445.8
21	0.0337	0.344	0.170	13.03	1091.7	3.59	3.11	304.0	355.3
22	0.0337	0.344	0.180	13.43	918.7	3.46	3.11	265.4	303.3
23	0.0337	0.344	0.172	14.03	1129.7	3.56	3.11	317.0	354.2
24	0.0337	0.344	0.166	15.10	1368.4	3.65	3.11	375.3	410.3
25	0.0337	0.344	0.162	15.46	1513.0	3.70	3.11	408.4	436.9
26	0.0337	0.344	0.187	16.95	1000.0	3.38	3.11	296.1	309.8
27	0.0337	0.344	0.186	23.20	1398.3	3.39	3.11	412.6	422.4
28	0.0337	0.344	0.179	24.67	1722.2	3.47	3.11	495.7	496.4
29	0.0337	0.344	0.203	27.38	1132.2	3.20	3.11	353.4	346.0
30	0.0337	0.344	0.203	28.80	1191.1	3.20	3.11	371.8	355.8
31	0.0337	0.344	0.194	29.27	1482.8	3.30	3.11	449.5	420.2
32	0.0337	0.344	0.199	30.96	1402.5	3.25	3.11	432.2	394.2
33	0.0337	0.344	0.218	31.07	902.6	3.06	3.11	294.9	262.2
34	0.0337	0.344	0.245	31.45	486.1	2.84	3.11	171.2	148.1
35	0.0337	0.344	0.203	32.45	1341.9	3.20	3.11	418.8	351.8
36	0.0337	0.344	0.226	33.41	800.4	2.99	3.11	267.7	217.6
37	0.0337	0.344	0.190	34.94	1932.4	3.34	3.11	578.0	452.4
38	0.0337	0.344	0.242	35.07	578.4	2.86	3.11	202.1	151.0
39	0.0337	0.344	0.200	35.32	1564.2	3.24	3.11	483.5	337.8

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0332	0.345	0.120	9.10	1895.7	3.51	3.73	540.3	1412.2
2	0.0332	0.345	0.104	9.39	2523.8	3.79	3.73	666.1	1439.2
3	0.0332	0.345	0.120	9.43	1965.3	3.51	3.73	560.1	1080.2
4	0.0332	0.345	0.115	9.45	2136.2	3.59	3.73	595.1	1057.3
5	0.0332	0.345	0.153	9.94	1166.9	3.08	3.73	378.8	630.7
6	0.0332	0.345	0.133	10.52	1763.7	3.32	3.73	531.1	837.7
7	0.0332	0.345	0.119	10.68	2261.4	3.53	3.73	641.6	965.7
8	0.0332	0.345	0.136	10.79	1717.4	3.28	3.73	523.4	755.8
9	0.0332	0.345	0.128	10.81	1972.8	3.39	3.73	582.0	809.5
10	0.0332	0.345	0.108	10.92	2758.5	3.71	3.73	743.0	998.4
11	0.0332	0.345	0.119	11.14	2360.4	3.53	3.73	669.7	871.7
12	0.0332	0.345	0.150	11.77	1459.5	3.11	3.73	468.8	592.2
13	0.0332	0.345	0.139	12.05	1820.7	3.24	3.73	561.4	689.3
14	0.0332	0.345	0.130	12.46	2197.7	3.36	3.73	653.8	781.1
15	0.0332	0.345	0.124	13.79	2690.5	3.45	3.73	780.4	908.3
16	0.0332	0.345	0.141	13.79	2011.4	3.22	3.73	625.0	709.2
17	0.0332	0.345	0.128	14.06	2565.4	3.39	3.73	756.8	837.7
18	0.0332	0.345	0.126	14.26	2690.6	3.42	3.73	787.1	850.1
19	0.0332	0.345	0.177	14.46	1060.2	2.85	3.73	372.1	392.3
20	0.0332	0.345	0.179	28.85	2029.3	2.83	3.73	716.6	737.2
21	0.0332	0.345	0.190	30.03	1668.7	2.74	3.73	608.4	610.7
22	0.0332	0.345	0.177	30.18	2213.3	2.85	3.73	776.9	760.6
23	0.0332	0.345	0.194	32.14	1634.5	2.71	3.73	602.7	575.0
24	0.0332	0.345	0.215	34.52	1076.2	2.57	3.73	419.3	389.4
25	0.0332	0.345	0.220	36.23	1001.0	2.54	3.73	394.8	356.3
26	0.0332	0.345	0.206	36.30	1401.9	2.63	3.73	533.8	466.7
27	0.0332	0.345	0.211	36.94	1267.6	2.59	3.73	488.9	412.4
28	0.0332	0.345	0.203	37.23	1542.3	2.65	3.73	582.6	470.6
29	0.0332	0.345	0.212	38.05	1275.0	2.59	3.73	493.0	374.6

