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PR-2930™-LVLC AND CORASEAL™ AMBIENT U1800: HIGH PERFORMANCE ADHESIVES FOR MILITARY APPLICATION

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ABSTRACT

This paper investigates two high-performance structural adhesives, PR-2930™-LVLC and CORASEAL™ Ambient U1800, classified as Group I under the MIL-PRF-32662 specification, emphasizing their potential role in structural and armor applications. The study highlights the adhesives' unique properties, including PR-2930-LVLC's superior adhesion and CORASEAL Ambient U1800's remarkable combination of strength and flexibility. Rigorous testing, including hot-wet conditioning and elevated temperature assessments, demonstrates their durability under extreme conditions. The paper also details the adhesives' performance in Mode I and II strength and toughness evaluations, revealing PR-2930-LVLC's high strength and CORASEAL Ambient U1800's superior toughness. These findings underscore the potential of these adhesives to enhance performance during high impact-rate events and to support lightweight vehicle design, addressing a significant gap in adhesive technology for military applications.

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1. INTRODUCTION

Structural adhesives play a crucial role in various industrial applications. One application where high-performance structural adhesive bonding is essential is in vehicle structures and armor applications. This paper presents two adhesives meeting the rigorous performance requirements of 'Group I' according to the MIL-PRF-32662 Specification [1]. PR-2930™-LVLC (LVLC = low viscosity, low cure) is a one-component, structural epoxy adhesive, and CORALSEAL™ Ambient U1800 is a two-component polyurethane adhesive. The objective of this paper is to explore their unique properties, applications, and performance characteristics.

Robert Jensen [2] of the US Army Research Lab (ARL) identified a gap in adhesive technology that he believed would be useful for bonding armor assemblies with an increased ballistic damage tolerance. In ARL-SR-03711, Jensen defines several

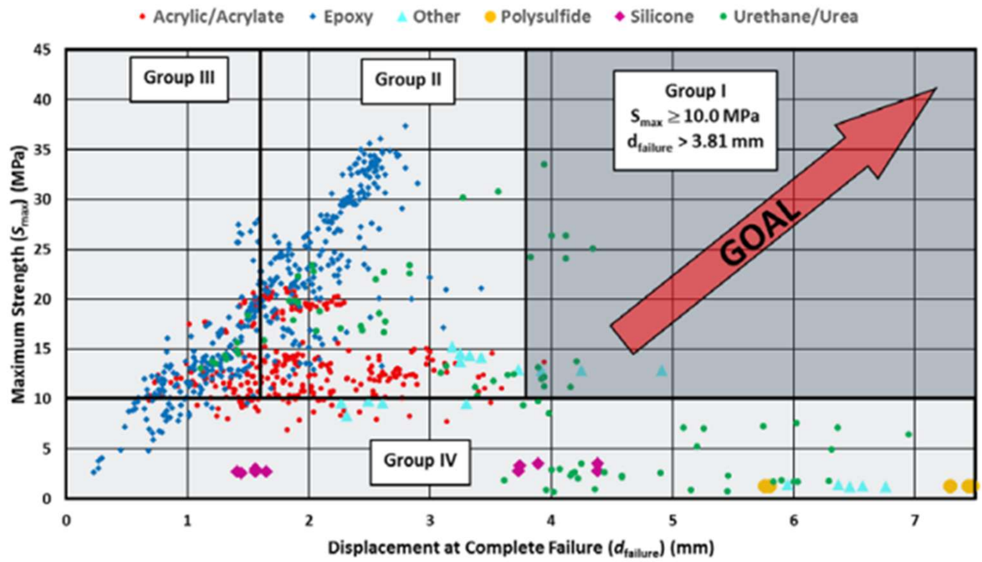

Figure 2: Experimental data collected by the ARL team showing where various chemistries land on the adhesive grouping graph.

