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A Physics-Based Time-Partitioned Shear Modulus Model for Polyvinyl Butyral (PVB) Interlayers: Entanglement-Hydrogen Bond Dynamics in Pristine and Humidity/UV-Aged Materials

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Abstract

The shear response of Polyvinyl butyral (PVB) interlayers governs laminated glass structural performance, yet a unified physics-based model predicting shear modulus under environmental aging remains absent. This paper integrates shear-mode dynamic mechanical thermal analysis, solid-state nuclear magnetic resonance, and Fourier transform infrared spectroscopy to elucidate molecular mechanisms under humidity and UV exposure. Testing validates time-temperature superposition for pristine and aged states, revealing a dual-network system driven by entanglements and reversible hydrogen bonding. A time-partitioned shear modulus model, dividing relaxation into four zones with distinct molecular mechanisms, achieves high accuracy using ten interpretable parameters, surpassing traditional Prony series in efficiency and clarity. Humidity accelerates relaxation without altering modulus, whereas UV induces non-monotonic evolution. These effects are captured in the proposed model, advancing predictive modeling of environmentally responsive viscoelasticity in interlayer.

Keywords

Polyvinyl butyral (PVB), Laminated glass, Shear modulus modeling, Environmental effects

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1. Introduction

Laminated glass (LG) is a widely utilized multi-layered composite in modern architecture, automotive, and photovoltaic applications, where the structural safety relies fundamentally on the shear modulus (*G*) of the polymeric interlayer, primarily polyvinyl butyral (PVB) (Martín et al., 2020). Before glass fracture, the interlayer transfers shear forces between glass plies, dictating the flexural behavior of the LG spanning the theoretical range between zero and full shear transfer (Ivanov, 2006). However, as a typical amorphous polymer, PVB demonstrates pronounced viscoelastic characteristics. Its shear modulus is not a constant value but is highly sensitive to ambient temperature and loading duration, varying by several orders of magnitude. This variability poses substantial challenges for long-term performance prediction and structural design.

To characterize the time- and temperature-dependent shear property of PVB interlayer, dynamic mechanical analysis (DMA) and the time-temperature superposition (TTS) principle are routinely employed to construct relaxation master curves. The master curves are conventionally described using generalized Maxwell models, such as the Prony series (Duser et al., 1999). A standard Prony series often requires 11-13 exponential parameters (Hooper et al., 2012; Pelayo et al., 2017; Biolzi et al., 2020; Centelles et al., 2021; Arauz Moreno et al., 2022; Xie et al., 2024). More importantly, such phenomenological models lack a foundation in the material's intrinsic molecular relaxation mechanisms, limiting their generalizability. Alternative piecewise mathematical models offer computational parameter reduction (Viviani et al., 2023), but they still lack a direct correlation to the polymer's composition, hindering their extension to specific environmental ages.

In practical service environments, PVB interlayers are inevitably exposed to aging factors, particularly humidity and ultraviolet (UV) radiation (Udi et al., 2023; Lu et al., 2025). Although environment-induced degradation has been observed on large-strain stiffness and strength (Andreozzi et al., 2015; Botz et al., 2019; Centelles et al., 2020; Knight et al., 2022; Chen et al., 2023), a clear research gap remains in quantifying the specific magnitude of small-strain *G* evolution suitable for structural input. Because current models lack a molecular basis, they cannot reliably quantify these aging effects by mapping them onto specific parameter evolutions.

To bridge the gaps, this study systematically investigates the shear relaxation behavior of PVB interlayers under varying levels of humidity and UV aging. By elucidating the underlying dual-network mechanisms, a novel, physically interpretable time-partitioned shear modulus model is proposed. By segmenting the master curve into four distinct relaxation zones defined by three characteristic times, this model captures the viscoelastic response efficiently and demonstrates how environmental degradations can be quantitatively integrated.

2. Materials and Experimental Methods

2.1. Materials and Conditioning

The investigated material is Trosifol® UltraClear PVB (Kuraray Co., Ltd.), a standard commercial interlayer widely adopted in architectural applications. To replicate the thermal history of laminated glass production, the as-received 1.52 mm-thick PVB films underwent a standard lamination process. Non-stick polytetrafluoroethylene (PTFE) films were inserted between the PVB and glass to prevent adhesion. Following this process, the processed films were die-cut into circular specimens with a nominal diameter (Ø) of 8 mm for subsequent testing.