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0336	0.343	0.078	5.20	2023.4	3.00	5.03	674.1	1459.6
2	0.0336	0.343	0.103	7.96	2133.4	2.69	5.03	793.9	1493.8
3	0.0336	0.343	0.098	8.23	2380.3	2.74	5.03	868.4	1503.7
4	0.0336	0.343	0.130	8.61	1492.9	2.45	5.03	609.4	993.9
5	0.0336	0.343	0.118	9.32	1970.5	2.55	5.03	774.0	1204.4
6	0.0336	0.343	0.107	9.47	2385.9	2.65	5.03	901.4	1349.0
7	0.0336	0.343	0.094	9.54	2931.8	2.79	5.03	1052.0	1522.6
8	0.0336	0.343	0.119	9.56	1989.7	2.54	5.03	784.2	1102.1
9	0.0336	0.343	0.090	9.96	3250.2	2.84	5.03	1146.3	1569.1
10	0.0336	0.343	0.121	10.92	2199.2	2.52	5.03	872.5	1166.0
11	0.0336	0.343	0.127	10.96	1999.9	2.47	5.03	808.8	1057.4
12	0.0336	0.343	0.103	10.99	2943.9	2.69	5.03	1095.5	1403.1
13	0.0336	0.343	0.102	11.03	3001.7	2.70	5.03	1112.7	1398.0
14	0.0336	0.343	0.113	11.43	2619.1	2.59	5.03	1011.2	1247.7
15	0.0336	0.343	0.090	11.90	3881.4	2.84	5.03	1368.9	1660.3
16	0.0336	0.343	0.095	12.32	3729.5	2.78	5.03	1343.9	1603.4
17	0.0336	0.343	0.123	13.37	2605.1	2.50	5.03	1040.3	1221.7
18	0.0336	0.343	0.130	15.03	2607.7	2.45	5.03	1064.5	1231.3
19	0.0336	0.343	0.152	23.33	2747.2	2.30	5.03	1193.3	1360.2
20	0.0336	0.343	0.152	23.98	2823.1	2.30	5.03	1226.3	1377.9
21	0.0336	0.343	0.162	24.09	2350.1	2.24	5.03	1047.1	1160.1
22	0.0336	0.343	0.167	24.82	2197.5	2.22	5.03	991.0	1083.0
23	0.0336	0.343	0.170	24.87	2074.6	2.20	5.03	942.2	1015.9
24	0.0336	0.343	0.164	25.89	2430.3	2.23	5.03	1088.1	1157.6
25	0.0336	0.343	0.175	26.07	1966.3	2.18	5.03	903.4	948.5
26	0.0336	0.343	0.158	26.22	2761.0	2.27	5.03	1217.9	1262.0
27	0.0336	0.343	0.157	26.73	2868.4	2.27	5.03	1262.1	1290.6
28	0.0336	0.343	0.173	26.87	2110.7	2.19	5.03	965.3	974.1
29	0.0336	0.343	0.180	27.13	1846.3	2.15	5.03	857.8	854.1
30	0.0336	0.343	0.166	27.58	2490.0	2.22	5.03	1120.2	1100.3
31	0.0336	0.343	0.173	27.65	2171.8	2.19	5.03	993.2	962.1
32	0.0336	0.343	0.168	27.80	2413.4	2.21	5.03	1090.9	1041.7
33	0.0336	0.343	0.185	27.91	1709.0	2.13	5.03	802.7	755.2
34	0.0336	0.343	0.164	28.25	2651.6	2.23	5.03	1187.1	1099.6
35	0.0336	0.343	0.179	28.38	1971.4	2.16	5.03	913.9	832.5
36	0.0336	0.343	0.173	28.85	2266.2	2.19	5.03	1036.4	927.3
37	0.0336	0.343	0.196	29.51	1420.3	2.08	5.03	682.6	598.6
38	0.0336	0.343	0.159	30.65	3166.5	2.26	5.03	1400.3	1199.9
39	0.0336	0.343	0.182	31.63	2063.7	2.14	5.03	963.0	801.8
40	0.0336	0.343	0.193	32.67	1681.0	2.09	5.03	802.9	641.7

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0626	0.376	0.243	49.31	1184.3	2.29	3.97	518.2	1361.3
2	0.0626	0.376	0.244	52.87	1252.2	2.28	3.97	549.0	1207.1
3	0.0626	0.376	0.245	53.18	1242.0	2.28	3.97	545.7	1079.5
4	0.0626	0.376	0.275	59.43	892.1	2.15	3.97	415.4	761.6
5	0.0626	0.376	0.276	59.43	878.4	2.14	3.97	409.8	707.6
6	0.0626	0.376	0.293	59.76	674.1	2.08	3.97	324.1	532.5
7	0.0626	0.376	0.264	60.21	1068.1	2.19	3.97	487.3	767.1
8	0.0626	0.376	0.285	61.67	791.3	2.11	3.97	375.2	568.9
9	0.0626	0.376	0.263	62.76	1130.2	2.20	3.97	514.6	754.4
10	0.0626	0.376	0.251	62.90	1349.3	2.25	3.97	600.1	853.0
11	0.0626	0.376	0.280	63.34	879.6	2.13	3.97	413.4	571.1
12	0.0626	0.376	0.261	63.45	1177.0	2.21	3.97	533.9	718.5
13	0.0626	0.376	0.278	64.34	921.9	2.14	3.97	431.7	566.7
14	0.0626	0.376	0.266	65.19	1122.4	2.18	3.97	514.0	659.2
15	0.0626	0.376	0.267	66.57	1129.0	2.18	3.97	518.0	649.6
16	0.0626	0.376	0.285	66.86	857.8	2.11	3.97	406.7	499.3
17	0.0626	0.376	0.283	66.95	886.7	2.12	3.97	418.9	503.8
18	0.0626	0.376	0.276	67.17	992.8	2.14	3.97	463.2	546.0
19	0.0626	0.376	0.280	67.23	933.7	2.13	3.97	438.8	507.3
20	0.0626	0.376	0.278	68.79	985.6	2.14	3.97	461.5	523.6
21	0.0626	0.376	0.252	68.81	1455.2	2.24	3.97	648.5	722.3
22	0.0626	0.376	0.280	68.86	956.2	2.13	3.97	449.4	491.4
23	0.0626	0.376	0.272	68.95	1083.9	2.16	3.97	502.0	539.1
24	0.0626	0.376	0.279	69.53	980.7	2.13	3.97	460.0	485.2
25	0.0626	0.376	0.283	69.97	926.8	2.12	3.97	437.9	453.6
26	0.0626	0.376	0.283	70.46	933.2	2.12	3.97	440.9	448.5
27	0.0626	0.376	0.278	70.55	1010.8	2.14	3.97	473.3	472.7
28	0.0626	0.376	0.288	70.70	864.7	2.10	3.97	412.2	404.0
29	0.0626	0.376	0.315	70.99	555.2	2.01	3.97	276.9	266.3
30	0.0626	0.376	0.274	71.37	1088.0	2.15	3.97	505.8	476.9
31	0.0626	0.376	0.294	72.13	800.4	2.08	3.97	385.5	356.0
32	0.0626	0.376	0.296	72.51	778.7	2.07	3.97	376.3	340.0
33	0.0626	0.376	0.293	72.95	822.9	2.08	3.97	395.6	349.1
34	0.0626	0.376	0.326	73.77	479.1	1.97	3.97	243.1	208.9
35	0.0626	0.376	0.291	75.49	879.6	2.09	3.97	421.4	351.4
36	0.0626	0.376	0.284	75.95	990.2	2.11	3.97	468.7	376.4
37	0.0626	0.376	0.351	77.33	336.9	1.90	3.97	177.4	135.1

