STRATO
glass interlayers

EN 16613:2019 STANDARD

STRATO® SENTINEL

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Introduction

In December 2019, the **EN 16612** and **EN 16613 standards** were designed and published and they are closely related to each other: in fact, the first one determines the **resistance of glass panels** to lateral loads by calculation, while the second one specifies the **mechanical properties of the interlayer** used to make laminated safety glass.

These standards have been under construction for years and their issue finally formalizes the importance of the choice of the interlayer. Therefore, they will replace or complete the individual regulations in the different European Union countries.

Selecting the type of film to be used is a very important decision: it determines the behaviour of laminated glass, whose **properties** depend on **the temperature** and **the loads** to which it is subjected.

This report shows the experimental results of characterization tests of **STRATO® SENTINEL** interlayer, produced by Satinal SpA in accordance with Annex A of **EN 16613:2019 [1].**

Note

The tests were carried out in a certified external laboratory. The data provided in the following pages should not be used to establish specification limits or used alone as the basis of design; they are not intended to substitute for any testing you may need to conduct to determine for yourself the suitability of a specific material for your particular purposes. Final determination of suitability of any material or process and whether there is any infringement of patents is the sole responsibility of the user. Since Satinal cannot anticipate all variations in actual end-use conditions, Satinal makes no warranties and assumes no liability in connection with any use of this information. The duplication (partial or total), distribution, publication, copying, transmission, sale, adaptation etc. of all contents is forbidden.

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1. Samples identification

In accordance with Annex A, samples of 1100 mm length and 360 mm width consisting of laminated glass composed of two 8 mm layers of float glass and one layer of STRATO® SENTINEL interlayer composed of 0.9mm thermoplastic polymer, were tested.
The company supplied two samples of material as the first sample showed breakage at different temperatures under load (1 sample at 20°C after stabilization, 2 samples at 40°C and 1 sample a 60° C). The reported results refer to the first sampling for 20°C and 30°C, while the second sampling for 40°C, 50°C and 60°C.
The samples are identified by the **test temperature**, the **sample number** (1 or 2) and a **sequential number** (1 to 3).

2. Test procedure

The tests were carried out in accordance with the configuration stipulated in **ISO EN1288-3:2016** (4 point bending test - Fig. 1). The samples were loaded with a constant load of 1150 N and the displacements were monitored with one LVDT transducer positioned in the centreline and one on the support (HBM WI10), in order to assess rubber subsidence between the support and the glass (Fig.2).
The data acquisition (with HBM's spider 8) took place with a sampling rate of 100 Hz for the loading phases and the following 10 minutes, equal to 1Hz for the first hours and subsequently with sampling every 10 seconds.
The tests were carried out at the following temperatures: 20°C, 30°C, 40°C, 50°C, 60°C, controlled in chamber Tecam type M100A, S.N. N0133.
Three samples were tested at each temperature.
The samples were kept in the chamber in a vertical position until the test temperature was reached.
The load was maintained for a minimum time to ensure constant displacement. In accordance with the standard, the displacement **can be assumed constant** when the variation between two displacements acquired four hours apart is less than 1%.

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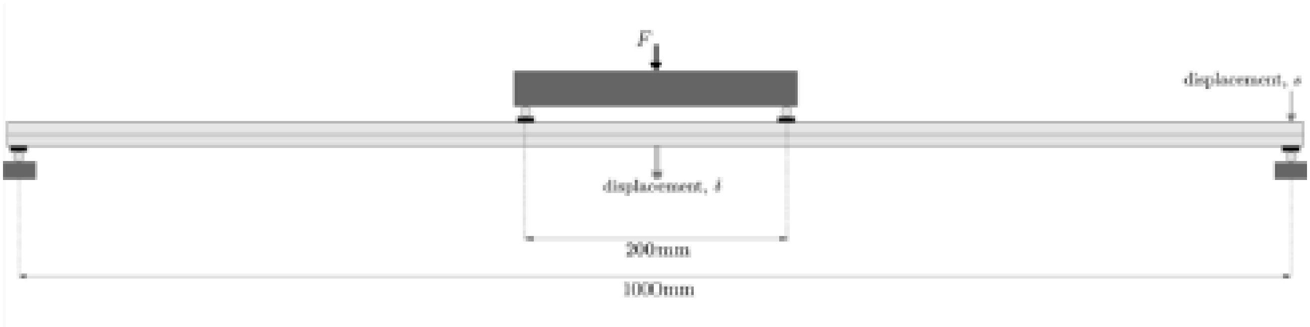

