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Technical comments for the selection of high quality toughened glass

This technical note is intended to summarize the key design and quality features to consider during the selection of toughened glass insulators for overhead transmission lines.

1. Recommendations for selecting high quality toughened glass

- Submission of at least three Performance Certificates issued by independent utilities from countries outside of the country of manufacturing, confirming very low self-shattering of glass insulators to guarantee low maintenance costs in operation.
- Perform Steep Front Wave test as a sample test on insulators taken at random out of production batch.
- Use only glass insulators assembled with hot cured alumina cement
- Perform Residual Strength test according to a test procedure based on IEC and CSA standards where a thermal preconditioning is required prior to the mechanical test itself which should achieve >80% of the mechanical rating.

One of the reason for toughened glass insulators to be today the preferred ceramic insulator for transmission overhead lines is the fact that unlike porcelain, toughened glass does not puncture, does not age and offers the best conditions for live line work. Nevertheless a few key elements linked to the quality of manufacturing are to be considered.

a. **Purity of the glass**: when melting the raw materials in the furnace, impurities will be generated coming from either un-melted raw material or particles coming from the refractory bricks in contact with the glass (figure 1). Such impurities if not properly eliminated will be the root cause of spontaneous shattering over the years, (especially during the first years of service). While a few shattered discs do not pose a problem for the operation of the line, it is nevertheless important to reduce to a minimum the number of stubs (broken glass insulator). To this effect Sediver has deployed over the last 30 years customized processes and screening methods eliminating the glass shells containing these impurities. The performance of Sediver glass insulators is well established by utilities which perform precise counts of shattered discs on their lines and the performance certificates attached to this document demonstrate (from independent sources) the unique performance of Sediver insulators with a shattering rate at or below 1/10000 discs a year. Such documents are key in the ability of a utility to verify the performance of a glass insulator manufacturer.

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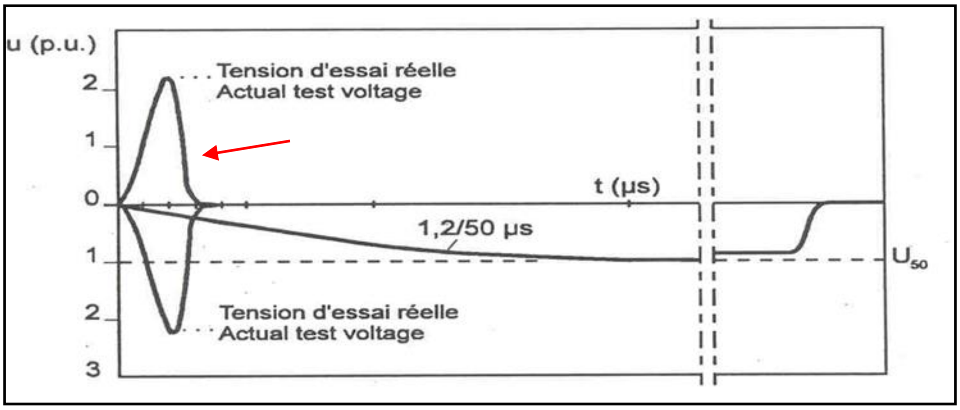
Figure 1: inside of a furnace after several years of operation: refractories are eroded (top). Examples of typical impurities found in glass (bottom)

b. **Quality of molding**: when molding the glass shell from a liquid drop into the final shape of the disc several defects (among other aspects) can be generated by the contact between the tooling and the glass itself. If not properly managed this operation can induce weaknesses which could make the glass shatter under severe overvoltage events during operation, as well as bringing a higher sensitivity to thermo-mechanical stresses... for this reason it is very important to know what defects to look for at the stage of manufacturing through a detailed inspection of every glass shell. Steep front testing is a test producing severe overvoltage conditions aimed at finding defects in dielectrics. This test should be performed not only as a type test but also at the stage of sample testing with samples randomly selected from any given lot.
Steep front has been introduced more than 20 years ago to replace the classical ANSI oil puncture test known to be too much driven by the type and quality of the oil used for the test. Steep front is a severe overvoltage in air therefore with a perfect reproducibility and is fully described in IEC 61211. Additionally CSA 411.1-16 offers a protocol (figure 2) where such characteristics are tested in combination with a thermo-mechanical preconditioning. Progressively we see utilities concerned about quality and performance pushing such tests at the level of sample tests.
(Note that, worldwide, steep front testing has largely replaced the old ANSI oil test, especially since it also weeds out low quality porcelain insulators in which the structure of the porcelain material, mainly internal microcracks are not easily spotted with the old procedure).



