Bottom structure proposals to increase the thermal cycles resistance

Application to Ultra Clear Glass & Electric boosting applications

TC 11 meeting at SGRP - 2023-12-13

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Furnace A
Post Mortem audit by GPR - General overview

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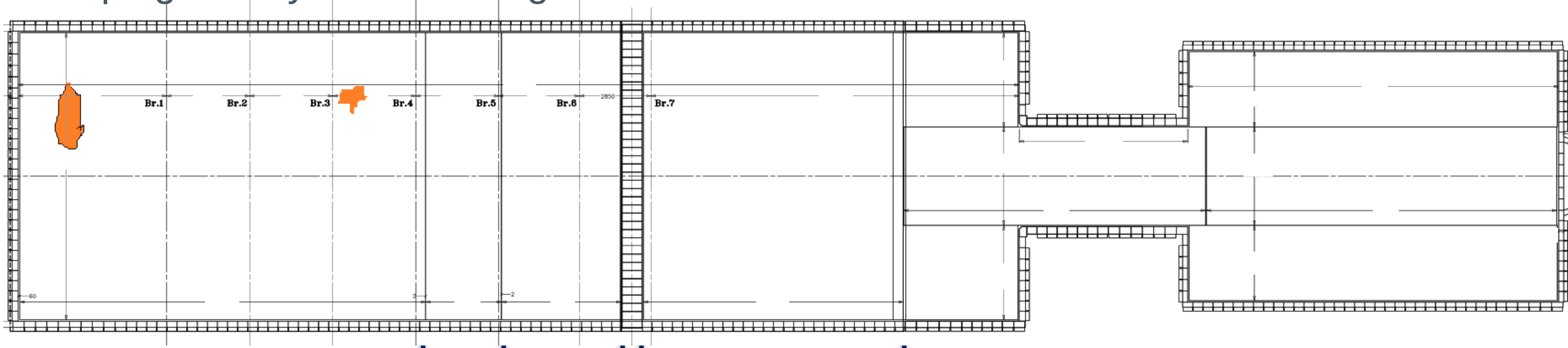
Campaign : 15 years – clear glass



Thicknesses: 120mm | 200m | 150mm | 100mm | 75mm

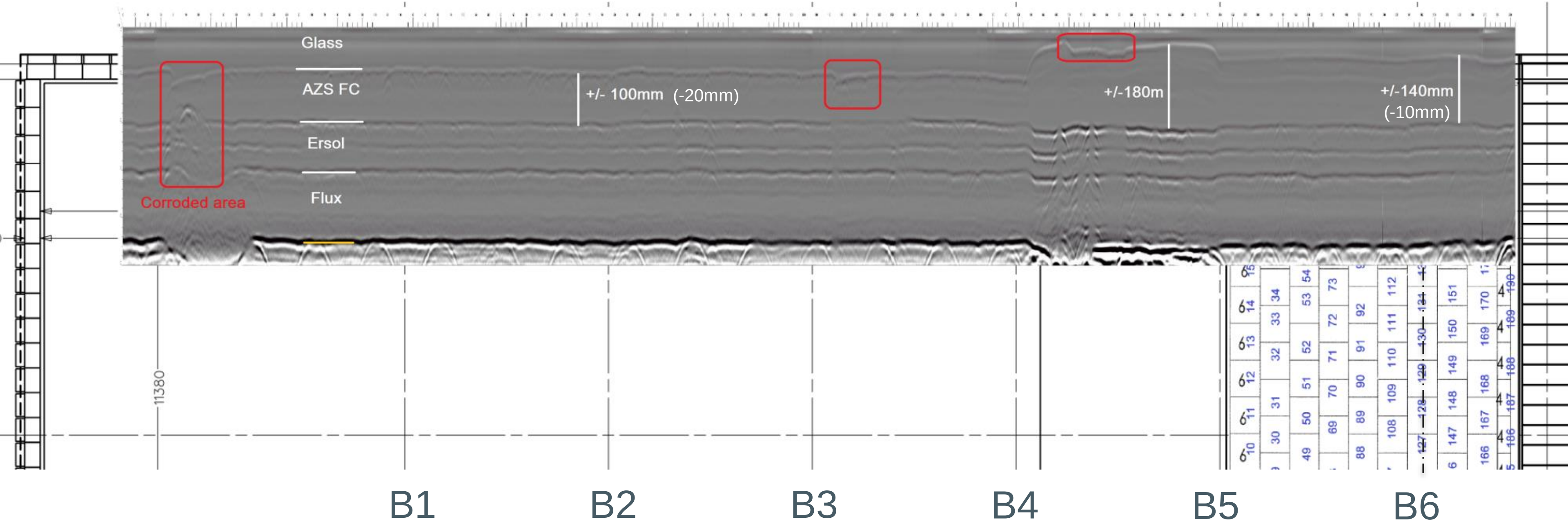
Few local glass infiltration indicated in orange
Homogenous wear -20mm)

