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JUNE 28 - 30, 2017. TAMPERE, FINLAND

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GPD 25 YEARS

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ALL EYES ON GLASS.

GLASS PERFORMANCE DAYS 2017

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GPD 25 YEARS

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

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Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Agenda of presentation

- Aim of the research
- Thermal process on heat treated glass
- Frame of the research
- Fragmentation vs Surface Compression
- Flexural Bending Strength vs Surface Compression
- Conclusions

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

AIM of RESEARCH

Define a correlation between the following parameters in heat treated glass:

- bending strength tested according EN 1288-3;
- fragmentation tested according relevant Standards;
- surface compression measured with Laser Gasp

The research is the development of a previous one carried out at SSV; the experimental data are increased and the correlation is extended considering the emissivity of coated glass and enamelled one too.

The correlations could be used for a non destructive product control in FPC.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Why to extend the research?

- Coated glass (low-e, selective and reflective glass), in function of the climatic zone and law requirements for specific projects, are more and more requested.
- In the recent years also the enamelled glass increases in specific applications where the designer would like to hide some elements, create an opaque surface, for artistic propose.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

- From 2002 thousands of thermally treated glass panes were tested in SSV:

  TT = tempered glass without or with HST

  HS = heat strengthened glass

- The data have been collected to evaluate a correlation between the Surface Compression Stress (SC) and the other characteristics:
  - ✓Fragmentation (FR)
  - ✓Flexural Bending Strength (FB).

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Thermal process on heat treated glass

The convention, during heat transfer in the tempering process, plays a crucial role with introduction of the low-e glass: glass with high emissivity absorbs heat while one with low emissivity reflects it.

The presence of a side with lower emissivity may involve an asymmetrical heating and the curvature of the pane with unlikely no homogeneous residual stresses.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

EN Standards define B1 as coated glass with $0.89 \geq \varepsilon > 0.25$.

In this range a large wide of products exist and the heat treatment differs greatly from glass to glass.

For this reason the authors divided:

B1 ($\varepsilon = 0.89$)

B1_bis ($0.89 > \varepsilon > 0.25$)

(but also in B1_bis ε range is too large)

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Undesired residual stress on glass surface may be caused mainly by:

- no uniformity of pane heating on its plane and between the two surfaces
- different quenching speed from point to point of pane
- presence of holes, notches, that induce differential heating and quenching rate

It is necessary to control the process at every stage to avoid these problems.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Frame of the research

The research is developed according to test procedure reported in:

- EN 12150-1 for thermally toughened glass (TT)
- EN 14179-1 for heat soaked thermally toughened glass (data included in TT)
- EN 1863-1 for heat strengthened glass (HS)

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Up to day, only the ASTM C1048:2012 and ISO Standards specify a surface compressive stress requirement

Standard Reference	Heat Strengthened	Thermally Toughened
EN 1863-1:2012	No value is indicated	--
EN 12150-1	--	No value is indicated
EN 14179-1:2016	--	No value is indicated
ASTM C1048:2012	24÷52 MPa (thickness equal or lower than 6 mm)	69 MPa
ISO/DIS 22509 rev.:2016	25÷55 MPa	--
ISO/FDIS 12540:2016	--	80 MPa minimum for FB 90 MPa minimum for FR

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Whereas the EN Standards define the bending strength limits and the minimum number of fragments.

Standard Reference	clear float and coated	Enamelled
EN 1863-1:2012	70 N/mm^2 (FB)	45 N/mm^2 (FB)
EN 12150-1:2015	120 N/mm^2 (FB)	75 N/mm^2 (FB)
EN 14179-1:2016	120 N/mm^2 (FB)	75 N/mm^2 (FB)
Glass thickness 4÷12 mm	40 TT (FR)	40 TT (FR)
5 mm	30 TT (FR)	30 TT (FR)

The assessment for FR differs between HS and TT glass.

In case of HS glass the only indication of Conformity (C) or not (NC) has been considered to evaluate the minimum SC necessary to get it.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Number of specimens for SC vs FR

Thickness (mm)-**HS**	4		5		6		8		10		12		15		Total	
	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
Clear Float	35	5	68	3	134	6	129	21	106	26	45	10	--	--	517	71
B1: ε=0.89	--	--	5	0	10	15	5	5	5	0	5	0	--	--	30	20
B1_bis: 0.25<ε<0.89	--	--	--	--	5	0	5	0	5	5	5	0	--	--	20	5
B2: 0.1<ε<=0.25	--	--	--	--	20	0	5	0	--	--	0	5	--	--	25	5
B3: ε<=0.1	--	--	15	0	25	5	15	5	23	10	0	5	--	--	78	25
Enamelled	--	--	10	0	8	0	3	0	5	10	--	--	--	--	26	10
Thickness (mm)-**TT**	4		5		6		8		10		12		15		Total	
	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
Clear Float	248	27	252	19	283	15	286	19	310	55	227	38	104	10	1710	183
B1: ε=0.89	30	0	20	0	95	0	65	0	30	0	--	--	--	--	240	0
B1_bis: 0.25<ε<0.89	20	0	5	0	53	7	56	9	60	5	--	-	--	--	194	21
B2: 0.1<ε<=0.25	37	3	10	0	55	0	30	0	15	0	10	0	--	--	157	3
B3: ε<=0.1	99	12	25	0	92	13	136	14	85	10	13	2	--	--	450	51
Enamelled	30	0	14	0	15	0	7	3	25	0	5	0	--	--	96	3

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Number of specimens for SC vs FB

Thickness (mm)-**HS**	4		5		6		8		10		12		15		Total	
	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC	C	NC
Clear Float	19	0	57	0	102	0	87	0	83	0	31	2	--	--	379	2
B1: ε=0.89	--	--	3	0	8	0	5	0	3	0	3	0	--	--	21	0
B1_bis: 0.25<ε<0.89	--	--	--	--	4	0	4	0	4	0	4	0	--	--	16	0
B2: 0.1<ε<=0.25	--	--	13	0	24	0	--	--	--	--	--	--	--	--	37	0
B3: ε<=0.1	--	--	11	9	40	0	53	0	31	-	2	0	--	--	137	9
Enamelled	--	--	--	--	--	--	--	--	17	0	--	--	--	--	17	0
Thickness (mm)-**TT**	4		5		6		8		10		12		15		Total	
	C	NC	C	NC	C	NC	C	C	C	NC	C	NC	C	NC	C	NC
Clear Float	119	0	140	1	162	1	146	2	221	1	145	2	82	0	1015	7
B1: ε=0.89	21	3	15	0	82	0	66	0	20	0	--	--	--	--	204	3
B1_bis: 0.25<ε<0.89	15	0	4	0	33	1	40	0	52	0	--	--	--	--	144	1
B2: 0.1<ε<=0.25	25	0	7	0	51	0	20	1	11	0	8	0	--	--	122	1
B3: ε<=0.1	81	0	25	0	90	1	126	4	95	1	23	5	--	--	440	11
Enamelled	70	5	30	0	24	0	4	0	50	4	7	0	--	--	188	9

The FB specimens are less because, if the sampling did not pass FR, the test was stopped. For this reason the NC specimens are also limited.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

The data refers to different producers (tempering process differs for ovens, their technology of heating and convention, tempering recipes related to glass thickness and type).