The prepared specimens were divided into three environmental conditioning groups (Table 1 and Fig. 1): Pristine, Humidity-aged, and UV-aged. Pristine control specimens were preserved in sealed, light-proof bags to prevent initial degradation.

Humidity-aged specimens were conditioned in a climate chamber at 65 °C for 48 hours to achieve absorption equilibrium across five relative humidity levels: 10%, 25%, 45%, 65%, and 85% RH. This duration was determined based on a preliminary numerical analysis of water vapor diffusion (Lu et al., 2025), indicating that the duration of 48 hours is sufficient to achieve absorption equilibrium and uniform moisture distribution within the specimens.

UV-aged specimens were subjected to accelerated photo-oxidative aging in a xenon-arc chamber maintained at 30 °C and 30% RH to eliminate moisture-UV coupling effects. To replicate the exact spectral and sealed conditions of actual architectural glazing, a float glass filter and PTFE edge-sealing were applied to the UV-aged specimens. Artificial aging durations were calibrated against Shanghai's annual total UV radiation (150 MJ/m^2) to represent 0, 1, 2, and 5 years of natural equivalent exposure.

Table 1: Experimental matrix on aging conditions and characterization methods.

Material Group	Aging Conditions	Characterization
Pristine	/	DMA: -20-140 ℃, 0.1-10 Hz, 0.1% strain FTIR: ATR mode, 4000-600 cm^{-1} NMR: ^{13}C-MAS
Humidity-aged	65 ℃, 48 h (Equilibrium) 10%, 25%, 45%, 65%, 85% RH	DMA: -20-90 ℃, 0.1-10 Hz, 0.1% strain
UV-aged	30 ℃, 30% RH 1,2,5 years (Equivalent dose)	DMA: -20-90 ℃, 0.1-10 Hz, 0.1% strain

Note: For each aging condition, a representative specimen was subjected to comprehensive frequency-temperature sweeps (16-21 temperatures per DMA sweep) to ensure sufficient data density for robust master curve construction.

2.2. Experimental Characterization

Shear oscillation tests (DMA) were conducted using a Discovery HR 2 parallel-plate rheometer (TA Instruments) to evaluate the viscoelastic behavior of the PVB interlayers. A constant shear strain amplitude of 0.1% was applied to ensure the material operated strictly within its linear viscoelastic regime. Temperature-frequency sweeps were performed from 0.1 to 10 Hz. For pristine PVB, a broad temperature range of -20 °C to 140 °C was implemented to fully capture the relaxation spectrum. For aged specimens, the maximum temperature was restricted to 90 °C to prevent water content loss during testing.

To establish the molecular structural basis for the mechanical response, the chemical composition and supramolecular interactions of the interlayers were characterized. The FTIR spectroscopy (Thermo Scientific Nicolet iS50 in ATR mode) was utilized to identify functional groups, successfully confirming the presence of robust hydrogen-bonding associations among the hydroxyl groups. Additionally, solid-state ^{13}C NMR spectroscopy was employed to identify the chemical environment of carbon atoms, enabling the quantitative determination of the vinyl butyral, vinyl alcohol, and plasticizer mass fractions within the polymer network.

