Qualification Testing for PCFBC Applications (Task 3.3)

Eight, 1.5 m, PRD-66 candle filters were received from DuPont on March27, 1997. In the manufacturing process, either a coarse or medium grade hoop wrapped membrane was applied to the outer surface of the filter elements. The results of the room temperature gas flow resistance measurements of the eight, as-manufactured, 1.5 m, candle filters are shown in Figures 6 and 7. Both sets of filter elements met the Westinghouse gas flow resistance tolerance of<1 in-wg/fpm for as-manufactured candles.

During April 1997, one candle of each filter element type was subjected to high temperature, high pressure (HTHP), simulated pressurized fluidized-bed combustion (PFBC) testing in Westinghouse's test facility in Pittsburgh, PA. Testing included exposure of the PRD-66 candle filters with alternate monolithic and advanced fiber reinforced candle filter elements in order to support pressurized circulating fluidized-bed combustion (PCPBC) test initiatives in Karhula, Finland. The filter array was subjected to 120 hours of steady state operating conditions at temperatures of 1550^0F, and subsequently 2200 accelerated pulse cycling, and 12 mild thermal transients events.

Post-test inspection of the filter army indicated that both PFBC-exposed PRD-66 filter elements remained intact. As a result, both elements, and an unexposed filter of each element type were subsequently subjected to mechanical strength characterization, and x-ray diffraction and microstructural analyses. The results of these efforts are summarized in the following sections.[4]

Figure 8 provides photographs of the residual dust cake layer that remained along the outer surface of the qualification-tested filter elements. Due the manner in which the qualification test was performed, the thin dust cake layer was considered to reflect the conditioned layer that generally remains attached to the outer surface of the candle during field exposure. Post-test gas flow resistance measurements of the qualification-tested candles are provided in Figure 9. The coarse membrane-coated filter element initially had a lower pressure drop in comparison the medium membrane-coated filter element. After qualification testing, this relationship was retained

Bulk Strength Analysis

As shown in Table 3, the strength of the coarse and medium membrane qualification tested DLC PRD-66 candle filters tended to be greater than the strength of comparable as-manufactured filter elements. As previously demonstrated by Westinghouse, the bulk strength of the DLC PRD-66 matrix tended to increase during simulated or field exposure [2] This was considered to result from the bulk vs. barrier filtration characteristics of the material, whereby submicron and micron fines penetrated through the membrane of the PRD-66 filter element and become entrapped within the filter wall. Although divot formations along the outer membrane did not occur during the qualification test program, the potential may still exist during extended

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[4] Sections of both the coarse and medium membrane-coated, qualification-tested, PRD-66 filter elements were also returned to DLC on June 20, 1997, for additional inspection and characterization.

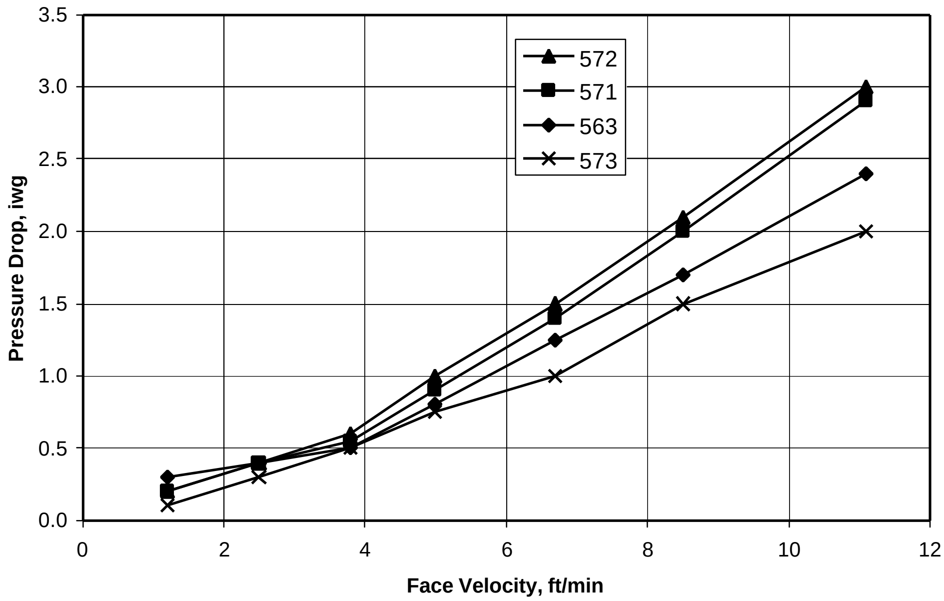

Figure 6 – Room temperature gas flow resistance measurements of the course membrane PRD-66 candle filters.

