Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10685

Impact of the residual quartz to the expected lifetime of C-130 alumina porcelain high voltage insulator

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Motivation

It is a known fact that residual quartz in a C-130 alumina porcelain high voltage insulator can negatively affect the expected lifetime. Residual quartz (SiO_2) decreases porcelain's mechanical strength as it causes internal stresses and microcracks. During cooling, quartz transition (from β to α at 573 °C, so-called "quartz-zone") results in particle volume change which causes stresses sufficient to crack the quartz particles interface with the matrix. The severity of the microcracks depends on particle size and cooling rate. The microcracks propagate in the body under normal service stresses and may ultimately lead to the failure of an insulators before the anticipated lifetime. It is recommended that the residual quartz be kept below 1% of the microstructure and some utilities and OEM's manufacturing high voltage equipment have introduced the residual quartz limitation in their own specifications.

Objects of investigation

There is very little published data on what exactly the critical value for the quartz content and particle size is and how it would affect the lifetime of an insulator. Recent studies of field-aged high voltage insulators reveal increased field aging and loss of mechanical strength with increasing quartz content. This aspect is important to understand when the remaining lifetime of aging porcelain insulators in an overhead line or substation is evaluated.

Method

In this study, quartz particles, as "calibrated defects", were intentionally added to C-130 alumina porcelain body laboratory test bars to simulate the effect in laboratory conditions. We hoped that would allow us to quantify the influence of quartz on quartz-free porcelain composition. The quartz content was confirmed by a mineralogical analysis of the fired samples.

Experimental setup

In this study quartz grains with a size of 200 µm and 64 µm were chosen as defects. The 64 µm fraction was selected because this fraction is close to the A. Rawat and R. S. Gorur findings, that samples with > 50 µm quartz failed on punctuation. Fassbinder proposes that the optimum strength is achieved when the residual quartz is not bigger then 20 µm.

The base-material was the standard industrial C-130 granulate used for the manufacturing post insulators in PPC Insulators at Cab. The basic recipe is:

•	Feldspar	26 %
•	Chamotte	20 %
•	Clay	20 %
•	Alumina	34 %

The quartz particles were mixed into the base-body in the wet laboratory mill by 1 wt.%, 2 wt. % and 4 wt.%. Test-bars with 0 wt.% added quartz were made of the same batch of body to get the baseline. The body was pressed in the laboratory (Fig. 1) and extruded with the laboratory extruder (Fig. 2) to a 10 mm diameter and 150 mm long test-bars.

After drying the bars were manually glazed by dipping (Fig. 1). After glazing the samples were fired in the normal production kiln (Fig. 2). On the Figure 5 we see a ready fired Test bar.

Fig 1. Manual sample glazing in laboratory

Fig 2. Sample firing on the production kiln.

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Experimental setup

The 3 point-bending machine (Fig. 3) was used to break and submit the samples under cyclic loading. First the base-strength was tested, then other samples were cycled with 50 % and 80 % of the measured breakage strength and after cycling loaded to breakage. It was decided to start with 100 and 500 cycles. (Fig. 7) . The limitation factor is that the 3-point bending machine allows about 200 cycles per working day.

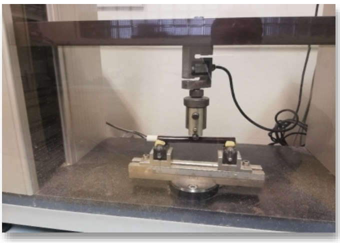

Fig 3. The laboratory 3 point-bending machine.

After the breakage the test-bars were inspected to be sure that the breakage was not caused by an external defect on the glazing or impurities on the body. (Fig. 4)

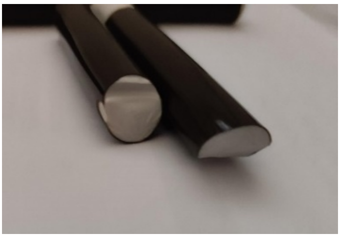

Fig 4. A broken test-bar ready for brakeage surface inspection.

Results

10 samples of two test series with 64 µm and 200 µm quartz particles were broken at the 3-point bending test-machine without cycling. The results are on the table 1.

Quartz		Rmo (MPa)	Standard deviation	Weibull modulus
64 µm	0%	194.45	7.06	30.7
	1%	184.56	10.00	20.6
	2%	182.70	5.32	37.4
	4%	179.07	4.10	48.1
200 µm	0%	192.44	4.74	44.7
	1%	135.01	13.67	10.4
	2%	132.25	12.41	11.5
	4%	113.57	3.16	36.2

Table 1. Base-line results

Results

The first observation here was that the drop of the mechanical strength was visible already at 1 wt.% of added quartz. Increasing the quartz further didn't have the same impact, apart from the samples of 4 wt.% of 200 µm quartz particles, where another drop was observed.
The first cycling was selected to be 50 % and 80 % of the measured average breakage force for 100 cycles for the 200 µm quartz particle size test series.
On the figure 5, we can see the results of the first two cycling series.