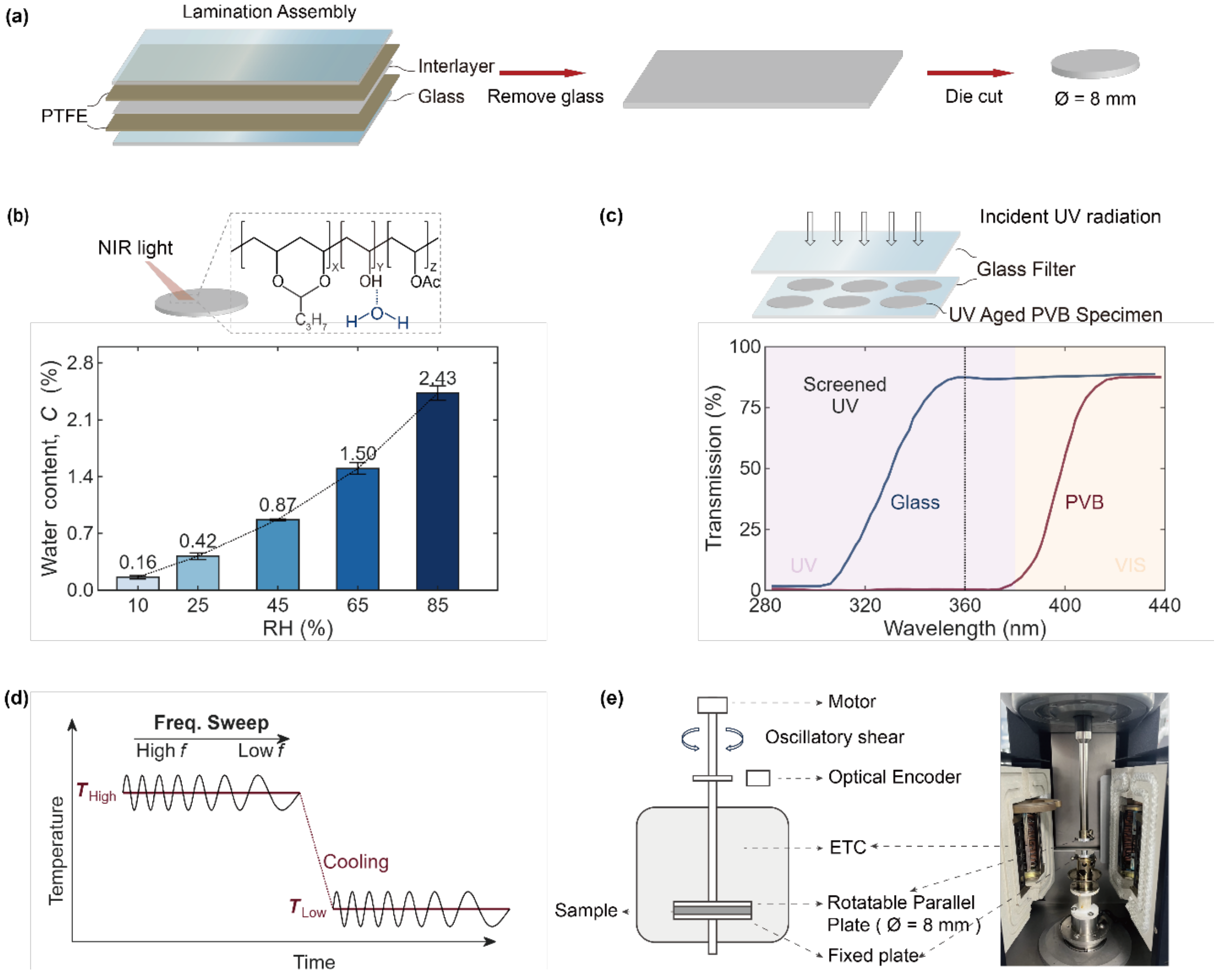

Fig. 1: Material and methods. (a) Specimen preparation.
(b) Humidity-aged PVB: Water content quantification via NIR spectroscopy.
(c) UV-aged PVB: Spectral filtering by glass to screen out short-wave UV.
(d) Temperature-Frequency Sweep. (e) Shear oscillation test setup using parallel plate rheometer.

3. Test Results and Analysis

3.1. Molecular Structure and Composition

The molecular structure and chemical composition of the PVB interlayer were elucidated using FTIR and solid-state ^{13}C NMR spectroscopy. The analysis quantitatively determined the final mass fraction as 49.22 wt% vinyl butyral (VB), 24.28 wt% vinyl alcohol (VA), and 26.50 wt% plasticizer. Crucially, the FTIR spectra revealed significant shifts and broadening of the O-H stretching band. These features confirm the presence of strong intramolecular and intermolecular hydrogen bonding networks among the hydroxyl groups (VA units), which significantly influences the material's viscoelasticity.

3.2. Thermo-rheological Simplicity

To evaluate the validity of the time-temperature superposition (TTS) principle, van Gurp-Palmen (vGP) plots were constructed by plotting the phase angle against the complex modulus. For pristine PVB interlayers, the vGP curves (Fig. 2) showed excellent overlap across the entire test temperature range from -20 °C to 140 °C. This consistency confirms that the material exhibits thermo-rheological simplicity. Furthermore, the vGP plots for humidity- and UV-aged PVB interlayers also exhibited clear overlaps.

This indicates that the primary relaxation dynamics retain thermo-rheological simplicity even after aging, suggesting that moisture absorption and UV-induced microstructural changes do not fundamentally disrupt the time-temperature equivalence.