Comparison between a lightning impulse test and a steep front test (red arrow)

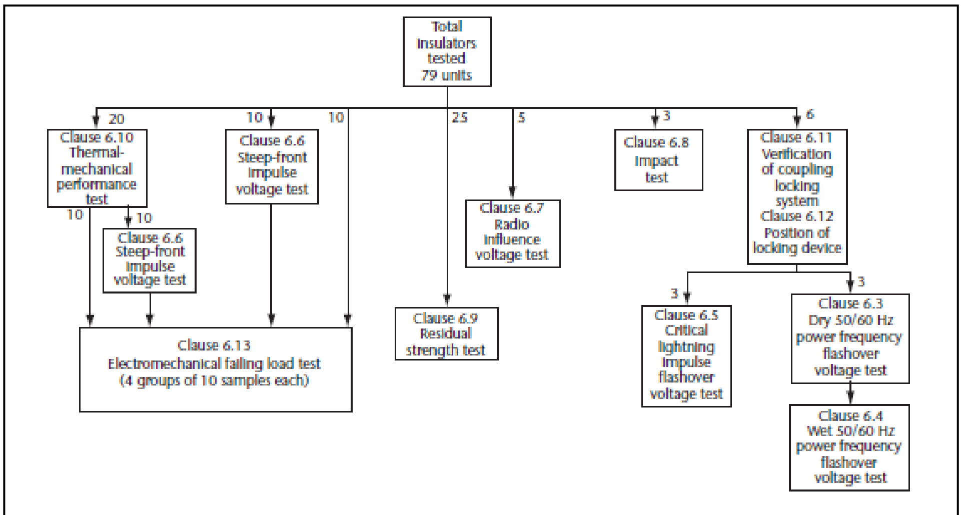
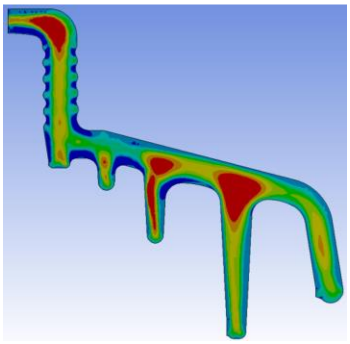


Figure 1
Schedule B type test program
(See Clause 6.2.4.2.)

Figure 2: extract of CSA 411.1-16; Appendix D

c. **Toughening:** in this step of the process the glass shell is rapidly cooled down providing a balance between internal extension forces and compressive forces along the surface of the glass shell (figure 3). This operation will therefore make the glass mechanically very strong (4 times stronger than porcelain in an impact strength test) but it is also the reason why toughened glass has a binary behavior (figure 4). Either intact or totally shattered toughened glass has this unique ability to be binary offering the easiest inspection technique for maintenance crews. Likewise since any damage to the glass results in a complete shattering (thanks to toughening) any electrical flashover of a string will result in an external flashover and not an internal puncture like for porcelain.

The toughening process needs to be completely under control and "low quality manufacturers" have promoted the idea that "more toughening is better" with a claim that their glass is stronger. Reality is different and toughening needs to be adjusted to impart the proper strength all along the profile of the glass disc.



