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Revised EN 16613: Overview of Changes and Impact on Glass Design

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Abstract

EN 16613 *Determination of interlayer viscoelastic properties* was first published in 2019 as a complementary standard to EN 16612 *Determination of the lateral load resistance of glass panes by calculation*. Both standards were prepared by CEN TC129/WG8 *Mechanical Strength*. At the same time, work on the future Eurocode EN 19100 *Design of Glass Structures* was progressing in TC250/SC11/WG1. Like EN 16612, this standard series requires reliable interlayer modulus properties for structural design of laminated glass. This working group expressed concerns over the basic measurement methodology and data processing in the determination of modulus values of interlayers to EN 16613. Therefore, it was decided to revise EN 16613 relatively shortly after its publication. The revision was executed under the umbrella of TC129/WG3 Laminated Glass, where more of the required expertise was available. This resulted in publication of a revised EN 16613 in 2025. This revised standard is intended to serve as a basis for interlayer modulus properties in the EN 19100 series. This paper describes the background of the key improvements in EN 16613 between 2019 and 2025, as well as the impact on reliable glass design.

Keywords

Interlayer, EN 16613, Modulus, EN 16612, EN 19100

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1. Introduction

Accurate modelling of the behavior of laminated glass in glazing assemblies requires an understanding of the interlayer behavior for the load scenarios under consideration. FprEN 19100 *Design of glass structures — Part 1: General rules* stipulates that structural analysis of glass shall be performed using an appropriate mechanical model for the interlayer shear transfer, as a function of the complexity and mechanical behavior of the glazing, including its supports. Shear interaction between two or more glass panes in laminated glass can affect the stresses, internal forces, and deformations the glazing assembly experiences under load. The effect can be completely absent for conditions where the interlayer modulus is low (no coupling, i.e. $G < 0.1$ MPa). In this case, the laminate behaves as two individual glass panes. The effect can also lead to near complete coupling of the two glass panes (full coupling) if the interlayer modulus is high enough (i.e. $G > 10$ MPa) (Kuntsche et al. 2019). In this case, the laminate behaves like a piece of monolithic glass of the same thickness. The effect can be favourable, associated with reduced stresses and deformations or unfavourable, mostly in association with increased stress levels. The latter scenario occurs less frequently, but examples exist, such as in small IGU's and cold bent glass. Accurate and reliable determination of the relevant interlayer modulus properties is thus important.

Generic guidance for the determination of modulus properties of plastic material is provided in standards ISO 6721-1 and ASTM D4065 *Plastics - Determination of Dynamic Mechanical Properties*. The ISO standard has twelve parts and the ASTM D4065 has a number of more specific standards associated with it. Depending on the methodology, either a shear modulus G is determined, or a Young's (tensile) modulus E is determined. The primary basis for method selection is the sensitivity of the method relative to the modulus of the material to be studied. Therefore, most methods in the ISO 6721 series have a recommended modulus range. An overview of the various ISO 6721 methods and their recommended range is provided in Table 1.

Table 1: Dynamic mechanical methods in ISO 6721 series.
Methods that have been applied to interlayers are on a light grey background.

Reference	Method	Modulus Type	Recommended Range (MPa)
ISO 6721-2	Torsion-pendulum	G	None provided
ISO 6721-3	Flexural vibration (acoustic materials)	NA	
ISO 6721-4	Tensile vibration	E	10 MPa to 5 GPa
ISO 6721-5	Flexural vibration	E	10 MPa to 200 GPa
ISO 6721-6	Shear vibration	G	0.1 MPa to 50 MPa
ISO 6721-7	Torsional vibration	G	10 MPa to 50 GPa
ISO 6721-8	Longitudinal and shear vibration (wave pulse)	G	10 MPa to 200 GPa
ISO 6721-9	Tensile vibration (sonic pulse)	E	10 MPa to 200 GPa
ISO 6721-10	Oscillatory plate/plate	G	Up to 10 MPa
ISO 6721-12	Compressive vibration	E	10 MPa to 200 GPa

Given that 1) interlayers in laminated glass are loaded in shear primarily, and 2) an optimal resolution in the transition range from no coupling to fully coupled (0.1 to 10 MPa) is desirable, it would make sense to select either ISO 6721-6 or ISO 6721-10 as candidate methodologies for interlayer modulus determination. However, the first specific draft standard regarding modulus determination proposed for interlayers in laminated glass, prEN 16613:2013, specified ISO 6721-4 Tensile vibration as its basis. The scope of ISO 6721-4 mentions that although materials with moduli outside the recommended range may be studied, alternative modes of deformation should yield higher accuracy (i.e. a shear mode for E'<10 MPa).

prEN 16613:2013 eventually was not published due to concerns over the associated design standard prEN 16612:2013. Various academic and industry authors pointed out the shortcomings of prEN 16613:2013 with regards to the methodology chosen shortly after the publication of the draft standard (Andreozzi 2014 et al.; Kuntsche et al. 2015; Zhang et al. 2015). Nevertheless, when EN 16613 (CEN, 2019) was finally published in 2019, the recommended measurement method remained tensile vibration as described in ISO 6721-4.