Corrosion @ bubblers

Good state
Homogeneous wear
(-10mm)

Furnace A - Melter overview (GPR survey)

Campaign : 15 years – clear glass



Furnaces B & C
Post Mortem audit by GPR - General overview

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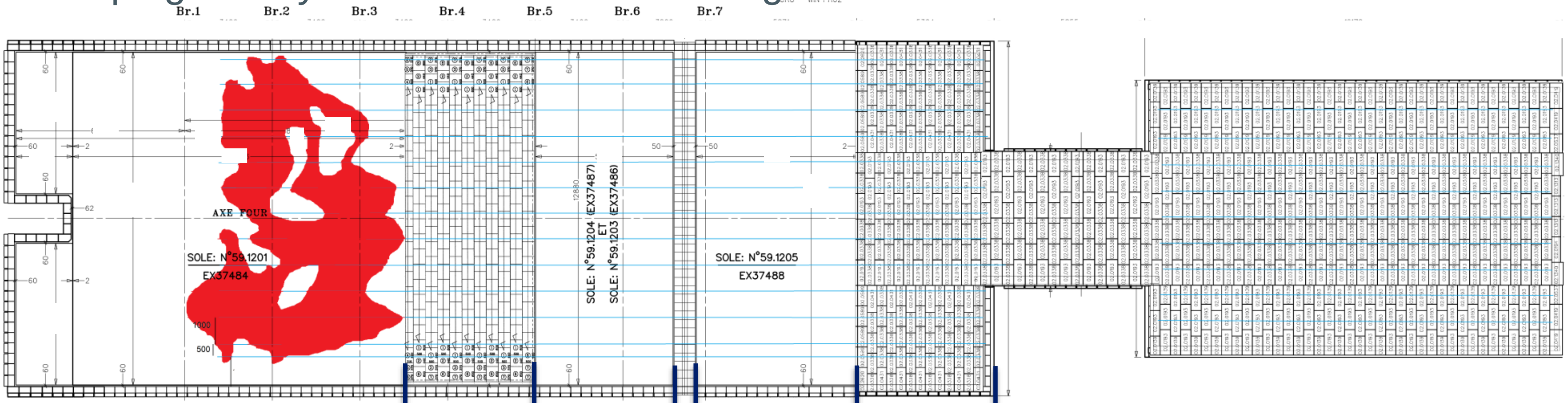
Campaign : 18 years – clear & ultra clear glass



Thicknesses: 120mm | 200mm | 120mm & 75mm | 100mm

Strong corrosion & glass infiltration
Red area = AZS paving disappeared

Corrosion @ bubblers

Good state & no glass infiltration
Sub pave not corroded

Moderate corrosion

Al2O3 paving - ridged

Good state (salvaged area)

Furnace B - Melter overview (central line)