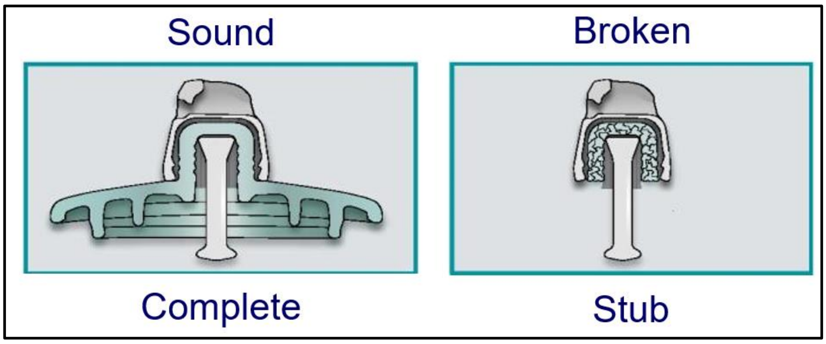


Figure 3 and 4 : internal stress of toughened glass. Binary behavior of toughened glass

As can be seen in figure 5, some glass shells from some manufacturers do not shatter completely when damaged which can pose a major risk in the behavior of a stub either electrically or mechanically. Some experts started to recommend to examine the size of the glass culets after a glass insulator has shattered to verify if the size is consistent on a 360° rotation. Some utilities who had already some "low quality glass" in their stock have also noticed a deep difference in the size of such culets compared to reputable manufacturers.

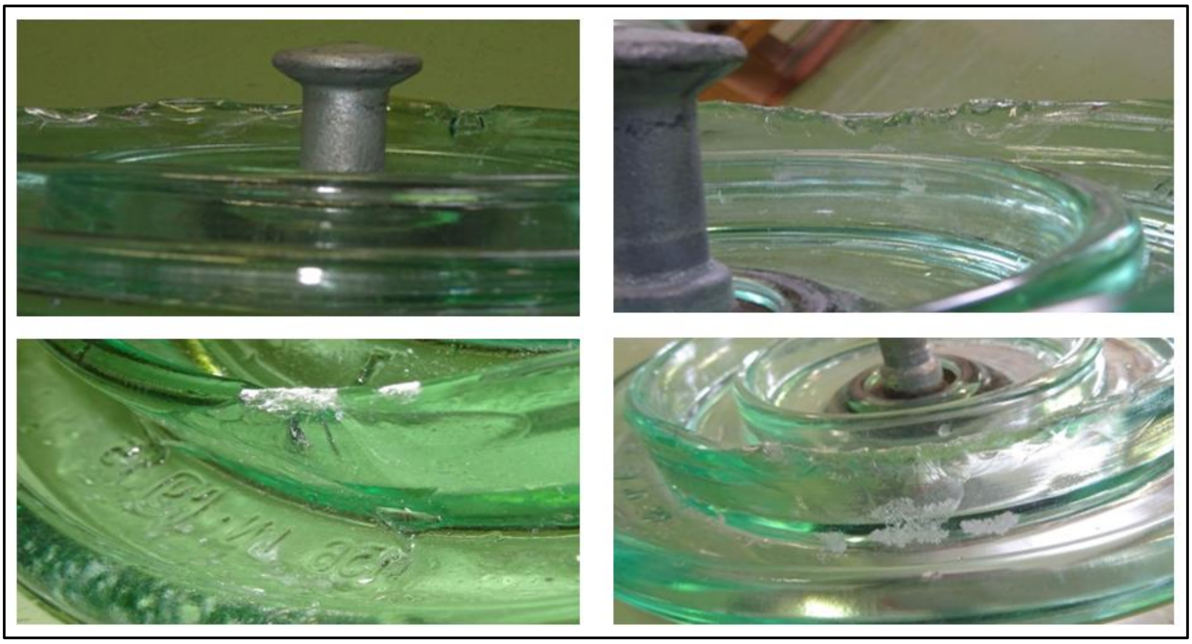


Figure 5: low quality glass with bad toughening: no shattering while damaged

d. **Cement and assembly techniques:** the assembly of the cap and the pin on the glass shell is made using cement. While Portland is less and less used (for reasons related to the risk of cement growth leading to either radial crack in porcelain or shattering of the glass) we see today a trend towards Alumina cement. The advantage of the latter is the fact that it is chemically inert and not expansive like Portland is. The particularity of alumina cement is in the curing process. The simplest and cheapest curing method is when the insulators are cured in cold water. Doing this makes the cement to cure in a hexagonal crystal which is unstable. It will progressively convert into a cubical shape (figure 6).