Picture 1 - Experimental test layout

Picture 2 - Test samples

3. Experimental results

The test specimens showed temperature-dependent behaviour, both in terms of the with regard to the displacements observed, as well as with regard to the time required to reach their stabilisation.
Picture 3 shows the **time-displacement graphs** (in the centreline and on the support (S)) for each test temperature and for each specimen (indicated by the progressive number). The graphs on the left show a zoom relative to the first 1000 seconds (loading phase), in the right-hand curves the displacements relative to the entire test. Picture 4 shows the actual displacements graphs (obtained by subtracting from the centreline displacement the support displacement caused by the tyre crushing).
The light-blue crosses indicate the moment when load stabilization occurred (displacement of less than 1% in the previous 4 hours).
Table 1 and Picture 5 show the displacements values measured and their average for each test specimen for a number of significant load instants.

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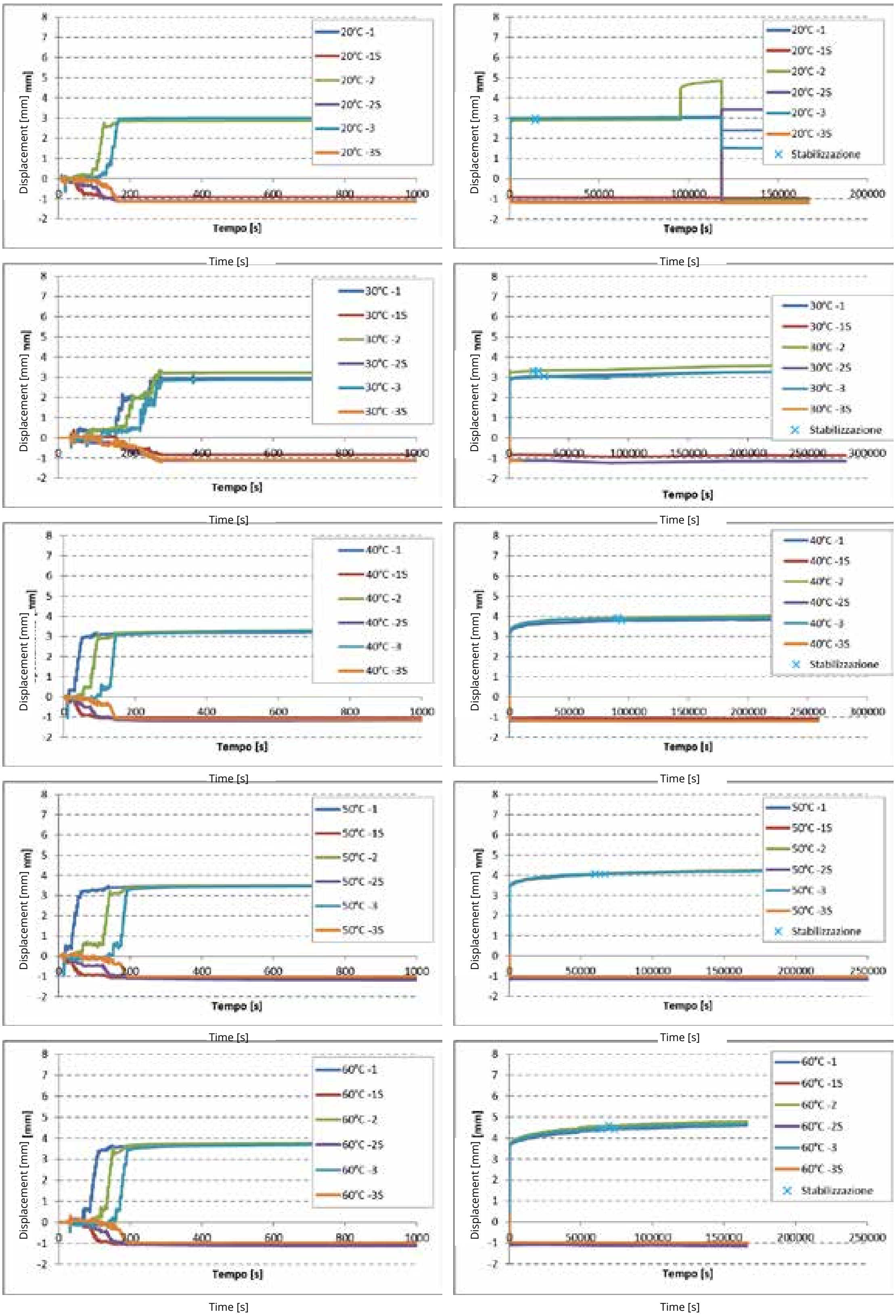