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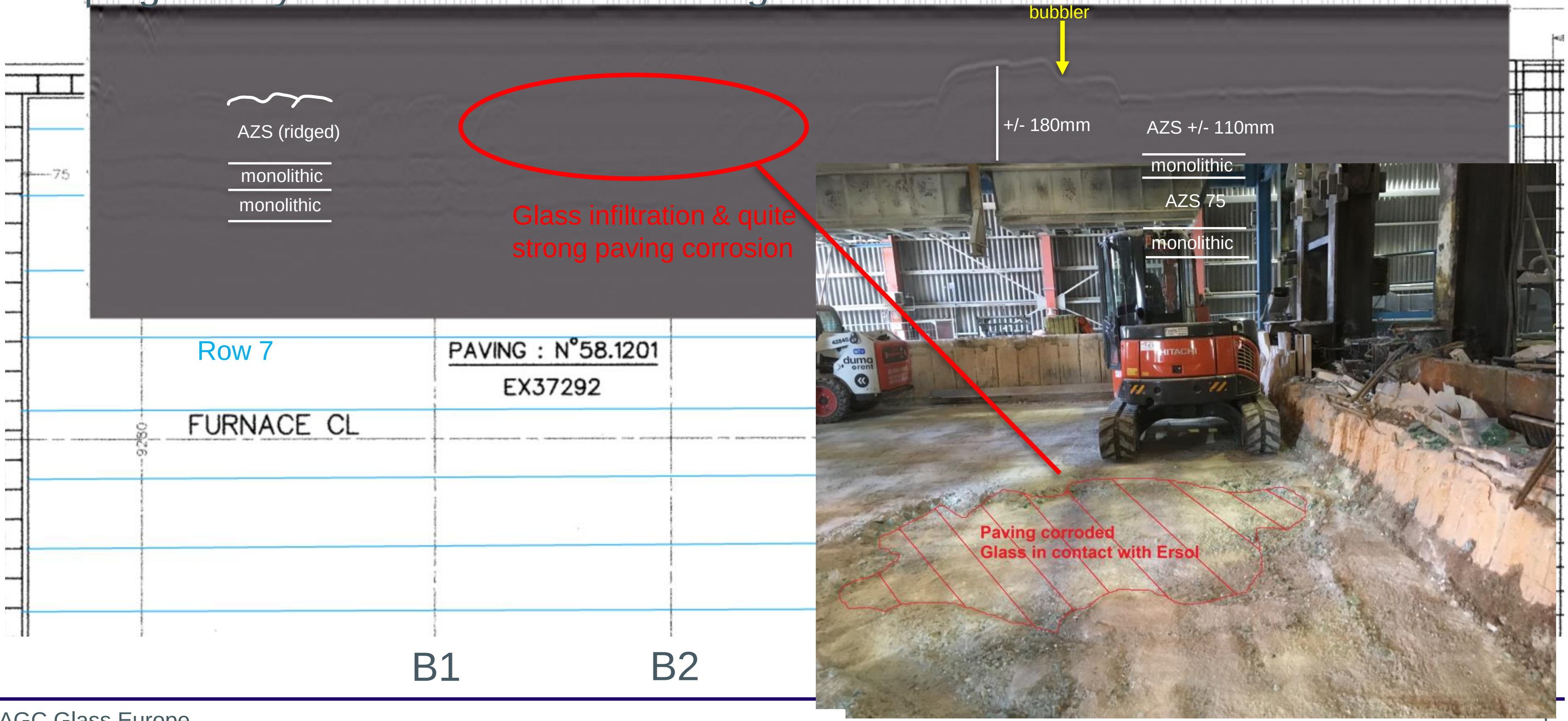
Campaign : 18 years – clear & ultra clear glass



Furnace C - Melter overview (central line)

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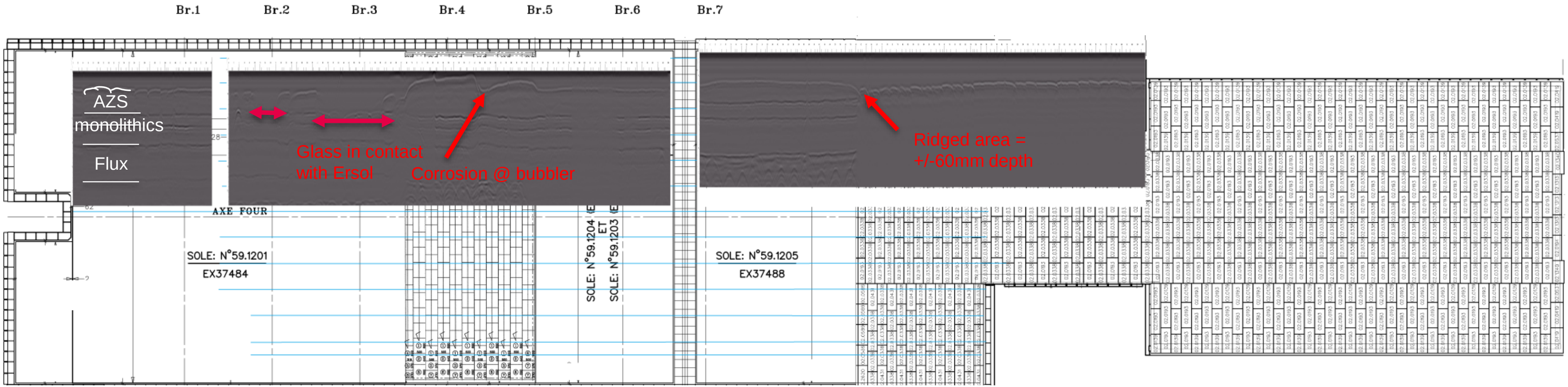
Campaign : 18 years – clear & ultra clear glass



