PHASTER® XP-K606: Hybrid-Polymerized Ambient-Cure Structural Foam for High-Tg Reinforcement in Automotive Body-in-White Applications.

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ABSTRACT

Structural reinforcement materials have historically relied on heat-activated foams cured in high-temperature E-coat ovens, creating a fundamental conflict between lightweighting goals and manufacturing realities especially during the acceleration towards low energy, no bake initiatives.

This paper presents PHASTER® XP-K606, a next-generation ambient-cure structural foam enabled by hybrid polymerization, a dual-network chemistry that combines phosphate–epoxy reactions with methacrylate radical polymerization. The resulting thermoset network achieves Tg above 100°C, 70–80% modulus retention at 80°C, and crash-relevant reinforcement without reliance on oven curing.

1. INTRODUCTION

Automotive manufacturers are increasingly pursuing strategies to reduce energy consumption, lower CO_2 emissions, and support flexible body in white (BIW) architectures for electrified and mixed material vehicles. High temperature E coat ovens, traditionally used to cure heat activated structural foams, represent one of the most energy intensive stages of vehicle production. As OEMs explore low energy and no bake manufacturing lines, the dependence of structural reinforcement materials on oven curing has become a significant constraint.

At the same time, BIW engineers continue to require localized reinforcement solutions capable of improving stiffness, increasing crash energy absorption, and enabling lightweighting without compromising manufacturability. This creates a fundamental engineering contradiction: **how to reinforce hollow sections and crash critical zones without relying on high temperature curing.**

Ambient cure foaming solutions offer a potential pathway, but their adoption has been limited by low Tg, poor modulus retention at elevated temperatures, and insufficient structural contribution. These limitations stem from the underlying polymer architectures of conventional two component (2K) systems, which typically form single network thermosets with inadequate crosslink density, molecular mobility during the cure (without external heating) and thermal stability.

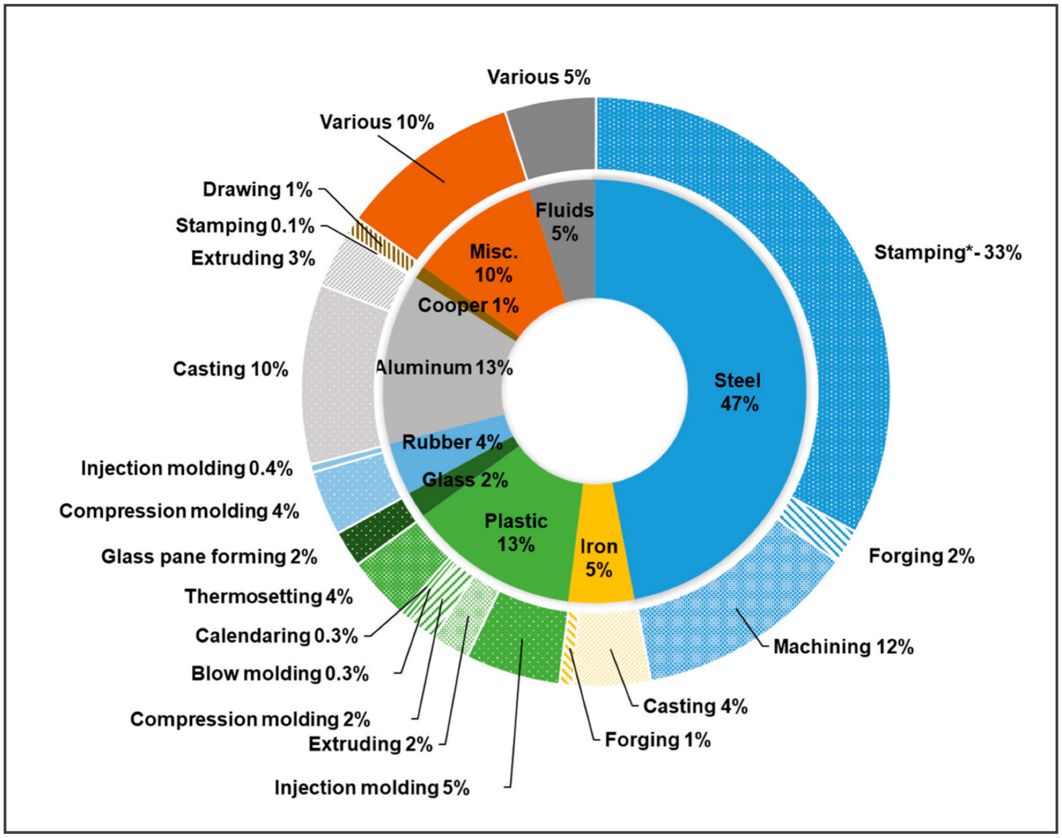


Figure 1: *Material Composition and Production Processes*

Source: Sato, F. E. K., & Nakata, T. (2020). Energy Consumption Analysis for Vehicle Production through a Material Flow Approach. Energies, 13(9), 2396. https://doi.org/10.3390/en13092396

