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Fatigue and Impact Resistant Structural Adhesive for Lightweight Light Motor Vehicles.

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ABSTRACT

Light motor vehicles have traditionally been constructed from metallic components assembled by welding, a joining method well suited to metals but fundamentally incompatible with polymer composite materials. The increasing substitution of these metallic structures with engineering thermoplastics and thermosetting composites—driven by the need to reduce vehicle mass, improve energy efficiency, and increase payload capacity—has therefore necessitated a transition toward adhesive bonding as the primary joining technology. This transition imposes stringent performance requirements on the adhesive, which must maintain high mechanical integrity under static, dynamic, and environmental loading while forming durable joints between chemically and mechanically dissimilar substrates.

This technical paper presents a heat activated epoxy film adhesive that expands during cure and demonstrates exceptional fatigue resistance, impact tolerance, and adhesion to engineering thermoplastics. The adhesive cures at temperatures between 135°C and 155°C, enabling compatibility with composite substrates while avoiding thermal degradation. Its controlled expansion of 40–70% facilitates gap filling in assemblies with dimensional variability. Through a formulation strategy combining phase separating tougheners, core–shell particles, thermoplastic polymer flexibilizer, and alkoxysilane modified epoxy resins, the adhesive achieves cohesive failure across all mechanical tests and exhibits high fracture energy (≥1850 J/m²), peel strength (≥5 N/mm), and stable performance under cyclic loading.

The present paper examines the adhesive's chemistry, toughening mechanisms, microstructure–property relationships, and performance validation, positioning it as a next generation solution for lightweight light motor vehicle structures requiring long term reliability.

01. INTRODUCTION

Light motor vehicles increasingly rely on composite materials to reduce structural weight, improve energy efficiency, and increase payload capacity. Traditional joining methods such as welding are incompatible with engineering thermoplastics and thermosetting composites, necessitating the use of structural adhesives. However, adhesives intended for transportation applications must satisfy a demanding combination of requirements, including high strength, high fracture toughness, resistance to cyclic loading, tolerance to impact events, and long term durability under variable environmental conditions. Achieving strong adhesion to low surface energy thermoplastics further challenges adhesive design, as does the need to accommodate dimensional variability inherent to composite structures.

The Heat-Activated Toughened Structural Adhesive with Low Expansion (L-F508 part of the L&L Bond solution) presented in this paper was developed to address these challenges through a combination of controlled expansion, advanced toughening mechanisms, and optimized interfacial chemistry. Its formulation enables structural bonding of thermoplastics and composites while maintaining cohesive failure across all tested conditions.

02. MATERIAL DESIGN AND CHEMISTRY OF THE L-F508 ADHESIVE

The formulation incorporates a combination of expansion agents, alkoxysilane-modified epoxy resins for excellent adhesion, optimized curing agent with carefully controlled chemistry and particle size distribution, accelerators, phase-separating and phase-separated tougheners. Two types of toughening mechanisms play key roles. First, phase-separating tougheners such as epoxy adduct of a carboxy terminated butadiene rubber (CTBN) increase flexibility and plastic deformation capacity during curing. Second, core–shell particles create a phase-separated toughened matrix, contributing mechanisms such as crack pinning, particle bridging, crack deflection, microcracking, and bifurcation. Selecting the right balance between these toughener types is essential to optimizing peel strength, fracture energy, and fatigue performance.