Observations

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The GPR analyses of the furnaces B & C pavings after 18years campaign indicated a similar evolution

1) Strong corrosion of the pavings upstream the bubblers area.
2) The paving dedicated to the bubbler area is corroded only at the bubblers location.
3) The paving between the bubblers and the dam wall is not corroded. The sub paving is not touched by the glass.
4) The Al_2O_3 paving is ridged in the stagnant area.
5) The Al_2O_3 paving is not corroded in the neck and in the conditioning end

Discussions (1/5)

- For furnaces B & C, we observed a similar corrosion in the pavings whilst in the past, the pavings were moderately corroded.
- The strong corrosion observed in the area upstream the bubblers can be linked to the **high pull** at furnace C (over 750 TPD from 2006 to 2009 with a peak of 800 TPD in 2007) and due to the ultra clear glass production. The strong hypothesis related to the fact that the paving located at lower temperature is severely corroded at B2/B3 whilst at higher temperatures the paving is moderately corroded (from port 4 to upstream alumina paving) is explained by the paving rise and the subsequent upward drilling corrosion. The paving rise could be induced by the **ZrO_2 hysteresis** due to the **thermal cycles** caused by the transitions **ultra clear / clear glass** and by the high pulls.
- At first, we envisage to place the paving under the side walls (fig A) instead of inside the side walls (fig B) in order to allow the extra expansion under the side wall during the thermal cycles (pull & glass transitions).