Sometime the rollers influence glass bending strength.

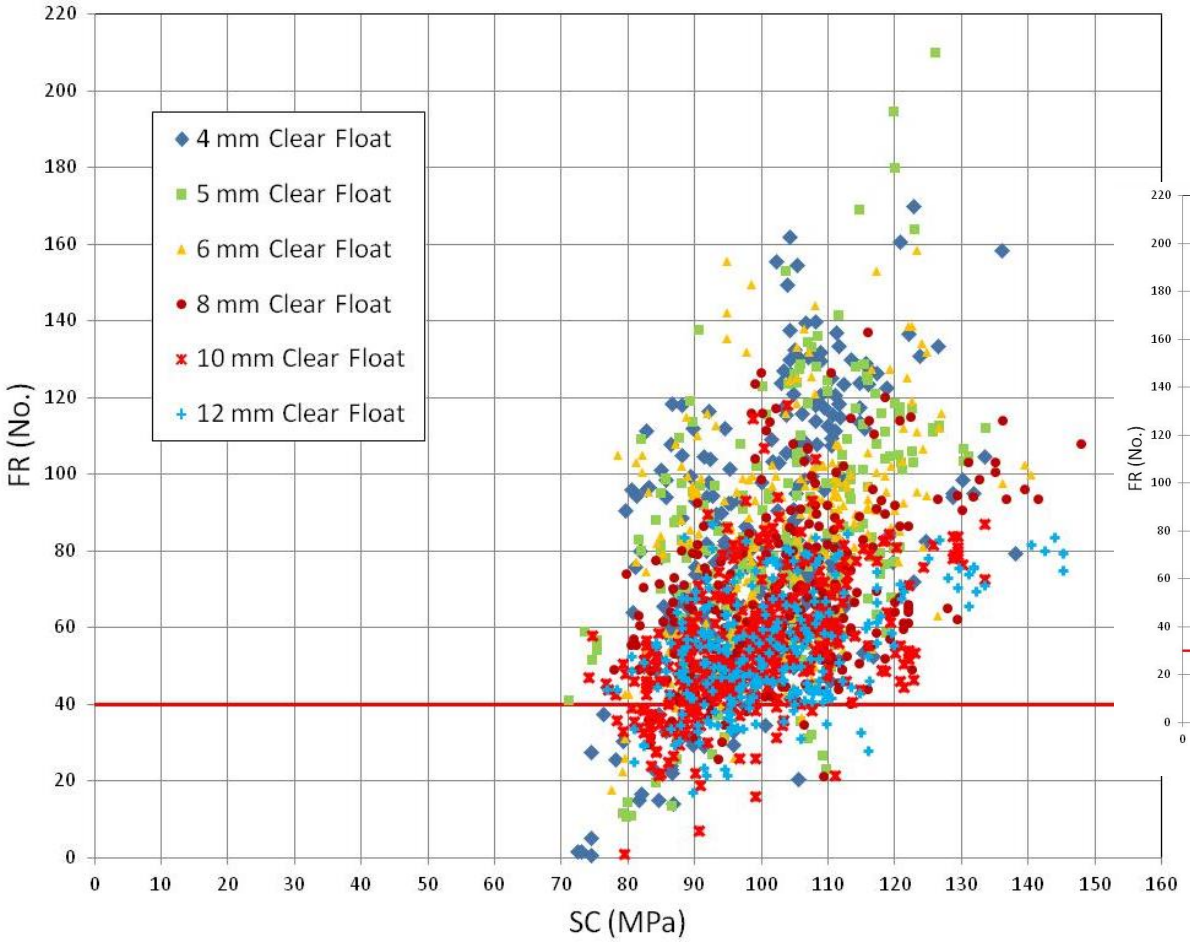
Sometime this effect is amplified when the side placed in contact with tempering rollers and the process is not well controlled.

			SC (MPa)		FB (N/mm^2)	
Producer	Glass Type	Tensile side	Mean	Dev. St.	Mean	Dev. St.
A	10 mm Clear Float TT	no roller	107.0	6.8	194.4	23.8
		roller	106.0	7.4	138.2	8.3
B	10 mm Clear Float TT	no roller	105.5	1.9	202.0	26.8
		roller	104.6	2.2	165.0	18.1
	10 mm Clear Float HS	no roller	43.7	2.4	129.8	11.9
		roller	43.8	0.9	81.7	10.1

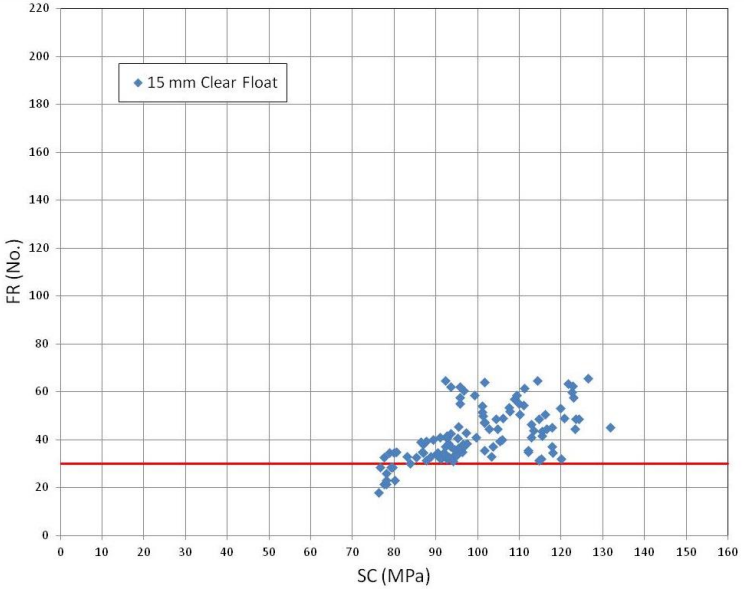
This is an extreme case but this can influence the correlation SC vs FB