There was another issue with EN 16613:2019. As in its 2013 precursor, no clarity was provided on which modulus type was to be determined and reference was made to "interlayer modulus" only. Whereas the interlayer shear relaxation modulus (G_{int}) is the key variable in glass design, the interlayer complex (G* or E*) and/or storage modulus (G' or E') are more direct outputs of a modulus determination to any of the standards listed in Table 1. In addition, guidance on data processing in EN 16613:2019 was very succinct. This left the practitioner of the standard a choice for modulus type determined and data processing, resulting in frequent updates on interlayer modulus properties by producers between 2015 and 2020.

In 2021, TC250/SC11/WG1 published the precursor to the Eurocode for Design of Glass Structures as technical specification. This group was reluctant to adopt EN 16613:2019 as basis of modulus properties to be used in laminated glass design for the reasons previously outlined. Therefore, it was decided to revise EN 16613 relatively shortly after its publication. The revision was executed under the umbrella of TC129/WG3 Laminated Glass, where more of the required expertise was available. This resulted in publication of a revised EN 16613 in 2025.

2. Measurement method

Any method selected for measurement of primary data must be able to generate a master curve for modulus that covers temperatures and durations associated with conventional load scenarios in building design. More specifically, the temperature range and durations of Table D.2 of EN 16612 need to be covered. Since primary data are typically generated in the frequency range of 0.1 to 100 Hz, data must be collected well above the glass temperature of common interlayers such as PVB (T_g around 25 ^oC for conventional interlayer) and EVA (Tg around – 25 ^oC) to cover longer duration loads (e.g., cavity pressure and snow loads). In the well-established practice of time-temperature superposition (TTS), data collected at higher temperatures are used to predict the behaviour of material exposed to longer duration loads. In practice, this means collecting primary data up to at least 60^o to 80 ^oC. Under these conditions, the interlayers are typically relatively viscous. When reviewing the schematic depiction of deformation modes in Figure 1, it becomes clear why ISO 6721-4 and ISO 6721-7 are not recommended for relatively soft materials. Free standing samples with a high aspect ratio could creep away or show irreversible stretching or out-of-plane movement for these deformation modes.

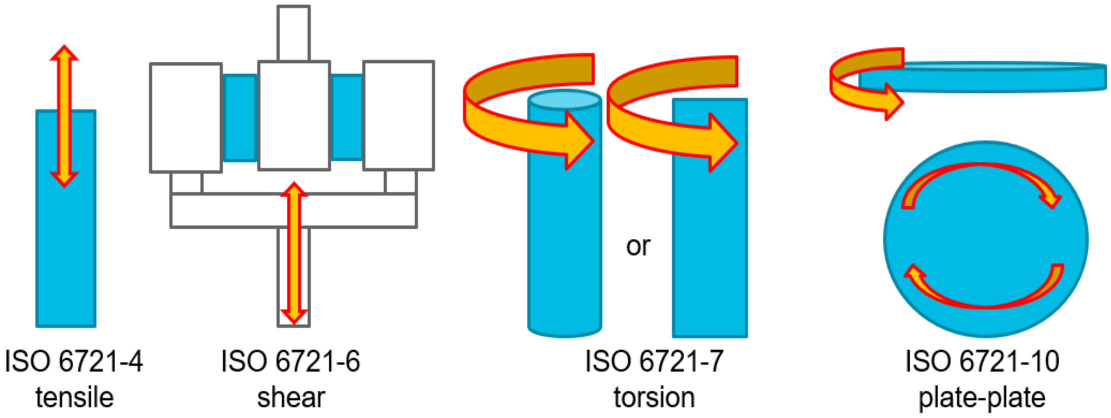

Fig. 1: Schematic depiction of deformation modes applied to interlayers.