2. BACKGROUND & PROBLEM DEFINITION

Structural reinforcement materials used in BIW applications must satisfy a demanding combination of thermal, mechanical, and processing requirements. High glass transition temperature is essential to ensure that the material maintains stiffness under elevated service temperatures, particularly in regions exposed to powertrain heat or high thermal loads. Modulus retention at elevated temperatures is equally critical, as it directly influences the material's ability to contribute to crash energy absorption and structural stability.

Traditional 2K ambient cure foams typically exhibit Tg values in the range of 60–70°C and experience dramatic reductions in storage modulus at temperatures above 60°C. As a result, ambient cure foams have historically been restricted to sealing, NVH, or nonstructural applications.

In contrast, heat activated foams achieve high crosslink density through oven curing, enabling Tg values above 100°C and strong modulus retention. However, their dependence on high temperature ovens restricts their use to specific stages of the manufacturing process and prevents their integration into low energy or no bake BIW lines and aftermarket solutions.

3. HYBRID POLYMERIZATION

PHASTER® XP-K606 addresses the limitations of traditional ambient cure foams through a hybrid polymerization mechanism that combines two polymerization methods to create one thermoset network. This hybrid architecture significantly increases crosslink density, enhances thermal stability, and improves mechanical performance.

3.1 PHOSPHATE–EPOXY REACTION (GENERATION 1 CHEMISTRY)

A first-generation network is formed through the reaction of phosphate functional curatives with epoxy groups. This reaction produces a thermoset backbone with strong covalent crosslinks and contributes to the compressive strength and rigidity of the material.

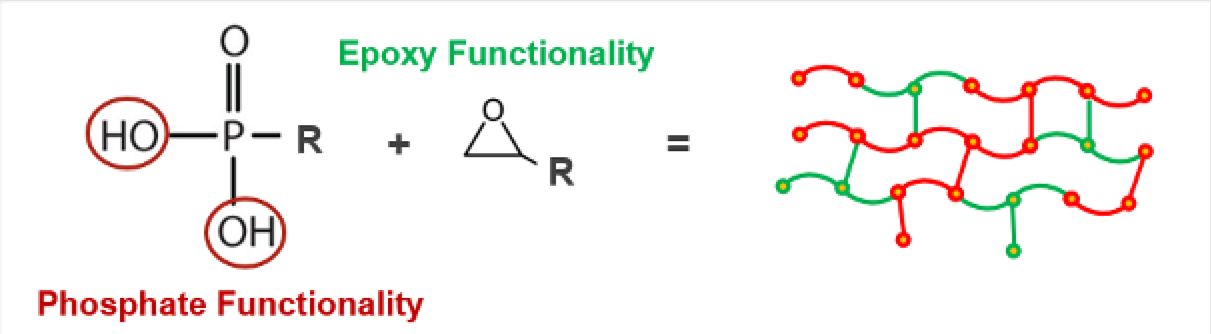


Figure 2: *Generation 1 polymerization mechanism*

3.2 HYBRID METHACRYLATE RADICAL POLYMERIZATION (GENERATION 2 ADDITION)

The second-generation network forms through epoxy-phosphate step-growth polymerization and methacrylate radical polymerization initiated by peroxide or azo initiators. These reactions occur simultaneously and result in a single, highly crosslinked network.