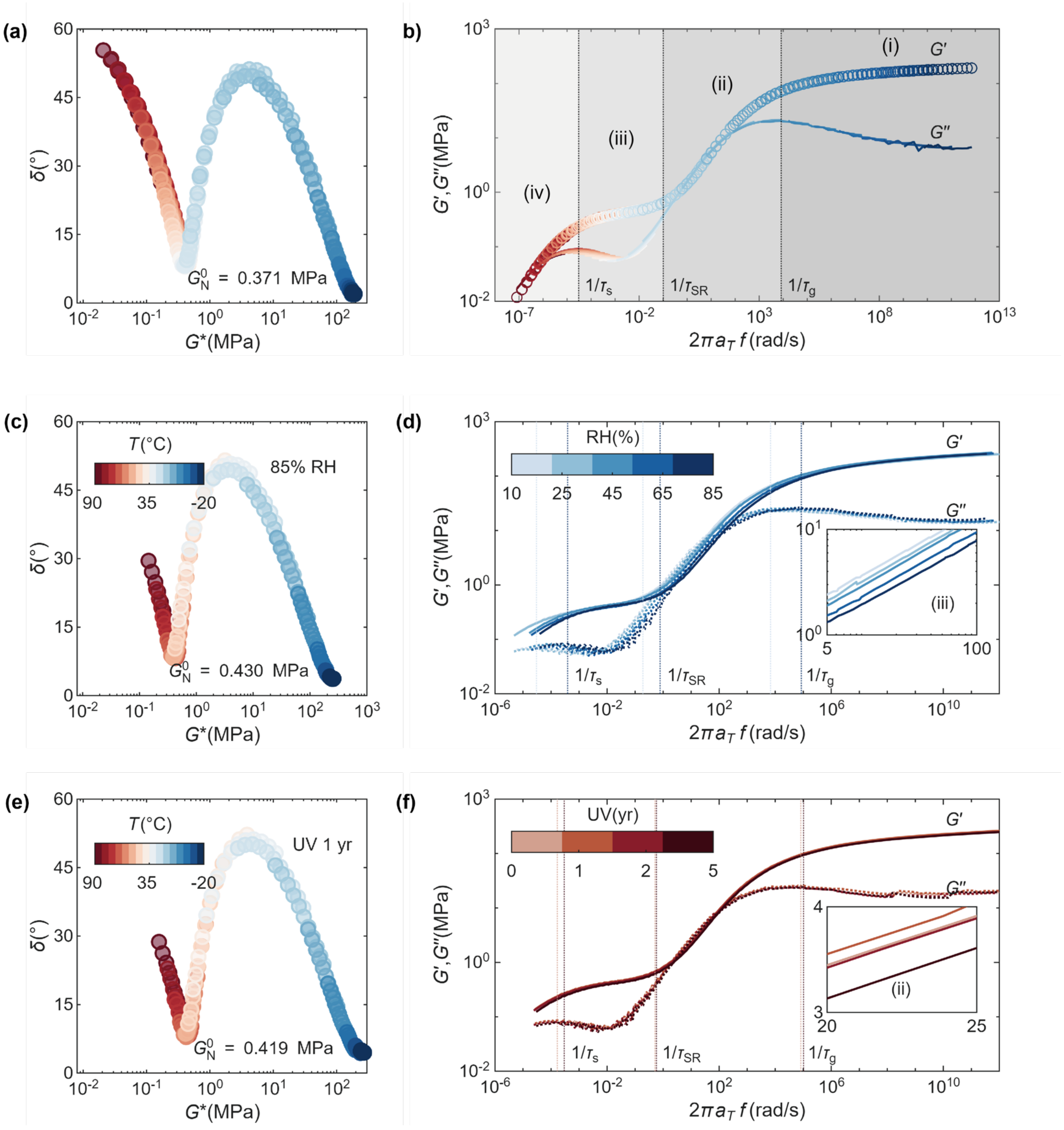

Fig. 2: Application of TTS for pristine and aged PVB interlayers. (a, c, e) van Gurp-Palmen (vGP) plots; (b, d, f) Master curves at Tref = 30 °C. Rows represent (a-b) Pristine, (c-d) Humidity-aged, and (e-f) UV-aged conditions.

3.3. Master Curves and Effect of Environmental Aging

Based on the validated TTS principle, dynamic mechanical data were horizontally shifted to construct master curves at a reference temperature of 30 °C. The pristine PVB master curve displays a characteristic inverse S-shape (Fig. 2). However, a notable feature is the gradual decline in the storage modulus (*G*') beyond the rubbery plateau at low frequencies. This continued modulus decay reflects ongoing, long-term molecular relaxation processes.

