

# CHARACTERIZATION OF A NEW AFFORDABLE HIGH TEMPERATURE LIQUID MOLDING RESIN SYSTEM

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## ABSTRACT

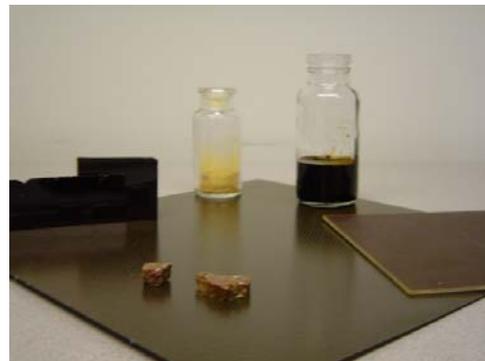
A new, affordable, thermally stable resin system suitable for liquid molding processes (e.g. resin transfer molding (RTM), compression molding, vacuum assisted RTM, resin infusion, etc.) has been developed in our laboratory. Initial characterization of the physical, thermal, rheological, crosslinking, durability, and mechanical properties are presented for neat resin and reinforced composite laminates (S-2 glass and T650-35 carbon fiber). The described resin system, P<sup>2</sup>SI 635LM, exhibits a good balance of performance, processability, and affordability.

KEY WORDS: Resin Transfer Molding (RTM), Resins/Materials – High Temperature, High Temperature Composite Materials/Structures

## 1. INTRODUCTION

Future defense, space, and commercial aerospace systems require lighter weight, more thermally stable, higher performance, durable organic matrix composite materials than traditionally available. For many systems, new materials are enabling and necessary to reach performance goals, weight requirements, extend component lifetime, reduce toxicity and pollution, and be amenable to fabrication restrictions. These needs have resulted in considerable investment by the DoD, NASA, and industry over the past twenty years, with significant progress being made. For the most severe synergistic environments, requiring chemical-thermal-moisture resistance and excellent mechanical performance, polyimides have proven most reliable. PMR-15 has been successfully used for over 15 years, and the Air Force developed AFR-PE-4 is presently being qualified for the F-35 Joint Strike Fighter program.

Unfortunately, higher performance, more environmentally friendly polymer matrices are often significantly more costly than previous generation materials. Niche monomers, including fluorinated and electronics grade raw materials required for thermal stability, control material pricing. To compensate, lower cost manufacturing approaches, including resin transfer molding (RTM), resin infusion, compression molding, and vacuum assisted RTM (VARTM), have been implemented, but for high temperature applications the selection of materials processable by these techniques with adequate performance at elevated temperature are few. NASA's PETI 330 has a glass transition temperature ( $T_g$ ) of  $\sim 330^\circ\text{C}$ , is RTM processable, exhibits good mechanical performance, but is somewhat cost prohibitive [1]. AFRPE<sup>®</sup>-LM, a fluorinated RTM resin manufactured by



**Figure 1:** Various product forms of P<sup>2</sup>SI 635LM.

Performance Polymer Solutions (P<sup>2</sup>SI) has a T<sub>g</sub> of ~375°C, good elevated temperature mechanical properties and toughness [2], but sells for over \$300/lb. At a previous SAMPE Technical Conference, Maverick Corporation presented a low cost RTM resin system (MM 10.8) with a dry T<sub>g</sub> of 305°C and good mechanical performance up to 260°C [3].

P<sup>2</sup>SI recently completed an internal research effort to bridge the price and performance gap between bismaleimides and fluorinated RTM polyimides. A multivariable design of experiments was followed, using both cost and performance (physical, thermal, mechanical, and processing) factors. An initial characterization of the down-selected system from our research effort, designated P<sup>2</sup>SI 635LM, is presented.

## **2. EXPERIMENTAL**

### **2.1 Materials**

#### ***2.1.1 Liquid Molding Resin***

P<sup>2</sup>SI 635LM is a low molecular weight, melt processable, solvent-free, crosslinkable imide oligomer based on similar functionality as polymers described by Harris *et al.* [4]. This resin system was engineered through a design of experiments methodology in our laboratory with significant emphasis on commercial potential (i.e. formulated from reasonably priced monomers), optimizing performance (viscosity, pot-life, T<sub>g</sub>, mechanical properties, and durability) within the constraints of commercially available, affordable raw materials.