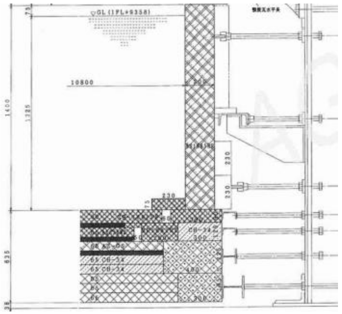

Fig A : AZS paving under side wall

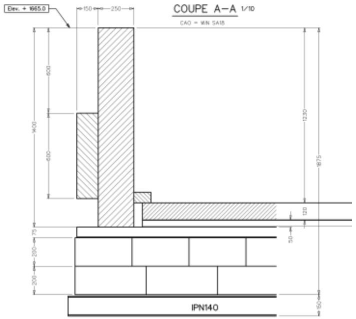

Fig B : AZS paving inside side wall

Discussions (2/5) – production history of furnace A

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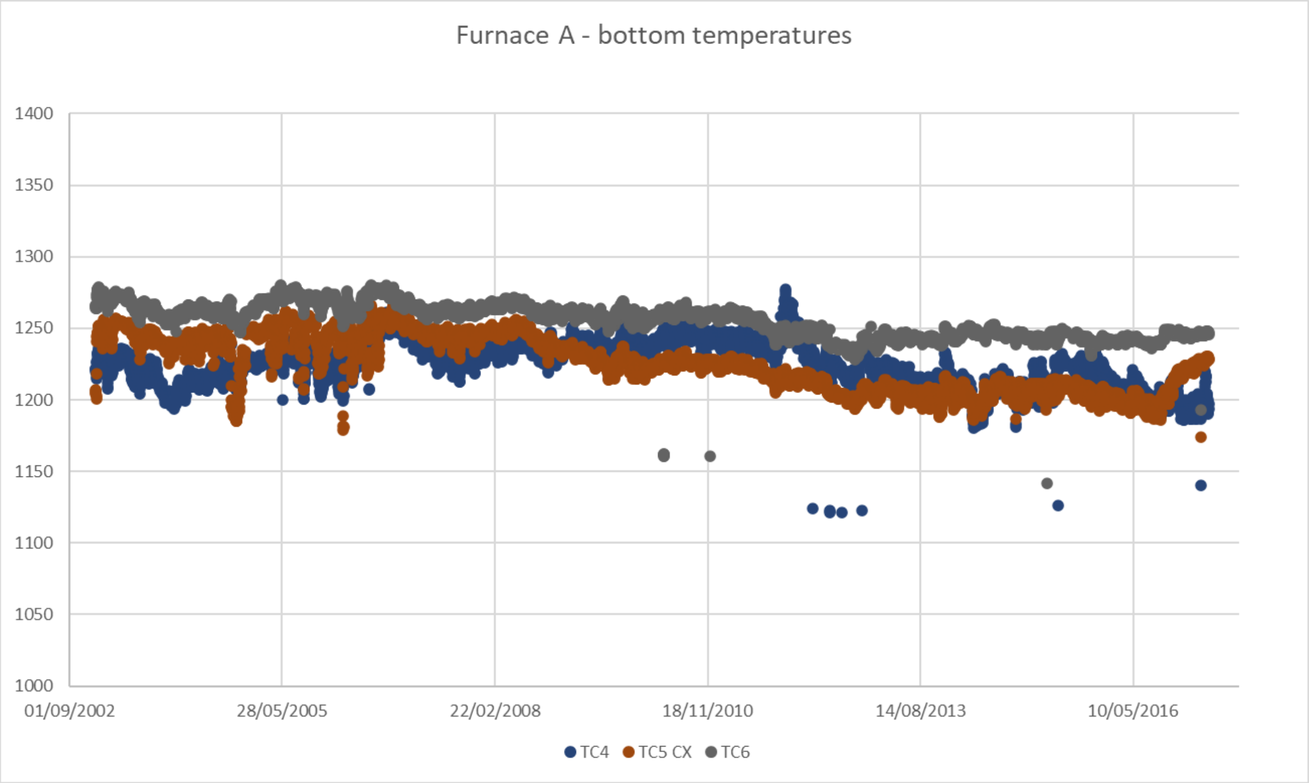
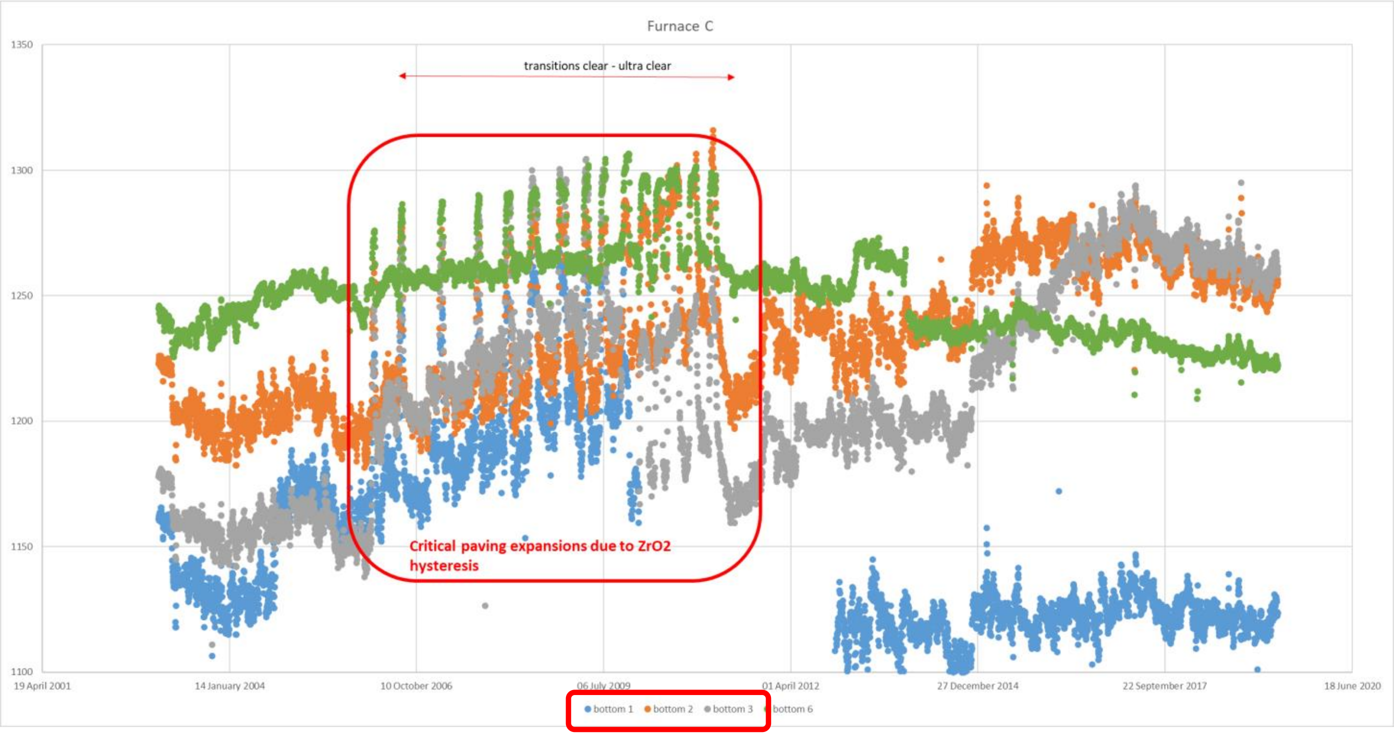
Year	Pull (TPD)
2004	529
2005	547
2006	551
2007	574
2008	576
2009	551
2010	569
2011	548
2012	516
2013	522
2014	564
2015	542
2016	557



