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Viscoelastic Behavior, Interfacial Mechanics, and Reliability of Polymer Interlayers in Laminated Glass Composites: A Comprehensive Review

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Abstract

The laminated glass systems are regarded as hybrid polymer–glass composites where the viscoelastic behavior of polymer interlayers mostly controls mechanical response. These interlayers (polyvinyl butyral (PVB), ionoplast, ethylene-vinyl acetate (EVA), etc.) have time-, temperature- and rate-dependent properties which significantly affect shear transfer, energy dissipation, and fracture resistance. But the baseline polymer-relevant processes at the molecular and interfacial level are to a large extent unknown [1]. This review provides a materials-focused viewpoint on the polymer interlayers in laminated glass systems, with a focus on viscoelastic constitutive behaviour, molecular mobility, and interfacial adhesion. The effects of polymer composite (chain dynamics and glass transition behaviour) on creep, stress relaxation, and thermomechanical behaviour are discussed in detail. Advanced modeling strategies such as nonlinear viscoelastic formulations and probabilistic frameworks are reviewed for accurate prediction of time- and uncertainty-dependent material behavior. In addition, the contribution of polymer interlayers to post-fracture load transfer and the overall composite reliability are also studied from a materials science perspective. As well, new progress on nanocomposite interlayers, bio-based polymers, and data-driven materials modelling techniques is discussed. Major research gaps in multi-scale characterization and long-term performance prediction are highlighted, providing critical guidance for the design of high-performing, durable, and sustainable polymer–glass composite material systems [2]. Macroscopic properties can be traced back to molecular chain dynamics and relaxation spectra.

Keywords: Polymer interlayers, viscoelasticity, laminated glass composites, interfacial adhesion, creep and stress relaxation, polymer nanocomposites, reliability modeling, thermo-viscoelastic behavior

INTRODUCTION

The laminated glass systems are a type of hybrid composite material where the polymer interlayers have a preponderant influence on the resulting mechanical and long-term performance. In contrast with classical monolithic materials, the behaviour of these material systems is heavily influenced by the viscoelastic response of the polymer phase, which affects the stress transfer, the energy absorption, and the integrity of potential material systems. Consequently, the time, temperature and loading rate dependent nature is implicit in the mechanical behaviour.

Polymer interlayers such as polyvinyl butyral (PVB), ionoplast, and ethylene-vinyl acetate (EVA) can be considered as complex materials due to their molecular structure, which involves factors such as chain mobility, entanglement density, and intermolecular forces. These parameters control essential features such as shear modulus, the damping capacity, and relaxation behaviors.

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Especially glassy–rubbery transitions have a significant impact on the thermo-viscoelastic response and thus polymer interlayers are extremely sensitive to environmental conditions [3].

From the viewpoint of polymer physics, the interaction of stiff glass plies and compliant interlayers can be modeled as a layered composite material system in which the interlayer controls the interfacial stress transfer and the deformation compatibility. The performance of this interaction is closely related to interfacial adhesion mechanisms, and these include surface chemistry, physical bonding, and environmental exposure. Degradative mechanisms like moisture ingress and UV radiation can degrade polymer composites and diminish interfacial integrity, leading to compromised long-term durability.

While laminated glass material systems have been thoroughly investigated, most of this research is focused on macroscopic behavior without significant consideration of the polymer system rheology and the multiscale interactions. Traditional models apply simplified hypotheses that omit nonlinear viscoelasticity, ageing phenomena, and molecular-level mechanisms, which result in inaccuracies in long-term performance prediction [4]. Hence, the current review takes the polymer viewpoint and highlights the viscoelastic behavior, molecular mechanisms, interfacial interactions, and the reliability of the polymer interlayers used in laminated glass composites. With this thesis in mind, the aim is to consider a complete picture of the material response by combining suitable concepts from condensed matter physics, rheology, and composite mechanics to enable the design of new state-of-the-art high–performance polymer–glass composite materials systems.

To provide a unified understanding, the viscoelastic behavior, interfacial adhesion, and reliability of laminated glass systems can be integrated into a coupled multi-scale framework. At the molecular scale, polymer chain mobility governs relaxation phenomena, which influence macroscopic properties such as shear modulus and damping. At the structural scale, these properties control stress transfer between glass plies and interlayer, thereby affecting load-bearing capacity and failure mechanisms. Furthermore, environmental effects such as temperature and moisture act across scales, modifying both viscoelastic response and interfacial bonding. This integrated framework enables a more comprehensive prediction of laminated glass performance under real service conditions.