The unusual, recommended thickness of sample specimen in EN 16613:2019 (2.3 mm thickness) may have been an effort to reduce these undesired effects. ISO 6721-6 does not suffer these drawbacks, but even from the schematic it is clear that sample preparation and clamping is complex. The normal force needed to retain the samples creates deviations from the pure shear stress state (Kuntsche et al. 2015). During revision of EN 16613:2019 by TC 129/WG3, it was found that major interlayer producers and glass producers characterizing interlayers preferred using ISO 6721-10. Therefore, in EN16613:2025, ISO 6721-10 (see Figure 2) was specified to be the preferred method of measurement, although the other methods remain available as alternative methods.

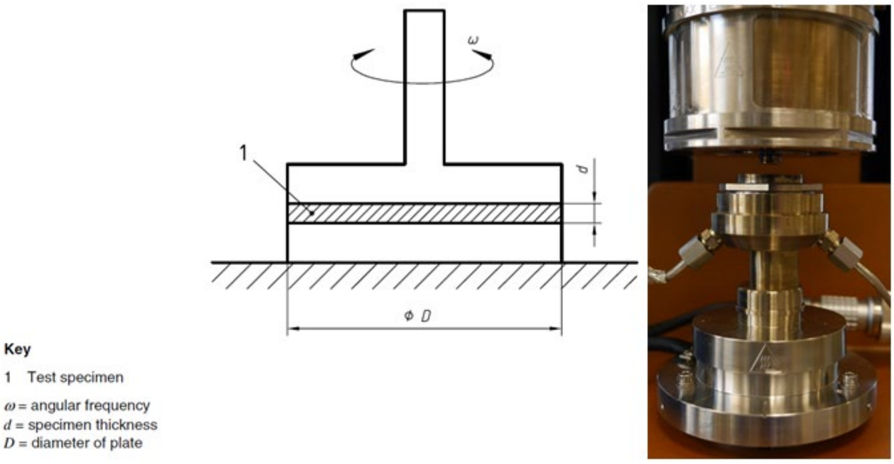

Fig. 2: Measurement in plate/plate geometry: schematically (left) and actual equipment (picture right).

Besides the changes in primary method selection from tensile to shear, other improvements in execution guidance were included, especially for the temperature-frequency sweeps that generate the core data for determination of the interlayer shear relaxation modulus (G_{int}). These included more detailed guidance for the temperature program to be used for common interlayer materials such as PVB, EVA, and ionomer and avoidance of high frequency measurements at 100 Hz or over as originally defined. This represented the very limit of even the ISO 6721-4 tensile method, leading to inaccurate results for softer materials. The recommended frequency range for the plate-plate methodology in ISO 6721-10 is 0.01 to 100 rad.s^{-1} (or approximately 0.0016 to 16 Hz). The suggested minimum range for testing in EN 16613:2025 is 0.1 to 10 Hz, in line with the measurement standard.

3. Data processing and expression of results

EN 16613:2019 specified that the data of frequency sweeps at different temperatures should be used to determine a master curve. Curve fitting was to be applied to determine Williams-Landel-Ferry (WLF) parameters C_1 and C_2. No further guidance was provided beyond reference to a 1980's textbook.

Prior to executing time-temperature sweeps, EN 16613:2025 recommends executing amplitude sweeps to establish that the testing regime of the frequency sweeps is within the linear viscoelastic regime of mechanical behavior. EN 16613:2025 instructs to generate master curves for both G' and G" by horizontal shifting only. Annex C details that shift factors α_T can be approximated using time-temperature superposition only if continuous master curves are provided for both G' and G". Three options to fit the shift factors are provided on Annex C for optimal fit (WLF, Arrhenius and polynomial), and thus accuracy for calculating G_{int}. Annex C also provides details on the determination of the Prony series that describes G_{int} as a function of time/duration with reference to recent literature in the field. An option is provided to generate a reduced Prony series with a limited number of elements (10) vs. a description of the full master curve, which typically comprises more than 20 elements. This is possible because for low and high modulus values, accuracy is less important (coupling is either complete or absent) and less common (durations in EN 16612 vary between 3 seconds and 3 weeks, permanent loads excluded). In addition, it is clearly stated that the shear relaxation modulus $G_{int}(t)$, as calculated from the Prony series in the frequency domain, should not exceed the measured shear storage modulus G' values under the same condition (see also Härth 2019).

EN 16613:2025 is much clearer and more explicit than its predecessor in terms of data processing and properties to be reported, addressing some of the key ambiguities that existed for the practitioner.