Picture 3 - Load curves centreline displacement and support (S)- Zoom load phase (left) and total curves (right) (20°C and 30°C sampling 1, 40°C, 50°C and 60°C sampling 2)

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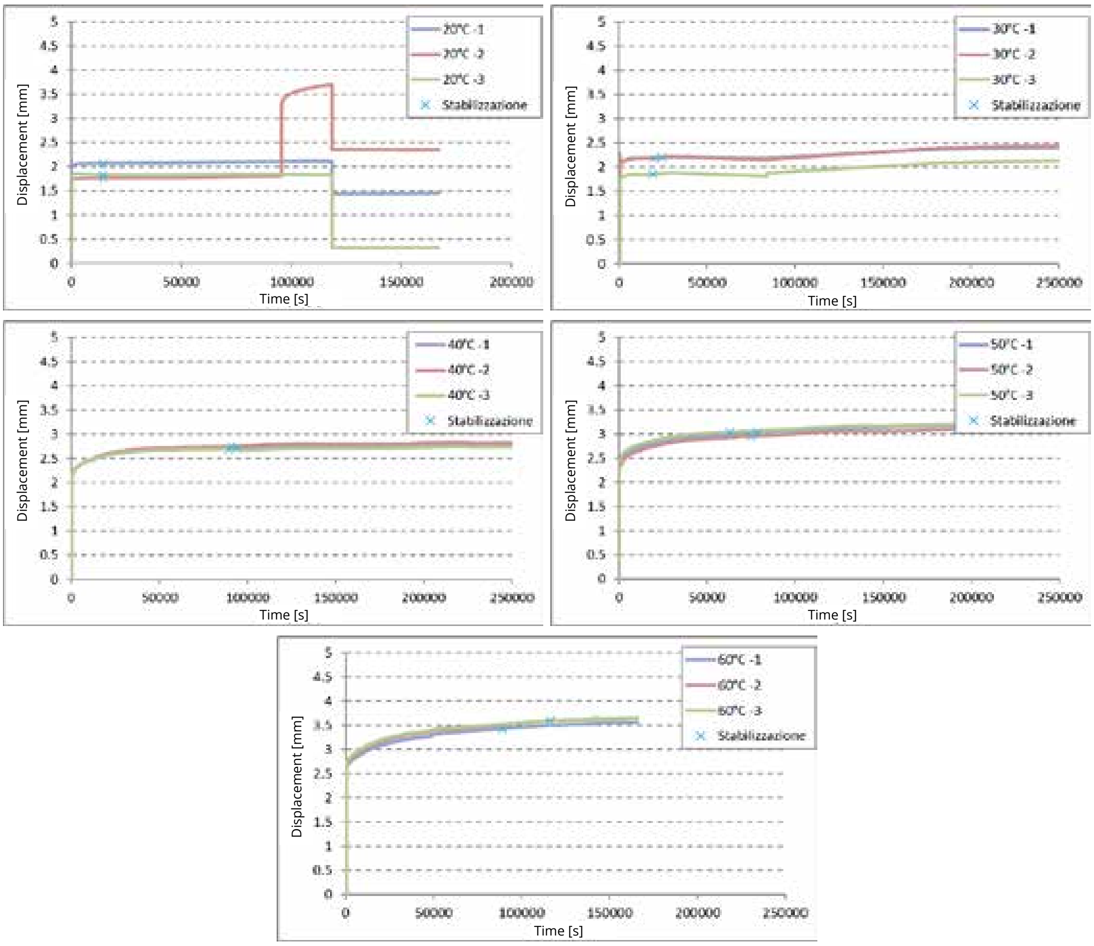
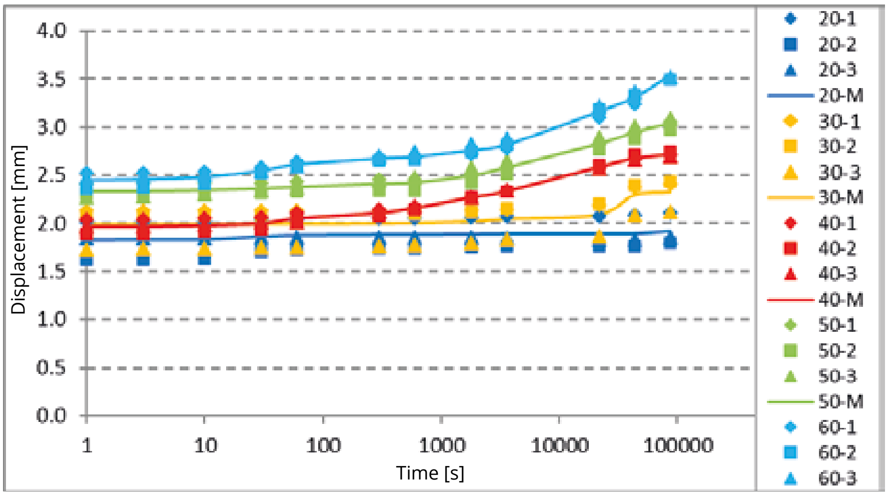


Picture 4 – Load curves effective displacement in centreline



Picture 5 – Displacement vs Time

Sample 20°C-2 shows a sudden increase in displacement associated with glass breakage.

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Table 1 - Actual displacement for different significant load instants