The importance of this study is particularly evident in safety-critical applications such as automotive windshields, architectural facades, and protective glazing systems, where failure can have severe consequences. Understanding the coupled viscoelastic and interfacial behavior of polymer interlayers is essential for improving impact resistance, post-fracture safety, and long-term durability. Therefore, this review aims to bridge the gap between material-level behavior and engineering design requirements.The entire multi-scale generalization framework of polymer-interlayered glass system composites is schematically depicted in Figure 1.

This review follows a structured narrative approach to analyze the viscoelastic and interfacial behavior of polymer interlayers in laminated glass systems. Relevant literature was collected from major scientific databases including Scopus, Web of Science, and ScienceDirect. Keywords such as “polymer interlayers”, “laminated glass”, “viscoelasticity”, “creep behavior”, and “interfacial adhesion” were used.

The selection criteria focused on peer-reviewed journal articles published between 1990 and 2024, emphasizing experimental, numerical, and review studies related to mechanical performance and durability of laminated glass composites. Studies addressing polymer physics, interfacial mechanics, and reliability modeling were prioritized.

The collected studies were categorized based on material type, mechanical behavior, environmental effects, and modeling approaches. A comparative and critical analysis was then performed to identify key trends, limitations, and research gaps. This study adopts a structured narrative review approach, incorporating comparative and critical analysis rather than a fully systematic review.

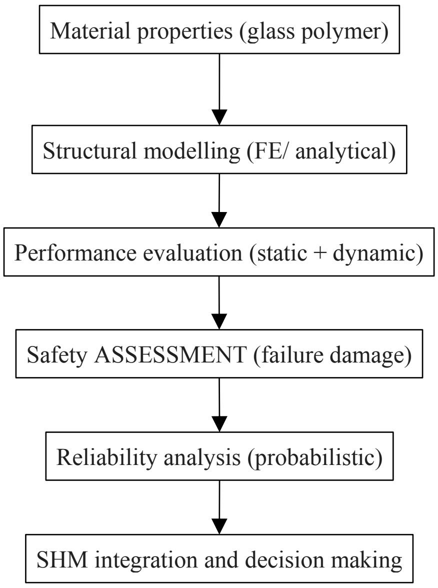

Figure 1. Integrated framework for performance, durability, and reliability assessment of polymer–glass composite material systems.

Table 1. Comparison of polymer interlayers.

Interlayer	Shear modulus (MPa)	Tg (°C)	Creep resistance	Adhesion strength
PVB	0.4–1	~20–25	Low	High
Ionoplast	10–100	~55	Very high	Very high
EVA	5–20	~-15–0	Moderate	Moderate

MATERIALS AND POLYMER-INTERLAYER MATERIAL SYSTEMS

Laminate glass constructions consist of rigid two-dimensional plies of glass bonded by polymer interlayers that control the overall mechanical behaviour. From a materials perspective, these types of material systems can be regarded as layered composites in which the polymer phase controls the shear transfer and the energy dissipation. The competing mechanics of elastic glass and viscoelastic polymer produce a complex temperature-, loading-rate-, and environment-dependent mechanical behaviour. The relevant material properties of the glass and polymer interlayer in the laminated systems employed in this study are summarized in Table 1.

A critical comparison of interlayer materials reveals significant differences in mechanical performance. PVB exhibits high damping and adhesion but suffers from low stiffness and high creep, making it less suitable for load-bearing applications. Ionoplast interlayers provide superior stiffness and reduced creep, enabling better structural performance, particularly in high-load conditions. EVA offers improved environmental resistance and UV stability but has moderate mechanical strength. Therefore, the selection of interlayer material should be application-specific, balancing stiffness, durability, and environmental resistance.

Laminated Glass as a Hybrid Polymer Composite

Laminated glass acts as a layered composite system where the structural load is distributed between the brittle glass plies and the deformable polymer interlayer. The polymer phase facilitates relaxation of stress and stops catastrophic failure by holding the material together after cracking. This coupled interaction leads to nonlinear mechanical behavior dictated by interfacial adhesion, polymer rheology, and environmental conditions.