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0601	0.3798	0.233	43.26	1231.3	2.46	3.79	501.4	1373.4
2	0.0601	0.3798	0.242	44.35	1112.1	2.41	3.79	462.0	1050.0
3	0.0601	0.3798	0.249	45.99	1042.4	2.37	3.79	439.6	894.3
4	0.0601	0.3798	0.248	46.53	1070.0	2.38	3.79	450.3	845.7
5	0.0601	0.3798	0.257	53.00	1067.0	2.33	3.79	457.5	806.9
6	0.0601	0.3798	0.271	53.33	866.0	2.27	3.79	381.9	639.1
7	0.0601	0.3798	0.271	53.38	866.7	2.27	3.79	382.2	611.5
8	0.0601	0.3798	0.259	54.60	1066.6	2.32	3.79	459.3	706.2
9	0.0601	0.3798	0.255	54.80	1136.8	2.34	3.79	485.5	720.3
10	0.0601	0.3798	0.256	56.91	1163.1	2.34	3.79	497.7	714.9
11	0.0601	0.3798	0.290	59.49	710.7	2.19	3.79	324.8	452.7
12	0.0601	0.3798	0.252	60.61	1314.4	2.36	3.79	557.8	756.0
13	0.0601	0.3798	0.287	60.92	764.6	2.20	3.79	347.6	458.8
14	0.0601	0.3798	0.267	61.32	1059.8	2.29	3.79	463.7	597.1
15	0.0601	0.3798	0.300	61.94	625.6	2.15	3.79	291.1	366.0
16	0.0601	0.3798	0.255	63.97	1326.9	2.34	3.79	566.6	696.3
17	0.0601	0.3798	0.252	64.97	1408.9	2.36	3.79	597.9	718.7
18	0.0601	0.3798	0.291	66.19	777.6	2.18	3.79	356.0	418.9
19	0.0601	0.3798	0.248	66.75	1535.0	2.38	3.79	645.9	744.3
20	0.0601	0.3798	0.289	67.28	817.1	2.19	3.79	372.7	420.8
21	0.0601	0.3798	0.288	67.86	837.8	2.20	3.79	381.5	422.1
22	0.0601	0.3798	0.275	67.88	1034.7	2.25	3.79	459.8	498.6
23	0.0601	0.3798	0.261	68.04	1289.4	2.31	3.79	557.4	592.5
24	0.0601	0.3798	0.220	69.26	2352.3	2.53	3.79	929.2	968.2
25	0.0601	0.3798	0.248	70.13	1612.7	2.38	3.79	678.7	693.0
26	0.0601	0.3798	0.286	70.48	899.4	2.20	3.79	408.0	408.3
27	0.0601	0.3798	0.251	70.50	1551.7	2.36	3.79	657.2	644.0
28	0.0601	0.3798	0.250	70.55	1575.7	2.37	3.79	665.9	638.6
29	0.0601	0.3798	0.308	70.97	625.3	2.12	3.79	295.0	276.7
30	0.0601	0.3798	0.249	71.15	1612.5	2.37	3.79	680.0	622.8
31	0.0601	0.3798	0.276	71.79	1077.1	2.25	3.79	479.6	428.1
32	0.0601	0.3798	0.276	73.48	1102.4	2.25	3.79	490.9	426.0
33	0.0601	0.3798	0.283	73.48	984.8	2.22	3.79	444.3	373.3
34	0.0601	0.3798	0.258	73.73	1462.2	2.33	3.79	628.3	507.2
35	0.0601	0.3798	0.277	75.17	1109.9	2.24	3.79	495.1	377.6

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0616	0.3774	0.277	46.06	673.9	2.18	3.89	308.9	825.2
2	0.0616	0.3774	0.292	49.09	564.3	2.12	3.89	265.7	591.9
3	0.0616	0.3774	0.268	51.69	869.6	2.22	3.89	391.9	783.5
4	0.0616	0.3774	0.289	56.18	678.3	2.14	3.89	317.7	587.8
5	0.0616	0.3774	0.238	57.00	1484.7	2.36	3.89	629.4	1095.3
6	0.0616	0.3774	0.287	57.20	713.4	2.14	3.89	333.0	550.8
7	0.0616	0.3774	0.277	58.69	858.8	2.18	3.89	393.6	623.1
8	0.0616	0.3774	0.271	61.07	981.2	2.21	3.89	444.7	677.4
9	0.0616	0.3774	0.245	61.36	1448.8	2.32	3.89	623.4	917.4
10	0.0616	0.3774	0.282	61.81	835.4	2.16	3.89	386.4	551.0
11	0.0616	0.3774	0.248	62.05	1403.7	2.31	3.89	607.8	841.8
12	0.0616	0.3774	0.253	62.21	1309.2	2.29	3.89	572.7	772.0
13	0.0616	0.3774	0.315	62.39	487.5	2.04	3.89	238.7	313.7
14	0.0616	0.3774	0.285	62.81	809.1	2.15	3.89	376.3	482.7
15	0.0616	0.3774	0.298	63.57	661.7	2.10	3.89	314.9	394.8
16	0.0616	0.3774	0.297	64.01	677.5	2.11	3.89	321.9	394.7
17	0.0616	0.3774	0.250	65.32	1435.8	2.30	3.89	624.3	749.5
18	0.0616	0.3774	0.282	65.46	884.7	2.16	3.89	409.3	481.3
19	0.0616	0.3774	0.282	65.46	884.7	2.16	3.89	409.3	471.8
20	0.0616	0.3774	0.286	66.43	842.1	2.15	3.89	392.4	443.5
21	0.0616	0.3774	0.297	67.01	709.3	2.11	3.89	337.0	373.6
22	0.0616	0.3774	0.311	67.66	565.9	2.06	3.89	275.3	299.4
23	0.0616	0.3774	0.281	69.86	959.4	2.17	3.89	443.0	472.9
24	0.0616	0.3774	0.319	70.86	517.2	2.03	3.89	254.9	267.0
25	0.0616	0.3774	0.280	71.88	1003.0	2.17	3.89	462.3	475.1
26	0.0616	0.3774	0.291	72.15	843.1	2.13	3.89	396.4	399.6
27	0.0616	0.3774	0.290	73.48	872.9	2.13	3.89	409.6	405.0
28	0.0616	0.3774	0.302	73.75	718.1	2.09	3.89	344.1	333.5
29	0.0616	0.3774	0.288	74.62	915.7	2.14	3.89	428.2	406.6
30	0.0616	0.3774	0.300	75.35	758.7	2.09	3.89	362.3	336.7
31	0.0616	0.3774	0.301	76.06	753.1	2.09	3.89	360.3	327.3
32	0.0616	0.3774	0.278	76.11	1096.2	2.18	3.89	503.3	446.2
33	0.0616	0.3774	0.291	76.51	894.0	2.13	3.89	420.3	362.6
34	0.0616	0.3774	0.284	78.49	1027.4	2.15	3.89	477.0	398.9
35	0.0616	0.3774	0.276	78.71	1169.9	2.19	3.89	535.2	430.6
36	0.0616	0.3774	0.296	81.40	876.0	2.11	3.89	415.4	316.5