4. Validation using four-point bending creep tests

EN 16613:2025 comprises an important safeguard for unintentional mistakes in the measurement of the properties on small interlayer samples or the subsequent relative extensive data processing. In addition to the indirect determination of the interlayer shear relaxation modulus G_{int} using dynamic mechanical measurements, G_{int} is also to be determined directly on laminated glass specimen in four-point bending creep tests as a function of temperature as illustrated in Figure 3. This test is executed using the principles of EN 1288-3.

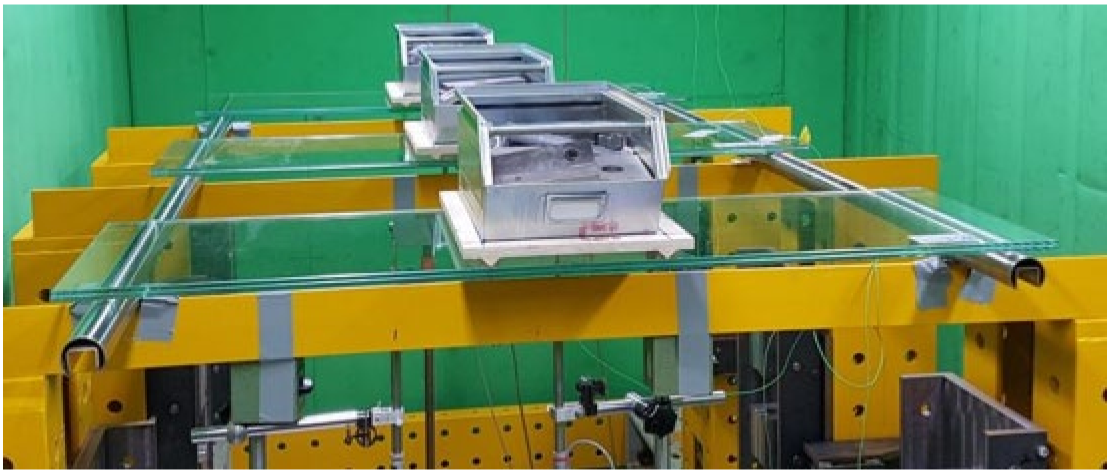

Fig. 3: Four-point bending verification set up in temperature chamber (picture courtesy of Institute of Structural Engineering, University of the German Armed Forces, München, Germany).

Deflection measurements are converted to an effective thickness value of the laminate as a function of time and duration. The effective thickness can be converted to a coupling parameter η, which can subsequently be converted to G_{int}. The applicable formulas are provided in Annex A of EN 16613:2025. These data can then be used to assess the accuracy of the G_{int} data derived from the DMTA measurements. An example is provided in Figure 4 (Stevels and D'Haene 2020).