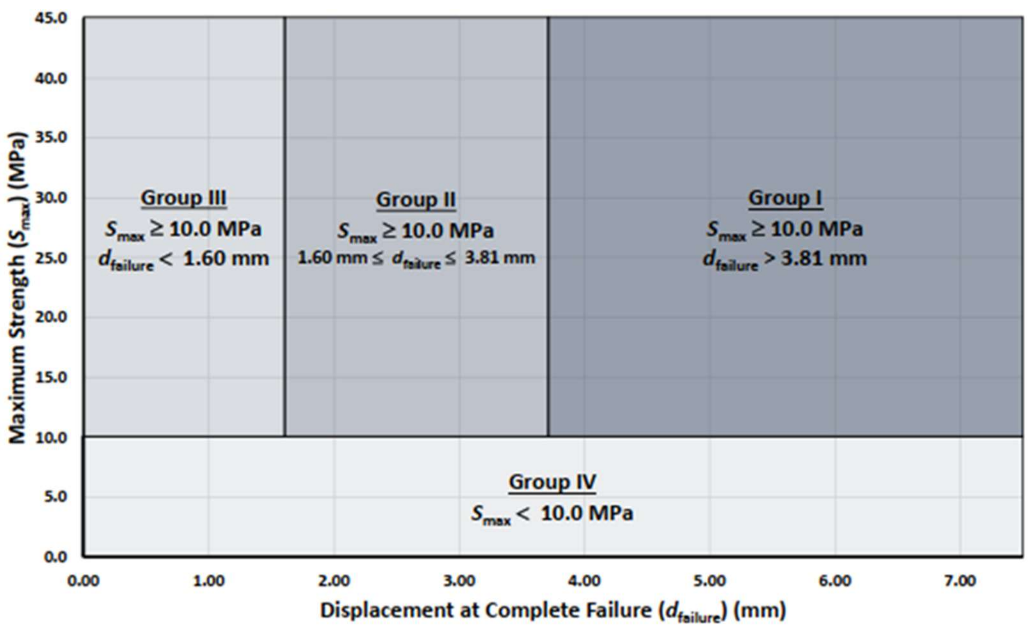

Figure 1: Adhesive grouping based on the lap joint maximum strength and displacement at failure.

groups of adhesives which fall into different areas of a lap shear maximum strength vs. displacement at failure (Figure 2) as defined by ASTM D-1002-10 [3]. Adhesives that are strong and inflexible (Groups II and III) or weak and very flexible (Group IV) are widely available on the market; adhesives possessing both strength and flexibility (Group I) are not widely available. The development of such adhesives could support vehicle light-weighting efforts.

Group I Adhesives, as outlined in the MIL-PRF-32662 specification [4], are specifically designed for structural and armor applications. These adhesives are engineered to provide exceptional bonding capabilities under demanding conditions, ensuring structural integrity and durability. The specification classifies adhesives based on single-lap-joint performance prepared from 2024-T3 aluminum tested at room temperature (23°C ±2°C). A Group I adhesive is defined as one that achieves a maximum average strength of greater than or equal to 10.0 MPa and a minimum average displacement at failure of greater than 3.81 mm.

Jensen [2] and team generated nearly 900 experimental data points to populate this graph with existing technology. Figure 2 shows the spread of these data points categorized by the adhesive chemistry wherein a significant lack of adhesives falling into the Group I category can be seen.

Adhesives must also perform after different conditioning tests, including hot-wet conditioning, which involves water immersion for 14 days at 63°C ±3°C, followed by testing at 23°C ±2°C. Additionally, an elevated temperature test is conducted at 71°C ±3°C. The sample must maintain 75% and 50% of its maximum average lap shear strength, respectively. Furthermore, adhesives must be tested in a crack extension test, which is carried out at 60°C ±1.1°C and 100% relative humidity for five weeks [4].

The purpose of this paper is to compare the properties of two Group I adhesives: PR-2930-LVLC and U1800. The PR-2930-LVLC adhesive is a low viscosity, low cure version of the original PR-2930 adhesive, presented at GVSETS in 2018 [5]. PR-2930-LVLC is a one-component, heat-cured epoxy paste adhesive that can achieve full cured properties at temperatures less than 140°C in one hour. The low-viscosity paste adhesive allows for good flow and wet-out during application and cure. The U1800 adhesive is a fully ambient curing, two-component polyurethane adhesive. It possesses a surprising combination of strength and flexibility which allows for very high toughness.

2. EXPERIMENTAL PROCEDURES

Single-lap-joints were prepared and tested according to ASTM D1002-10 [3] using 2024-T3 aluminum substrate (AL2024, 1.6 mm thick) with an overlap length of 12.7mm. All aluminum substrates were first wiped with methyl ethyl ketone (MEK), rinsed with acetone, then cleaned with Chemdeox 395 or a PPG proprietary deoxidizer prior to bonding. After bonding and cure, all lap joints were tested on an Instron frame model 5567 with a 30 kN loadcell.