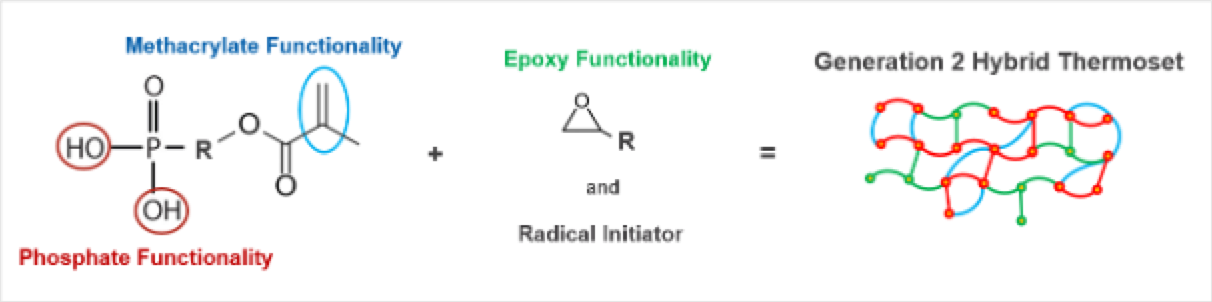


Figure 3: *Generation 2 Hybrid polymerization mechanism*

4. MATERIAL PROPERTIES AND THERMAL PERFORMANCE

The hybrid polymerization mechanism of XP-K606 yields a unique combination of ambient cure capability and high temperature performance. Dynamic mechanical analysis (DMA) shows tan delta Tg values between 115–125°C, comparable to heat activated foams and significantly higher than traditional ambient cure systems. Storage modulus measurements indicate that XP-K606 retains 70–80% of its room temperature modulus at 80°C, whereas conventional 2K foams retain less than 1%.

Description	2K Structural Foam (Generation 1)	XP-K606 (Generation 2)	Heat-Activated Structural Foam
T_g (°C), tan delta*	60-70	115-125	110-120
Storage Modulus, 23°C (MPa)*	450-500	400-500	650-700
Storage Modulus, 80°C (MPa)*	<5	300-400	400-450
Storage Modulus Retention (80°C/23°C)*	<1%	70-80%	60%
Volume Expansion (%)	130-160	85-100	220-320

* T_g and storage modulus data acquired via DMA

Table 1. *Property comparison*

Compression Cylinder Testing with High Temperature Post Bake

High temperature post bake testing further confirms the thermal robustness of XP-K606. Compression cylinder samples subjected to 150°C and 200°C for up to 45 minutes showed no significant changes in density, compressive peak stress, or compressive modulus. These results provide confidence that XP-K606 can withstand typical E-coat temperatures and therefore be used in today's BIW stage if necessary.

Sample	Control	150°C, 30 min post bake	150°C, 45 min post bake	200°C, 30 min post bake	200°C, 45 min post bake
Density (g/cc)	0.75-0.80	✓	✓	✓	✓
Compressive Peak Stress (MPa)	33-37	✓	✓	✓	✓
Compressive Modulus (MPa)	1,200-1,400	✓	✓	✓	✓

Table 2. *Temperature Resistance of XP-K606*

5. STRUCTURAL REINFORCEMENT METHODOLOGY

To evaluate the structural reinforcement capabilities of XP-K606, hollow metal tubes were reinforced using a localized fill strategy. A 150 mm span of XP-K606 was injected into the tube, allowing the material to expand and bond to the internal surfaces.

Three point bend testing was conducted to assess the structural contribution of the reinforced tubes.

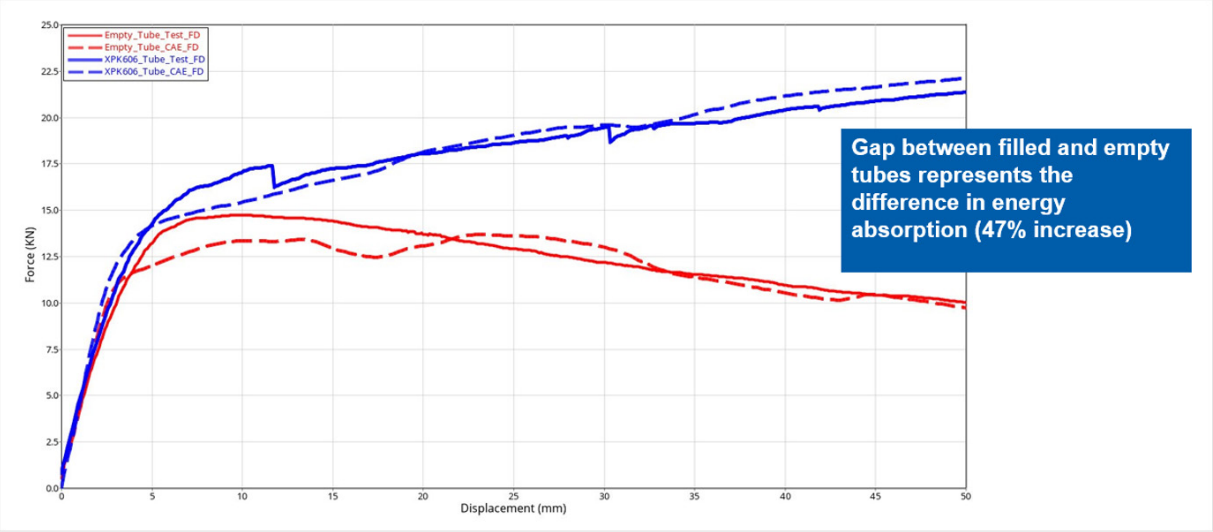
The test setup, shown in Figure 4 below, included a fixed support span and a central loading pin. Both empty and reinforced tubes were tested under identical conditions to isolate the effect of the reinforcement.