Furnace A – campaign 15 years:
No thermal cycles – stable pull – paving not corroded

Discussions (3/5) – production history of furnace C

year	Pull (TPD)
2004	739
2005	729
2006	753
2007	799
2008	763
2009	760
2010	696
2011	695
2012	598
2013	659
2014	700
2015	691
2016	689
2017	624
2018	621
2019	580



Furnaces B (similar to C) & C – campaigns 18 years:
Critical thermal cycles – pull changes – paving corroded

Discussions (4/5) – ZrO2 expansion & hysteresis

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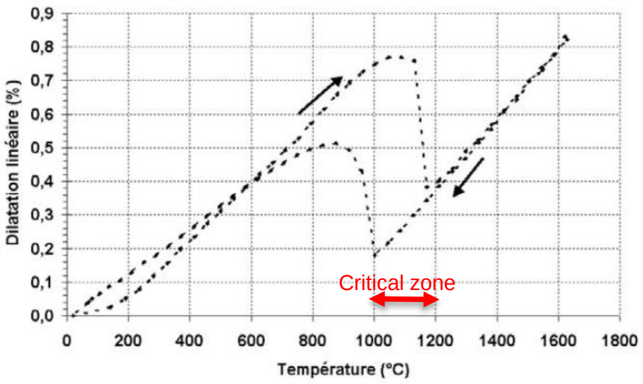
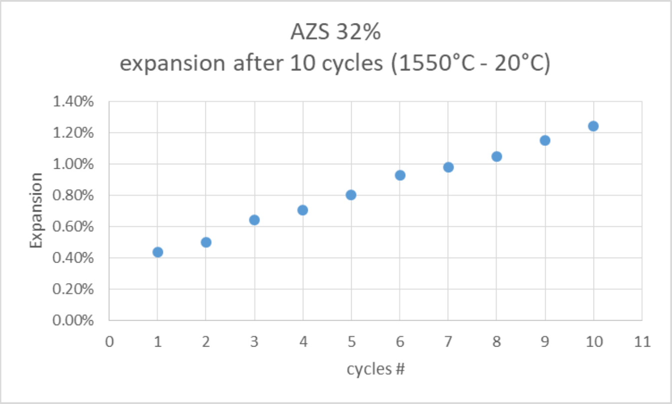


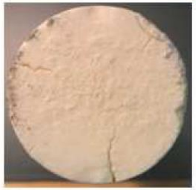
AZS 32% expansion



AZS 32% expansion during each cycle

Note: such expansion can be measured from exsudation Dunkl(*) tests

* Test procedure for determination of glass phase exsudation from Fused Cast AZS material (1995)



AZS 32% cracks induced by thermal cycles

Discussions (5/5) –> critical hysteresis shift

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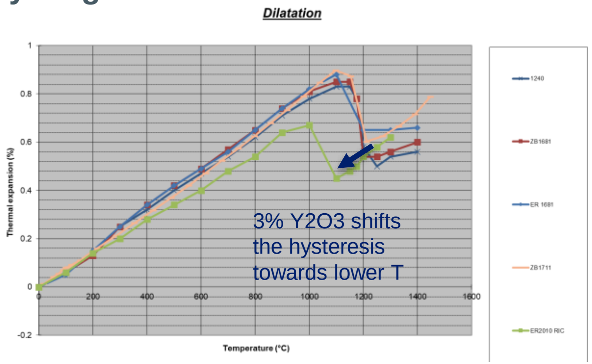
Suppliers introduced a few Yttrium in order to stabilise partially the zirconia allotropic transformation responsible of the hysteresis expansion during thermal cycles at 1100°C-1200°C. It result is a shift to the critical expansion at lower temperatures, lower than the paving temperatures.