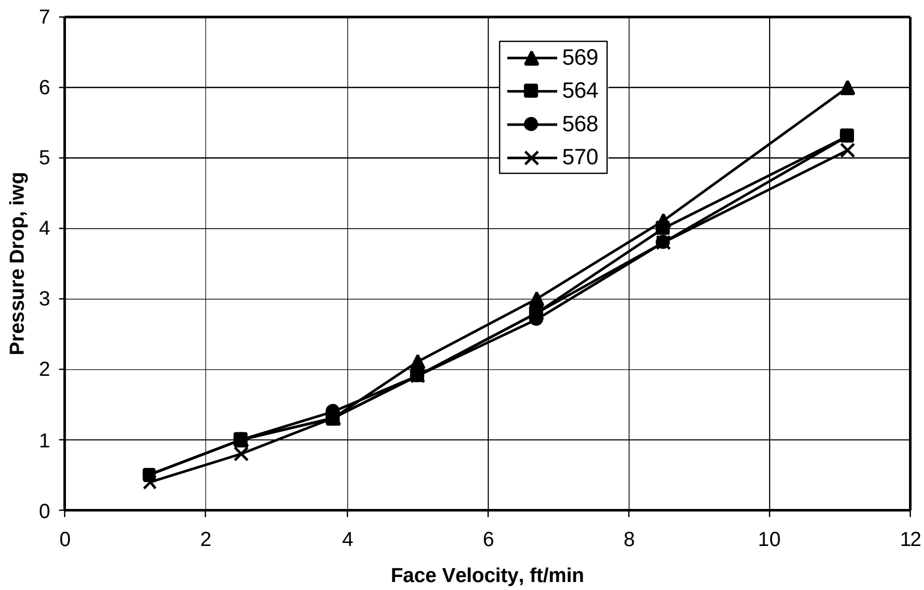

Figure 7 – Room temperature gas flow resistance measurements of the medium membrane PRD-66 candle filters.