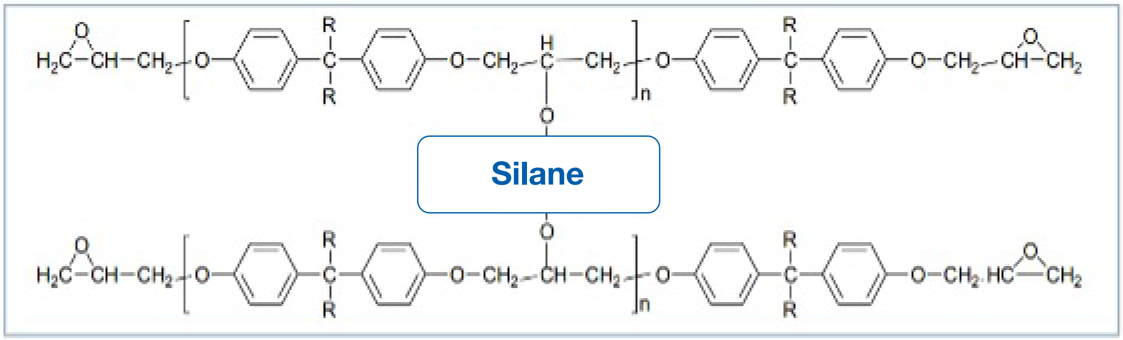


Figure 1. *Chemical structure of alkoxysilane modified epoxy*

During cure, the adhesive undergoes a controlled volumetric expansion of 40–70% when heated to 135–155°C even **without a heating ramp.** This expansion enables the material to fill gaps between substrates, compensating for manufacturing tolerances common in composite assemblies.

The curing agent system was optimized to ensure uniform crosslinking at relatively low temperatures. A controlled particle size distribution and the inclusion of accelerators allow the adhesive to cure fully without exceeding the thermal limits of composite substrates even without a heating ramp.

A dual mechanism toughening system was incorporated into the formulation. Phase separating tougheners, specifically carboxy terminated butadiene nitrile (CTBN), form rubbery domains during cure that increase plastic deformation capacity and enhance peel strength. In parallel, core–shell particles introduce a second toughening mechanism through crack pinning, crack deflection, particle bridging, and microcracking. The balance between these two toughener types was found to be critical for optimizing fracture energy, peel strength, and fatigue performance.

03. TOUGHENING MECHANISMS AND MICROSTRUCTURE–PROPERTY RELATIONSHIPS

The synergy between phase separating and phase separated tougheners results in a microstructure capable of dissipating large amounts of energy during crack propagation. CTBN derived rubber domains promote shear yielding and increase ductility, while core–shell particles interact directly with the crack front, forcing deviations in crack path and increasing the energy required for fracture. The combination of these mechanisms yields a highly toughened matrix with fracture energies exceeding 1850 J/m^2.

The evolution of microstructure during cure plays a central role in determining the adhesive's mechanical performance. The phase separation of CTBN occurs concurrently with epoxy crosslinking, while core–shell particles remain dispersed throughout the matrix. The resulting morphology provides multiple energy absorbing mechanisms that operate across different length scales.

Figure 2. *Photos Phase-separating toughener (left), Phase-separated toughener (right).*

04. ADHESION TO ENGINEERING THERMOPLASTICS

Achieving cohesive failure when bonding engineering thermoplastics represents a significant advancement, given the inherent challenges associated with their low surface energies. The alkoxysilane modified epoxy resin system enhances interfacial adhesion through improved wetting and potential chemical interactions. The adhesive consistently achieved lap shear strengths of ≥9 MPa with cohesive failure across multiple thermoplastic substrates.

Lap shear strength at room temperature[3]	> 9 MPa
Lap shear strength at -55°C[3]	> 14 MPa
Lap shear strength at +85°C[3]	> 6 MPa
Lap shear strength at room temperature after 750 hours in demineralized water at 40°C[3]	> 9 MPa
Lap shear strength at room temperature after 1000 hours in dry heat at +80°C[3]	> 10 MPa
Lap shear strength at room temperature after 750 hours in dry heat at +120°C[3]	> 10 MPa
Lap shear strength at room temperature after 750 hours at 70°C and 95% relative humidity[3]	> 9 MPa
Lap shear strength at room temperature after 1000 hours in lubrication oil at 23°C[3]	> 9 MPa
Lap shear strength at room temperature post environmental cycles [3,4]	> 9 MPa

3) Substrates: abraded engineering plastic composite, 1.6 mm thickness. Bondline: 12,5 mm length, 25 mm width, 1.5 mm cured thickness. 10 mm/min test rate
4) After 8 cycles (+40°C 90% RH /-40°C/ + 70°C 50% RH) and 7 cycles (+55°C 25% RH /room temperature water immersion).
All failures obtained are cohesive

Table 1. *Lap shear strength*

05. ADHESION TO ENGINEERING THERMOPLASTICS

The adhesive cures within a temperature window of 135–155°C, making it compatible with most composite manufacturing processes. During cure, the adhesive exhibits low viscosity, enabling effective wetting of substrates prior to expansion. The material demonstrates stable storage behavior, with a shelf life of two months at +23°C and up to three years at –18°C.