For this research effort, P<sup>2</sup>SI 635LM imidized powder was prepared using standard synthesis procedures for imide oligomers: amic ester-acid oligomers were synthesized in a polar solvent and followed by bulk imidization. Complete imidization and solvent removal was achieved after a 260°C/4h final isothermal hold, verified by thermogravimetric analysis (TGA) of imidized powder.

#### ***2.1.2 Textile Reinforcements***

16781 S-2 glass fabric finished with 1059 sizing (JPS Glass) and T650-35 carbon fiber, 8 harness satin fabric sized with commercial epoxy-based UC309 (Cytac Carbon Fibers LLC and Fabric Development Inc.) were used as reinforcements for composite laminates.

### **2.2 Resin Characterization**

#### ***2.2.1 Cure Behavior***

Crosslinking characteristics were determined by differential scanning calorimetry (DSC) using a TA Instruments Q100 differential scanning calorimeter. Neat resin specimens were heated under dynamic conditions (2–10°C/min) and cured isothermally (280–380°C) for 8 h to characterize the cure behavior of the resin. Oligomer T<sub>g</sub>, processing window, cure kinetics, and crosslinked polyimide glass transition temperature were determined. Fourier transform infrared spectroscopy (FTIR, Perkin-Elmer Spectrum BX) was used to both confirm imidization and monitor crosslink formation.

### 2.2.2 Rheology

Dynamic and isothermal melt viscosities were determined over the range of 220-360°C using a Brookfield viscometer equipped with a high temperature control system. Parallel plate rheometry was also used to record the dynamic melt viscosity (Rheometrics Scientific, ARES®). Amide formation, imidization, and cure were monitored via dynamic mechanical analysis (DMA) using a TA Instruments 2980 dynamic mechanical analyzer.

### 2.2.3 Thermal Stability

Initial resin thermal stability predictions were made using the method developed by Toop [5], which involves dynamic heating of resin samples in the TGA instrument (TA Instruments Hi-Res Auto TGA 2950), recording the temperature of a specific decomposition (based on weight loss), and applying Equations 1 and 2 to generate predictive thermal decomposition plots. For this study, heating rates of 1-20°C/min and a nitrogen atmosphere were used.

$$Q = -\frac{R}{C} \left[ \frac{d \log_{10} \beta}{d\left(\frac{1}{T}\right)} \right] \quad (1)$$

$$\ln t_f = \frac{Q}{RT_f} + \ln \left[ \frac{Q}{\beta R} \times p\left(\frac{Q}{RT_c}\right) \right] \quad (2)$$

In the above equations,  $Q$  is the activation energy for a particular degree of decomposition,  $R$  is the universal gas constant,  $C \approx 0.4569$ ,  $t_f$  is the predicted lifetime at a particular degree of decomposition,  $\beta$  is the heating rate,  $T$  represents temperature, where subscripts  $f$  and  $c$  denote failure temperature and constant conversion point, respectively, and the function  $p(Q/RT_c)$  is an integral value (see Ref. 5 for a detailed discussion).

## 2.3 Laminate Fabrication

Composite laminates were fabricated via a resin infusion technique of imidized powder under vacuum. This approach is similar to high temperature vacuum assisted resin transfer molding (VARTM). Pressure was applied (345 kPa) after infusion for consolidation. Based on the DSC results a cure temperature of 371°C/1h was used to cure the laminates; no postcure was used. 10 ply S-2 glass fiber laminates and 8 ply carbon fiber laminates were fabricated to a target fiber volume fraction of 55%.

## 2.4 Environmental Aging

### 2.4.1 Thermal Aging

Both T650-35 carbon fiber and S-2 glass reinforced laminates were aged in a flowing air convection oven at 316°C for 100 h to assess the thermo-oxidative stability (TOS) of the polyimide composites. The P<sup>2</sup>SI 635LM liquid molding resin was designed for service use at maximum temperature of 288°C; limited exposure at the elevated temperature of 316°C was used as an accelerated test.