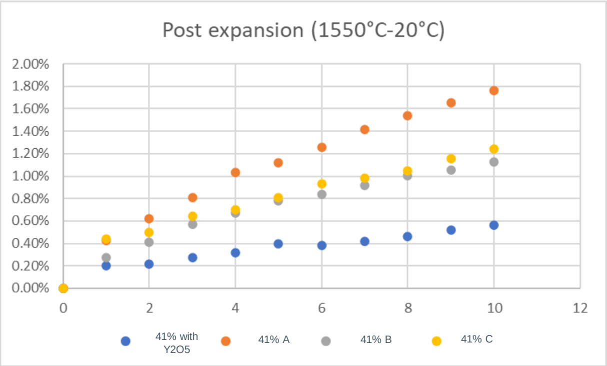
The material developed for UC glass can also be an asset for the pavings exposed to higher thermal cycles than in the past, typically induced by the extensive use of electric boosting.

Laboratory analyses indicated that the expansion hysteresis due to the heating up and cooling down can be reduced by a factor 2 to 3.

The Yttrium addition to about 3% does not penalise the corrosion resistance and allow the use of 40% ZrO_2.

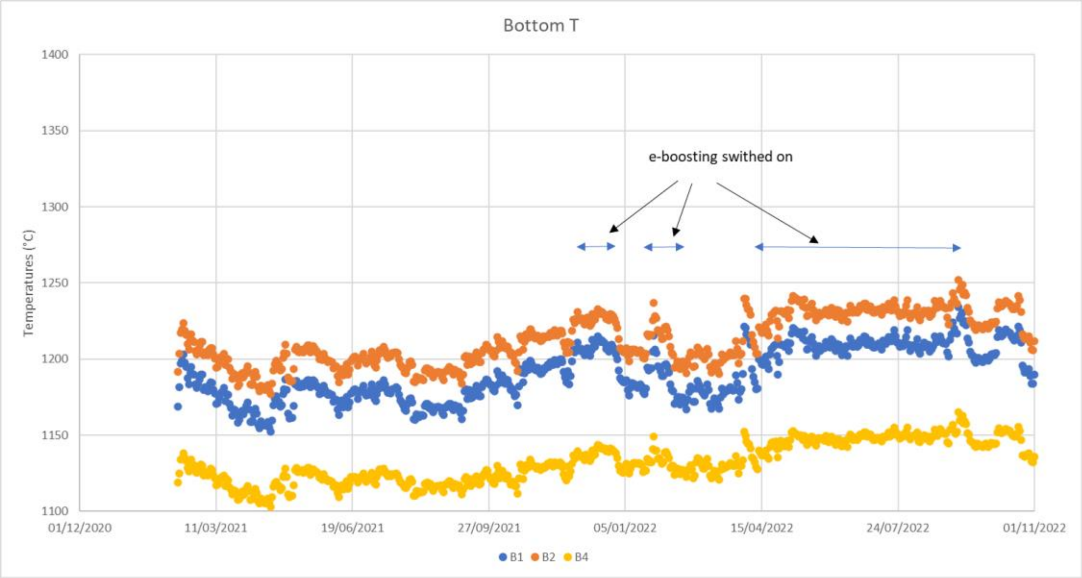
Other alternative material with linear expansion (for example zircon) could also be considered at these temperatures ranges whilst **thickness increase will not essentially improve the corrosion resistance in the low temperatures area with thermal cycling.**





Furnaces that might be affected by bottom corrosion

Electric boosting -> local overheating at electrodes and thermal cycling during on/off periods



Some thermal cycles are visible in the pavings due to the electric power variations and the critical cycles are observed on the pavings at B1/B2/B4. At present, these cycles are less sensitive than with UC glass transition but must be carefully followed

Furnaces that might be affected by bottom corrosion (3/3)