Under environmental exposure, the master curves revealed distinct degradation mechanisms. For Humidity-aged PVB, the curves underwent a progressive rightward shift along the frequency axis as relative humidity increased. This horizontal shift suggests that absorbed water enhances molecular mobility and effectively accelerates relaxation times (plasticization) without significantly altering the intrinsic plateau stiffness. The UV-aged PVB specimens showed no significant horizontal shift, implying stable relaxation speeds. Instead, a prominent non-monotonic vertical shift in the modulus was observed: a transient hardening (modulus increase) after one year of exposure, followed by a gradual softening (modulus decrease) over prolonged irradiation.

4. Physics-Based Time-Partitioned Model

4.1. Dual-Network Mechanism and Model Formulation

As established by the structural characterization, the viscoelastic response of the PVB interlayer is fundamentally governed by a dual-network mechanism: topological chain entanglements and physical hydrogen-bond associations. Theoretical calculations based on polymer physics reveal that the intrinsic entanglement modulus contributed purely by the polymer backbone is significantly lower than the experimentally measured rubbery plateau modulus. This discrepancy confirms that reversible hydrogen bonds among vinyl alcohol (VA) units provide a supplementary dynamic reinforcement to the network.

Because these two mechanisms operate on distinct timescales, the shear relaxation master curve can be systematically partitioned into four zones delineated by three characteristic relaxation times (τ_g, τ_{SR}, τ_d), as illustrated in Fig. 3:

- (i) Glassy Zone ($t \leq \tau_g$): At highly short timescales, molecular mobility is restricted to the localized motion of side chains and local backbone torsions, resulting in a stiff, solid-like behavior.
- (ii) Segmental Sticky-Rouse Zone ($\tau_g < t \leq \tau_{SR}$): As time progresses, localized chain segments begin to relax. However, their motion is hindered by reversible hydrogen bonds acting as transient stickers. These stickers introduce significant frictional damping, forcing the segments to undergo dynamic equilibration through repeated breaking and reforming of bonds.
- (iii) Diffuse Plateau Zone ($\tau_{SR} < t \leq \tau_d$): In this intermediate regime, topological constraints typically create a flat rubbery plateau. However, the progressive relaxation of shorter chains and the dynamic dissociation of hydrogen-bond stickers result in a sloped modulus decay rather than a constant value.
- (iv) Disentanglement Zone ($t > \tau_d$): At long timescales, topological constraints begin to relax, reflecting the progressive escape of polymer chains from their entanglement tubes and the onset of macroscopic viscous flow.

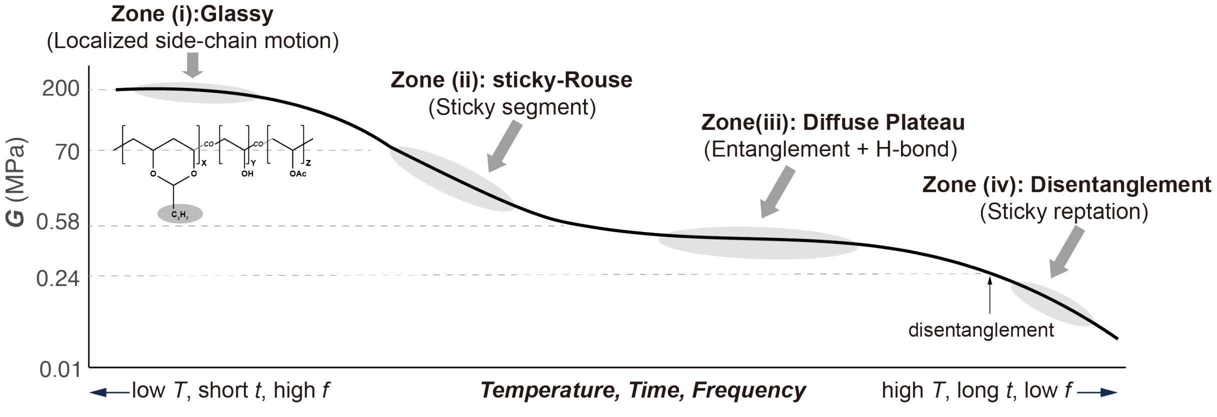

Fig. 3: Schematic illustration of the dual-network mechanism and the four relaxation zones delineated by characteristic times in the master curve.