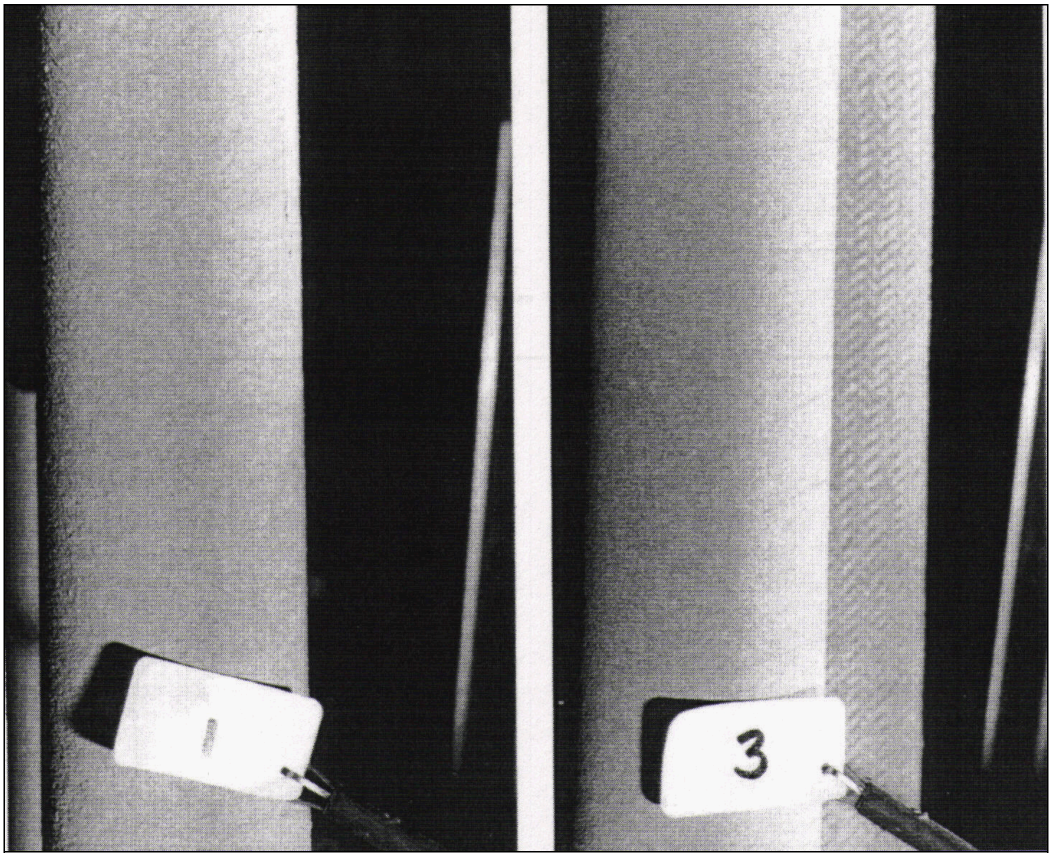

Figure 8 – Photograph illustrating the residual ash cake layer that remained along the outer surface of the PRD-66 candle filters after qualification testing that was conducted under simulated PFBC conditions.

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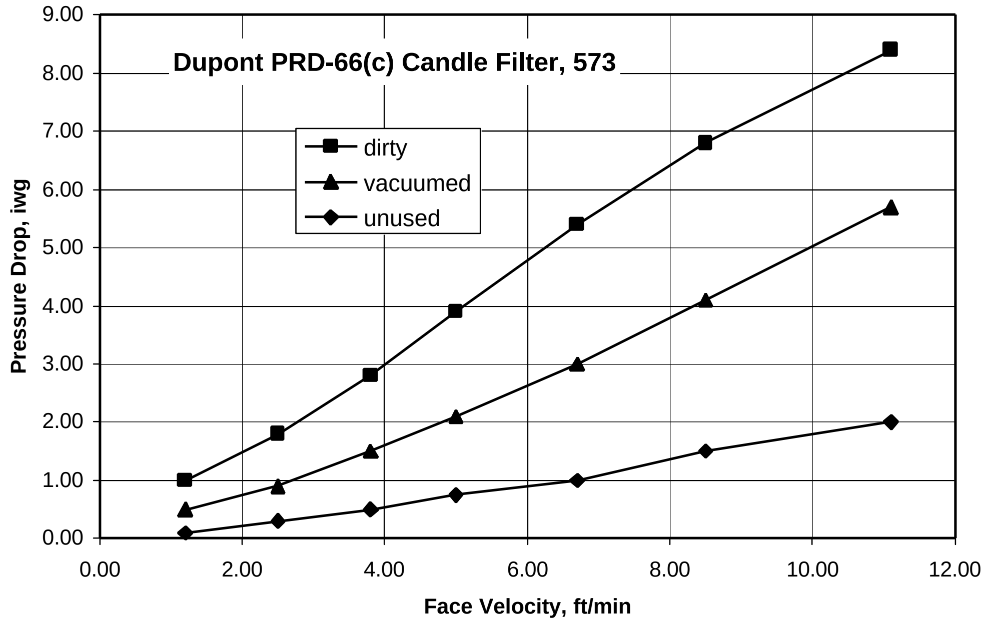