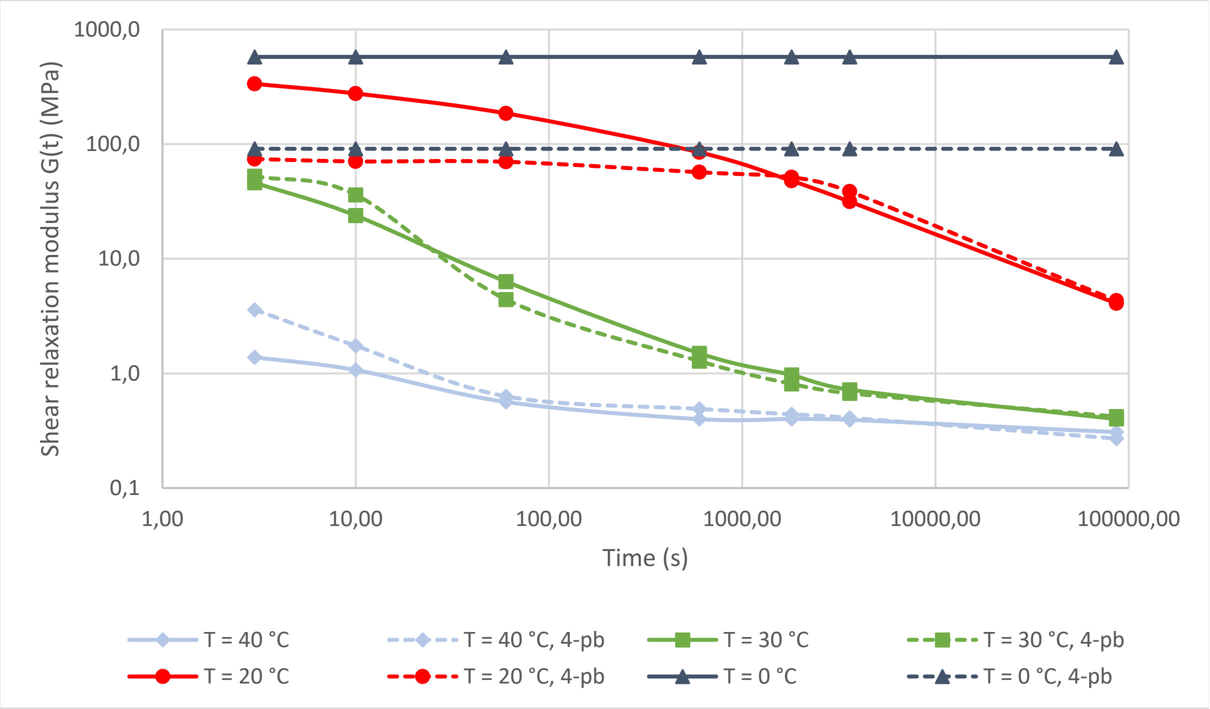

Fig. 4: Shear relaxation modulus for stiff PVB for durations between 3 seconds and 24 hours at different temperatures for the model of Table 3 (solid lines), and as derived from four-point bending experiments (dotted lines).

There are some limitations to the bending creep tests in terms of their ability to generate a full spectrum of G_{int} values. It takes a few moments to load sample specimens and any movement or slippage of the laminated glass samples during loading should be settled prior to measurement of deflection data that can be converted to an effective thickness. Measurements at relatively short durations are therefore difficult - but still relevant from a design perspective (e.g., a 3s duration for wind loads. EN 16613 suggests ten times the loading time as a cut-off for interlayer modulus calculation. In addition. The bending creep tests generate a macroscopic response. If conditions result in no coupling or full coupling, the interlayer modulus is either below (no coupling) or above the (full coupling) threshold, but it is not clear by how much. In other words, a four-point bending experiment cannot discriminate between a G_{int} modulus of 20 or 200 MPa (both full coupling) or 0.02 or 0.2 MPa (both no coupling for this specimen size). The effect for full coupling is illustrated by the curves at 0 °C in Figure 4. Therefore, the revised EN 16613 limits the validation check to modulus values between 0,5 and 10 MPa.

5. Use with EN 16612/shear transfer coefficient ω

There is somewhat of a normative inconsistency between EN 16612:2019 and EN 16613:2025 in that the former standard still refers to stiffness families in informative Annex D, whereas the latter standard no longer gives guidance on stiffness family determination. It is important to note that the body text of EN 16612 specifies that the resistance to bending of laminated glass shall be evaluated using a suitable engineering formula or calculation method which takes into account the plastic or viscoelastic properties of the interlayer material and its variation with temperature and load duration. In addition, the viscoelastic properties of the interlayer materials are required to be determined according to EN 16613. This text is fully applicable with the revised EN 16613. If needed, a stiffness family can still be determined with EN 16613:2019. Although ω values can be generated directly now using EN 16613, it is not suggested to use these values with the effective thickness equations D.1 and D.2 of Annex D of EN 16612, as the conservative element in the default ω values in Table D.3 is lost. If an analytical approach is preferred, the use of the methodology of FprEN 19100-2 Annex A would likely result in more accurate results (see below).

6. Use with FprEN 19100/coupling factor η

FprEN 19100-1 recognizes three levels of model sophistication for dealing with interlayer shear transfer that are subject to a National choice. These are 1) a limit state approach without explicit consideration of the effect of temperature and/or load duration on the interlayer, 2) analytical methods as further specified in FprEN 19100-2 Annex A and 3) numerical models. The G_{int} modulus values determined to EN 16613:2025 can be used directly either with approach 2 or approach 3. Care has been taken to ensure that the analytical formulas in Annex A of FprEN 19100-2 and Annex A of EN 16613 are consistent. It is of interest to note that a similar approach has been recently adopted in ASTM E3491 *Determination of Laminated Glass Effective Thickness*.

7. Engineering considerations & Conclusions

Revised EN 16613 has improved from its previous version in recommending a more suitable test method, providing more and better guidance for the test procedure and data processing, and comprises a safeguard in requiring bending test creep tests on laminated glass in addition to dynamic mechanical measurements. The standard revision in TC129/WG3 has been executed in close coordination with TC250/SC11(WG1) and EN 16613 is explicitly cited in FprEN 19100-1 stating that design values for the interlayer stiffness may be determined according to the test method described in EN 16613. For the specifying engineer, reference to interlayer modulus properties determined to EN 16613 should be a widely acceptable choice unless specific national regulations are in place.

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