### 2.4.2 Moisture Conditioning

An S-2 glass laminate was conditioned at 100% relative humidity and 50°C for approximately 30 days (water submersion). An equilibrium moisture level was reached after approximately 15 days, but the panel was aged an additional 15 days to further assess the hygrothermal durability.

## 2.5 Laminate Characterization

### 2.5.1 Physical Properties

Composite laminates were characterized by optical and scanning electron microscopy (cross-sectional inspection) for void content and microcrack inspection.

### 2.5.2 Thermal Properties

Glass transition temperature of the cured laminates (control and aged) was determined by DMA at heating rates of 5°C/min in air using the single cantilever mode. Moisture saturated composite specimens were heated at various heating rates to obtain a more accurate determination of the “wet  $T_g$ ”. Equivalent heating rate TGA scans were performed on a saturated composite sample from the same laminate to assess the moisture loss during the DMA scan.

### 2.5.3 Mechanical Properties

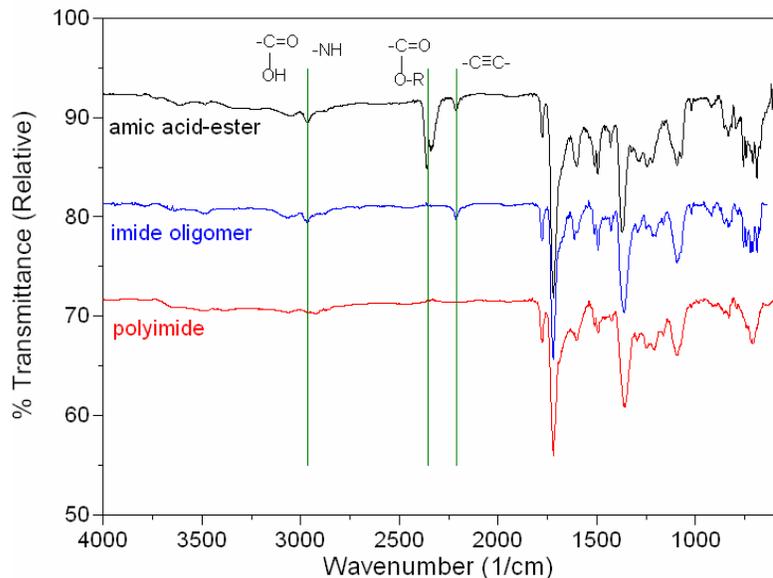
Flexural properties (3-point bend, ASTM D790) and apparent interlaminar shear strength (ILSS, ASTM D2344) were measured at 23°C for control and aged materials using an Instron 4484 150kN load frame. Eight specimens per condition were measured and averaged to calculate the standard deviation.

## 3. RESULTS AND DISCUSSION

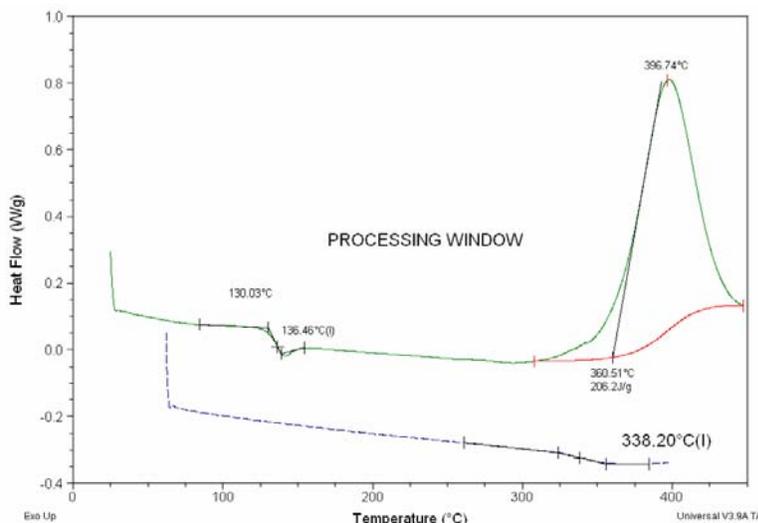
### 3.1 P<sup>2</sup>SI 635LM Resin Characterization