Temperature	Time	Time	Displacement [mm]			
[°C]	[s]	[h]	Lastra 1	Lastra 2	Lastra 3	Media
20(1)	1	0.0003	2.014	1.631	1.841	1.828
	3	0.0008	2.014	1.630	1.850	1.831
	10	0.0028	2.016	1.638	1.842	1.832
	30	0.0083	2.035	1.700	1.855	1.863
	60	0.0167	2.045	1.730	1.857	1.877
	300	0.0833	2.051	1.740	1.861	1.884
	600	0.1667	2.054	1.743	1.859	1.885
	1800	0.5000	2.059	1.751	1.855	1.888
	3600	1.0000	2.071	1.762	1.845	1.893
	21600	6.0000	2.080	1.767	1.836	1.894
	14405	4.0014	2.074	1.763	1.837	1.891
	43200	12.0000	2.084	1.769	1.834	1.896
	86400	24.0000	2.113	1.802	1.851	1.922
30 (1)	1	0.0003	2.129	2.087	1.733	1.983
	3	0.0008	2.129	2.087	1.735	1.984
	10	0.0028	2.129	2.088	1.737	1.985
	30	0.0083	2.128	2.089	1.753	1.990
	60	0.0167	2.128	2.088	1.755	1.990
	300	0.0833	2.127	2.090	1.764	1.994
	600	0.1667	2.127	2.095	1.774	1.998
	1800	0.5000	2.130	2.118	1.802	2.017
	3600	1.0000	2.140	2.151	1.829	2.040
	21600	6.0000	2.196	2.199	1.863	2.086
	21046	5.8461	2.200	2.192	1.854	2.082
	43200	12.0000	2.377	2.402	2.092	2.290
	86400	24.0000	2.406	2.430	2.126	2.321
40 (2)	1	0.0003	2.044	1.890	1.967	1.967
	3	0.0008	2.045	1.891	1.976	1.971
	10	0.0028	2.048	1.910	1.988	1.982
	30	0.0083	2.062	1.935	2.013	2.004
	60	0.0167	2.114	2.028	2.018	2.053
	300	0.0833	2.141	2.069	2.123	2.111
	600	0.1667	2.168	2.143	2.178	2.163
	1800	0.5000	2.274	2.268	2.272	2.271
	3600	1.0000	2.341	2.334	2.339	2.338
	21600	6.0000	2.576	2.610	2.573	2.586
	43200	12.0000	2.659	2.707	2.665	2.677
	51242	14.2338	2.668	2.715	2.673	2.685
	86400	24.0000	2.709	2.748	2.693	2.717
50 (2)	1	0.0003	2.415	2.309	2.276	2.333
	3	0.0008	2.415	2.309	2.282	2.335
	10	0.0028	2.418	2.315	2.301	2.345
	30	0.0083	2.425	2.323	2.337	2.361
	60	0.0167	2.432	2.330	2.370	2.377
	300	0.0833	2.451	2.336	2.442	2.410
	600	0.1667	2.453	2.340	2.477	2.423
	1800	0.5000	2.487	2.422	2.578	2.496
	3600	1.0000	2.570	2.513	2.657	2.580
	21600	6.0000	2.820	2.766	2.890	2.825
	43200	12.0000	2.940	2.887	3.005	2.944
	72166	20.0462	3.031	2.952	3.046	3.010
	86400	24.0000	3.050	2.972	3.084	3.035
60 (2)	1	0.0003	2.521	2.360	2.478	2.453
	3	0.0008	2.526	2.374	2.485	2.461
	10	0.0028	2.535	2.410	2.509	2.485
	30	0.0083	2.577	2.525	2.552	2.551
	60	0.0167	2.641	2.611	2.592	2.615
	300	0.0833	2.683	2.652	2.693	2.676
	600	0.1667	2.685	2.662	2.739	2.695
	1800	0.5000	2.721	2.743	2.821	2.762
	3600	1.0000	2.774	2.809	2.884	2.822
	21600	6.0000	3.100	3.177	3.217	3.165
	43200	12.0000	3.244	3.327	3.364	3.312
	107286	29.8017	3.425	3.591	3.600	3.475
	86400	24.0000	3.417	3.489	3.518	3.539

Stabilization time

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4. Experimental Data Analysis

4.1 Evaluation of the tangential elasticity modulus G of the interlayer

The tangential modulus value **evaluation of elasticity** was carried out in accordance with the standard (EN 16613:2019 §A.4) assuming maximum displacement.
In particular, the equivalent thickness of a monolithic glass (hmono) was evaluated using the following formula:

$$h_{mono} = \sqrt[3]{\frac{F(2L_S^3+L_B^3-3L_S L_B^2}{8E_G bw} + \frac{60QL_S^4}{384E_G bw}} \quad (1)$$

in which:
F: applied force equal to 1150 N
Q: element self-weight equal to 0.144N/m
LS, LB: distance between supports and loading knives (1000 mm and 200 mm respectively)
EG: glass elastic modulus assumed to be 70000 MPa
b: beam width subjected to load equal to 360 mm
w: decrease measured during the test
The shear transfer coefficient is evaluated using the relation:

$$\omega = \frac{h_{mono}^3 - \sum_k h_k^3}{12\sum_k (h_k h_{m;k}^2)} \quad (2)$$

in which:
hk, hm;k: are respectively the thicknesses of the single layer of glass and the distance between the centre of gravity of the individual k-th pane and the centre of gravity of the laminated section, which are respectively 8 mm and 4.4 mm.
Finally, the tangential elasticity modulus G of the interlayer was evaluated by inverting the formula of Wölfel-Bennison [3]:

$$\omega = \frac{1}{1+9.6\frac{h_{int}EI_s}{GL_S^2 h_m^2}} \quad (3)$$

in which:
hk is the interlayer thickness assumed to be 0.9 mm

$I_s = \sum_k (h_k h_{m;k}^2)$.

It is noted that the coefficient 9.6 assumed in Eq.3 is the one commonly adopted [3], however in the
complete treatment of Wölfel [4] the coefficient for the assumed load condition is 10.17.

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In the present analysis the value 9.6 was chosen, which leads to lower values tangential elasticity modulus, and therefore more cautious.

Tables 2 and 3 show the **displacement values**, the resulting equivalent thickness hmono(Eq.1), the shear transfer coefficient ω (Eq. 2), the tangential elasticity modulus G and the elasticity modulus E (evaluated as E=2(G+v) assuming v=0.5) measured at different loading times for the various temperatures considered (Figure 6). However, the interlayer proved to be particularly rigid, so that at low temperatures showed extremely rigid behaviour, leading to coefficient ω values (above 1) such that the glass is considered monolithic. In such cases, the theory adopted does not allow the modulus of tangential elasticity and consequently is impossible to construct master curves.

It is noted that the nominal values of the thicknesses were assumed (both for glass and interlayer) and having recorded extremely modest displacement values, deviations from the nominal values can influence considerably in the final result.

Table 2 - Maximum displacement and equivalent thickness for different significant load instants

Loading duration	Temperature [°C]					Temperature [°C]				
	20	30	40	50	60	20	30	40	50	60
	Displacement [mm]					h_{mono} [mm]				
1 s	2.014	2.129	2.044	2.276	2.478	17.96	17.63	17.87	17.24	16.76
3s	2.014	2.129	2.045	2.282	2.485	17.96	17.63	17.87	17.23	16.74
10s	2.016	2.129	2.048	2.301	2.509	17.95	17.63	17.86	17.18	16.69
30 s	2.035	2.128	2.062	2.337	2.552	17.90	17.63	17.82	17.09	16.60
1 m	2.045	2.128	2.114	2.370	2.592	17.87	17.63	17.67	17.01	16.51
5 m	2.051	2.127	2.141	2.442	2.693	17.85	17.63	17.60	16.84	16.30
10 m	2.054	2.127	2.178	2.477	2.739	17.84	17.63	17.50	16.76	16.21
30 m	2.059	2.130	2.274	2.578	2.821	17.83	17.63	17.24	16.54	16.05
1 h	2.071	2.151	2.341	2.657	2.884	17.79	17.57	17.08	16.37	15.93
6h	2.080	2.199	2.610	2.890	3.217	17.77	17.44	16.47	15.92	15.36
12h	2.084	2.402	2.707	3.005	3.364	17.75	16.93	16.27	15.72	15.14
24 h	2.113	2.430	2.748	3.084	3.518	17.67	16.87	16.19	15.58	14.91

Table 3 - Shear transfer ω coefficient, tangential elasticity modulus G and the elasticity modulus E for different significant load instants