AGRBW-8A2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0604	0.3759	0.107	7.38	910.7	2.67	5.02	340.7	708.3
2	0.0604	0.3759	0.091	8.81	1277.2	2.85	5.02	448.0	808.5
3	0.0604	0.3759	0.141	8.83	761.3	2.40	5.02	317.9	527.5
4	0.0604	0.3759	0.133	8.85	832.2	2.45	5.02	339.5	530.1
5	0.0604	0.3759	0.121	9.07	968.8	2.55	5.02	380.7	566.5
6	0.0604	0.3759	0.121	9.19	980.7	2.55	5.02	385.3	551.0
7	0.0604	0.3759	0.137	9.23	831.1	2.42	5.02	343.1	474.0
8	0.0604	0.3759	0.126	9.79	991.2	2.50	5.02	395.8	530.4
9	0.0604	0.3759	0.126	9.81	993.5	2.50	5.02	396.7	517.2
10	0.0604	0.3759	0.169	10.03	631.2	2.23	5.02	283.3	360.2
11	0.0604	0.3759	0.128	10.23	1014.5	2.49	5.02	407.7	506.3
12	0.0604	0.3759	0.134	10.24	952.0	2.44	5.02	389.6	473.4
13	0.0604	0.3759	0.122	10.50	1109.1	2.54	5.02	437.2	520.5
14	0.0604	0.3759	0.172	10.72	651.4	2.21	5.02	294.5	343.7
15	0.0604	0.3759	0.124	11.39	1178.0	2.52	5.02	467.4	535.4
16	0.0604	0.3759	0.150	12.37	965.6	2.34	5.02	413.3	464.9
17	0.0604	0.3759	0.160	12.72	887.8	2.28	5.02	389.9	430.8
18	0.0604	0.3759	0.159	14.95	1054.9	2.28	5.02	462.2	501.9
19	0.0604	0.3759	0.190	16.30	798.6	2.13	5.02	375.6	400.9
20	0.0604	0.3759	0.155	17.93	1323.7	2.31	5.02	574.1	602.5
21	0.0604	0.3759	0.154	18.15	1355.3	2.31	5.02	586.2	604.9
22	0.0604	0.3759	0.169	23.02	1448.6	2.23	5.02	650.2	659.6
23	0.0604	0.3759	0.212	28.74	1065.7	2.04	5.02	523.6	522.0
24	0.0604	0.3759	0.187	28.98	1472.5	2.14	5.02	688.2	674.1
25	0.0604	0.3759	0.208	33.92	1324.9	2.05	5.02	646.0	621.3
26	0.0604	0.3759	0.221	34.10	1122.4	2.00	5.02	560.7	529.0
27	0.0604	0.3759	0.196	34.43	1565.9	2.10	5.02	745.6	689.2
28	0.0604	0.3759	0.225	35.54	1108.5	1.99	5.02	557.7	503.9
29	0.0604	0.3759	0.236	36.74	984.3	1.95	5.02	504.7	444.4
30	0.0604	0.3759	0.236	38.03	1018.8	1.95	5.02	522.4	445.8
31	0.0604	0.3759	0.223	36.68	1175.3	2.00	5.02	589.2	480.9

AGRBW-1C2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0274	0.428	0.072	0.91	586.1	4.56	4.09	128.5	377.1
2	0.0274	0.428	0.073	0.96	606.1	4.53	4.09	133.8	330.4
3	0.0274	0.428	0.079	1.18	686.0	4.36	4.09	157.5	350.9
4	0.0274	0.428	0.083	1.36	745.5	4.25	4.09	175.3	363.0
5	0.0274	0.428	0.088	1.56	795.6	4.13	4.09	192.5	376.2
6	0.0274	0.428	0.092	1.78	857.3	4.04	4.09	212.0	394.9
7	0.0274	0.428	0.093	1.80	855.3	4.02	4.09	212.6	380.1
8	0.0274	0.428	0.094	1.87	873.9	4.00	4.09	218.4	376.5
9	0.0274	0.428	0.095	1.93	891.7	3.98	4.09	224.0	373.9
10	0.0274	0.428	0.097	2.05	915.2	3.94	4.09	232.2	376.4
11	0.0274	0.428	0.098	2.07	911.4	3.92	4.09	232.4	366.6
12	0.0274	0.428	0.104	2.16	867.9	3.81	4.09	227.9	350.5
13	0.0274	0.428	0.101	2.25	946.0	3.86	4.09	244.8	367.8
14	0.0274	0.428	0.104	2.45	984.3	3.81	4.09	258.4	379.7
15	0.0274	0.428	0.105	2.47	978.1	3.79	4.09	258.0	371.2
16	0.0274	0.428	0.105	2.51	995.7	3.79	4.09	262.7	370.3
17	0.0274	0.428	0.106	2.54	989.2	3.77	4.09	262.1	362.5
18	0.0274	0.428	0.107	2.65	1016.8	3.76	4.09	270.7	367.4
19	0.0274	0.428	0.113	3.00	1050.7	3.66	4.09	287.3	382.9
20	0.0274	0.428	0.120	3.54	1107.1	3.55	4.09	311.7	408.2
21	0.0274	0.428	0.145	5.54	1138.5	3.24	4.09	351.7	452.6
22	0.0274	0.428	0.129	5.76	1556.8	3.43	4.09	454.1	574.8
23	0.0274	0.428	0.150	6.36	1196.3	3.18	4.09	375.7	467.6
24	0.0274	0.428	0.155	6.98	1199.3	3.13	4.09	382.7	468.6
25	0.0274	0.428	0.157	7.23	1196.4	3.11	4.09	384.2	462.8
26	0.0274	0.428	0.174	9.07	1083.0	2.96	4.09	365.7	433.5
27	0.0274	0.428	0.184	10.12	984.5	2.88	4.09	341.7	398.5
28	0.0274	0.428	0.194	14.21	1116.3	2.81	4.09	397.5	456.1
29	0.0274	0.428	0.205	15.28	938.0	2.73	4.09	343.2	387.3
30	0.0274	0.428	0.223	16.01	643.5	2.62	4.09	245.3	272.3
31	0.0274	0.428	0.216	18.17	862.9	2.66	4.09	323.9	353.4
32	0.0274	0.428	0.229	18.17	632.5	2.59	4.09	244.3	261.9
33	0.0274	0.428	0.235	18.90	570.9	2.56	4.09	223.3	235.0
34	0.0274	0.428	0.235	20.97	633.3	2.56	4.09	247.7	255.8
35	0.0274	0.428	0.239	21.06	579.7	2.54	4.09	228.6	231.3
36	0.0274	0.428	0.234	21.46	663.5	2.56	4.09	259.0	256.3
37	0.0274	0.428	0.241	21.51	565.8	2.53	4.09	224.0	216.3
38	0.0274	0.428	0.235	21.60	652.1	2.56	4.09	255.1	239.3
39	0.0274	0.428	0.238	23.04	648.9	2.54	4.09	255.4	231.3
40	0.0274	0.428	0.262	23.66	421.7	2.42	4.09	174.0	149.8