Polymer Interlayers: Composite and Viscoelastic Behavior

Polymer-based interlayers (PVB, EVA, ionoplast) are highly viscoelastic materials due to their molecular structure. Their mechanical behavior is driven by chain mobility, entanglement density, and thermally activated transitions between glassy and rubbery states. These factors influence the shear modulus, damping ratio, and creep behavior, which, in turn, affect the performance of the composites in a direct manner. The effect of polymer interlayers on mechanical response can be clearly observed in the load–deflection behavior of laminated glass systems. shown in Figure 2.

Further, the interlayer may deteriorate when exposed to the air, such as yellowing and debonding, and this may suggest that the mechanical performance of the service units has been compromised. Polymer interlayers exhibit time-dependent viscoelastic behavior, the detailed mechanisms of which are discussed in Section 3 [5]. The viscoelastic behaviour of polymer interlayers with creep and stress relaxation is illustrated in Figure 3 for two different loading conditions.

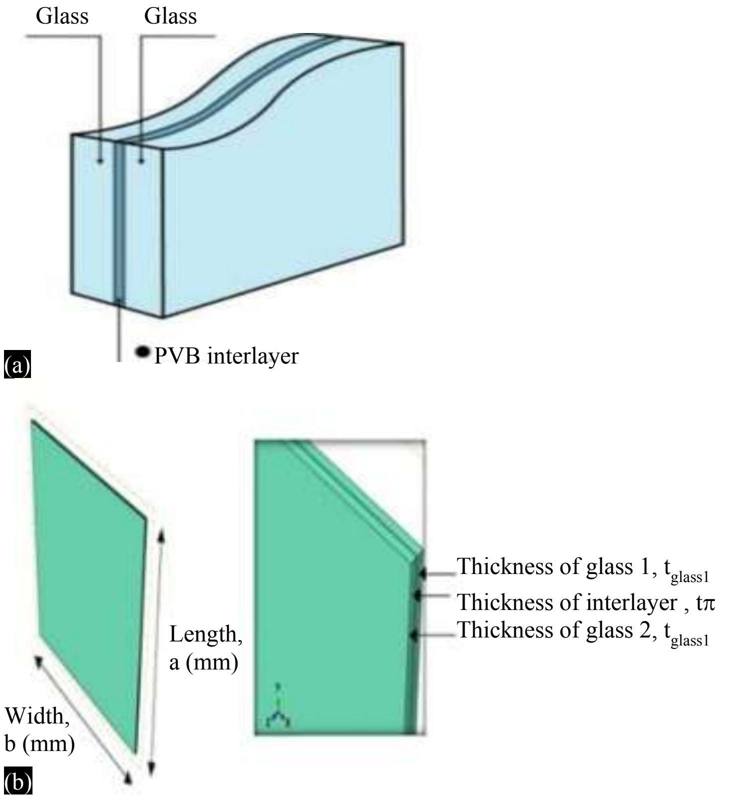

Figure 2. (a), (b) Schematic representation of laminated glass composite action showing glass plies and polymer interlayer with shear interaction.

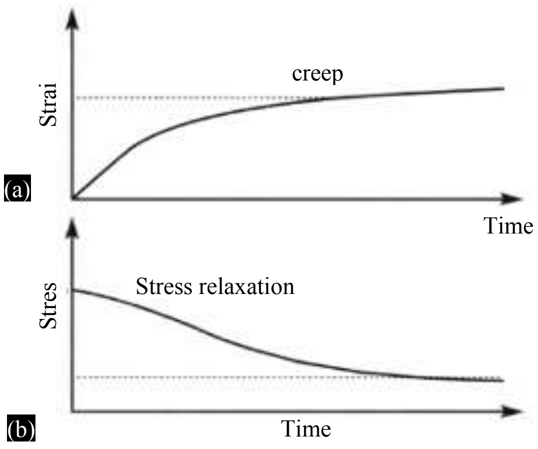

Figure 3. Typical viscoelastic response of polymer interlayers: (a) creep and (b) stress relaxation.

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Interfacial Mechanics and Adhesion

Interfacial bonding between glass and polymer layers greatly influences the mechanical response of laminated glass composites. The adhesion mechanism is governed by the physical and chemical interaction, which determines the efficiency in the transfer of load and resistance to delamination. Interfacial strength can be deteriorated by environmental conditions such as moisture and temperature, which may result in reduced durability [6].