Loading duration	Temperature [°C]					Temperature [°C]					Temperature [°C]				
	20	30	40	50	60	20	30	40	50	60	20	30	40	50	60
	ω					G [MPa]					E [MPa]				
1 s	1	1	1	1	0.97					74.6					223.7
3s	1	1	1	1	0.97					67.2					201.5
10s	1	1	1	1	0.95					49.3					147.9
30 s	1	1	1	1	0.93					33.6					100.7
1 m	1	1	1	1	0.91					25.7					77.2
5 m	1	1	1	0.99	0.87				178.2	16.2				534.6	48.5
10 m	1	1	1	0.97	0.85				76.3	13.8				229.0	41.3
30 m	1	1	1	0.92	0.82				27.9	10.9				83.8	32.6
1 h	1	1	1	0.89	0.79				18.6	9.3				55.9	28.0
6h	1	1	0.91	0.79	0.68			23.3	9.2	5.2			69.9	27.6	15.7
12h	1	1	0.86	0.75	0.64			15.3	7.3	4.3			46.0	21.9	13.0
24 h	1	0.99	0.85	0.73	0.60		343.2	13.4	6.4	3.7		1029	40.2	19.2	11.0

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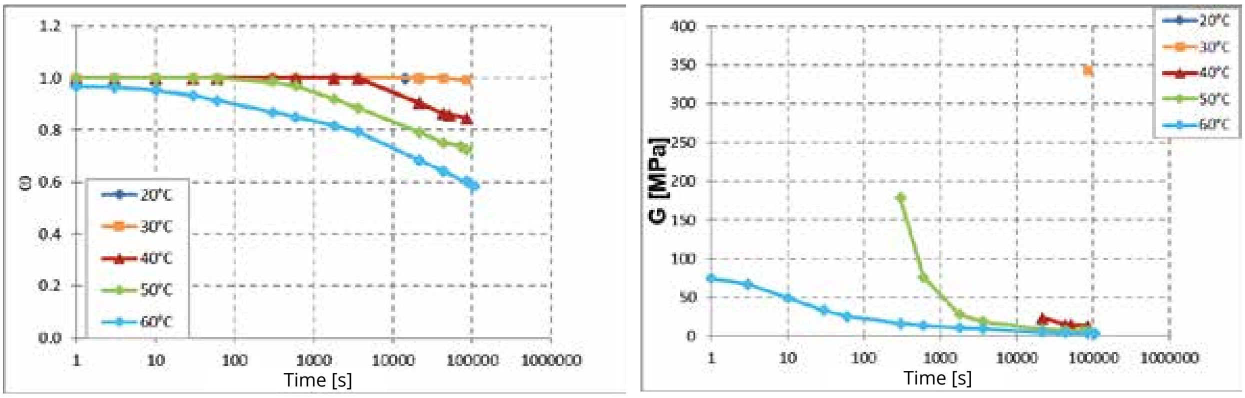

Picture 6 - Shear transfer ω coefficient and tangential elasticity modulus G at different temperatures and for different load durations

On the basis of the results obtained, however, it is possible to assess the **interlayer stiffness family** in accordance with Annex A of EN16613 (Table 4), except for load conditions 8 and 9.

Table 4 - Interlayers stiffness family

Loading conditions		Time	Temperature	Stiffness family
1	Wind gust load (Mediterranean areas)	3 sec	35°C	2
2	Wind gust load (other regions)	3 sec	20°C	2
3	Wind storm load (Mediterranean areas)	10 min	35°C	2
4	Wind storm load (other regions)	10 min	20°C	2
5	Balustrade loads, no crowds (e.g. building use categories A, B1, C1,E by EN 1991-1-1)	30 sec	30°C	2
6	Balustrade loads, crowds	5 min	30°C	2
7	Maintenance loads	30 min	40°C	2
8	Snow loads - external canopies, roofs of unheated buildings	3 weeks	20°C	-
9	Snow loads - roofs of heated buildings	5 days	20°C	-
10	Climatic loads IGU Summer	6 hours	40°C	2
11	Climatic loads IGU Winter	12 hours	20°C	2
12	Permanent	50 years	60°C	-

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5. Conclusions

The results of the experimental campaign relate to two different samplings that in both cases **showed extremely rigid behaviour**.It is considered that the proposed values indicate a high interlayer stiffness.

6. Bibliographic references

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