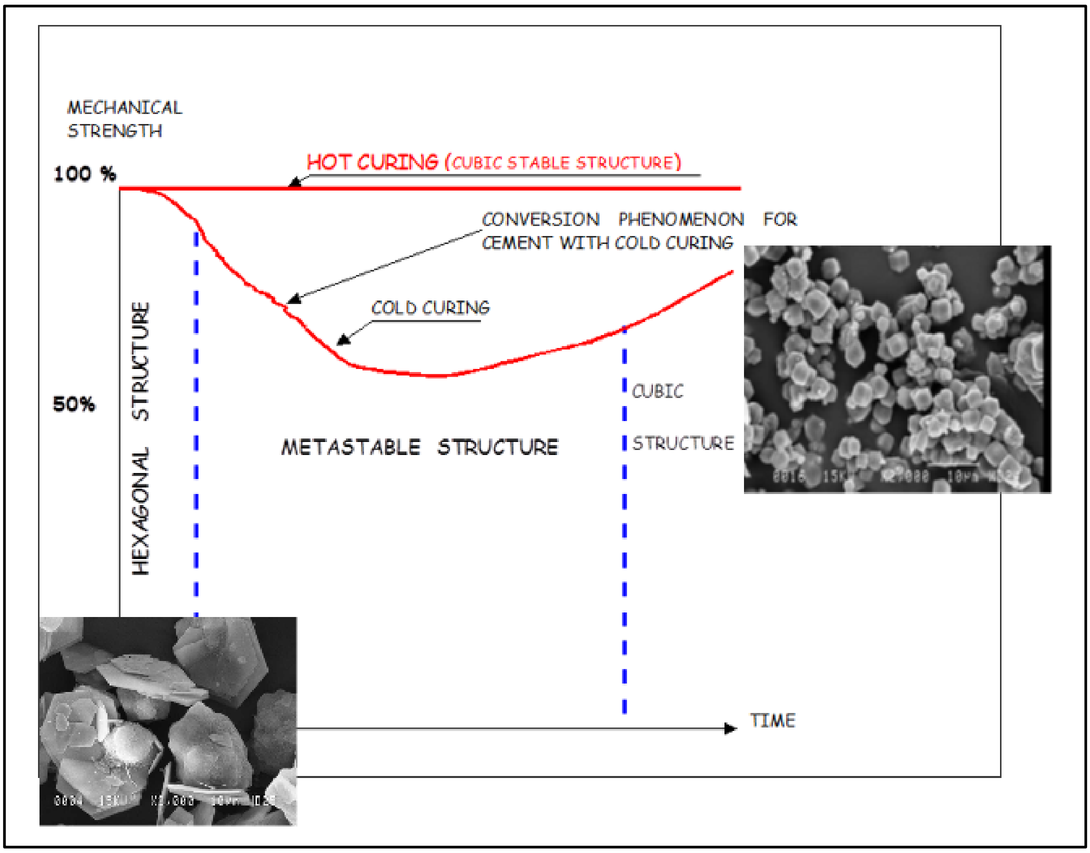


Figure 6: crystallographic structure of alumina cement as a function of curing and instability of the mechanical strength of cold cured cement over time

This conversion process translates into a decrease of the mechanical strength of the insulator which can reach 50% below the initial strength of the insulator (figure 7). To avoid this, good manufacturers will use only hot cured alumina cement which process takes place in a tank of water at an average temperate of 160F.