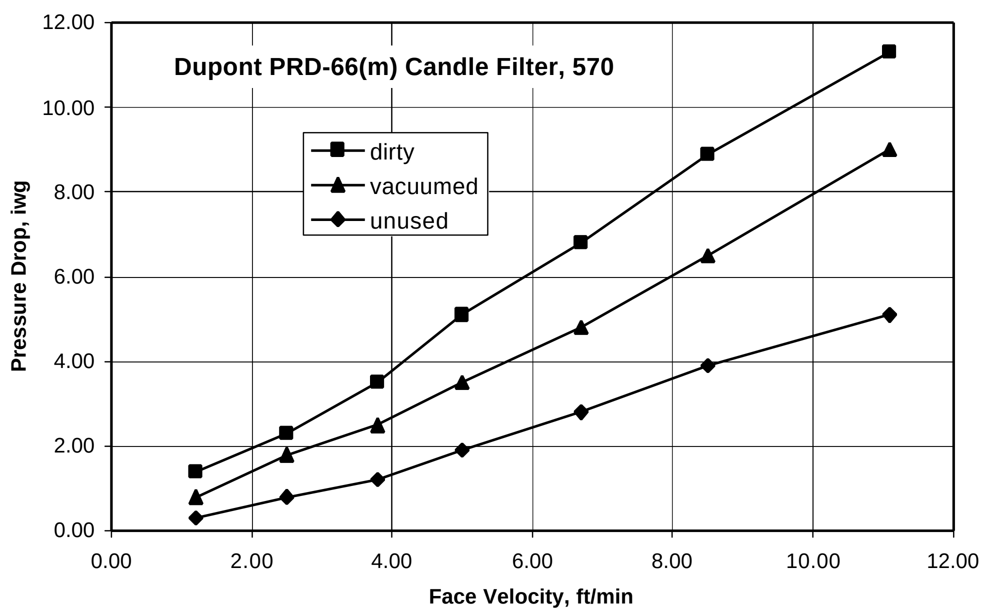

TABLE 3

ROOM TEMPERATURE AND PROCESS STRENGTH OF THE AS-MANUFACTURED AND QUALIFICATION-TESTED DUPONT PRD-66 CANDLE FILTERS					
Candle Identification Number	Status	C-Ring Compressive Strength, psi		C-Ring Tensile Strength, psi	
		25-degC	843-degC	25-degC	843-degC
DuPont PRD-66 (Coarse Membrane)					
D-563c	As-Manufactured	955+/-62 (9)	962+/-92 (8)	809+/-154 (9)	1009+/-103 (7)
D-573c	Qualification Tested	1214+/-67 (9)	1210+/-86 (9)	990+/-82 (9)	1195+/-166 (9)
DuPont PRD-66 (Medium Membrane)					
D-564m	As-Manufactured	990+/-130 (9)	883+/-79 (9)	846+/-105 (9)	918+/-104 (9)
D-570m	Qualification Tested	1021+/-127 (9)	1019+/-88 (9)	973+/-165 (9)	1193+/-149 (8)

TABLE 4

ULTIMATE LOAD APPLIED DURING STRENGTH CHARACTERIZATION OF THE AS-MANUFACTURED AND QUALIFICATION-TESTED DUPONT PRD-66 CANDLE FILTERS					
Candle Identification Number	Status	C-Ring Compressive Load-to-Failure, psi		C-Ring Tensile Load-to-Failure, psi	
		25-degC	843-degC	25-degC	843-degC
DuPont PRD-66 (Coarse Membrane)					
D-563c	As-Manufactured	8.2+/-0.5 (9)	8.2+/-0.9 (8)	5.2+/-1.1 (9)	6.7+/-0.7 (7)
D-573c	Qualification Tested	10.3+/-0.6 (9)	10.3+/-0.6 (9)	6.4+/-1.2 (9)	7.6+/-1.0 (9)
DuPont PRD-66 (Medium Membrane)					
D-564m	As-Manufactured	8.0+/-0.9 (9)	7.3+/-0.6 (9)	5.2+/-0.6 (9)	5.7+/-0.6 (9)
D-570m	Qualification Tested	8.3+/-1.0 (9)	8.3+/-0.8 (9)	6.1+/-0.9 (9)	7.4+/-0.8 (8)

field operation, particularly if thermal expansion of the ash fines occurs within the filter wall during plant startup cycles [3], or hydration of the ash resulted during shutdown cycles.

In relation to alternate filter elements [4], the PRD-66 candle filter body was considered to be a moderately low load bearing matrix (Table 4). Additional material properties as burst strength, modulus, and Poisson's ratio, which were developed at Westinghouse are provided in Table 5.