Building upon this physical framework, the viscoelastic behavior is mathematically formulated by assigning specific decay functions to each zone. The short-time relaxation in the Glassy zone is described by the Kohlrausch-Williams-Watts (KWW) stretched exponential function (Williams & Watts, 1970). In contrast, the intermediate and long-time regimes are dominated by segmental dynamics and disentanglement, which exhibit pronounced power-law dependencies. The comprehensive time-partitioned shear modulus model, $G(t)$, is expressed as

$$G(t)=\begin{cases} G_g \exp\left[-\left(t/t_g\right)^{\beta}\right], 0<t\leqslant\tau_g \\ G_u\left(t/\tau_{SR}\right)^{-\alpha_{ii}}, \tau_g<t\leqslant\tau_{SR} \\ G_u\left(t/\tau_{SR}\right)^{-\alpha_{iii}}, \tau_{SR}<t\leqslant\tau_d \\ G_l\left(t/\tau_d\right)^{-\alpha_{iv}}, t>\tau_d \end{cases} \tag{1}$$

Here, G_u and G_l represent the characteristic reference moduli at τ_SR, τ_d, respectively. The exponents α_ii, α_iii and α_iv quantify the power-law decay rates in zones (ii), (iii), and (iv). The physical interpretation and fitted values of model parameters, determined via nonlinear least squares fitting, are summarized in Table 2 and Fig. 4.

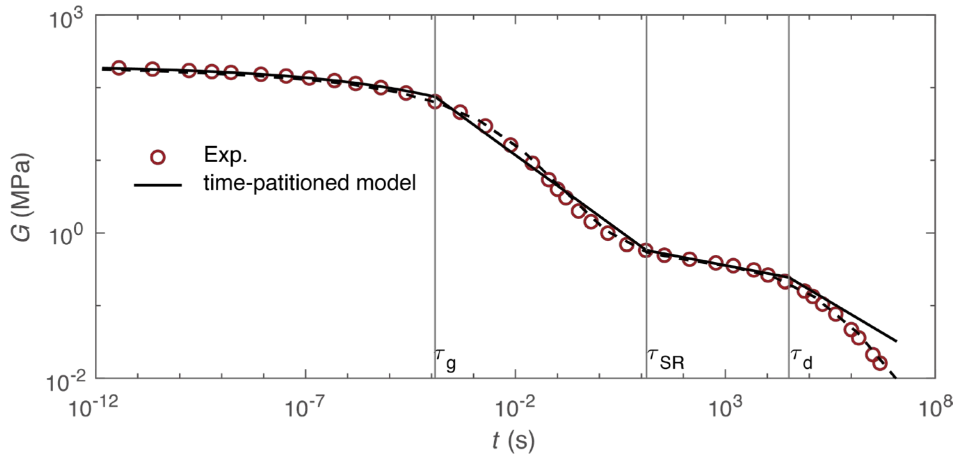

Fig. 4: Comparison between predictions of the time-partitioned model and the experimental master curve.

Table 2: Physical interpretation and fitted values of the time-partitioned viscoelastic model parameters.

Parameters	Physical interpretation	Value
G_g(MPa)	Instantaneous glassy modulus	200.91
G_u(MPa)	Upper plateau modulus	0.75
G_l(MPa)	Lower plateau (entanglement) modulus	0.25
τ_g(s)	Glassy relaxation time	1.23E-4
τ_{SR}(s)	Sticky-Rouse relaxation time	3.28
τ_d(s)	Disentanglement relaxation time	3.12E+4
β	Stretching exponent for Zone (i)	0.14
α_ii	Power-law decay exponent for Zone (ii)	0.45
α_iii	Power-law decay exponent for Zone (iii)	0.12
α_iv	Power-law decay exponent for Zone (iv)	0.50

Unlike the conventional generalized Maxwell model (Prony series), which relies on mathematical curve-fitting and requires at least 20 Maxwell elements (yielding 41 parameters) to capture the broad relaxation spectrum, this proposed model achieves exceptional accuracy using only 10 physically meaningful parameters. This compact structure significantly enhances computational efficiency for structural simulations while offering direct physical interpretability by linking macroscopic modulus changes to specific molecular mechanisms.

4.2. Integration of Environmental Effects

To evaluate the model's capability in capturing environmental degradation, the time-partitioned framework was applied to the master curves of humidity- and UV-aged PVB interlayers via nonlinear least-squares fitting. Unlike the generalized Maxwell model (Prony series), which requires adjusting dozens of phenomenological parameters, the proposed model successfully maps specific environmental actions onto isolated physical parameters, as summarized in Table 3 and Table 4.