2.1. PR-2930-LVLC Preparation and Cure

Single-lap-joints with PR-2930-LVLC were prepared using the substrate cleaning procedure above. The adhesive bondline thickness was controlled through the addition of spherical glass beads (0.25 mm diameter). The samples were cured for 1 hr. at 135 °C in an oven.

2.2. U1800 Preparation and Cure

The single-lap-joints with U1800 were prepared beginning with the same substrate cleaning procedure as PR-2930-LVLC. After the deoxidizing bath, the substrate was further prepared for bonding by the addition of a primer layer. In some cases, the primer layer was a 0.25 mm thick layer of PR-2930 applied to the bonding area of the lap shear via a drawdown bar. This layer was baked at 180 °C for 30 minutes. For comparison in other tests, the substrate was wiped with a 10% solution of an aminosilane adhesion promoter dissolved in MEK. The solution was applied to lint-free gauze and quickly wiped over the surface to avoid over-application of the aminosilane. This layer was allowed to dry for at least 20 minutes. The bondline thickness was controlled through the addition of spherical glass beads (0.76 mm diameter). Samples were cured at 25 °C and 50% relative humidity (% RH) for seven days.

2.3. Tier I Testing

PR-2930-LVLC specimens were tested at a pull rate of 1.3 mm/min following the guidelines of ASTM D1002-10. U1800 specimens were tested at a pull rate of 13 mm/min.

2.4. Tier II Testing

Both adhesives were tested under "hot-wet" (Tier II, Part 1) and high-temperature (Tier II, Part 2) conditioning in accordance with MIL-PRF-32662 [1]. Hot-wet conditioning involves submerging the fully cured lap joints in water maintained at 63 °C for 14 days. Upon completion of the hot-wet conditioning, specimens can be patted dry and tested no later than 30 minutes after removal from the water. High temperature testing entails conditioning the test chamber for 45 minutes and the fully cured joints for at least 10 minutes at 71 °C, then pulling the joints while at temperature.

2.5. Tier III Testing

Stress corrosion cracking (G_{ISCC}) test samples were prepared for both adhesives. The double cantilever beam (DCB) samples for the crack extension test were created by bonding two 304.8 mm x 455.6 mm x 12.7 mm 2024-T3 aluminum plates with a 25.4 mm Teflon tape separator placed along one side between the plates. After curing, the bonded plates were cut into DCB samples with a width of 25.4mm in accordance with MIL-PRF-32662. Tapped bolts were utilized to initiate the crack. The initial crack length was measured, and the samples were then subjected to elevated temperature and moisture conditions of 60 °C at 100% RH for five weeks. Following this exposure, the crack length was measured again. A passing Tier III sample has a minimum G_{ISCC} of 0.61 kJ/m2 [1] calculated using Equations 1 and 2.

2.6. Dynamic Mechanical Analysis

Dynamic mechanical analysis (DMA) was collected on free films of both PR-2930-LVLC and U1800 using single cantilever beam configuration on a TA Instruments Q800 with a temperature ramp rate of 3 °C/ per minute, a strain of 0.10%, and a frequency of 1 Hz.

3. RESULTS AND DISCUSSION

3.1. MIL-Spec Testing

Table 1 demonstrates that, despite being different chemistries with very different bulk properties, both PR-2930-LVLC and U1800

Table 1: Lap shear results from Tiers I, II Part 1 (hot-wet), and II Part 2 (high temperature).

			Tier I		Tier II Part 1		Tier II Part 2	
Adhesive	**Pretreatment**	**Primer**	**Max Strength (MPa)**	**Disp. at Failure (mm)**	**Max Strength (MPa)**	**% Retention of Initial Max Strength**	**Max Strength (MPa)**	**% Retention of Initial Max Strength**
PR-2930-LVLC	PPG proprietary deoxidizer	None	50.6	7.4	35.5	70	42.7	84
U1800	ChemDeox 395	Silane wipe	24.0	4.1	17.7	74	12.5	52
U1800	ChemDeox 395	PR-2930	20.7	4.6	26.6	129	11.2	54

[1] meet the Group I classification criteria. It is interesting to note the PR-2930-LVLC achieves a very high displacement at failure (7.4 mm) by yielding the substrate, while U1800 reaches high displacements (> 4 mm) within the adhesive layer due to its extremely flexible nature.