06. MECHANICAL PERFORMANCE

The L-F508 adhesive exhibits a tensile modulus of approximately 950 MPa, a tensile strength of 18 MPa, and an elongation at break of around 3%, as measured according to ISO 527. These values reflect a balance between stiffness and ductility appropriate for structural bonding applications.

Lap shear testing (ISO 4587) consistently produced strengths of ≥9 MPa with cohesive failure, while floating roller peel strength (ISO 4578) reached ≥5 N/mm. Double cantilever beam (DCB) testing demonstrated fracture energies of ≥1850 J/m², confirming the adhesive's high toughness. Wedge impact peel tests (ISO 11343) achieved ≥20 N/mm, further validating the material's impact resistance.

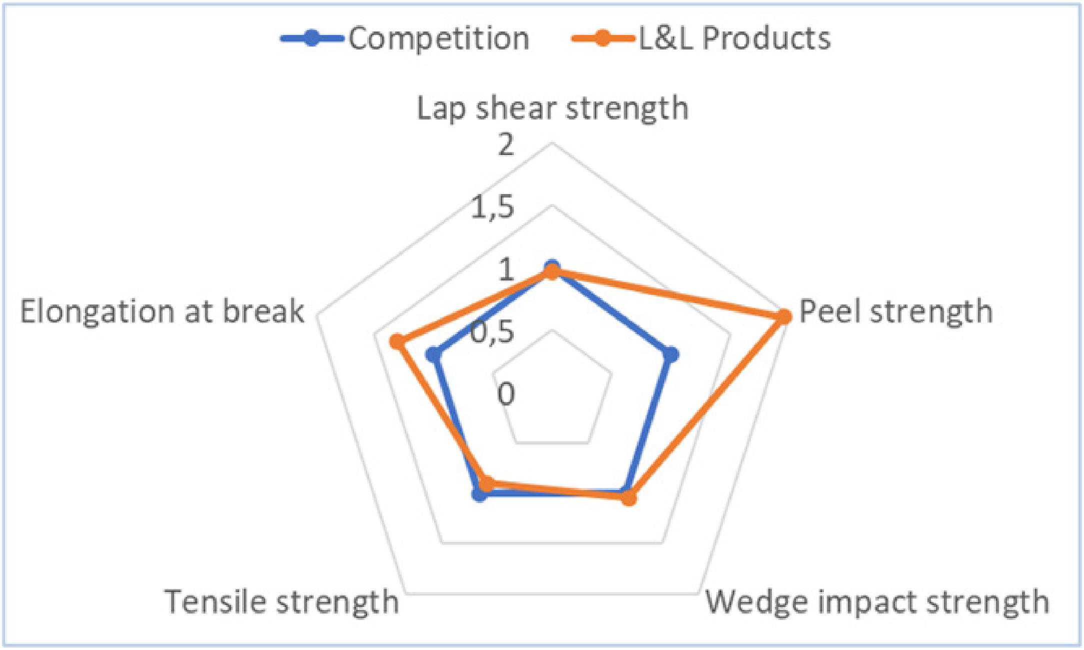


Figure 3. *Comparison mechanical performance of L-F508 vs competition (epoxy structural adhesive)*

07. FATIGUE AND IMPACT RESISTANCE

Fatigue resistance was evaluated under cyclic loading conditions representative of real world vehicle use, including load levels of 400 N (child load) and 800 N (adult load). The adhesive withstood thousands of cycles without failure, demonstrating its suitability for applications involving repeated mechanical stresses. Impact resistance testing confirmed the adhesive's ability to absorb high energy events without compromising structural integrity.