CAE simulations were performed using material properties measured from XP-K606 samples. The simulations incorporated accurate density, modulus, and expansion behavior, and used refined mesh regions in the reinforced zone to capture local stiffness variations. This approach enabled direct comparison between predicted and measured structural performance.

Figure 4: *Test method*

6. RESULTS AND DISCUSSION

The force–displacement curves obtained from three point bend testing reveal a substantial increase in structural performance for the reinforced tubes. As shown in Figure 5 below, the reinforced tubes exhibit higher peak force, greater energy absorption, and delayed onset of collapse compared to empty tubes. The area under the force–displacement curve indicates an approximate 47% increase in energy absorption with only an 8% increase in mass.



Gap between filled and empty tubes represents the difference in energy absorption (47% increase)

Figure 5: *Force-displacement curve of empty and reinforced tubes*

CAE simulations showed strong agreement with physical testing, with peak force predictions within 5–7% of measured values and energy absorption predictions within 5%. These results can be found in Table 3.

Run	Model Details	Results		Energy Improvement (%)	Weight (Kg)	Notes
		Peak Force (N)	Energy (J)			
1	Empty Tube Test Data	14733.0	605.8	-	1.63	470 mm support span
2	Empty Tube CAE Data	13694.8	587.8	-3.0	1.63	1.63 kg tube weight 2.11 mm tube thickness 38.1 mm outer dimensions
3	Reinforced Test Data	21366.0	889.8	46.9	1.759	with 150 mm span of XP-K606
4	Reinforced CAE Data	19969.7	847.8	40.0	1.759	with 150 mm span of XP-K606

Table 3. *CAE to test correlation*

To contextualize these results, steel up-gauging was evaluated as an alternative reinforcement strategy. Figure 6 below shows how energy absorption of a reinforced tube can be matched by up-gauging the tube. Increasing the tube wall thickness from 2.1 mm to 2.7 mm produced a similar improvement in energy absorption, but resulted in a 28% increase in mass, as seen in Table 4.