AGRBW-2C2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0287	0.4278	0.069	0.91	569.4	6.60	3.33	86.3	323.0
2	0.0287	0.4278	0.076	1.13	643.5	6.23	3.33	103.4	312.9
3	0.0287	0.4278	0.076	1.16	656.1	6.23	3.33	105.4	281.4
4	0.0287	0.4278	0.077	1.18	659.5	6.18	3.33	106.8	260.5
5	0.0287	0.4278	0.079	1.25	677.8	6.08	3.33	111.4	253.2
6	0.0287	0.4278	0.079	1.25	677.8	6.08	3.33	111.4	238.7
7	0.0287	0.4278	0.079	1.27	689.9	6.08	3.33	113.4	231.0
8	0.0287	0.4278	0.080	1.29	692.3	6.04	3.33	114.7	223.4
9	0.0287	0.4278	0.081	1.31	694.5	5.99	3.33	115.9	217.0
10	0.0287	0.4278	0.082	1.36	708.0	5.95	3.33	119.0	214.9
11	0.0287	0.4278	0.085	1.49	745.6	5.82	3.33	128.1	223.7
12	0.0287	0.4278	0.087	1.56	757.2	5.74	3.33	131.9	223.4
13	0.0287	0.4278	0.088	1.60	767.9	5.70	3.33	134.7	221.6
14	0.0287	0.4278	0.089	1.65	778.0	5.66	3.33	137.4	219.9
15	0.0287	0.4278	0.091	1.76	807.2	5.59	3.33	144.5	225.3
16	0.0287	0.4278	0.092	1.80	815.9	5.55	3.33	147.0	223.6
17	0.0287	0.4278	0.093	1.87	834.0	5.52	3.33	151.2	224.7
18	0.0287	0.4278	0.094	1.89	831.8	5.48	3.33	151.8	220.4
19	0.0287	0.4278	0.110	2.78	966.0	4.99	3.33	193.7	275.1
20	0.0287	0.4278	0.115	3.07	988.3	4.86	3.33	203.6	282.9
21	0.0287	0.4278	0.115	3.09	995.5	4.86	3.33	205.1	279.0
22	0.0287	0.4278	0.121	3.47	1018.1	4.71	3.33	216.2	288.1
23	0.0287	0.4278	0.121	3.49	1024.7	4.71	3.33	217.6	284.1
24	0.0287	0.4278	0.164	4.54	643.8	3.92	3.33	164.1	210.0
25	0.0287	0.4278	0.168	5.78	762.0	3.87	3.33	197.1	247.2
26	0.0287	0.4278	0.213	5.92	307.7	3.35	3.33	91.8	112.8
27	0.0287	0.4278	0.152	6.89	1213.0	4.11	3.33	295.4	356.1
28	0.0287	0.4278	0.176	8.38	949.0	3.76	3.33	252.4	298.2
29	0.0287	0.4278	0.207	17.08	1016.3	3.41	3.33	298.0	344.9
30	0.0287	0.4278	0.250	22.06	491.6	3.05	3.33	161.4	183.1
31	0.0287	0.4278	0.255	22.24	447.6	3.01	3.33	148.7	165.2
32	0.0287	0.4278	0.274	25.42	388.1	2.88	3.33	134.6	146.3
33	0.0287	0.4278	0.282	25.44	372.8	2.83	3.33	131.6	139.9
34	0.0287	0.4278	0.274	26.22	400.3	2.88	3.33	138.9	144.1
35	0.0287	0.4278	0.277	26.85	401.1	2.86	3.33	140.1	141.8
36	0.0287	0.4278	0.322	27.38	604.3	2.62	3.33	231.0	227.5
37	0.0287	0.4278	0.283	27.96	409.0	2.83	3.33	144.7	138.3
38	0.0287	0.4278	0.277	28.22	421.7	2.86	3.33	147.3	135.9
39	0.0287	0.4278	0.283	29.02	424.6	2.83	3.33	150.2	132.7
40	0.0287	0.4278	0.303	30.80	509.7	2.71	3.33	187.9	156.0