Time-Dependent and Environmental Effects

Polymer interlayers are subjected to time-dependent processes such as creep and stress relaxation, which affect their stiffness and strain state during long-term loading. Environmental exposure, such as ultraviolet (UV) radiation and moisture, can degrade polymer composites and their mechanical performance. As such, the modeling of the composite response must incorporate thermo-viscoelastic coupling [7].

VISCOELASTIC MECHANICAL BEHAVIOR OF POLYMER–GLASS COMPOSITES

The viscoelastic response of polymer interlayers, which governs the shear transfer, the deformation compatibility between laminated glass plies, and the energy dissipation, dominates the mechanical behavior of laminated glass composites. Polymer interlayers display time, temperature, and rate-dependent behaviour, which leads to nonlinear stress–strain curves and changing stiffness during the mechanical loading, different from the behaviour of an elastic material. The viscoelastic behavior can be represented through relaxation modulus and complex modulus forms. Master curves obtained by time–temperature superposition serve as indicators of long-term behavior. The mechanical and physical properties of typical interlayer materials are shown in Table 2.

Load–Deformation Response and Viscoelastic Effects

The shear modulus of the interlayer, which is temperature and time-loading-dependent, plays a dominant role in the load–deformation response of polymer–glass composites. The polymer is more stiff in a glassy state at lower temperatures or higher loading rates, producing a more rigid composite. On the other side, under the conditions of high temperature or long-time loading, the interlayer is in a rubbery state, and its stiffness is minimum while its strain and deformation are maximum.

Quantitative comparison of interlayer materials highlights the trade-offs between stiffness, damping, and durability. Ionoplast interlayers provide significantly higher stiffness, improving load transfer efficiency, whereas PVB offers superior damping but suffers from long-term creep. EVA demonstrates balanced performance with enhanced environmental resistance. Such quantitative comparisons are essential for selecting appropriate materials for specific engineering applications.

Table 2. Summary of mechanical performance parameters.

Parameter	Influencing factors	Effect on performance
Load–deflection	Interlayer stiffness, thickness	Controls stiffness and deformation
Natural frequency	Mass, stiffness, boundary conditions	Affects vibration serviceability
Damping ratio	Viscoelastic interlayer	Energy dissipation
Residual strength	Interlayer adhesion	Post-fracture safety

Table 3. Performance comparison.

Property	PVB	Ionoplast	EVA
Stiffness	Low	High	Medium
Damping	High	Medium	Medium
Durability	Moderate	High	High
Cost	Low	High	Moderate

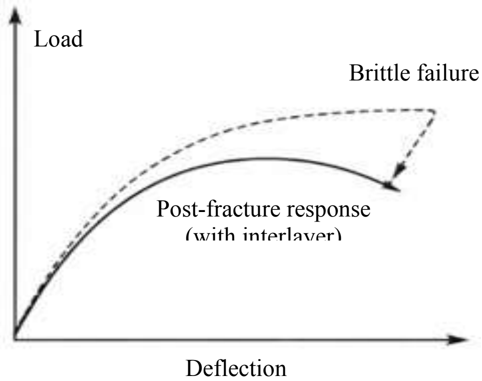

Figure 4. Conceptual load–deflection behavior of laminated glass material systems.

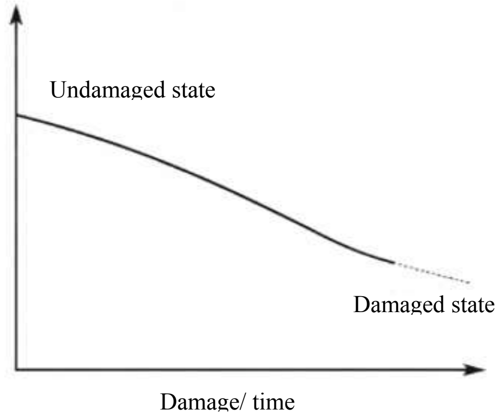

Figure 5. Variation of natural frequency with structural degradation in laminated glass material systems.