X-ray Diffraction Analysis

An alternate explanation for increased strength conceivably is through crystallization of the matrix as a response of the material to the process gas chemistry and operating temperature. X-ray diffraction (XRD) analyses of the PRD-66 filter matrix identified the presence of 30% cordierite and ~50% α-alumina, with mullite as a minor phase. The XRD patterns for the as-manufactured coarse and medium membrane matrices, and qualification-tested coarse and medium matrices appeared to be virtually identical. Since neither the qualification test exposure nor coarseness of the membrane affected phase assemblage, the concept of increased bulk strength as a result of fines infiltration was supported.

Microstructural Characterization

Sections of the PRD-66 filter matrices were removed from the qualification-tested filter elements, and were subjected to microstructural analyses via scanning electron microscopy energy disperse x-ray analyses (SEM/EDAX). Figures 10 and 11 illustrate the surface morphology of the coarse membrane-coated, qualification-tested, PRD-66 filter element. Random areas of ash were identified along the outer surface of the "cleaned" filter element (i.e., Area 1, Figure 10: relatively ash-free surface; Area 2, Figure l0: presence of fines). Although what appeared to be limited adherence of ash along the outer surface of the element, when viewed at higher magnification (Area 1, Figure 11), fines were readily seen to entrapped between adjacent, slurry deposited alumina-rich grains which formed the outer membrane surface. When viewed in cross-section, the fine graine membrane was seen to be adherently bonded to the underlying filament wound support fiber bundle structure (Figure 12). At higher magnification, ash fines were seen to be attached to individual grains contained within the membrane layer(Figure 13). Based on the microstructural analyses of the "cleaned", coarse membrane-coated, PRD-66 filter, the open porosity of the element was nearly completely retained after being subjected to simulated PFBC, qualification testing.

Similar microstructural analyses were conducted on the medium membrane-coated, qualification-tested, PRD-66 filter element. As shown in Figure 14 (i.e., Area 1), areas of ash were retained along the outer surface of the candle. When viewed at higher magnification, ash fines (Area 1, Photo 3, Figure 15; Photo 4, Figure 15) were seen to be contained between adjacent alumina-rich grains that were present in the outer membrane (Area 2, Photo 3, Figure 15). When fresh fractured, the cross-sectioned PRD-66 filter wall appeared to retain its relatively open porosity through both the membrane, as well as underlying filament wound structural support (Figure 16). At higher magnification (Figure 17), isolated ash fines were identified to adhere to either the outer surface of the alumina-rich membrane grains, or to the outer surface of the filament wound fiber bundles.

TABLE 5

MATERIAL PROPERTIES OF THE AS-MANUFACTURED AND QUALIFICATION-TESTED DUPONT PRD-66 CANDLE FILTERS					
Candle Identification Number	**Status**	**Burst Pressure, psi**	**Ultimate Hoop Stress, psi**	**Modulus, psi x 10^6**	**Poisson's Ratio**
DuPont PRD-66 (Coarse Membrane)					
D-563c	As-Manufactured	148	555	7.96	0.86
D-573c	Qualification Tested	158	597	6.11	0.82
DuPont PRD-66 (Medium Membrane)					
D-564m	As-Manufactured	180	691	7.09	0.84
D-570m	Qualification Tested	170	653	5.42	0.84

TABLE 6

Pressurized Circulating Fluidized-bed Combustion Testing at the Foster Wheeler Test Facility in Karhula, Finland - TS2-97	
Date	September 4, 1997 – November 7, 1997
Number of Filter Elements Tested	8
Filter Operating Temperature, deg.C	700 - 750
Filter Operating Pressure, bar	9.5 - 11
Coal Feed	Eastern Kentucky
Sorbent	Florida Limestone
Time, hrs	581 (6)*, 342 (1), 239 (1)
Face Velocity, cm/sec	2.8 - 4.0
Particle Load, ppmw	6000 - 9000
Particle Size, microns	< 1 - 150
Thermal Excursions	None
Number of Startup/Shutdown Cycles	7

* All elements remained intact. The number in parentheses indicates the number of elements exposed for the respective PCFBC operating hours.