For Humidity-aged PVB, quantitative analysis reveals that rising moisture content significantly alters the characteristic relaxation times. As relative humidity increases from 10% to 85%, these time thresholds decrease. In contrast, the reference moduli at transition points and the power-law exponents remain nearly invariant. This parameter isolation explicitly confirms the plasticization mechanism of moisture: absorbed water enhances molecular mobility and accelerates relaxation dynamics (manifesting as a horizontal translation of the master curve toward higher frequencies) without fundamentally altering the intrinsic stiffness of the topological entanglement network.

Table 3: Parameters of the time-partitioned viscoelastic model for Humidity-aged PVB interlayers.

Parameters	10% RH	25% RH	45% RH	65% RH	85% RH	mean	CV
G_g(MPa)	204.99	203.13	196.78	198.62	203.31	201.37	0.02
G_u(MPa)	0.52	0.57	0.63	0.57	0.60	0.58	0.07
G_l(MPa)	0.25	0.24	0.25	0.25	0.24	0.25	0.02
τ_g(s)	1.40E-04	1.11E-04	1.01E-04	9.60E-05	8.98E-05	-	-
τ_{SR}(s)	5.01E+00	4.90E+00	2.77E+00	2.43E+00	1.35E+00	-	-
τ_d(s)	3.54E+04	3.16E+04	5.70E+03	4.87E+03	2.43E+03	-	-
β	0.14	0.14	0.15	0.15	0.15	0.15	0.03
α_{ii}	0.49	0.47	0.49	0.50	0.50	0.49	0.02
α_{iii}	0.10	0.11	0.11	0.11	0.11	0.11	0.05
α_{iv}	0.30	0.31	0.30	0.30	0.32	0.31	0.04

The application of the model to UV-aged specimens yields a distinctly different pattern. The fluctuations across all relaxation timescales and frequency scaling exponents remain negligible over the 5-year equivalent exposure, indicating that UV irradiation does not significantly alter the material's relaxation rates. Instead, the environmental effects are entirely captured by the adjustment of the modulus parameters, which undergo a notable non-monotonic evolution. The moduli exhibit a transient hardening (initial increase) during the first year, followed by long-term softening (gradual decrease) from year 2 to year 5. Mechanistically, this aligns with the competing chemical processes occurring within the dual-network: initial UV exposure induces the polarization of hydroxyl groups and initiates crosslinking, temporarily strengthening the network. However, as exposure continues, oxidative degradation dominates, leading to chain scission and the disruption of the supramolecular hydrogen-bonded network.

Table 4: Parameters of the time-partitioned viscoelastic model for UV-aged PVB interlayers.

Parameters	0 yr	1 yr	2 yr	5 yr	Mean	CV(-)
G_g(MPa)	202.53	212.16	207.02	200.35	-	-
G_u(MPa)	0.66	0.67	0.64	0.61	-	-
G_l(MPa)	0.26	0.28	0.27	0.27	-	-
τ_g(s)	1.17E-04	9.30E-05	1.10E-04	1.14E-04	-	-
τ_{SR}(s)	1.82E+00	1.98E+00	2.05E+00	2.01E+00	-	-
τ_d(s)	5.51E+03	5.68E+03	3.93E+03	3.22E+03	-	-
β	0.20	0.20	0.18	0.18	1.93E-01	0.05
α_{ii}	0.49	0.48	0.49	0.49	4.86E-01	0.01
α_{iii}	0.11	0.11	0.11	0.11	1.12E-01	0.02
α_{iv}	0.33	0.33	0.31	0.31	3.18E-01	0.03

5. Conclusions

In this study, a novel physics-based time-partitioned shear modulus model was developed to predict the small-strain shear modulus (G) evolution of polyvinyl butyral (PVB) interlayers under humidity and UV aging. The main findings are summarized as follows:

- Experimental characterization validated the time-temperature superposition (TTS) principle for both pristine and aged PVB. The material's complex shear relaxation is fundamentally governed by a dual-network mechanism comprising topological chain entanglements (providing baseline elasticity) and reversible hydrogen bonds (offering dynamic reinforcement).
- Building on these molecular origins, the relaxation master curve was partitioned into four distinct zones (Glassy, Sticky-Rouse, Diffuse Plateau, and Disentanglement) delineated by three characteristic relaxation times. The resulting 10-parameter model offers enhanced physical interpretability and significant computational efficiency compared to traditional phenomenological methods like the Prony series.
- The proposed model quantifies specific environmental degradations. Humidity induces a plasticization effect that accelerates relaxation processes without altering the intrinsic plateau modulus, which is captured by systematically reducing characteristic relaxation time thresholds. In contrast, UV irradiation maintains stable relaxation rates but causes a non-monotonic evolution in material stiffness, i.e., an initial transient hardening followed by gradual long-term softening, captured through the targeted adjustment of critical modulus parameters.