#### 3.1.1 Resin Imidization and Cure

FTIR spectra for amidized (100°C/12h), imidized (260°C/4h), and cured (371°C/1h) P<sup>2</sup>SI 635LM are shown in Figure 2. Transmittance is relative in this figure since the spectra were shifted for clarity. Loss of the amide peaks at 2900-3200 cm<sup>-1</sup> and amic acid-ester at ~2350 cm<sup>-1</sup> indicates imidization. The free radical polymerization reaction (a partial acetylene addition crosslinking reaction) is visible through consumption of the phenylacetylene functionality at a wavenumber near 2210 cm<sup>-1</sup>. The presence of imide peaks at lower wavenumbers (specifically ~1780, ~1720, and ~1380 cm<sup>-1</sup>) indicates



**Figure 2:** FTIR spectra of P<sup>2</sup>SI 635LM after various stages of amidization, imidization, and cure.



**Figure 3:** DSC traces of P<sup>2</sup>SI 635LM imidized resin.

(oligomer  $T_g$ ) occurs at approximately 130°C but the crosslinking reaction does not commence at any appreciable rate until nearly 350°C, providing a processing window for liquid molding applications of ~220°C. Thermodynamic parameters (reaction enthalpy and oligomer  $T_g$ ) are summarized in Table I as a function of heating rate.

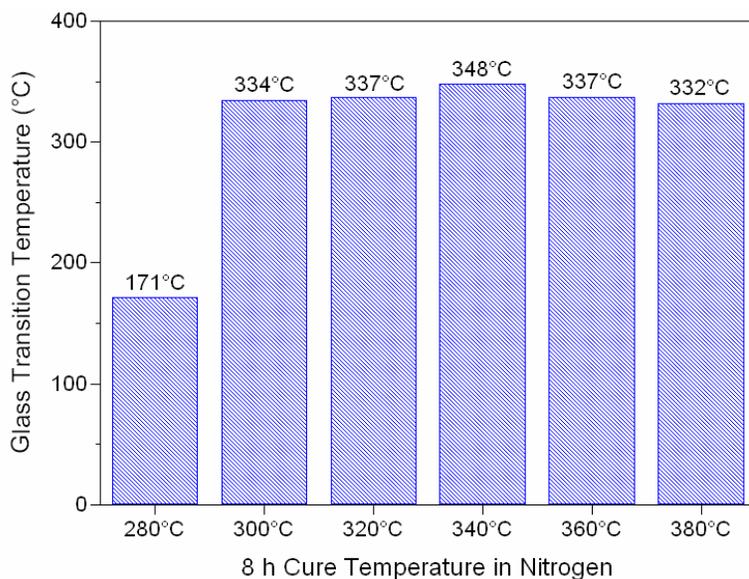
**Table I:** Thermodynamic properties of P<sup>2</sup>SI 635LM resin by DSC.

$dT/dt$	$T_{g}^{oligomer}$	$\Delta H_{reaction}$
2°C/min	127°C	211 J/g
5°C/min	131°C	233 J/g
10°C/min	136°C	208 J/g
<i>mean</i>	$131 \pm 5^\circ C$	$217 \pm 14 J/g$

Importantly, no apparent crystallization or liquid-crystalline behavior appears in the DSC trace. A number of thermoplastic and thermosetting polyimides are known to exhibit crystalline behavior which leads to processing difficulties and reductions in mechanical performance [6, 7].

Amorphous systems exhibit better processability (e.g. more consistent morphologies and no concerns of crystal growth at intermediate processing temperatures) than semi-crystalline polyimides; this is of critical importance to provide a robust liquid molding resin.