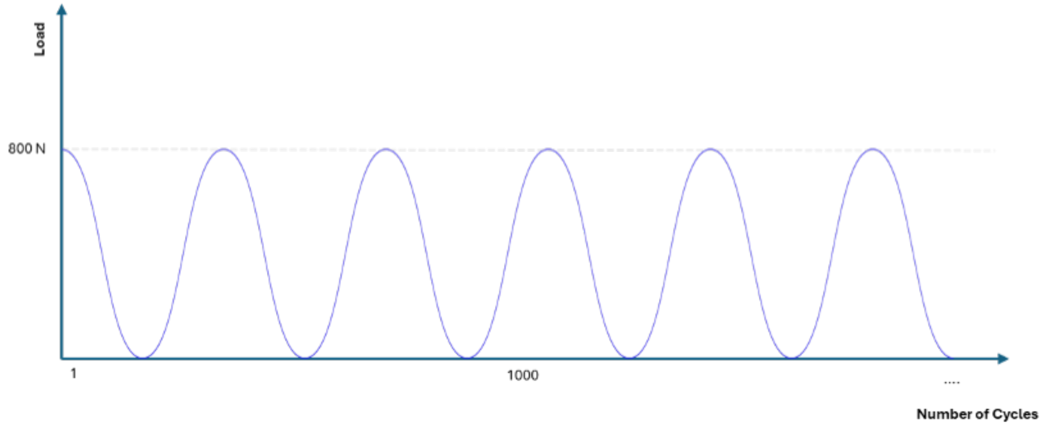


Figure 4. *Illustration of type of fatigue test (cyclic, load)*

08. ENVIRONMENTAL DURABILITY

The adhesive maintained its mechanical performance after exposure to temperature cycling, high humidity, and lubrication oil, indicating strong environmental durability. These results suggest that the adhesive is capable of long term performance in demanding service environments typical of lightweight light motor vehicle applications.

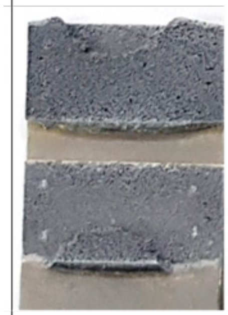
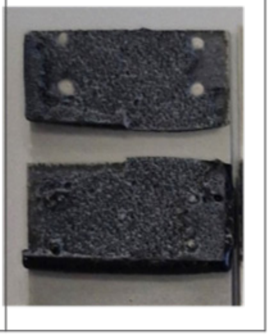
750 h in Deionized Water at 40°C	1000 h in Dry Heat at +80°C	750 h in Dry Heat at +120°C	750 h at 70 °C and 95% RH	1000 h in Lubrication Oil at 23°C
				

Table 2. *Summary of mechanical retention after aging*

09. DISCUSSION & CONCLUSION

The adhesive's performance can be attributed to the synergistic combination of controlled expansion, advanced toughening mechanisms, and optimized interfacial chemistry. The dual toughening system provides a microstructure capable of dissipating energy through multiple mechanisms, while the alkoxysilane modified epoxy resin enhances adhesion to thermoplastics. The controlled expansion during cure enables gap filling and ensures intimate contact between substrates, contributing to cohesive failure across all tests.

These characteristics position the adhesive as a promising solution for next generation lightweight light motor vehicle structures requiring high reliability under mechanical and environmental stresses. Future applications would focus on extending to recycled composite materials, which present unique surface characteristics and variability due to prior use and processing.

Another promising direction involves applying these bonding approaches to scenarios requiring high fatigue resistance and enhanced impact tolerance like wind turbine blades, sporting goods & protective equipment, sports infrastructure & civil engineering composites.

REFERENCES & NOTES

Link to patent : US9394468B2 - Structural adhesives

The corresponding authors of a paper are those to whom readers can address questions, requests for materials, or even suggestions for further work.

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Michel Awkal is a research and development engineer at L&L Products in France, specializing in formulation chemistry. He holds a PhD in polymer chemistry and brings more than twenty years of experience in the formulation and characterization of advanced materials, complemented by six years of expertise in polymer synthesis and chemical analysis.

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