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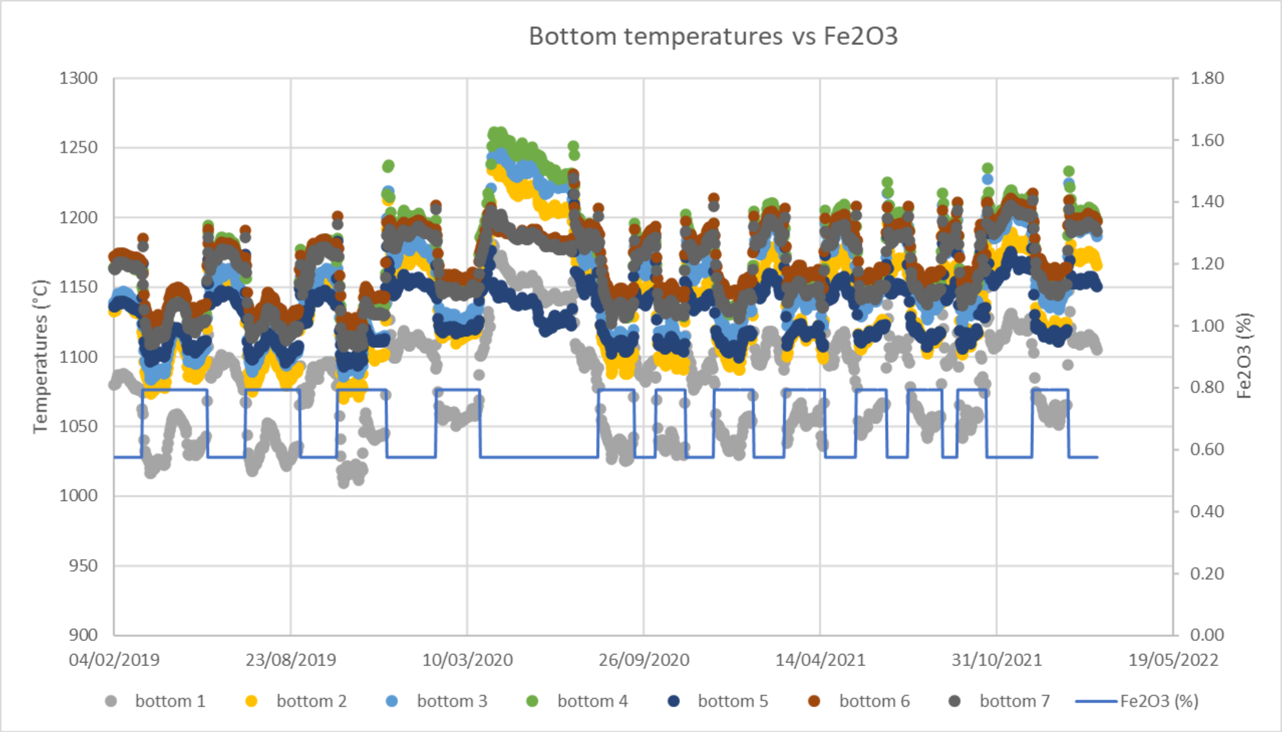
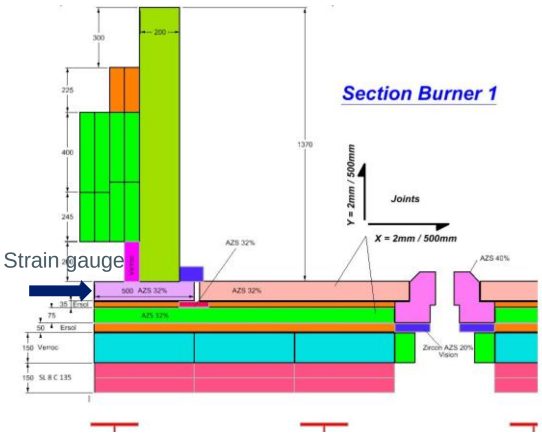
Glass transitions (% Fe2O3)



Pavings recommendations

- 2 root causes leading to critical thermal cycles in the pavings are detected: the glass transitions UC-Clear and, at lower degree but still to be analysed, the power variations in case of electric boosting use & colour changes. To avoid the stresses in the paving induced by these thermal cycles, we recommend the following:



1) Measure the paving movements by using mechanical strain gauges against the paving (see drawing)
2) Use of paving “sliding” under the tank wall
3) Use the partially stabilised AZS paving (with Y_2O_3) at the critical areas in order to avoid the strong paving expansion at lower temperatures or evaluate alternative materials with linear expansion.