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Fragmentation Vs Surface Compression



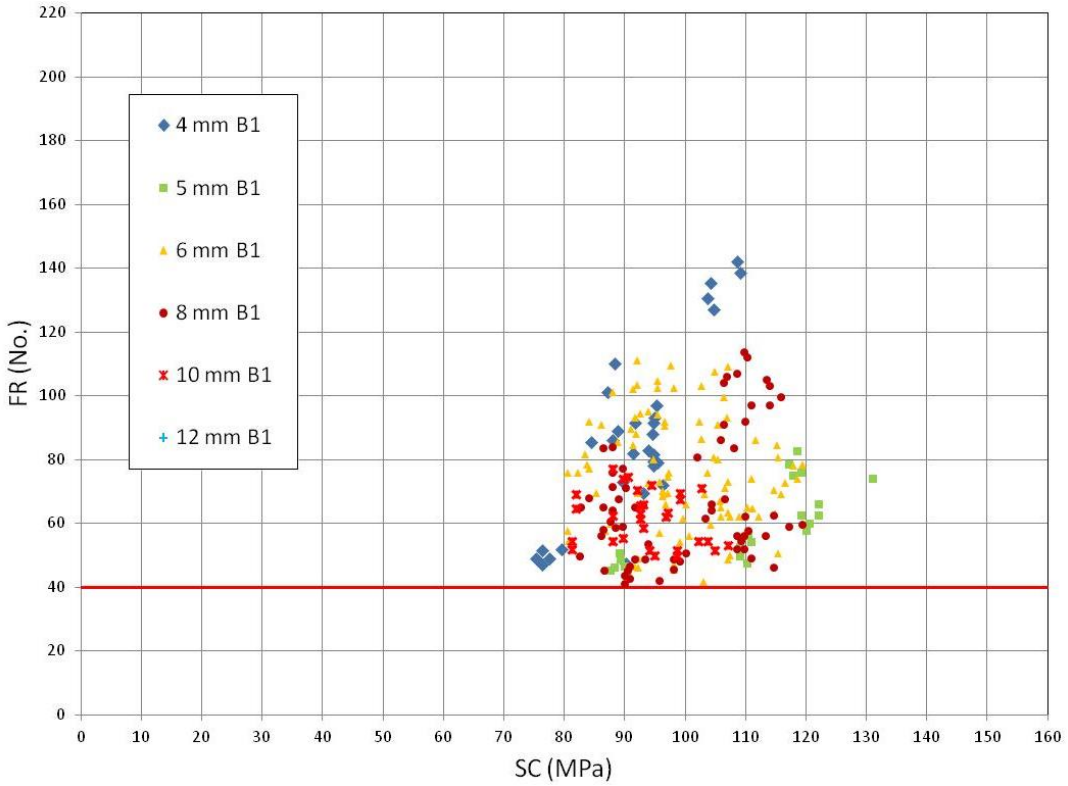
Clear Float Glass



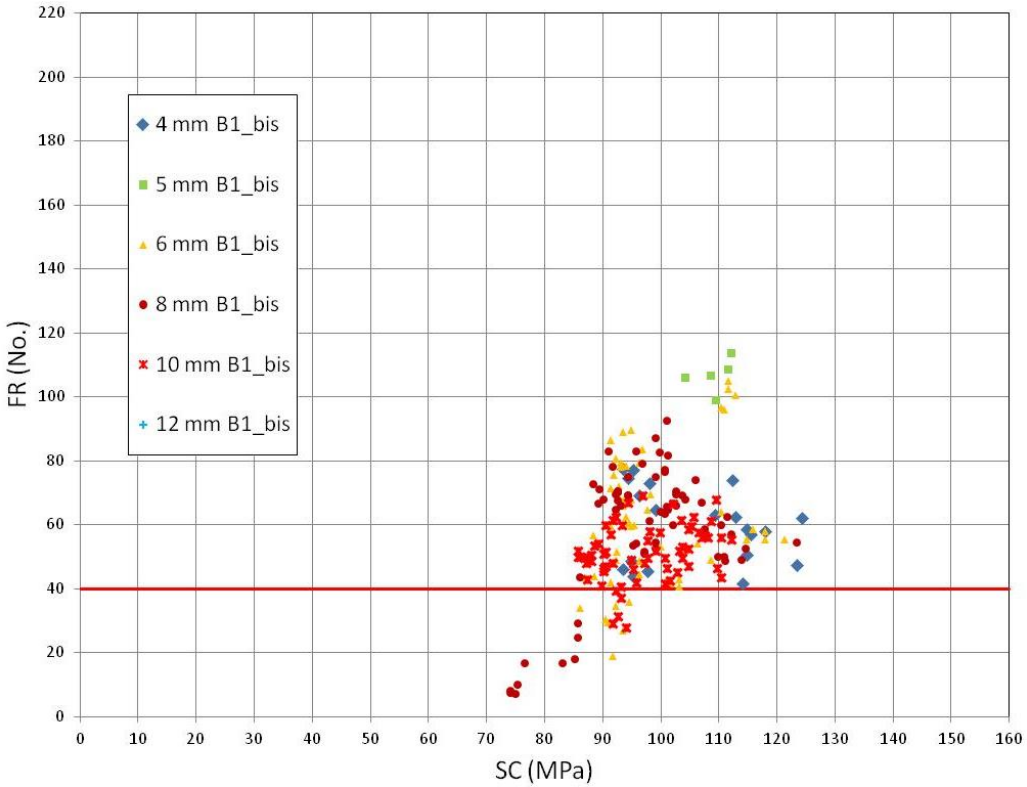
Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Coated Glass:

B1



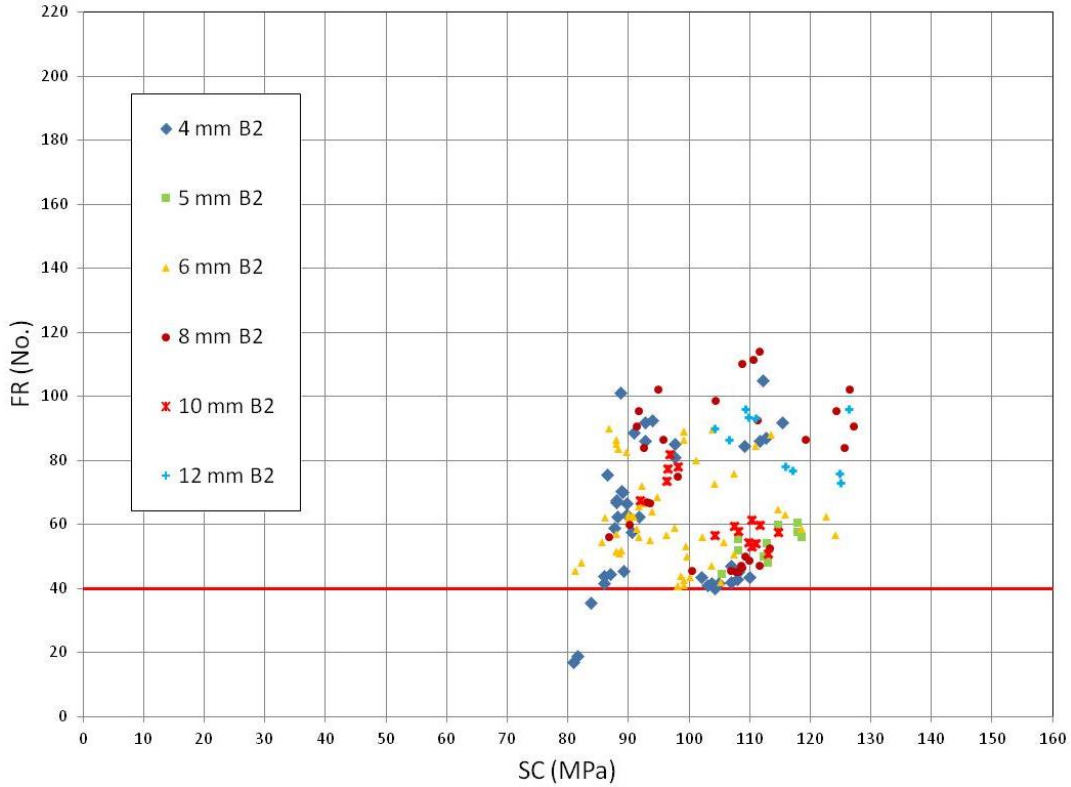
B1_bis



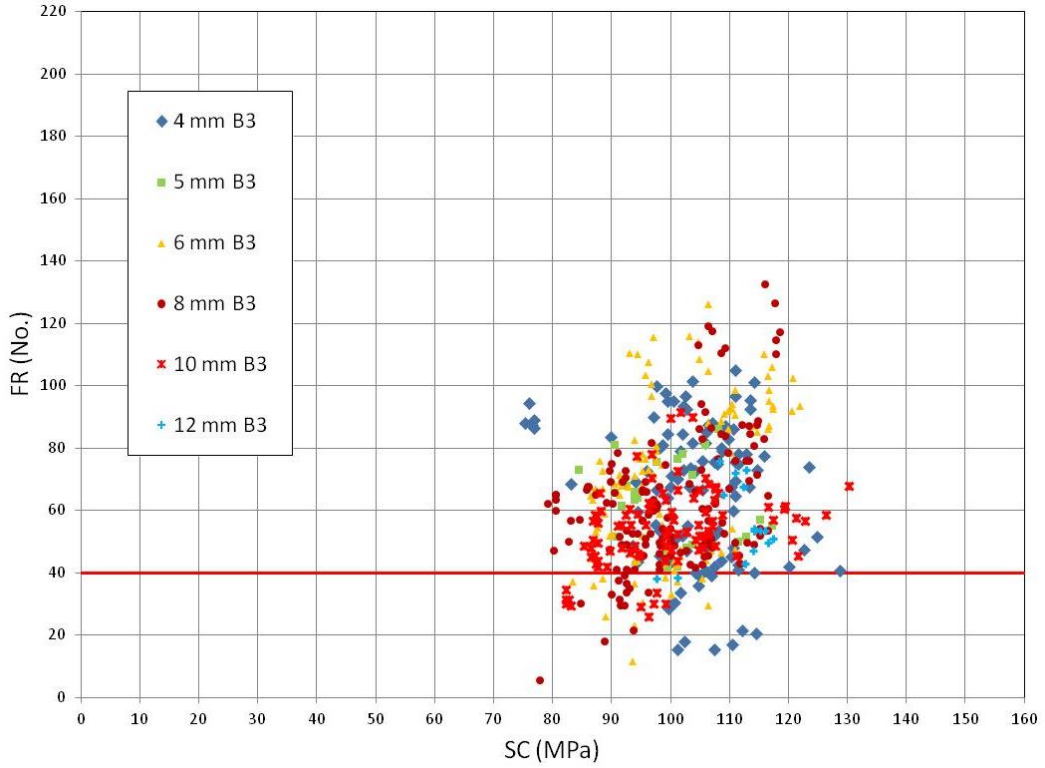
Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Coated Glass:

B2

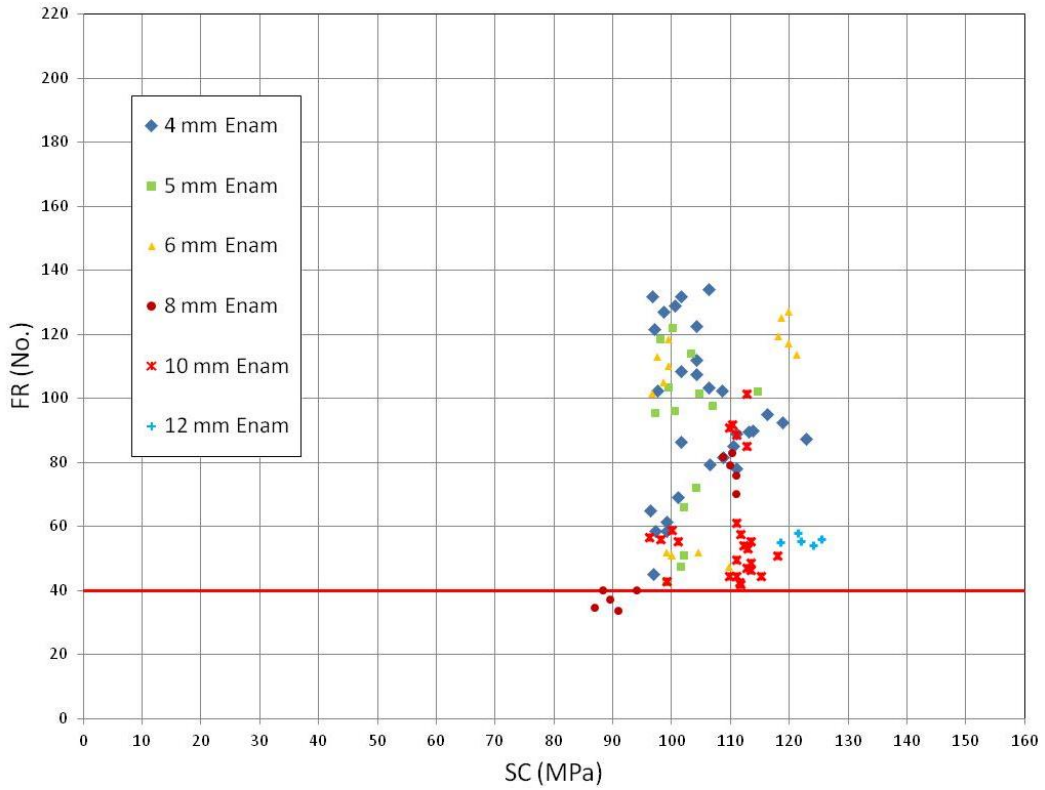


B3



Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Enammelled Glass



Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Minimum value SC (MPa) vs conform FR for TT in SSV specimens

	4 mm	5 mm	6 mm	8 mm	10 mm	12 mm	15 mm
Clear Float	80(7%)	80(6%)	80(4%)	80(6%)	80(14%)	80(14%)	80 (1%)
B1: e=0.89	75	88	81	83	81	--	--
B1_bis: 0.25<e<0.89	94	--	87(10%)	86	86(8%)	--	--
B2: 0.1<e<=0.25	86	--	81	87	92	104	--
B3: e<=0.1	99(11%)	85	86(11%)	79(9%)	86(5%)	108	--
Enamelled	96	97	97	91	96	--	--

Note: (%) incidence value of data in the limit value but NC to FB.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Incidence value (%) of NC data for SC (MPa) vs FR in TT with the proposed SC value

	Limit value	4 mm	5 mm	6 mm	8 mm	10 mm	12 mm	15 mm
Clear Float	90	2	3	2	3	6	11	0
B1: e=0.89	90	0	0	0	0	0	--	--
B1_bis: 0.25<e<0.89	95	0	--	0	0	0	--	--
B2: 0.1<e<=0.25	90	0	--	0	0	0	0	--
B3: e<=0.1	95	11	0	6	1	4	13	--
Enamelled	95	0	0	0	0	0	--	--

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

The value proposed in the previous paper (90 MPa) should be:

- confirmed by the increment of test data for clear float, B1 and B2
- revised considering the coated B1_bis, B3 and enamelled glass.

Also increasing the limit values some specimens have high SC but they are not conform (see % incidence), especially for B3.

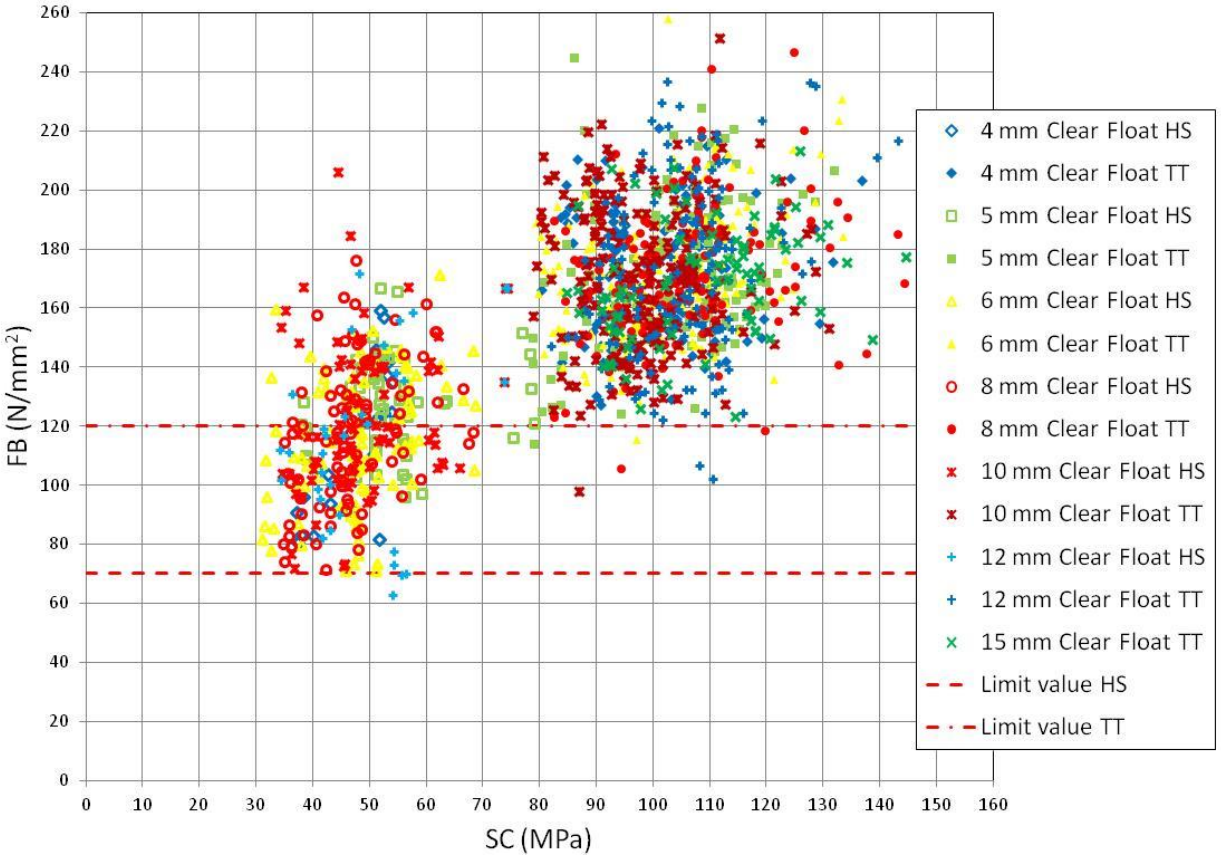
The reason could be that the SC is measured at tin side and the SC should be not homogeneous along the glass thickness, giving NC fragmentation pattern.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Maximum value SC (MPa) vs conform FR for HS in SSV specimens