This behavior is controlled by viscoelastic mechanisms, including creep and stress relaxation. Creep results in increasing strain under constant stress, and stress relaxation is a reduction of stress under constant strain. These phenomena relate directly to molecular chain mobility and relaxation processes in the polymer matrix and thus have a significant influence on the effective stiffness and load transfer in the composite material system. The change in dynamic characteristics with damage is demonstrated through the frequency response curve in Figure 4.

Dynamic Response and Frequency–Temperature Dependence

The dynamic response of polymer–glass composites is slightly coupled with the frequency-dependent viscoelastic behavior of the interlayer. Stiffness and damping of the composite are both affected by the variation of storage modulus and loss modulus of the polymer as a function of excitation frequency. Based on the time–temperature superposition, the mechanical responses at different temperatures can be translated into the frequency domain at the same temperatures. At high frequency, polymer chains cannot respond, so polymer stiffness is high, while at low frequency, chain mobility is enhanced and polymer stiffness is low, with maximum energy dissipation. This frequency-Temperature dependence is relevant to studying the dynamic behavior of laminated material systems in different environmental conditions [8]. The major research challenges and future outlook of the polymer-interlayered glass composite system are sketched in Figure 5.

Energy Dissipation and Damping Mechanisms

Polymer interlayers play a major role in energy dissipation via intrinsic damping mechanisms acting at the level of molecular friction and chain rearrangement. The viscoelasticity of the polymer can transform mechanical energy into thermal energy, and the composite material system's damping capability is improved by thermal energy generation.

The amount of damping depends on factors like polymer content, crosslink density, and temperature with respect to the glass transition region. Around the glass transition temperature, polymers have a peak performance as damping materials because of the higher molecular mobility. This property is of interest, especially in those applications involving vibration attenuation and energy absorption [9].

Post-Fracture Load Transfer and Polymer Bridging

After the fracture of the glass phase, the polymer interlayer is critical in sustaining load transfer via bridging mechanisms. The interlayer carries on tensile loads and it redistributes the load between the cracked areas, so the structural integrity is not lost immediately.

The efficiency of this mechanism is affected by the tensile strength of the interlayer, adhesion characteristics, and the degree of deformation. Polymer chains are highly deformed while resuming continuity, which accounts for the stored load carrying capacity. This result emphasizes the role of interlayer rheology and interfacial binding in defining composite toughness for after-fracture.

Modeling Approaches for Viscoelastic Composite Behavior

The prediction of the mechanical behavior of polymer–glass composites must rely on sophisticated modeling approaches that account for the viscoelastic nature of the constitutive behavior. Under large deformations as well as different environmental conditions, linear viscoelastic models cannot accurately describe the behavior, especially when considering nonlinearity.

Nonlinear viscoelastic model with finite element (FE) method has been more frequently adopted to predict time-dependent phenomena such as creep, stress relaxation, and temperature-dependent behavior. In addition, multiscale modeling techniques that connect molecular-level physics to macroscopic behavior offer even further understanding of the influence of the polymer composite on the overall composite.

The viscoelastic behavior of polymer interlayers can be described quantitatively by means of the relaxation modulus and the complex modulus. Then, time–temperature superposition rules are used to build master curves which can be used to predict the long-term behaviour of the material from short-term experimental data. Such rheological models are also necessary to characterize the frequency- and temperature-dependent response of polymer–glass composites.

From a design perspective, the viscoelastic behavior of polymer interlayers directly influences structural performance. For example, in high-temperature environments, reduced interlayer stiffness can lead to excessive deflections, compromising serviceability. Similarly, long-term creep effects must be considered in architectural applications where sustained loads are present. Therefore, integrating viscoelastic models into structural design codes is essential for improving prediction accuracy and ensuring safety.

FUNDAMENTAL THEORY OF VISCOELASTICITY AND INTERFACIAL MECHANICS

The behavior of polymer interlayers in laminated glass systems can be fundamentally described using viscoelastic theory and interfacial mechanics. Viscoelasticity combines elastic energy storage and viscous dissipation, which can be represented through constitutive models such as Maxwell, Kelvin–Voigt, and generalized rheological models. These models describe time-dependent phenomena including creep and stress relaxation.

Time–temperature superposition (TTS) is a key principle used to predict long-term behavior from short-term experimental data by constructing master curves. At the interface level, adhesion mechanisms involve mechanical interlocking, physical bonding, and chemical interactions, which govern stress transfer efficiency.