The absence of appreciable crystallinity provides wider latitude for processing. Figure 4 displays the glass transition temperature of the P<sup>2</sup>SI 635LM resin cured for 8 h at temperatures ranging from 280-380°C. With the exception of the lowest cure temperature (280°C), the cured neat resin samples displayed glass transition temperatures from 334°C to 348°C at DSC heating

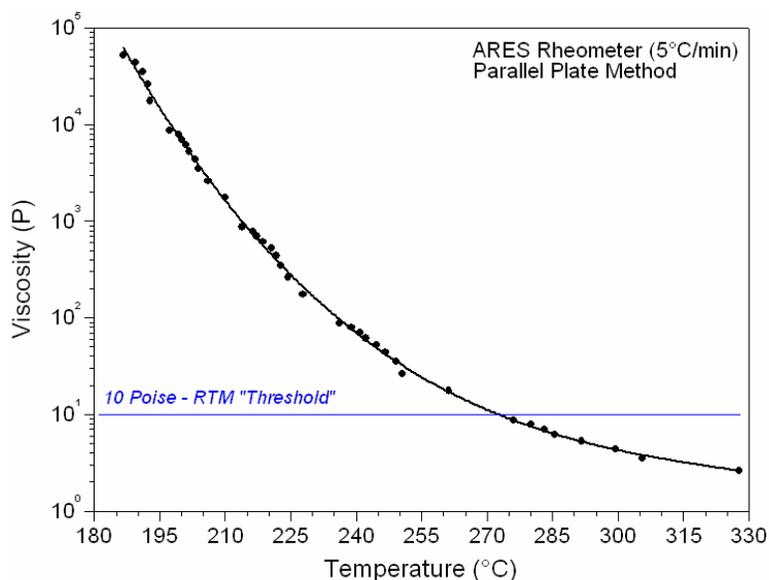


**Figure 4:**  $T_g$  of cured resin samples at various temperatures.

rates of 10°C/min. Interestingly, the highest glass transition temperature obtained (348°C) was for an intermediate cure temperature of 340°C. The lowest “completely cured”  $T_g$  was observed for the highest cure temperature (380°C). The reason for this behavior is unknown, but could be the result of partial thermal decomposition at higher cure temperatures or minor variations in network morphology resulting from different thermal histories. Based on the recorded  $T_g$  values and the absence of additional reaction exotherm or enthalpic melting in the DSC scans, complete cure can be achieved at temperatures as low as 300°C. Flexibility in the cure sequence provides a significant advantage for cure cycle design and amenability to composite component fabrication constraints in industry (e.g. tooling, seals, etc.).

### 3.1.2 Rheology

The dynamic melt viscosity (parallel plate method) of the liquid resin is shown in Figure 5. For high temperature resin transfer molding, it is desirable to obtain a melt viscosity of 10 Poise or lower. This industry “rule of thumb” is a useful initial parameter for ascertaining the feasibility



**Figure 5:** Dynamic melt viscosity of P<sup>2</sup>SI 635LM.

target melt viscosity posed by industry is only one factor for assessing the processability of polyimide resins for RTM applications, we feel that either measurement technique is sufficient for characterization, despite minor quantitative differences in the results.

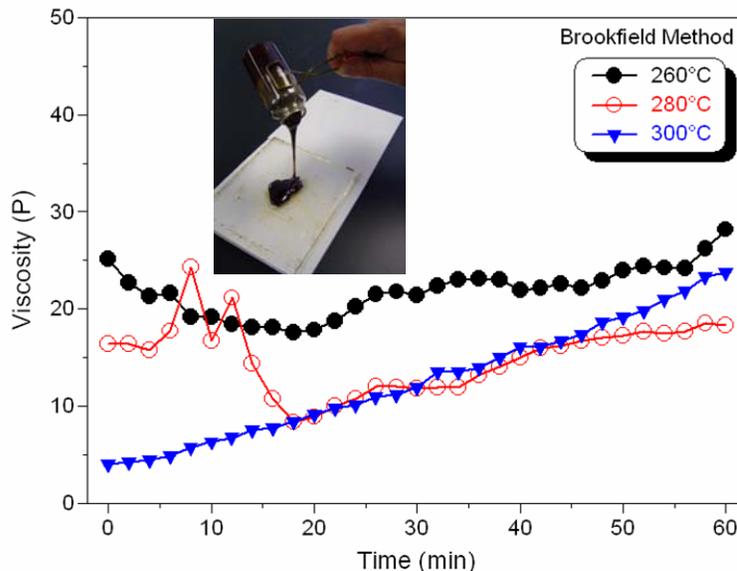
In order to ascertain the processing window (pot-life) of the P<sup>2</sup>SI 635LM system, isothermal viscosities were obtained using the Brookfield method at 260°C, 280°C, and 300°C for times up to 2 h. Liquid resins were maintained at the isothermal temperature for 10 minutes prior to recording viscosity and time. Figure 6 displays isothermal viscosity at these three temperatures for up to 1 h. After one hour at 300°C, the resin still has low enough melt viscosity to pour, as shown in the inset in Figure 6. Scatter in some of the initial data is a result of non-equilibrium temperature distribution at the early stages of the experiment. Interestingly, the melt viscosity at 280°C is very similar to the melt viscosity at 300°C; possibly a result of cure advancement (above 280°C) during dynamic heating to 300°C. No gelation was observed after 2 h for any of the isothermal cure temperatures, although the melt viscosity was extremely high after 2 h at 300°C. Therefore, the resin has a pot-life  $\geq 2$  h for temperatures up to 280°C, and  $\geq 1$  h