	4 mm	5 mm	6 mm	8 mm	10 mm	12 mm	15 mm
clear float	67	65	62	63	58	60	--
B1: e=0.89	--	60	51	56	--	--	--
B1_bis: 0.25<e<0.89	--	--	--	--	--	--	--
B2: 0.1<e<=0.25	--	--	63	--	--	--	--
B3: e<=0.1	--	56	64	55	52	--	--
Enamelled	--	61	71	--	50	--	--

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test



Flexural Bending Strength vs Surface Compression

Clear Float Glass

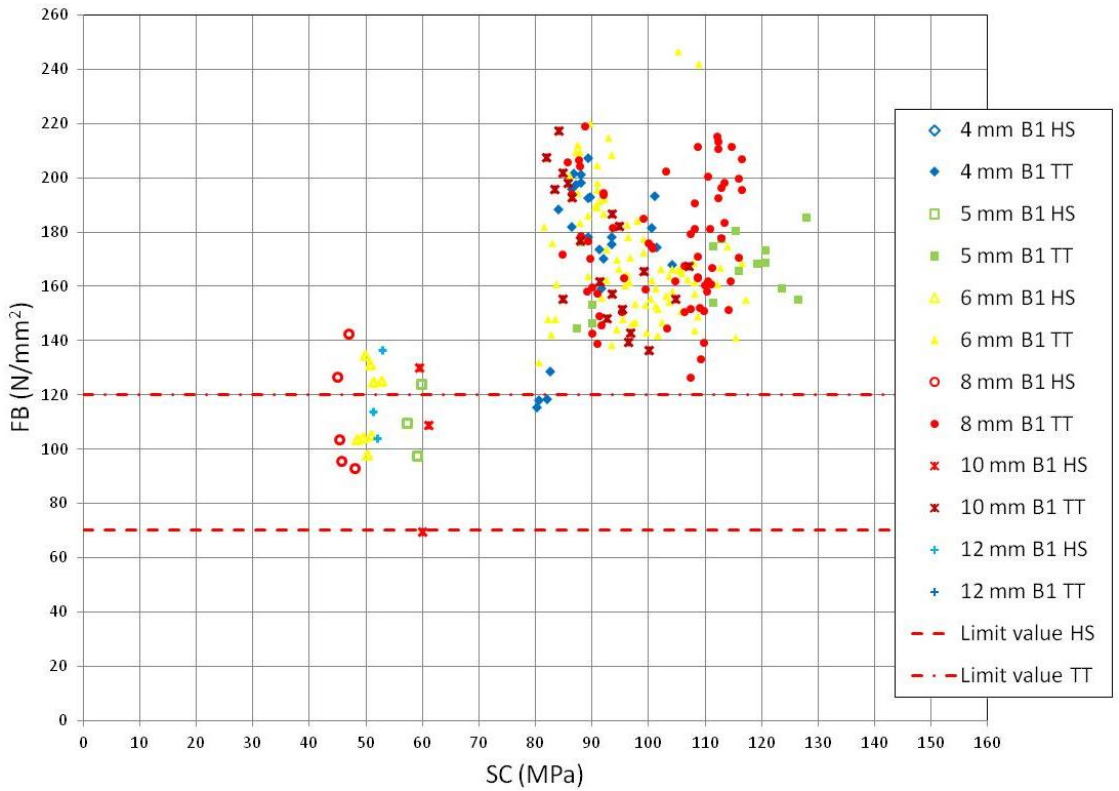
All glass thickness and side in tension were considered (tin, air, coated, un-coated, enamelled).

The data were not segregated, considering specimens with both central and edge fracture origin.

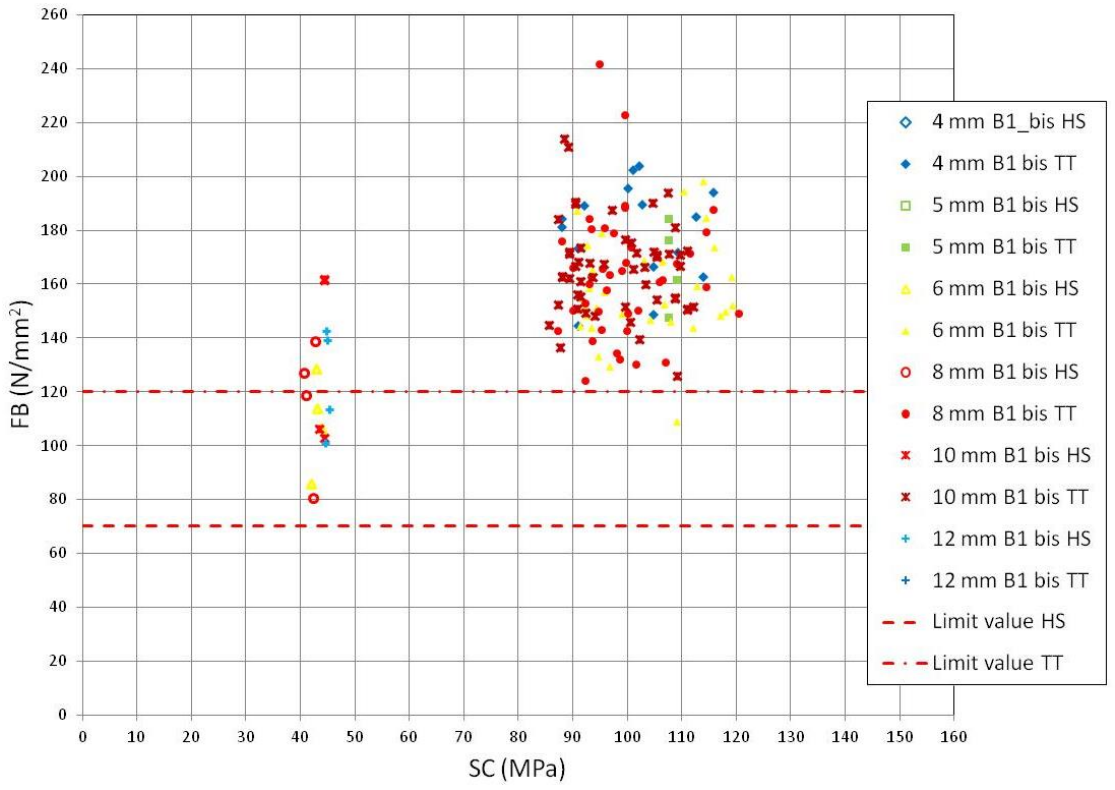
Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Coated Glass:

B1



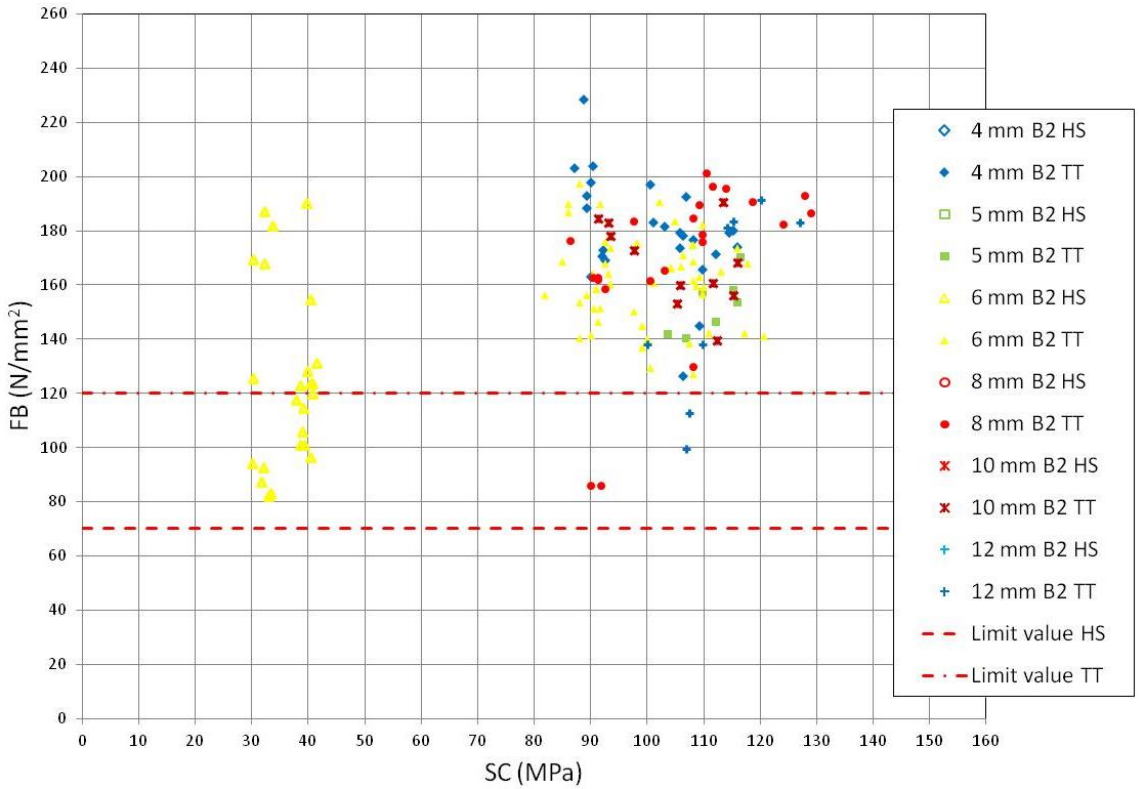
B1_bis



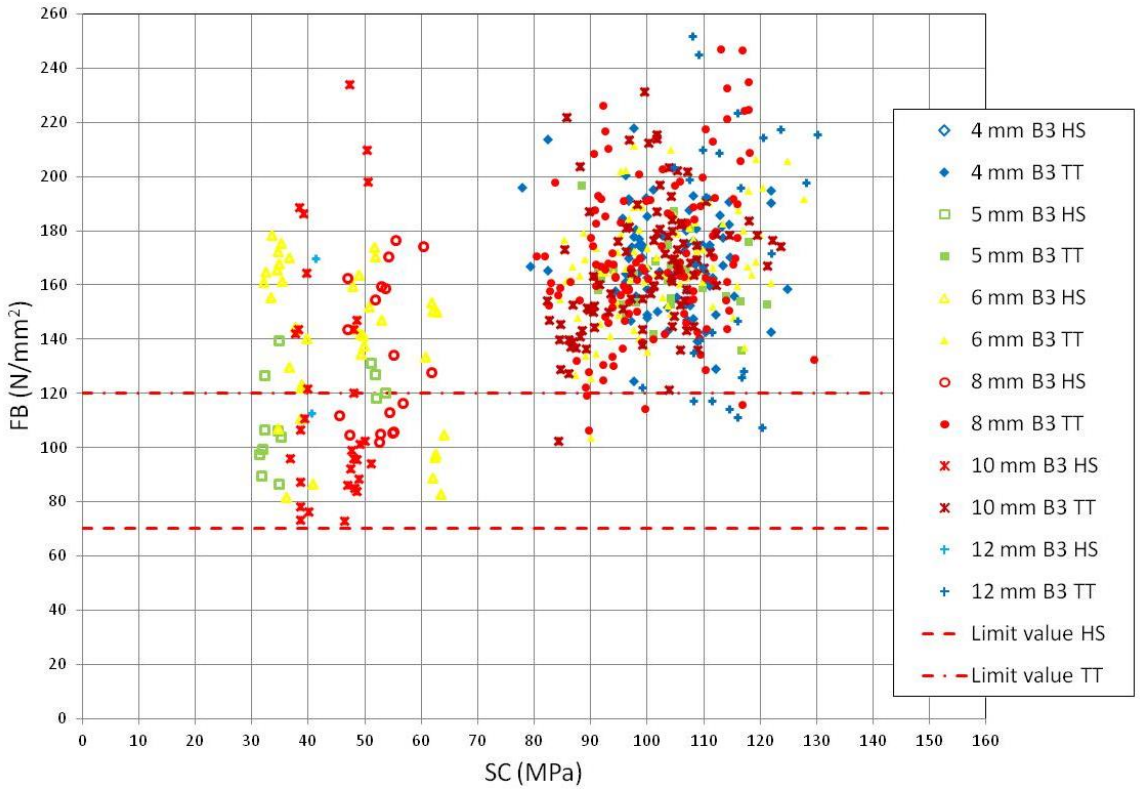
Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Coated Glass