Table 1 also shows that PR-2930-LVLC retains 70% of its initial maximum strength after undergoing hot-wet conditioning. Similarly, U1800 retains 74% of its initial maximum strength when applied to silane-wiped substrate and exhibits a remarkable 129% retention of its initial maximum strength when used with PR-2930 as a primer. This increase in lap shear strength may be caused by the extended heat of the conditioning allowing the bond between the PR-2930 primer layer and the adhesive to become stronger, while the bond between U1800 and the silane wipe primer is less influenced by the addition of heat. Additionally, Table 1 shows that, at high temperatures, PR-2930-LVLC retains 84% of its initial maximum strength, while PR-3931 retains 52% and 54% of its initial maximum strength with silane-wiped and PR-2930 primer respectively. Because U1800 is an ambiently cured system, it has a low glass transition temperature (T_g) and experiences some softening while at high temperatures. Despite softening, U1800 meets the required strength retention laid out in MIL-PRF-32662.

$$G_{ISCC} = \frac{y^2 E h^3\,[3(a+0.6h)^2 + h^2]}{16[(a+0.6h)^3 + ah^2]^2}$$

Equation 1: Equation for the calculation of G_{ISCC} (A) where y=opening displacement (2.54 mm), E=Young's modulus of 2024 T-3 aluminum (73.08 GPa), h=height of one beam (12.7 mm), b=width of one beam (25.4 mm), and a=crack length measured from loading point.

$$G_{ISCC} = \frac{0.00096578[3\left(\frac{a}{1000}+0.00762\right)^2 + 0.00016129]}{16[\left(\frac{a}{1000}+0.00762\right)^3 + \left(\frac{a}{1000}\right)0.00016129^{0}]^2}$$

Equation 2: Equation 1 simplified using provided constants.

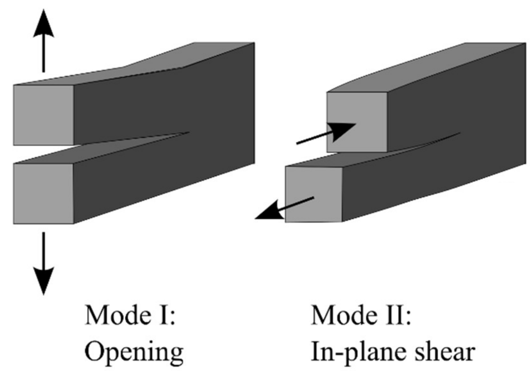

Figure 3: Example of the first two fracture modes Mode I and Mode II [7].

The stress corrosion cracking test for PR-2930-LVLC and U1800 have a G_{ISCC} of 1.08 kJ/m^2 and 1.06 kJ/m^2, respectively.

3.2. *Mode I and II Characterization*

Table 2 shows low-rate and impact-rate Mode I strength and toughness and Mode II (Figure 3) strength and toughness. There are interesting differences between the two adhesives seen in this testing. PR-2930-LVLC has a very high low-rate Mode I strength while U1800 has a much lower strength, due possibly to the difference in modulus between the two materials. However, U1800 shows a higher low-rate Mode I toughness compared to PR-2930-LVLC due to its combination of strength and flexibility. Similarly, PR-2930-LVLC has much higher Mode II strength compared to U1800, while U1800 has a higher toughness for the same reasons as above.

Figure 4 shows three sequential images taken by a high-speed camera during the impact-rate Mode I testing which shows how U1800 resists tearing and crack propagation.

Table 2: Mode I and Mode II strengths and toughness measured by Veryst Engineering [6].