of RTM processing. As shown in the figure, the melt viscosity drops below 10 Poise near 270°C. It should be noted that there has been significant discussion in the scientific community regarding the “true” melt viscosity obtained by various techniques (e.g. Brookfield, parallel plate, capillary rheometry, etc.) and the quantitative applicability of the respective rheological measurements to RTM processing. In our polyimide research we have found that similar results are obtained by both the Brookfield method and parallel plate technique. Since the 10 Poise

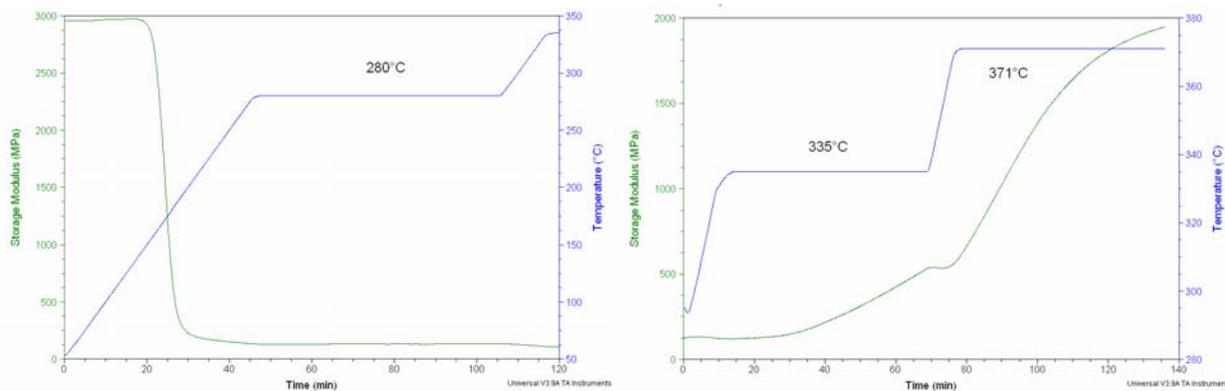
at 300°C. The combination of rheological measurements and cure kinetics suggest that the optimal injection regime for RTM applications is 260-280°C. Lower injection temperatures may be preferred for other liquid molding techniques that prefer slightly higher melt viscosities. There appears to be little or no advantage to heating to temperatures much above 280°C.

Although this resin system was engineered for liquid molding applications, we have fabricated laminates using standard polymerization of monomer reactants (PMR) processing routes in alcohol solvents. Very low vacuum and consolidation pressures must be used to avoid over-bleeding of resin. For PMR autoclave applications, it is desirable to obtain at least qualitative knowledge of both the solution and melt viscosity during cure for cure time-temperature-vacuum-pressure optimization.