AGRBW-3C2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0278	0.4273	0.054	0.98	786.7	9.50	3.01	82.8	376.4
2	0.0278	0.4273	0.054	0.98	786.7	9.50	3.01	82.8	297.9
3	0.0278	0.4273	0.055	1.02	811.4	9.38	3.01	86.5	270.9
4	0.0278	0.4273	0.058	1.20	914.8	9.06	3.01	101.0	286.4
5	0.0278	0.4273	0.060	1.29	956.2	8.85	3.01	108.0	283.3
6	0.0278	0.4273	0.060	1.31	972.7	8.85	3.01	109.9	270.2
7	0.0278	0.4273	0.062	1.40	1010.7	8.66	3.01	116.7	271.6
8	0.0278	0.4273	0.063	1.49	1060.3	8.57	3.01	123.7	274.3
9	0.0278	0.4273	0.065	1.58	1093.2	8.40	3.01	130.2	276.6
10	0.0278	0.4273	0.065	1.58	1093.2	8.40	3.01	130.2	266.0
11	0.0278	0.4273	0.066	1.62	1108.7	8.31	3.01	133.4	262.9
12	0.0278	0.4273	0.067	1.69	1138.5	8.23	3.01	138.4	263.7
13	0.0278	0.4273	0.070	1.91	1235.9	7.99	3.01	154.6	285.7
14	0.0278	0.4273	0.070	1.93	1250.2	7.99	3.01	156.4	280.7
15	0.0278	0.4273	0.073	2.11	1309.3	7.77	3.01	168.5	294.1
16	0.0278	0.4273	0.073	2.14	1323.1	7.77	3.01	170.2	289.5
17	0.0278	0.4273	0.073	2.16	1336.9	7.77	3.01	172.0	285.3
18	0.0278	0.4273	0.074	2.25	1372.6	7.70	3.01	178.2	288.5
19	0.0278	0.4273	0.073	2.51	1557.4	7.77	3.01	200.4	317.0
20	0.0278	0.4273	0.079	3.00	1709.8	7.38	3.01	231.9	358.7
21	0.0278	0.4273	0.084	3.07	1627.5	7.08	3.01	229.9	348.0
22	0.0278	0.4273	0.084	3.07	1627.5	7.08	3.01	229.9	340.7
23	0.0278	0.4273	0.100	3.29	1380.4	6.31	3.01	218.9	317.9
24	0.0278	0.4273	0.089	4.54	2240.3	6.81	3.01	328.8	467.9
25	0.0278	0.4273	0.100	4.72	1977.3	6.31	3.01	313.6	437.5
26	0.0278	0.4273	0.109	5.03	1838.6	5.96	3.01	308.8	422.5
27	0.0278	0.4273	0.100	5.36	2247.8	6.31	3.01	356.5	478.4
28	0.0278	0.4273	0.104	5.45	2151.4	6.14	3.01	350.2	461.1
29	0.0278	0.4273	0.089	5.47	2706.8	6.82	3.01	396.7	512.6
30	0.0278	0.4273	0.111	5.80	2058.8	5.88	3.01	350.0	443.7
31	0.0278	0.4273	0.117	6.03	1946.3	5.68	3.01	342.6	426.3
32	0.0278	0.4273	0.118	6.05	1922.8	5.65	3.01	340.4	415.7
33	0.0278	0.4273	0.100	6.05	2536.9	6.31	3.01	402.3	482.1
34	0.0278	0.4273	0.118	6.07	1929.9	5.65	3.01	341.6	401.6
35	0.0278	0.4273	0.109	6.07	2220.9	5.96	3.01	373.0	430.0
36	0.0278	0.4273	0.103	6.07	2433.8	6.18	3.01	393.6	444.9
37	0.0278	0.4273	0.110	6.32	2275.1	5.92	3.01	384.4	425.8
38	0.0278	0.4273	0.112	6.34	2213.5	5.85	3.01	378.5	410.6
39	0.0278	0.4273	0.110	6.36	2291.1	5.92	3.01	387.1	411.0
40	0.0278	0.4273	0.114	6.41	2168.1	5.78	3.01	375.1	389.4

AGRBW-3C2 (continued)

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
41	0.0278	0.4273	0.108	6.49	2412.3	5.99	3.01	402.6	408.1
42	0.0278	0.4273	0.113	6.69	2301.6	5.81	3.01	395.9	391.1
43	0.0278	0.4273	0.129	7.18	1912.1	5.32	3.01	359.1	345.0
44	0.0278	0.4273	0.117	7.83	2528.0	5.68	3.01	445.0	414.3
45	0.0278	0.4273	0.111	7.83	2776.6	5.88	3.01	472.0	423.7
46	0.0278	0.4273	0.135	9.83	2368.2	5.17	3.01	458.5	393.4
47	0.0278	0.4273	0.128	10.72	2900.5	5.35	3.01	542.0	435.5

AGRBW-4C2

#	#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)
1	0.0334	0.426	0.099	6.25	2090.9	5.01	3.43	417.3	1408.2
2	0.0334	0.426	0.095	6.25	2204.9	5.13	3.43	429.6	1179.2
3	0.0334	0.426	0.130	7.01	1523.6	4.28	3.43	356.4	865.3
4	0.0334	0.426	0.102	7.72	2480.3	4.93	3.43	503.7	1119.2
5	0.0334	0.426	0.130	7.94	1726.8	4.28	3.43	403.9	837.0
6	0.0334	0.426	0.173	8.01	890.9	3.62	3.43	246.2	481.3
7	0.0334	0.426	0.153	8.23	1266.1	3.89	3.43	325.7	605.7
8	0.0334	0.426	0.101	8.23	2680.5	4.95	3.43	541.2	962.9
9	0.0334	0.426	0.127	8.41	1909.3	4.33	3.43	440.6	753.3
10	0.0334	0.426	0.113	8.43	2331.9	4.64	3.43	502.7	828.8
11	0.0334	0.426	0.125	8.50	1985.6	4.37	3.43	454.0	723.8
12	0.0334	0.426	0.115	8.59	2310.1	4.59	3.43	503.1	777.3
13	0.0334	0.426	0.104	8.63	2699.7	4.87	3.43	554.4	831.7
14	0.0334	0.426	0.129	8.72	1923.7	4.29	3.43	448.0	653.3
15	0.0334	0.426	0.172	8.79	994.0	3.63	3.43	273.8	388.6
16	0.0334	0.426	0.110	8.81	2539.3	4.71	3.43	538.8	745.4
17	0.0334	0.426	0.109	8.85	2587.3	4.74	3.43	546.1	736.8
18	0.0334	0.426	0.107	8.87	2665.6	4.79	3.43	556.6	732.8
19	0.0334	0.426	0.162	9.10	1213.2	3.76	3.43	322.6	414.7
20	0.0334	0.426	0.117	9.19	2403.7	4.55	3.43	528.8	663.8
21	0.0334	0.426	0.111	9.27	2637.5	4.69	3.43	562.6	690.0
22	0.0334	0.426	0.145	9.32	1622.0	4.01	3.43	404.4	484.5
23	0.0334	0.426	0.096	9.41	3275.5	5.10	3.43	642.0	751.4
24	0.0334	0.426	0.117	9.54	2496.8	4.55	3.43	549.2	627.8
25	0.0334	0.426	0.117	9.61	2514.3	4.55	3.43	553.1	617.2
26	0.0334	0.426	0.107	9.63	2892.7	4.79	3.43	604.0	657.5
27	0.0334	0.426	0.110	9.70	2795.8	4.71	3.43	593.3	629.4
28	0.0334	0.426	0.154	9.83	1489.0	3.87	3.43	384.5	397.0
29	0.0334	0.426	0.109	9.85	2879.8	4.74	3.43	607.9	609.6
30	0.0334	0.426	0.112	10.76	3019.4	4.66	3.43	647.5	628.8
31	0.0334	0.426	0.140	10.92	2049.6	4.09	3.43	500.6	468.6
32	0.0334	0.426	0.120	11.05	2773.4	4.48	3.43	619.2	554.1
33	0.0334	0.426	0.120	11.08	2778.9	4.48	3.43	620.4	520.9