Table 4. Failure modes and safety implications.

Failure mode	Cause	Effect	Safety implication
Glass fracture	Tensile stress, impact	Crack propagation	Risk of brittle failure
Delamination	Moisture, ageing	Loss of composite action	Reduced stiffness
Interlayer creep	Long-term loading	Increased deflection	Serviceability issues

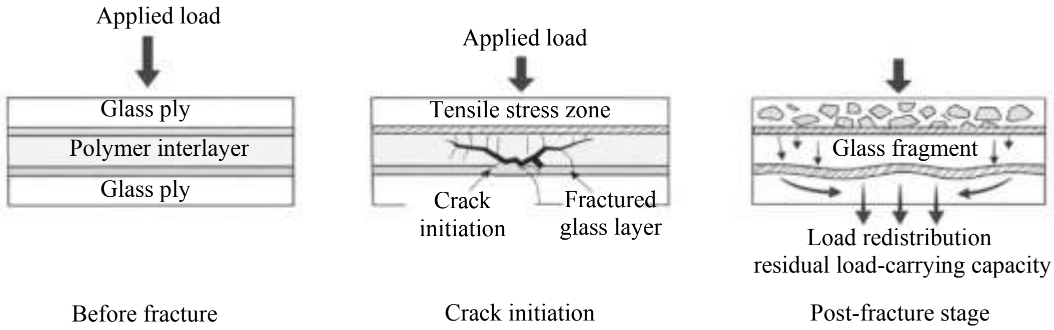

Figure 6. Laminated glass fracture behavior stages.

By integrating viscoelastic constitutive models with interfacial adhesion theory, a more comprehensive understanding of laminated glass behavior can be achieved, linking molecular-scale mechanisms to structural performance. The comparison of mechanical performance parameters under different loads is described in Table 4

Material Failure Modes and Critical Mechanisms

Polymer–glass composites have several modes of failure, such as tensile stress concentrations induced fracture of glass, interfacial delamination, shear deformation in the polymer interlayer, and localized debonding at interfaces. Of these, the fracturing of glass is the dominant mode of failure; nevertheless, the polymer interlayer stops immediate structural discontinuity by bridging across fractured zones.

The initiation of failure is also highly sensitive to surface flaws in glass and stress concentrations at interfaces. At the same time, the viscoelastic behavior of the polymer modifies the stress redistribution so that the failure process becomes dependent on the loading rate and environmental conditions. This coupled behavior illustrates the need to consider both brittle and ductile processes in failure [10].

Residual Load Transfer and Polymer Bridging Mechanisms

The interlayer is detached from the glass cells to which it remains adhered to broken glass pieces, allowing load-carrying capacity to be sustained. This phenomenon is related to the tensile strength and elongation capability of the interlayer as well as the bond strength at the interfaces. The polymer's capability of remaining intact and redistributing stresses greatly improves the damage tolerance of the composite material system. This type of post-fracture performance is a distinctive characteristic of laminated composites compared to monolithic brittle materials. Figure 6 illustrates the degree of fracturing behaviour.

Environmental Degradation and Polymer Ageing

Exposure to environmental conditions, including temperature, moisture, and UV radiation, has a strong effect on polymer interlayer durability. Under these conditions, the molecular composite can be altered, enter shear, and interfacial adhesion can be weakened.

Long-term mechanical property degradation is also influenced by the aging processes of chain scission, plasticization, and oxidation. These structural modifications result in enhanced creep, diminished load transfer efficiency, and increased sensitivity to interfacial failure. Hence, environmental effects should be considered in material characterization and in assessing long-term performance.

Interfacial Degradation and Adhesion Loss

The glass and polymer interface is pivotal in defining the performance of the composites. Interfacial adhesion can deteriorate as a result of moisture penetration, heating and cooling (thermal cycling), and chemical interactions, which cause partial or full delamination.

Reduction in adhesion efficiency impairs the stress transfer and weakens the composite action between the layers. Failure at the interface is frequently progressive and can substantially influence both stiffness and residual strength. To enhance long-term reliability, it is crucial to understand adhesion and its debonding mechanisms.