Figure 7 displays the dynamic mechanical behavior of the resin (a monomer solution supported on a fiberglass cloth) during a standard autoclave process. Initially, solvent loss and amic acid-ester formation results in a reduction in viscosity (as measured by dynamic stiffness) with heating. As imidization initiates, the modulus does not increase significantly with increased aromaticity (280°C isothermal hold) because the  $T_g$  of the completely imidized oligomer is significantly lower than the imidization temperature. For many PMR resins, an increase in modulus is observed during this imidization step due to more rigid imide oligomers. Upon heating to the cure regime (335-371°C), a significant increase in modulus is observed as the polyimide forms and the  $T_g$  approaches the cure temperature. Figure 7 also reinforces the melt viscosity and DSC results, emphasizing the large processing window for this material.



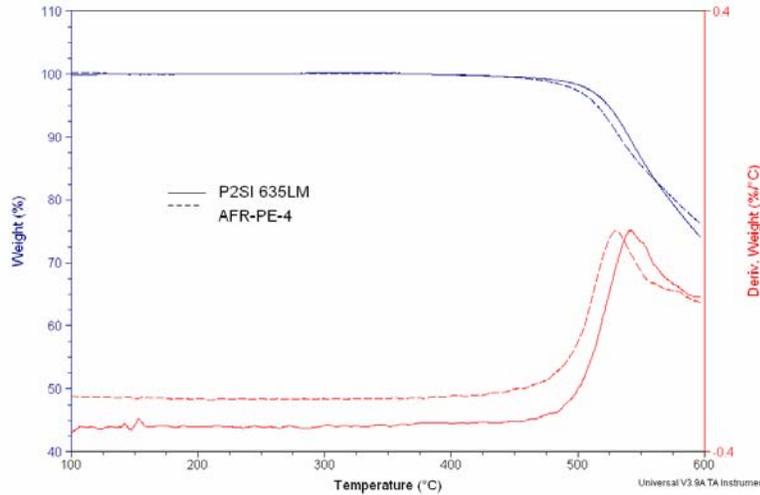
**Figure 6:** Isothermal melt viscosity of P<sup>2</sup>SI 635LM.



**Figure 7:** Imidization (left) and cure (right) of P<sup>2</sup>SI 635LM via DMA.

### 3.1.3 Thermal Stability

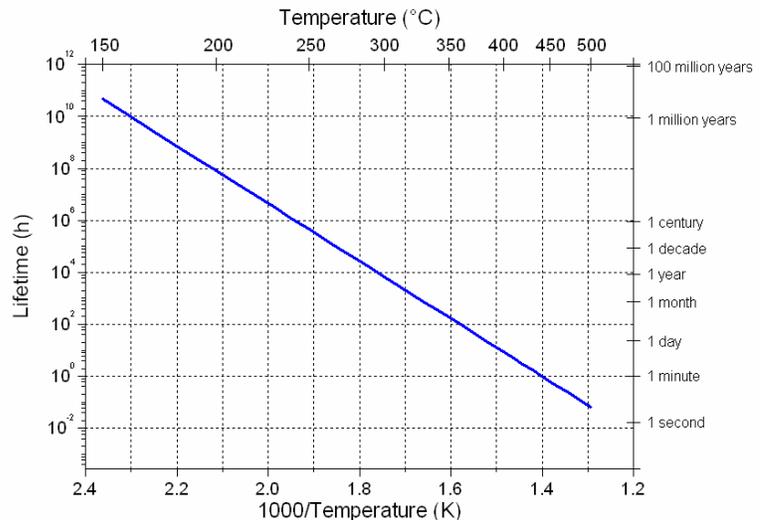
A dynamic TGA scan (10°C/min, nitrogen atmosphere) of P<sup>2</sup>SI 635LM cured neat resin is shown in Figure 8, along with the corresponding derivative. For comparison, the fluorinated high temperature PMR polyimide AFR-PE-4 is also displayed. AFR-PE-4 is a state-of-the-art



**Figure 8:** Dynamic TGA scans of AFR-PE-4 and P<sup>2</sup>SI 635LM cured neat resin specimens.

slightly lower resistance to thermal degradation than AFR-PE-4. However, for an RTM resin system, these results are extremely promising.