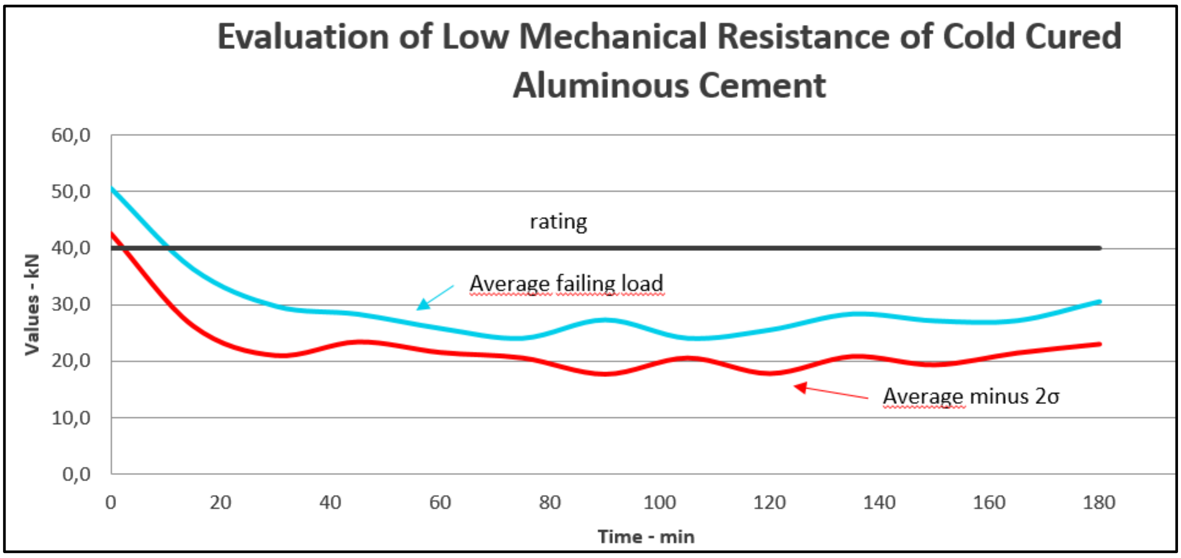


Figure 7: evaluation of the strength of alumina cement cold cured assembled insulators as a function of time in a hot bath (above 185F) accelerating the conversion from hexagonal structure to cubical crystal. This test helps visualizing the drop of strength which might occur otherwise after unpredictable time periods in service. (as low as 50% or less of the rating)

By doing so, the conversion to a stable cubical shape is immediate and the insulator has stable mechanical characteristics from the first day after production. This aspect is critical for mechanical reliability especially with new versions of ANSI C29 2B where mechanical strength is now required with 3 standard deviations, and the NESC code 2017 version where rule 277 is now allowing utilities to use insulators with effective loads at 65% of their ratings. (note that once again CSA 411.1-16 ask for a 4σ performance and many utilities are progressively shifting towards this requirement).

e. **<u>Residual strength test</u>** is a protocol designed to evaluate the mechanical performance of a broken insulator (porcelain or glass). ANSI C292-B is the least demanding test in this field with a strength requirement of 60% and without any thermal preconditioning. Sediver offers 80% with a test procedure based on IEC and CSA standards where a thermal preconditioning is required prior to the mechanical test itself. Specifications should evolve in this direction.
Another aspect of this test is the difference which might exist between mechanical test results on an intact insulator and the results on a stub (broken glass insulator). The values between the two conditions of an insulator should not be too different, and ideally one would expect the failure modes to be identical. Figure 8 below show an extract of test results from a "low performing manufacturer test report" where, even if the values remain acceptable, there is a huge difference between the range of values in residual strength test and those obtained on a normal insulator. This observation combined with the failure mode (a majority of pins pulled out) is a sign of a lack of control and mastering of the assembly method, cement properties and glass design.

N14
Rating: 140 kN
Failing load: 203kN
Residual: 120,8 kN

- Difference between intact and broken insulator: 40%
- All units fail by pin pull out

INSULATOR N°	BREAKDOWN FORCE (kN)	FRACTURE PATTERN
1	131,06	Pin disassembled
2	114,58	Pin disassembled
3	114,38	Pin disassembled
4	120,66	Pin disassembled
5	120,86	Pin disassembled
6	117,92	Pin disassembled
7	118,70	Pin disassembled
8	121,64	Pin disassembled
9	114,19	Pin disassembled
10	122,04	Pin disassembled
11	121,25	Pin disassembled
12	117,72	Pin disassembled
13	128,31	Pin disassembled
14	121,06	Pin disassembled
15	118,11	Pin disassembled
16	122,04	Pin disassembled
17	115,76	Pin disassembled
18	117,92	Pin disassembled
19	117,52	Pin disassembled
20	124,59	Pin disassembled
21	131,65	Pin disassembled
22	121,64	Pin disassembled
23	128,51	Pin disassembled
24	116,74	Pin disassembled
25	122,23	Pin disassembled