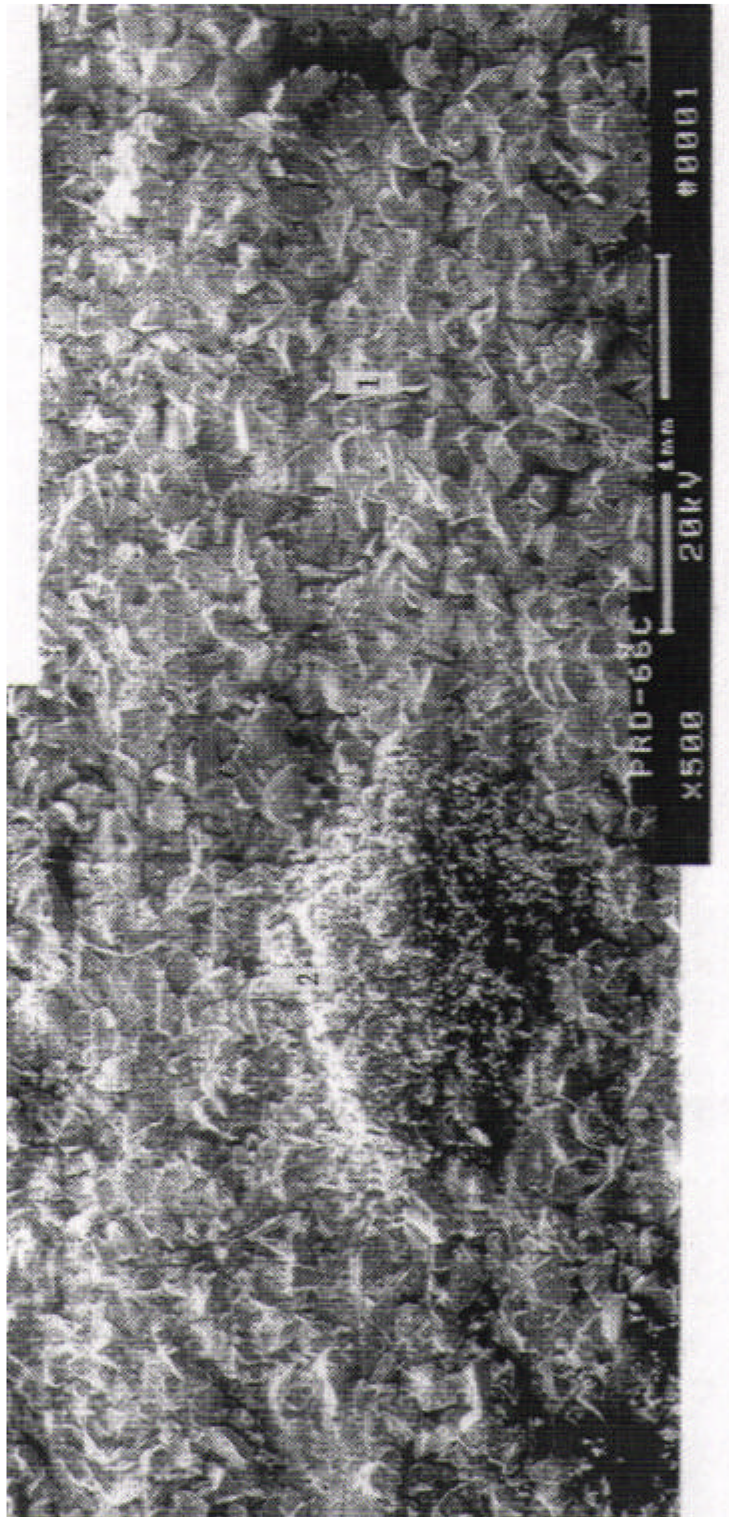

Figure 10 – Micrograph montage illustrating localized adherence of ash fines along the outer surface of the qualification-tested, coarse membrane-coated, PRD-66 filter element.