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References

Andreozzi, L., Briccoli Bati, S., Fagone, M., Ranocchiai, G., Zulli, F.: Weathering action on thermo-viscoelastic properties of polymer interlayers for laminated glass. Constr. Build. Mater. 98, 757–766 (2015)

Arauz Moreno, C., Piroird, K., Lorenceau, E.: Extended time–temperature rheology of polyvinyl butyral (PVB). Rheol. Acta 61, 539–547 (2022)

Biolzi, L., Cattaneo, S., Orlando, M., Piscitelli, L.R., Spinelli, P.: Constitutive relationships of different interlayer materials for laminated glass. Compos. Struct. 244, 112221 (2020)

Botz, M., Wilhelm, K., Siebert, G.: Experimental investigations on the creep behaviour of PVB under different temperatures and humidity conditions. Glass Struct. Eng. 4, 389–402 (2019)

Centelles, X., Martín, M., Solé, A., Castro, J.R., Cabeza, L.F.: Tensile test on interlayer materials for laminated glass under diverse ageing conditions and strain rates. Constr. Build. Mater. 243, 118230 (2020)

Centelles, X., Pelayo, F., Lamela-Rey, M.J., Fernández, A.I., Salgado-Pizarro, R., Castro, J.R., Cabeza, L.F.: Viscoelastic characterization of seven laminated glass interlayer materials from static tests. Constr. Build. Mater. 279, 122503 (2021)

Chen, X., Lin, B., Schuster, M., Chen, S., Xu, B.-X., Schneider, J.: Effect of moisture on the delamination properties of fractured PVB-laminated glass: A joint experimental and numerical study. Compos. Struct. 322, 117381 (2023)

Duser, A.V., Jagota, A., Bennison, S.J.: Analysis of glass/polyvinyl butyral laminates subjected to uniform pressure. J. Eng. Mech. 125, 435–442 (1999)

Hooper, P.A., Blackman, B.R.K., Dear, J.P.: The mechanical behaviour of poly(vinyl butyral) at different strain magnitudes and strain rates. J. Mater. Sci. 47, 3564–3576 (2012)

Ivanov, I.V.: Analysis, modelling, and optimization of laminated glasses as plane beam. Int. J. Solids Struct. 43, 6887–6907 (2006)

Knight, J.T., El-Sisi, A.A., Elbelbisi, A.H., Newberry, M., Salim, H.A.: Mechanical behavior of laminated glass polymer interlayer subjected to environmental effects. Polymers 14, 5113 (2022)

Lu, Y., Chen, S., Liao, W.: Time- and environment-dependent water content distribution in Polyvinyl Butyral (PVB) laminated glass: Interlayer and interface contributions. J. Build. Eng. 112, 113659 (2025)

Martín, M., Centelles, X., Solé, A., Barreneche, C., Fernández, A.I., Cabeza, L.F.: Polymeric interlayer materials for laminated glass: A review. Constr. Build. Mater. 230, 116897 (2020)

Pelayo, F., Lamela-Rey, M.J., Muniz-Calvente, M., López-Aenlle, M., Álvarez-Vázquez, A., Fernández-Canteli, A.: Study of the time-temperature-dependent behaviour of PVB: Application to laminated glass elements. Thin-Walled Struct. 119, 324–331 (2017)

Udi, U.J., M. Yussof, M., Isa, F.N., Abdullah, L.C.: Analysis of Environmental Stresses on the Mechanical Properties of Laminated Glass Composites: A Review of Experimental Results and Outlook. Pertanika J. Sci. Technol. 31, 2339–2359 (2023)

Viviani, L., Di Paola, M., Royer-Carfagni, G.: Piecewise power law approximation of the interlayer relaxation curve for the long term viscoelastic fractional modeling of laminated glass. Compos. Struct. 324, 117505 (2023)

Williams, G., Watts, D.C.: Non-symmetrical dielectric relaxation behaviour arising from a simple empirical decay function. Trans. Faraday Soc. 66, 80–85 (1970)

Xie, D., Yang, J., Zhao, C., Wang, X.: Comprehensive investigation into the thermal rheological behavior and relaxation characteristic of single/composite polymers in laminated glass. Thin-Walled Struct. 195, 111369 (2024)

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