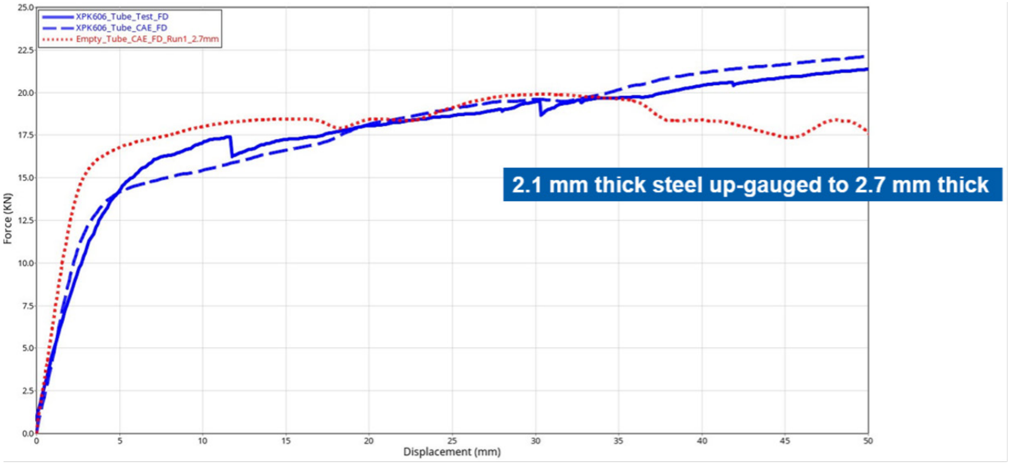


__Figure 6:__ Force-displacement curve of reinforced and up-gauged tubes

Run	Model Details	Results		Energy Improvement (%)	Weight (Kg)	Weight Increase from Original Tub (%)	Notes
		Peak Force (N)	Energy (J)				
1	Empty Tube Test Data 2.11 mm	14,733.0	605.8	-	1.63	-	470 mm support span
2	Empty Tube CAE Data 2.7 mm	19,894.2	892.32	47.3	2.086	27.9	2.7 mm thick
3	Reinforced Test Data	21,366.0	889.76	46.9	1.759	7.9	with 150 mm span of XP-K606
4	Reinforced CAE Data	19,969.7	847.84	40.0	1.759	7.9	with 150 mm span of XP-K606

***Table 4.** Reinforced vs. up-gauged tubes*

Dynamic impact testing further validated the structural performance of XP-K606. Reinforced tubes exhibited significantly reduced deflection under impact loading, consistent with quasi static results.

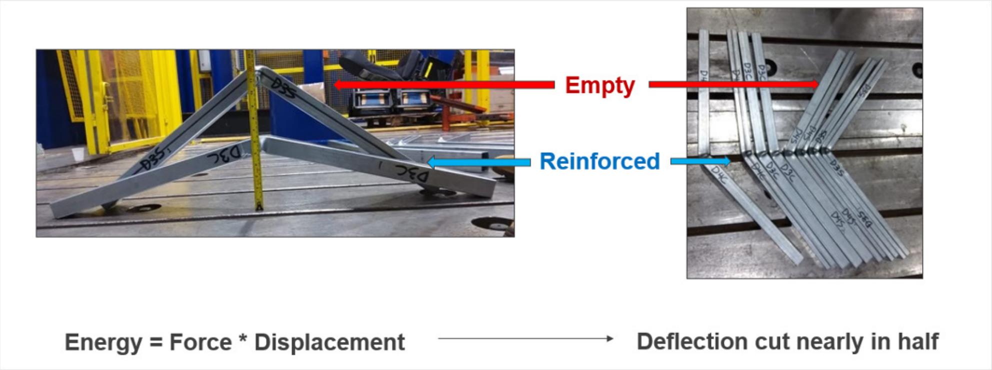


__Figure 7:__ Dynamic impact testing of XP-K606

7. IMPLICATIONS FOR BODY IN WHITE ENGINEERING

The performance of XP-K606 has significant implications for BIW engineering. The ability to achieve high temperature performance without oven curing enables reinforcement strategies compatible with low energy and no bake manufacturing lines. The lightweighting potential demonstrated by localized reinforcement offers an alternative to steel up-gauging, supporting mass reduction targets without compromising crash performance.

The strong correlation between CAE predictions and physical testing allows XP-K606 to be integrated into early stage design and simulation workflows, enabling engineers to optimize reinforcement strategies before physical prototypes are available. The material's compatibility with hollow sections and crash critical zones makes it suitable for a wide range of BIW applications, including pillars, rockers, rails, and other structural members. It is equally suitable for repairs of the aforementioned structures in body shops.

8. CONCLUSION

PHASTER® XP-K606 represents a significant advancement in ambient cure structural reinforcement materials. Through hybrid polymerization, XP-K606 achieves a hybrid thermoset architecture that delivers high Tg, strong modulus retention at elevated temperature, and crash relevant structural performance without reliance on high temperature ovens. Mechanical testing, CAE correlation, and structural reinforcement studies demonstrate the material's ability to increase energy absorption while minimizing mass, offering a lightweight alternative to steel up-gauging.

As OEMs continue to pursue low energy manufacturing strategies and lightweight BIW architectures, hybrid polymerized ambient cure foams such as XP-K606 provide a promising pathway for achieving structural performance targets without compromising process efficiency or design flexibility.

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Kevin Cox is a Research Engineer at L&L Products, specializing in the development of ambient-cured materials, ranging from structural reinforcement to sealing applications. His work focuses on polymer chemistry, hybrid polymerization mechanisms, and structure–property relationships that enable high-performance materials to cure at ambient temperature. Kevin leads programs spanning formulation development, mechanical testing, CAE correlation, and application engineering for hollow section reinforcement and crash relevant structures. He holds a degree in Chemical Engineering and has contributed to multiple internal research initiatives advancing lightweight structural solutions for next generation vehicles.

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