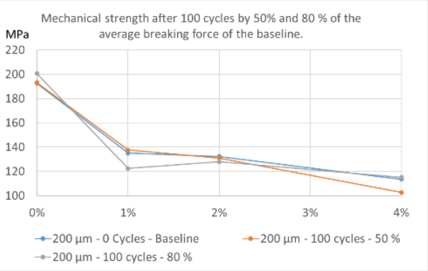

Fig 5. Mechanical strength after 100 cycles by 50% and 80 % of the average breaking force of the baseline.

We can see from the fig.5 , that there is not significantly difference between graphs. The conclusion was that the quantity of cycles was too low to cause measurable crack-growth. The similitude of the curves with high Weibull modulus is a clear indication that there was only one failure mode. This means the base material was homogenous, and eliminates the failures caused by impurities or non-homogeneous structure. Therefore, when there are measurable differences, it would be caused by the added quartz particles.

The cycling was increased to 500 cycles. The results are on the figure 6.

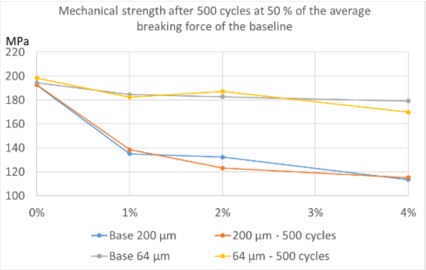

Fig 6. Mechanical strength after 500 cycles at 50 % of the average base-line breaking force.

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(continued)

Results

The mineralogical analysis was executed in an external laboratory and is presented in the table 2.

Quartz		Corundum (%)	Quartz (%)	Mullite (%)	Residue-SiO_2 (%)
64 µm	0%	32.56	0.89	19.7	46.8
	1%	32.73	0.63	19.5	47.1
	2%	31.00	0.71	19.3	49.0
	4%	32.16	1.68	20.0	46.2
200 µm	0%	34.19	0.86	19.6	45.3
	1%	33.17	1.17	19.2	46.4
	2%	31.84	1.75	19.0	47.4
	4%	32.09	3.11	18.9	45.9

Table 2. Mineralogical

Discussion

The baseline of the 3-point bending tests results allows us to immediately to confirm the important impact of quartz on the mechanical strength caused by as little as 1% of quartz in the mineralogical structure. This is fully in line with the Lieberman studies on the impact of the quartz content.

Further we can see the importance difference between 64 µm and 200 µm particle size. The size is known as a critical factor, but the critical limit is less evident as there are only a few papers referring to the quartz particle size. A. Rawat and R. S. Gorur showed that large size > 50 µm quartz particles did reduce the strength, while Fassbinder proposes that the size below 20 µm does not affect the strength.

The particle size of the C-130 body is directly related to raw-materials and the manufacturers milling process. 200 µm particles are rare on the plastic ceramic body, but they are not excluded as a residual fraction of the grain size distribution or contamination. A small 64 µm particle fraction is normally present plastic manufacturing process.

There is an interesting observation on the mineralogical analyses of the samples. The 200 µm size particles were increasing the quartz content proportionally to the added quartz content. The 64 µm samples did not show such a direct relationship. The samples 1 wt.% and 2 wt.% quartz showed similar quartz content to the base-material with 0 wt.% added quartz. Only 4 wt.% quartz addition was enough to show an increase of quartz above 1 wt.% after firing. This suggest that some of the 64 µm particles were melted to the glaze-phase during the firing process. In any case, the residual quartz particles were big enough to cause a loss of strength compared to the base material.

Discussion

At the beginning of the study there was no indication what the optimal cycling frequency and force would be. The cycling of the test bars by 100 and 500 times with 50% and 80% of the average strength was not enough to cause a measurable crack propagation. On real life the stress cycles counts from tenths of thousands to hundreds of thousands or more. But the laboratory equipment didn't allow such a high number of cycles.

Future studies should use the approach of cycling to failure, if possible, within a reasonable time frame.

Conclusions

- The test method of “calibrated defects” to study the impact on C-130 ceramic material does work. The results are repetitive, and the used base-material is sufficiently homogenous to eliminate multiple failure mechanisms. The method can be used to study any kind of impurities.
- Already 1% quartz reduced the mechanical strength by 5% with 64 µm particles and 30 % with 200 µm particles. Increasing the quartz did not change the strength loss. We can conclude that the quartz particle size is more critical than the quantity and between 40 µm and 50 µm.
- The cycling was too low to cause any crack propagation, even with 200 µm 4% quartz samples and 80% of average breaking load. This demonstrates excellent fatigue resistance of the C-130 ceramic even with high density of structural defects.

BIBLIOGRAPHY

J. Lieberman, “Avoiding Quartz in Alumina Porcelain for High Voltage Insulators. American Ceramic Society Bulletin, Vol. 80 No 6, July 2001

J. Lieberman, “Reliability of materials for High Voltage Insulators. American Ceramic Society Bulletin, Vol. 79, No 5, May 2000.

A. Rawat and R. S. Gorur: “Microstructure Based Evaluation of Field Aged and New Porcelain Suspension Insulators”. IEEE Transactions on Dielectrics and Electrical Insulation (Volume: 16, Issue: 1, February 2009)

Gunter Fassbinder: “A new Ceramic Body Concept for High Strength HV Insulators”, Materials Science, August 2002.