AGRBW-5C2

#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0628	0.4654	0.284	43.17	870.4	2.64	3.58	330.2	1036.4
2	0.0628	0.4654	0.237	45.48	1624.7	2.92	3.58	557.0	1433.7
3	0.0628	0.4654	0.309	51.42	740.1	2.52	3.58	294.3	673.0
4	0.0628	0.4654	0.262	52.38	1393.3	2.76	3.58	505.2	1060.6
5	0.0628	0.4654	0.270	52.51	1265.5	2.71	3.58	466.7	915.6
6	0.0628	0.4654	0.305	52.96	805.8	2.53	3.58	318.1	589.8
7	0.0628	0.4654	0.312	58.29	804.5	2.50	3.58	321.6	568.0
8	0.0628	0.4654	0.261	62.36	1679.3	2.76	3.58	607.6	1027.7
9	0.0628	0.4654	0.318	63.85	809.3	2.48	3.58	327.0	531.9
10	0.0628	0.4654	0.262	64.70	1721.1	2.76	3.58	624.1	979.4
11	0.0628	0.4654	0.331	65.34	685.5	2.42	3.58	283.3	430.0
12	0.0628	0.4654	0.340	65.90	604.7	2.38	3.58	253.6	373.2
13	0.0628	0.4654	0.320	66.61	820.3	2.47	3.58	332.6	475.1
14	0.0628	0.4654	0.284	66.63	1343.6	2.64	3.58	509.6	707.6
15	0.0628	0.4654	0.289	67.92	1282.8	2.61	3.58	491.3	663.8
16	0.0628	0.4654	0.280	68.08	1445.5	2.66	3.58	544.0	715.8
17	0.0628	0.4654	0.297	68.61	1164.6	2.57	3.58	452.9	580.7
18	0.0628	0.4654	0.294	68.75	1214.8	2.59	3.58	469.8	587.1
19	0.0628	0.4654	0.302	69.86	1107.8	2.55	3.58	434.9	529.9
20	0.0628	0.4654	0.275	69.93	1582.5	2.68	3.58	589.6	700.4
21	0.0628	0.4654	0.295	69.97	1220.0	2.58	3.58	472.7	547.4
22	0.0628	0.4654	0.285	70.17	1396.6	2.63	3.58	530.8	598.8
23	0.0628	0.4654	0.287	71.35	1383.4	2.62	3.58	527.8	579.7
24	0.0628	0.4654	0.269	73.68	1798.1	2.72	3.58	661.7	706.5
25	0.0628	0.4654	0.275	74.73	1691.4	2.68	3.58	630.1	653.0
26	0.0628	0.4654	0.284	75.26	1517.6	2.64	3.58	575.6	577.3
27	0.0628	0.4654	0.307	75.33	1114.9	2.52	3.58	441.7	426.8
28	0.0628	0.4654	0.324	76.49	889.0	2.45	3.58	363.0	335.2
29	0.0628	0.4654	0.302	81.42	1291.1	2.55	3.58	506.8	439.1

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0561	0.4582	0.209	37.83	1984.0	1.84	6.70	1078.9	2034.4
2	0.0561	0.4582	0.193	39.41	2484.0	1.88	6.70	1319.1	2237.8
3	0.0561	0.4582	0.227	42.81	1808.5	1.79	6.70	1008.1	1606.1
4	0.0561	0.4582	0.229	45.64	1880.8	1.79	6.70	1051.1	1600.5
5	0.0561	0.4582	0.234	48.97	1896.2	1.78	6.70	1066.5	1567.1
6	0.0561	0.4582	0.233	49.98	1959.4	1.78	6.70	1100.7	1570.0
7	0.0561	0.4582	0.230	51.47	2094.8	1.79	6.70	1172.2	1629.8
8	0.0561	0.4582	0.229	51.96	2141.1	1.79	6.70	1196.6	1626.6
9	0.0561	0.4582	0.238	53.22	1959.0	1.77	6.70	1107.5	1475.3
10	0.0561	0.4582	0.249	55.78	1781.0	1.75	6.70	1020.5	1334.6
11	0.0561	0.4582	0.267	55.94	1400.4	1.71	6.70	819.3	1053.3
12	0.0561	0.4582	0.261	56.49	1536.1	1.72	6.70	892.6	1129.4
13	0.0561	0.4582	0.260	56.67	1562.1	1.72	6.70	906.7	1130.1
14	0.0561	0.4582	0.240	57.14	2050.2	1.77	6.70	1161.9	1427.7
15	0.0561	0.4582	0.256	57.58	1675.3	1.73	6.70	967.9	1173.2
16	0.0561	0.4582	0.259	58.03	1621.3	1.73	6.70	940.0	1124.6
17	0.0561	0.4582	0.288	58.07	1075.6	1.67	6.70	643.6	760.3
18	0.0561	0.4582	0.231	58.32	2344.2	1.79	6.70	1313.5	1532.7
19	0.0561	0.4582	0.258	59.70	1690.6	1.73	6.70	979.1	1128.8
20	0.0561	0.4582	0.255	59.85	1764.8	1.73	6.70	1018.4	1160.4
21	0.0561	0.4582	0.255	60.10	1772.0	1.73	6.70	1022.6	1151.6
22	0.0561	0.4582	0.256	60.58	1762.7	1.73	6.70	1018.4	1133.6
23	0.0561	0.4582	0.246	60.65	2014.1	1.75	6.70	1149.9	1265.2
24	0.0561	0.4582	0.257	60.65	1741.0	1.73	6.70	1007.1	1095.2
25	0.0561	0.4582	0.237	61.74	2301.6	1.77	6.70	1299.5	1396.7
26	0.0561	0.4582	0.262	62.03	1663.8	1.72	6.70	967.9	1027.8
27	0.0561	0.4582	0.264	62.05	1619.4	1.72	6.70	944.2	990.3
28	0.0561	0.4582	0.266	62.10	1576.4	1.71	6.70	921.2	953.8
29	0.0561	0.4582	0.264	62.65	1635.0	1.72	6.70	953.4	973.6
30	0.0561	0.4582	0.270	66.63	1599.9	1.70	6.70	939.1	945.1
31	0.0561	0.4582	0.276	67.17	1481.4	1.69	6.70	875.3	866.7
32	0.0561	0.4582	0.262	68.66	1841.6	1.72	6.70	1071.4	1041.3
33	0.0561	0.4582	0.270	68.93	1654.9	1.70	6.70	971.4	922.9
34	0.0561	0.4582	0.249	70.35	2246.2	1.75	6.70	1287.1	1183.8