B2

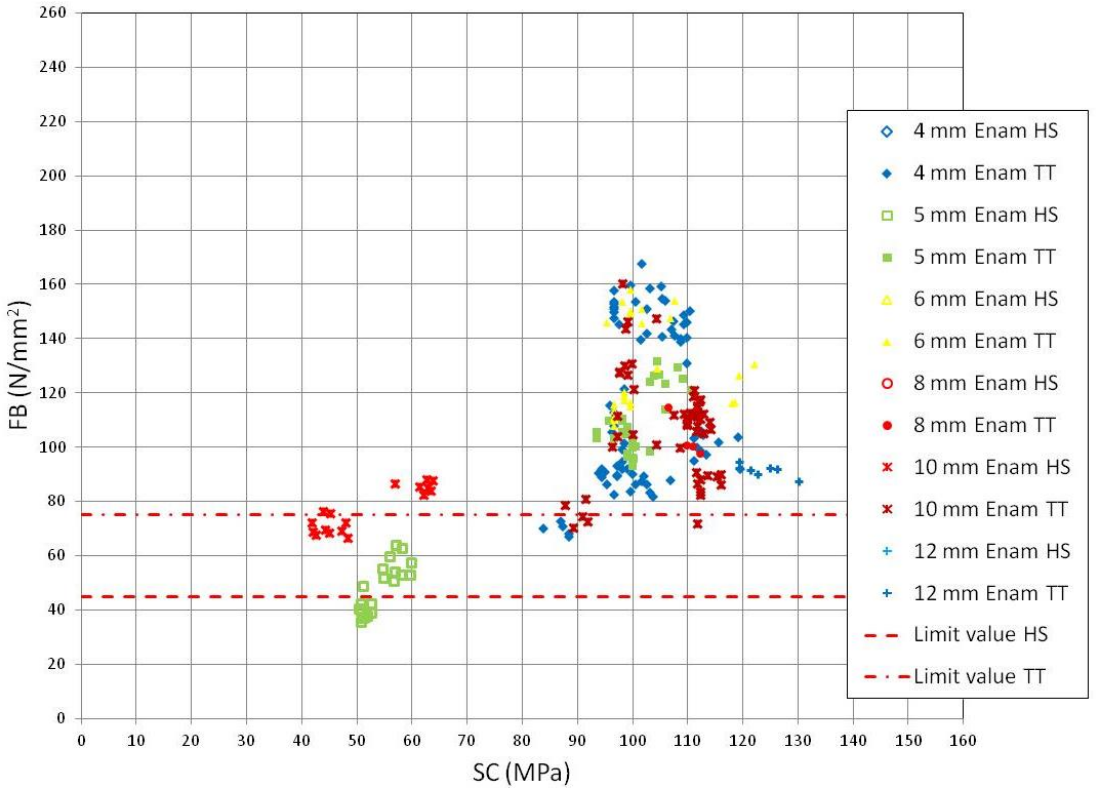


B3



Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Enammelled Glass



Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Minimum value SC (MPa) vs conform FB for HS in SSV specimens

	4 mm	5 mm	6 mm	8 mm	10 mm	12 mm	15 mm
Clear Float	37	38	31	35	34	34(6%*)	--
B1: e=0.89	--	--	48	--	--	--	--
B1_bis: 0.25<e<0.89	--	--	42	--	--	--	--
B2: 0.1<e<=0.25	--	--	30	--	--	--	--
B3: e<=0.1	--	31	32	45	37	--	--
Enamelled	--	50(5%)	--	--	42	--	--

Note: (%) incidence value of data which respect the SC reported limit value but they are NC to FB limit value.
* Sampling with high SC but with "roller effect"

Minimum value SC (MPa) vs conform FB for TT in SSV specimens

	4 mm	5 mm	6 mm	8 mm	10 mm	12 mm	15 mm
Clear Float	81	79(<1%)	79	83(1%)	79(<1%)	82(1%)	85
B1: e=0.89	83	87	81	85	82	--	--
B1_bis: 0.25<e<0.89	88	--	91(3%)	87	86	--	--
B2: 0.1<e<=0.25	87	--	82	86(9%)	--	--	--
B3: e<=0.1	78	88	85(1%)	81(2%)	82(1%)	99(18%)	--
Enamelled	94	94	95	--	91(4%)	--	--

Note: (%) incidence value of data which respect the SC reported limit value but they are NC to FB limit value.

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

The limit value of SC that has to be reached to respect the characteristic bending strength value of thermally toughened (TT) safety glass can be confirmed to be

- 85 MPa for clear float glass
- 90 MPa for coated glass
- no less than 95 MPa for enamelled glass

Incidence value (%) of NC data for SC (MPa) vs FB in TT with the proposed SC value

	Limit value	4 mm	5 mm	6 mm	8 mm	10 mm	12 mm	15 mm
clear float	85	0	0	<1	<1	<1	1	0
B1: e=0.89	90	0	0	0	0	0	0	--
B1_bis: 0.25<e<0.89	90	0	--	3	0	0	0	--
B2: 0.1<e<=0.25	90	0	--	0	9	--	--	--
B3: e<=0.1	90	0	0	1	1	0	17*	--
Enamelled	95	0	0	0	--	1	--	--

Note: * Sampling with high SC but with “strong roller effect"

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

The limit value of SC that has to be reached to respect the characteristic strength (FB) value of heat strengthened glass (HS) can be:

- 35 MPa for clear float glass
- 30÷50 MPa for coated glass
- 45 MPa for enamelled glass

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Conclusions

- The elaborated data goes across many years of laboratory tests on different type of glass provided by different Italian and European producers.
- The correlations between SC and FR or FB is accepted at Standard level (see ISO Standard) and it is useful during FPC (Factory Production Control).

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

- The limit value of SC proposed by the authors based on **THEIR** experimental data are reported in the following table.

Glass Type	FR_HS	FB_HS	FR_TT	FB_TT
	Upper bound	Lower bound	Lower bound	Lower bound
Clear Float	60	35	90	85
B1: e=0.89	55	50	90	90
B1_bis: 0.25<e<0.89	45	40	95	90
B2: 0.1<e<=0.25	55	30	90	90
B3: e<=0.1	60	40	95	90
Enamelled	60	45	95	95

Thermally toughened glass: correlation between surface compression, mechanical and fragmentation test

Acknowledgements

The technicians of SSV - SVP Laboratory, Mr. G. Negri and Mr. F. Comiati, are acknowledged for the execution of experimental tests during many years of activity in our Laboratory.

THANK YOU FOR THE ATTENTION