Adhesive	Substrate	Low-Rate Mode I Strength (MPa)	Low-Rate Mode I Toughness (N/mm)	Mode II Strength (MPa)	Mode II Toughness (N/mm)	Impact-Rate Mode I Strength (MPa)	Impact-Rate Mode I Toughness (N/mm)
U1800	4140 steel, 11 mm thick	4.50	6.20	16.0	31.4	19.0	18.0
U1800	7075 aluminum, 11 mm thick	4.70	10.1	20.5	24.0	24.0	23.0
PR-2930-LVLC	4140 steel, 11 mm thick	91.0	4.70	91.0	13.0	(not tested)	(not tested)

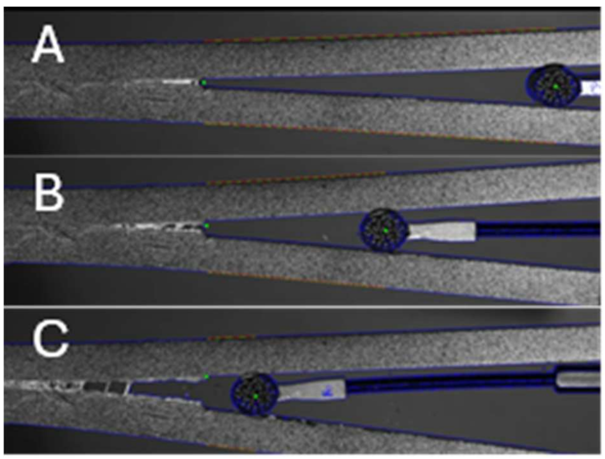

Figure 4: High-rate DCB testing in the beginning (A), middle (B), and end of test (C) [6].

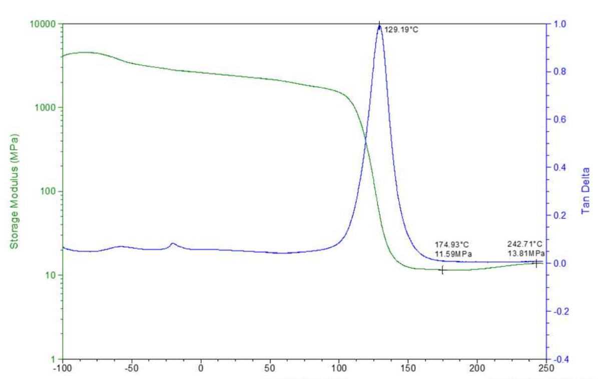

Figure 6: DMA temperature sweep on PR-2930-LVLC.

As the pin is pushed further towards the bonded section at a rate of 3.5 m/s, the adhesive can be seen stringing and stretching across the widening crack as it absorbs energy.

3.3. Dynamic Mechanical Analysis

Dynamic Mechanical Analysis (DMA) was conducted on both PR-2930-LVLC and U1800. Figure 6 illustrates that PR-2930-LVLC has a sharp tan delta peak at 129 °C. In contrast, Figure 5 shows that U1800 has a broad Tan Delta peak beginning at around -35°C due to its unique polymeric structure.

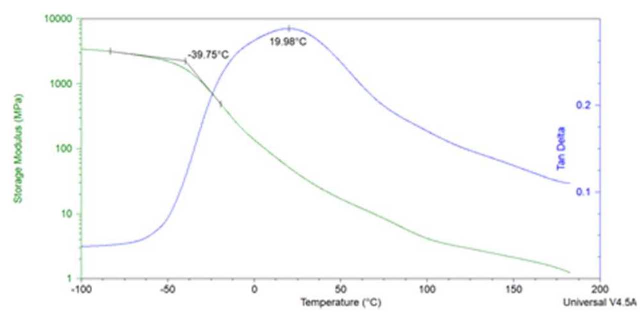

Figure 5: DMA temperature sweep on U1800

4. CONCLUSIONS

In summary, the two high-performance structural adhesives, PR-2930-LVLC and U1800, pass the MIL-PRF-32662 specification for structural and armor applications. They have exceptional bonding capabilities, durability under various extreme conditions, and their unique properties address a critical gap in adhesive technology. These findings suggest that these adhesives not only enhance performance during high-impact rate events but also support efforts in lightweight vehicle design, making them valuable for military applications. These results ultimately emphasize the potential for these adhesives to contribute to advancements in structural integrity and performance in demanding environments.

5. REFERENCES

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6. FIGURES AND TABLES

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9. ACRONYMS

LVLC – low viscosity low cure
ARL – Army Research Lab
MEK – methyl ethyl ketone
RH – relative humidity
DCB – double cantilever beam
G_{ISCC} – stress corrosion cracking
DMA – dynamic mechanical analysis
T_g – glass transition temperature