R = 140 kN.
$\overline{X}_R$= 120,84 kN.
s = 4,89 kN
$X_R \geq (1{,}2 \times proofload) + 1{,}645 \times s = 87{,}85 kN$

INSULATOR N°	MECH. FAILING LOAD (kN)	FRACTURE PATTERN
1	208,97	Glass
2	205,49	Glass
3	194,27	Glass
4	211,03	Glass
5	204,59	Glass
6	212,06	Pin
7	211,54	Glass
8	200,68	Glass
9	205,73	Glass
10	176,13	Cap

σ (kN) =	10,93	R =	140
$\overline{X}$ (kN) =	**203,05**		
$X \geq R + 3\sigma = 140 + 3 * 10{,}93 = 172{,}7$ kN			

<u>Figure 8:</u> Failure mode and spread of mechanical results in residual strength test of low quality insulators

f. **<u>Others</u>**: it is not uncommon to see some special features in some "low quality insulators". Among those figure 9 shows an example where some black varnish is covering the cement around the pin. While varnish is a normal feature on the pin metal itself (allowing a better mechanical stress distribution inside the insulator), it is not required on the cement itself. Furthermore, as can be seen the RIV level can radically change once this varnish disappears.

Some manufacturers, unable to have good RIV results will use this trick to pass type tests. This should not be allowed and clearly stated in a purchasing specification.

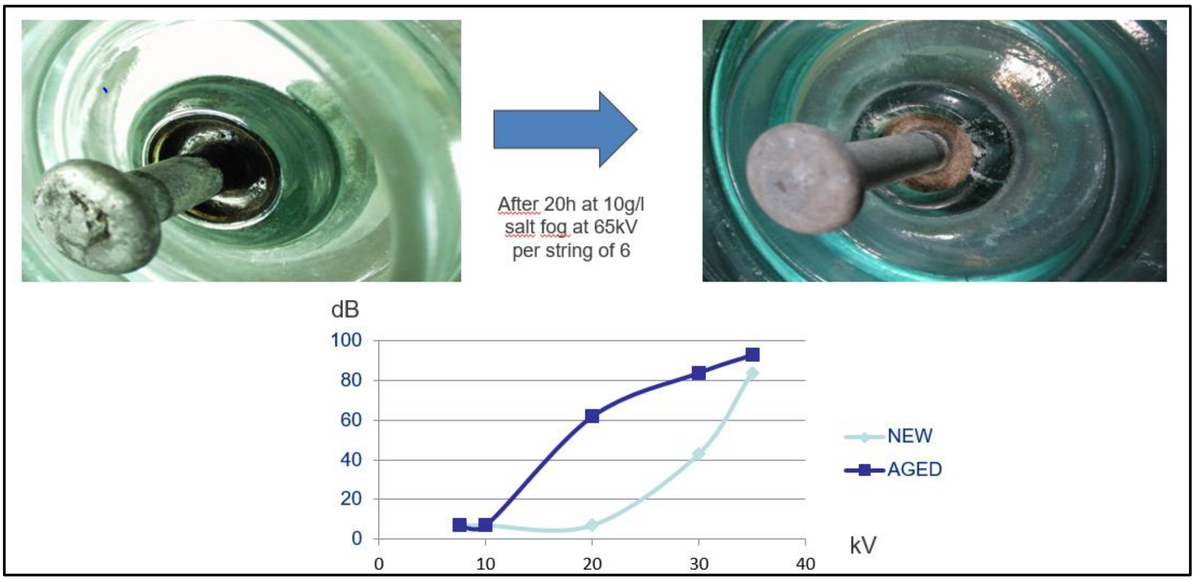


Figure 9: black varnish over the pin cement to mask poor RIV performance

Likewise some manufacturers are using plastic seals between the cap and the glass shell to reduce RIV, corona and discharges leading to cap base corrosion. It has been clearly established that most of this plastic rings do not last and produce more uncontrolled corona discharges and RIV once worn out compared to a good insulator. The benchmark in this field is a design where a “flock” material is bonded to the base of the cap prior to assembly (figure 10).

Figure 10: thermal degradation of plastic rings at the base of the cap (picture at right shows a cap with “flock” applied at the base of the cap prior to being assembled.