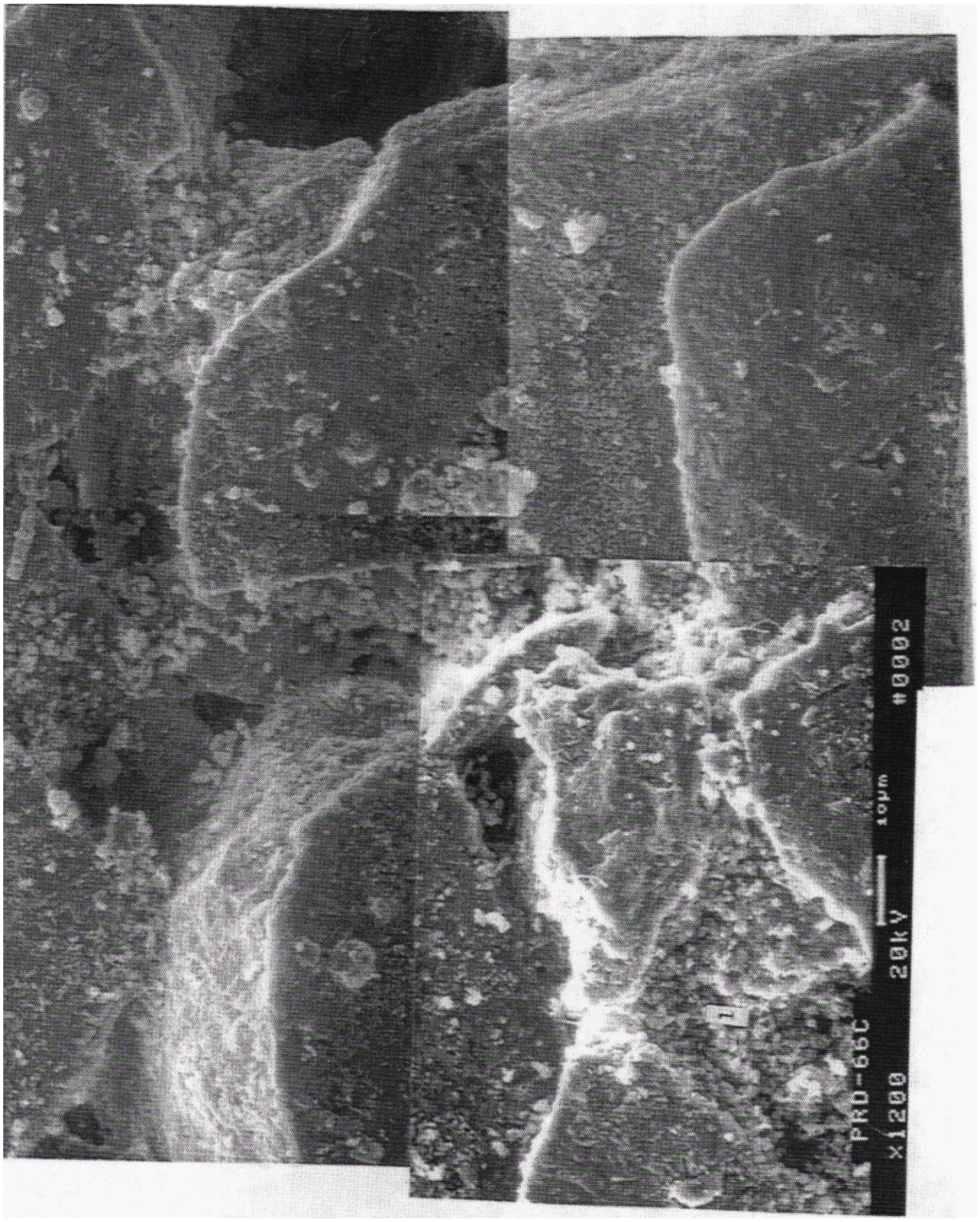

Figure 11 – Higher magnification micrograph montage illustrating the adherence of ash fines between adjacent alumina-rich grains present along the outer surface of the qualification-test, coarse membrane-coated, PRD-66 filter element.

Figure 12 – Micrograph montage illustrating the morphology of the cross-sectioned filter wall of the qualification-test, coarse membrane-coated, PRD-66 filter element.