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0579	0.4665	0.247	49.98	1662.9	2.01	5.43	829.1	1814.1
2	0.0579	0.4665	0.236	53.98	2056.8	2.04	5.43	1008.4	1936.6
3	0.0579	0.4665	0.316	56.63	722.8	1.83	5.43	394.6	701.3
4	0.0579	0.4665	0.272	57.83	1390.6	1.94	5.43	718.4	1207.3
5	0.0579	0.4665	0.282	58.45	1225.8	1.91	5.43	641.7	1031.8
6	0.0579	0.4665	0.272	59.45	1429.7	1.94	5.43	738.6	1144.8
7	0.0579	0.4665	0.265	60.05	1585.5	1.95	5.43	811.2	1218.2
8	0.0579	0.4665	0.253	60.38	1862.7	1.99	5.43	936.9	1368.3
9	0.0579	0.4665	0.253	60.92	1879.1	1.99	5.43	945.2	1346.1
10	0.0579	0.4665	0.253	62.19	1918.2	1.99	5.43	964.9	1342.9
11	0.0579	0.4665	0.272	62.21	1496.0	1.94	5.43	772.8	1053.0
12	0.0579	0.4665	0.299	67.30	1107.7	1.87	5.43	592.5	791.5
13	0.0579	0.4665	0.291	68.17	1259.4	1.89	5.43	667.0	874.5
14	0.0579	0.4665	0.281	68.32	1452.9	1.91	5.43	759.6	978.4
15	0.0579	0.4665	0.291	69.26	1279.5	1.89	5.43	677.7	858.1
16	0.0579	0.4665	0.288	70.39	1357.1	1.90	5.43	716.0	892.0
17	0.0579	0.4665	0.282	70.42	1476.7	1.91	5.43	773.1	947.9
18	0.0579	0.4665	0.299	71.35	1174.3	1.87	5.43	628.2	758.4
19	0.0579	0.4665	0.289	71.48	1358.8	1.89	5.43	717.8	853.6
20	0.0579	0.4665	0.284	72.57	1480.1	1.91	5.43	776.9	910.2
21	0.0579	0.4665	0.277	73.44	1650.1	1.92	5.43	858.2	990.7
22	0.0579	0.4665	0.277	73.71	1656.1	1.92	5.43	861.3	979.8
23	0.0579	0.4665	0.294	74.02	1309.9	1.88	5.43	696.4	780.5
24	0.0579	0.4665	0.275	74.24	1714.3	1.93	5.43	889.2	981.9
25	0.0579	0.4665	0.304	74.60	1140.7	1.86	5.43	613.9	667.7
26	0.0579	0.4665	0.292	75.69	1378.4	1.89	5.43	731.0	782.6
27	0.0579	0.4665	0.292	75.80	1380.5	1.89	5.43	732.0	771.2
28	0.0579	0.4665	0.295	76.18	1328.8	1.88	5.43	707.3	732.4
29	0.0579	0.4665	0.279	76.33	1668.7	1.92	5.43	870.1	884.6
30	0.0579	0.4665	0.307	76.91	1124.6	1.85	5.43	607.5	605.2
31	0.0579	0.4665	0.306	77.93	1156.8	1.85	5.43	624.1	607.5
32	0.0579	0.4665	0.298	78.13	1304.9	1.87	5.43	697.1	659.5
33	0.0579	0.4665	0.296	78.62	1351.7	1.88	5.43	720.4	654.6

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#	Average wall thickness (mm)	Average outer radius (mm)	Contact Diameter (mm)	Fracture load (N)	Local fracture stress (MPa)	Size effect parameter	Weibull modulus	Mean fracture stress (MPa)	Scale parameter (MPa)
1	0.0646	0.4628	0.282	64.41	1312.1	1.59	7.45	824.4	1389.1
2	0.0646	0.4628	0.250	64.70	1941.7	1.64	7.45	1181.1	1808.2
3	0.0646	0.4628	0.292	71.42	1279.5	1.58	7.45	811.4	1173.0
4	0.0646	0.4628	0.290	73.86	1358.1	1.58	7.45	859.7	1192.1
5	0.0646	0.4628	0.296	74.00	1258.0	1.57	7.45	800.7	1074.1
6	0.0646	0.4628	0.299	74.71	1220.6	1.57	7.45	779.0	1016.4
7	0.0646	0.4628	0.288	74.89	1413.0	1.58	7.45	892.8	1137.1
8	0.0646	0.4628	0.294	75.24	1313.2	1.57	7.45	834.3	1040.0
9	0.0646	0.4628	0.284	75.29	1495.2	1.59	7.45	941.2	1150.4
10	0.0646	0.4628	0.293	75.95	1343.1	1.58	7.45	852.5	1023.4
11	0.0646	0.4628	0.303	76.89	1190.8	1.56	7.45	762.7	900.1
12	0.0646	0.4628	0.292	77.71	1392.2	1.58	7.45	882.9	1025.3
13	0.0646	0.4628	0.285	77.93	1528.2	1.59	7.45	962.8	1100.9
14	0.0646	0.4628	0.294	79.45	1386.6	1.57	7.45	880.9	992.2
15	0.0646	0.4628	0.294	79.80	1392.8	1.57	7.45	884.9	982.1
16	0.0646	0.4628	0.306	79.91	1188.5	1.56	7.45	763.2	834.8
17	0.0646	0.4628	0.278	80.40	1722.5	1.60	7.45	1078.0	1161.9
18	0.0646	0.4628	0.296	81.40	1383.9	1.57	7.45	880.8	935.4
19	0.0646	0.4628	0.294	82.76	1444.4	1.57	7.45	917.7	959.7
20	0.0646	0.4628	0.311	83.20	1155.7	1.55	7.45	745.5	767.1
21	0.0646	0.4628	0.303	83.69	1296.2	1.56	7.45	830.2	839.5
22	0.0646	0.4628	0.320	83.96	1028.9	1.54	7.45	668.7	663.1
23	0.0646	0.4628	0.305	84.03	1266.7	1.56	7.45	812.8	787.3
24	0.0646	0.4628	0.320	84.47	1035.2	1.54	7.45	672.8	630.8

Endnotes

[1] J.R. Price, D.B. Aykac, J.D. Hunn, A.K. Kercher, in: Proceedings of Machine Vision Applications in Industrial Inspection XV, SPIE, vol. 6503, 2007, p. 650302.

[2] J.R. Price, D.B. Aykac, J.D. Hunn, A.K. Kercher, R.N. Morris, in: Proceedings of Machine Vision Applications in Industrial Inspection XIV, SPIE, vol. 6070, 2006, p. 60700H.

[3] A.K. Kercher, J.D. Hunn, J.R. Price, P. Pappano, J. Nucl. Mater. 380 (2008) 76.