Advanced Characterization and Monitoring of Material Degradation

Modern methods for assessing material decay are based on destructive and non-destructive characterization techniques that can identify changes in mechanical and interfacial properties. Vibration-based methods or acoustic emission and imaging techniques give information about the progression of damage and material performance while still in use without halting operation. These methods provide continuous quantitative evaluation of the viscoelastic behavior, stiffness changes, and interfacial status. The inclusion of such data into predictive material models enables an improved assessment of the degradation process and thus an enhanced reliability evaluation of the polymer–glass composite material system. An overview of the properties of the different reliability approaches with applicability to this work is summarized in Table 5.

Sources of Uncertainty in Laminated Glass Material Systems

Laminated glass composites are sensitive to a perturbation of the material properties, environmental conditions, geometry, and loading. Strength of glass is defect size dependent and polymer interlayers have time and temperature dependent viscoelastic properties. The short-term and long-term performance of the laminate is also influenced by environmental and random loadings, and thus, this evaluation, which is based on reliability, is required. Viscoelastic and interfacial property uncertainties have a dramatic effect on the reliability predictions. A number of uncertainties in viscoelastic parameters, interfacial strength, as well as the rate of environmental degradation have a strong impact on the predictions of systemability of recomposite, which is an indication of the need for probabilistic methods developed specially for polymer composite systems.

Probabilistic Modeling of Mechanical Performance

Reliability is evaluated by means of simplified state functions of the safe and failure states that include the ultimate, serviceability states, and the after-fracture state. Methods like First-Order Reliability Method (FORM), Monte Carlo simulation, and Stochastic Finite Element Analysis (SFEA) are employed to consider variability of materials, geometry, and loads and calculate the probability of failure [10].

Time-Dependent Reliability and Viscoelastic Effects

The viscoelastic nature of polymer interlayers is very critical for the long-term reliability. They suggested that reasonable stress relaxation, creep, and environmental aging would lead to stiffness degradation with time, also causing an increase in deflections and a change in the stress field. Thus, the time-dependent reliability analysis constitutes a necessary ingredient for the assessment of the service length and the provision of material behaviour certainty throughout the usage period [11].

Table 5. Reliability methods comparison.

Method	Type	Advantages	Limitations
FORM	Analytical	Fast, efficient	Approximation errors
Monte Carlo	Simulation	High accuracy	Computationally expensive
Stochastic FE	Numerical	Detailed modeling	Complex implementation

Table 6. Research gaps and future directions.

Research area	Current limitations	Future directions
Interlayer modeling	Simplified viscoelastic behavior; neglect of temperature and ageing effects	Development of nonlinear thermo-viscoelastic models
Long-term performance	Inadequate prediction of creep and environmental degradation	Time-dependent, environment-coupled modeling frameworks
Post-fracture behavior	Limited models for crack propagation and residual strength	Integration of fracture mechanics with numerical simulations
Reliability-based design	Lack of standardized probabilistic design methods	Development of code-oriented reliability frameworks
Shm integration	Limited real-time use of monitoring data	AI-driven SHM and digital twin-based assessment
Advanced polymer interlayers	Temperature sensitivity and limited durability	Development of nanocomposite and high-performance interlayers
Integrated frameworks	Fragmented analysis of performance, safety, and reliability	Unified multiphysics and reliability-based design approaches

RESEARCH GAPS AND FUTURE DIRECTIONS

Existing studies on laminated glass systems do not fully account for polymer behavior and the mechanics at the interface in multiple scales. Equivalent viscoelastic models are often inadequate for nonlinear and environmental effects. The prospective research topics include advanced polymer characterization, high-performance/nanocomposite interlayers, etc.

The production of sustainable, bio-based polymers and smart composite material systems is a potential path to next-generation applications. The synthesis of nanocomposite interlayers with tailored relaxation spectra is another important line of research. Table 6 outlines the major research gaps and future directions in the polymer -lined glass composite system of material systems.

Limitations in Multiscale Material Characterization

Currently, most of the research focuses on the macroscopic response, less on the multiscale interaction between the glass and the polymer interlayers [12]. The viscoelastic response is usually idealized in the form of an approximation, and the real service conditions cannot be emulated. The future work is motivated by the necessity of advancing to the high-tech multiscale characterization, interfacial effects, and nonlinear viscoelastic modeling involving ageing [13].