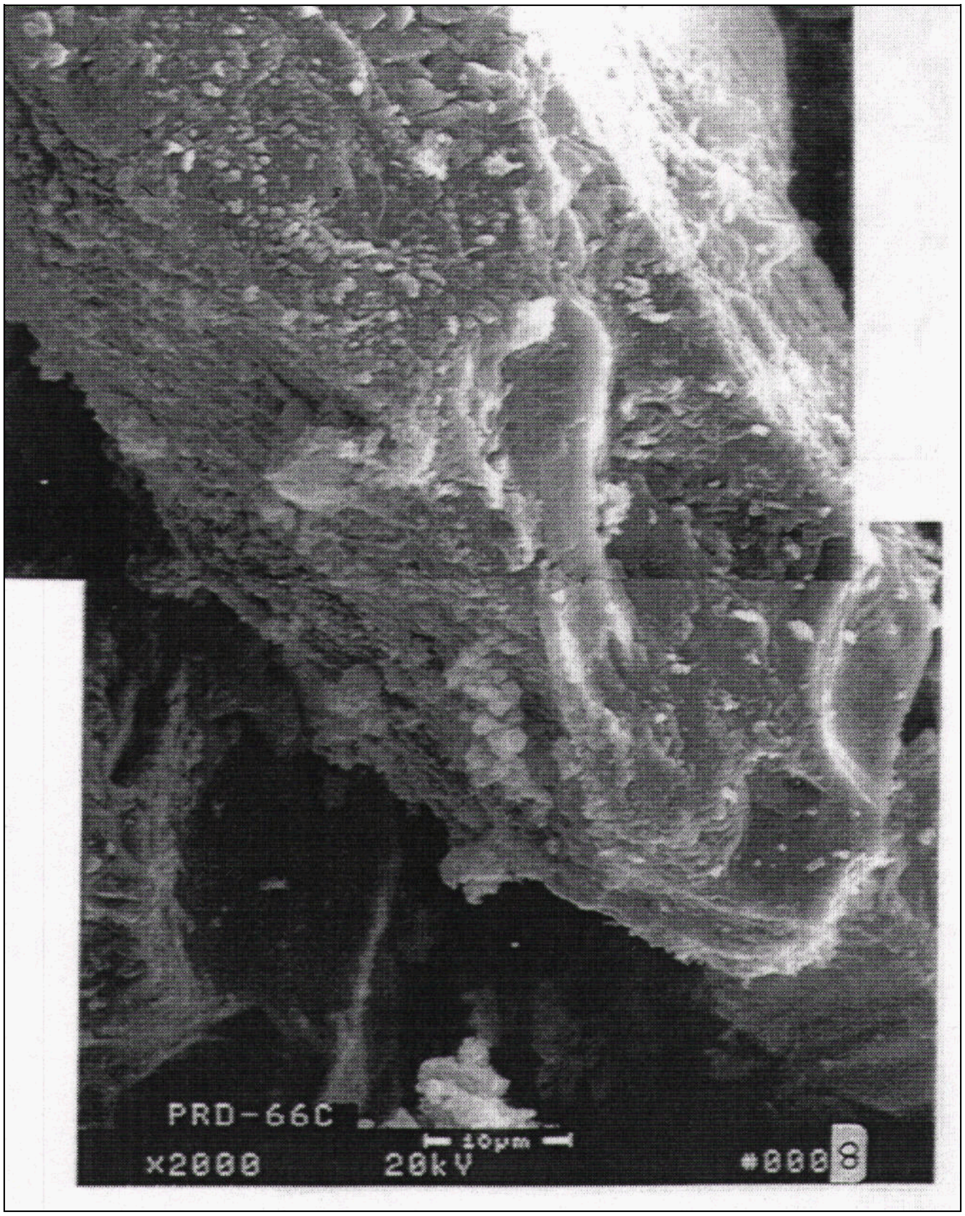

Figure 13 – Adherence of ash fines along the surface of the alumina-rich grains that were present within the outer surface membrane of the qualification-tested PRD-66 filter element.