Inadequate Modeling of Long-Term and Environmental Effects

The cause is inadequate simulation of long-term and environmental effects. Creep, stress relaxation and environmental degradation have a strong influence on long term behavior; these effects are neglected in models. Time-dependent stiffness degradation, moisture, UV radiation, and coupled thermo- mechanical processes should be taken into account in predictive models in order to make life cycle assessment accurate [14].

Gaps in Post-Fracture and Residual Capacity Modeling

Although experimentations validate other post-breakage behavior of relevance a predictive model of the residual load-carrying capacity remains scarce [15]. The following aspects cannot be well captured by today's approaches:

- Patterns of crack propagation and crack fragmentation.
- Interlayer tearing and debonding features.
- Membrane behavior of fractured glass-based material systems.

Advanced numerical fracture mechanics should be included in future studies for more accurate simulation of the post-failure states.

Discussion

The selection of polymer interlayers plays a critical role in the structural performance of laminated glass systems. Ionoplast interlayers are preferred for load-bearing applications due to their high stiffness and low creep behavior. PVB is more suitable for impact-resistant applications because of its high energy absorption capacity. EVA is advantageous in environments with high moisture and UV exposure due to its superior durability. Therefore, material selection must consider both mechanical performance and environmental conditions to ensure long-term reliability.

CONCLUSION

This review highlights that the performance of laminated glass composites is predominantly governed by the viscoelastic and interfacial behavior of polymer interlayers. Among the commonly used materials, ionoplast interlayers demonstrate superior stiffness and load-bearing capacity, whereas PVB provides enhanced damping and impact resistance. EVA offers improved durability under environmental exposure.

The integration of viscoelastic modeling, interfacial mechanics, and reliability analysis is essential for accurate prediction of long-term performance. From an engineering perspective, the selection of interlayer materials must consider application-specific requirements such as load conditions, environmental exposure, and safety demands.

Future research should focus on developing nonlinear thermo-viscoelastic models, advanced multiscale characterization techniques, and data-driven predictive frameworks. Additionally, the incorporation of sustainable and nanocomposite interlayers presents a promising direction for enhancing both performance and environmental compatibility.

REFERENCES

1. Findley WN, Lai JS, Onaran K. Creep and relaxation of nonlinear viscoelastic materials. New York: Dover; 1989.
2. Kinloch AJ. Adhesion and adhesives: science and technology. Dordrecht: Springer; 1987.
3. Mittal KL, editor. Polymer surface modification: relevance to adhesion. Vol. 1. Utrecht: VSP; 2009.
4. Bennison SJ, Sloan JG. The viscoelastic properties of polymer interlayers for laminated glass. J Mater Sci. 1999;34:545–556.
5. Van Duser A, Jagota A, Bennison SJ. Analysis of glass/polymer laminates subjected to uniform pressure. J Eng Mech. 1999;125(4):435–442.
6. Hooper PA. On the bending of laminated glass. Int J Mech Sci. 2013;75:1–12.
7. Kraus MA, Niederwald M. Influence of temperature and load duration on polymer interlayers. Glass Compos Eng. 2017;2:45–61.
8. Dorigato A, Pegoretti A. Viscoelastic behavior of polymer nanocomposites: Experimental and modeling aspects. Compos Part A. 2018;109:123–135.
9. Xu J, Li Y, Wang Z. Temperature-dependent viscoelastic properties of polymer composites. Polym Test. 2020;81:106211.
10. Zhang X, Wang Y, Li H. Nonlinear viscoelastic modeling of polymer materials under complex loading. Mech Mater. 2021;157:103831.
11. Hooper PA, Dear JP, Blackman BRK. The mechanical behaviour of laminated glass. Int J Solids Struct. 2012;49:3621–3632.
12. Bedon C, Amadio C. Structural and dynamic performance of laminated glass elements: A review. Eng Compos. 2019;180:1–18.
13. Galuppi L, Royer-Carfagni G. Effective thickness of laminated glass beams: New expression via variational approach. Compos Struct. 2018;187:425–435.
14. Andreozzi L, Berto F, Quaresimin M. Fracture behavior of laminated glass material systems. Compos Struct. 2019;208:882–892.
15. Kuntsche J, Schuster M, Schneider J. Post-fracture behavior of laminated glass. Glass Compos Eng. 2019;4:223–240.