Using the kinetic results obtained from the additional TGA experiments, a lifetime thermal stability prediction was generated (Figure 9). Although this kinetic thermal decomposition model is mostly of academic interest, it is still a useful tool for qualitative thermal stability assessment of high temperature organic materials. Similar curves have previously been generated for AFR-PE-4 and other polyimides [7] and the results obtained from the predictions in this research are similar. The activation energy for thermal decomposition of P<sup>2</sup>SI 635LM was found to be 476 kJ/mole, which is in agreement with other thermoset polyimides. AFR-PE-4 has shown to exhibit an extremely high activation energy for thermal decomposition (compared to most other thermoset polyimides) of 584 kJ/mole [7]. Similarly, the activation energy for a 5% mass loss value was found to be 212 kJ/mole whereas AFR-PE-4 has a reported value of 281 kJ/mole [7].



**Figure 9:** Thermal decomposition model (5% mass loss prediction) for P<sup>2</sup>SI 635LM neat resin.

### 3.2 P<sup>2</sup>SI 635LM Composite Characterization

#### 3.2.1 Laminate Physical Properties

S-2 glass and T650-35 laminate physical properties are summarized in Table II. Low values for laminate mass loss after aging at 316°C for 100 hours (0.73% and 0.51% for S-2 and T650-35 laminates, respectively) are encouraging. The T650-35 laminates had a thickness of approximately 2.70 mm whereas the S-2 laminates were ~2.35 mm thick.

**Table II:** Laminate physical properties for S-2 and T650-35.

Reinforcement	Aging Condition	Property Measured	Value
T650-35 8 HS	control	void content	< 2%
		microcrack inspection	none
	316°C/100 h	mass loss	0.51%
		microcrack inspection	none
		void content	< 2%
16781 S-2 Glass	control	void content	< 3%
		microcrack inspection	none
	moisture saturated	void content	5-10%
		moisture gain	1.7%
	316°C/100 h	mass loss	0.73%
		void content	5-10%

The S-2 glass laminate moisture gain of 1.7% was slightly higher than anticipated based on other polyimide composites. Unfortunately, it was discovered after environmental conditioning that the S-2 laminate used for moisture absorption and thermo-oxidative aging was of poor quality (i.e. high void content) due to over-bleeding during the fabrication process. This large void level most likely resulted in the recorded high equilibrium moisture content.



**Figure 10:** Optical micrographs (left to right) of (i) a low-quality S-2 glass laminate, (ii) a high-quality T650-35 laminate prior to thermo-oxidative aging, and (iii) T650-35 laminate cross-section after aging for 100 h at 316°C.

The S-2 laminate used for control property measurements and all T650-35 laminates were of satisfactory quality. Figure 10 displays micrographs for a poor quality S-2 laminate and a satisfactory T650-35 laminate before and after accelerated thermo-oxidative aging. No microcracking was observed in any of the laminates before or after their respective environmental conditioning by optical or scanning electron microscopy. However, comparison

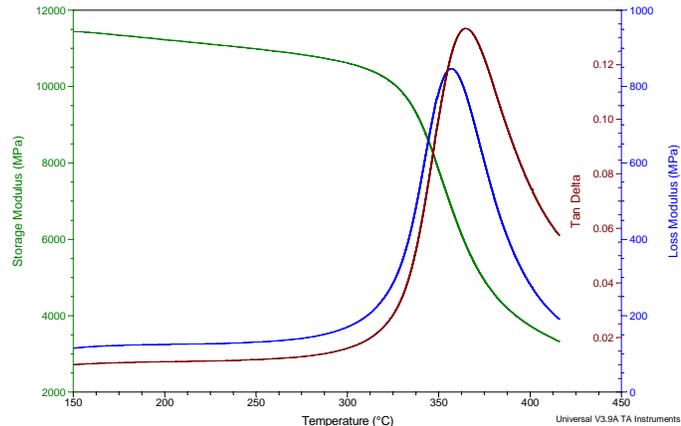
of the mechanical properties of control versus aged S-2 laminates has reduced quantitative significance since control properties were measured on a laminate of appreciably higher quality.

### 3.2.2 Laminate Thermal Properties

The glass transition temperatures measured by DMA at heating rates of 5°C/min are summarized in Table III, with a representative DMA scan shown in Figure 11.

**Table III:** Laminate T<sub>g</sub> values (DMA).

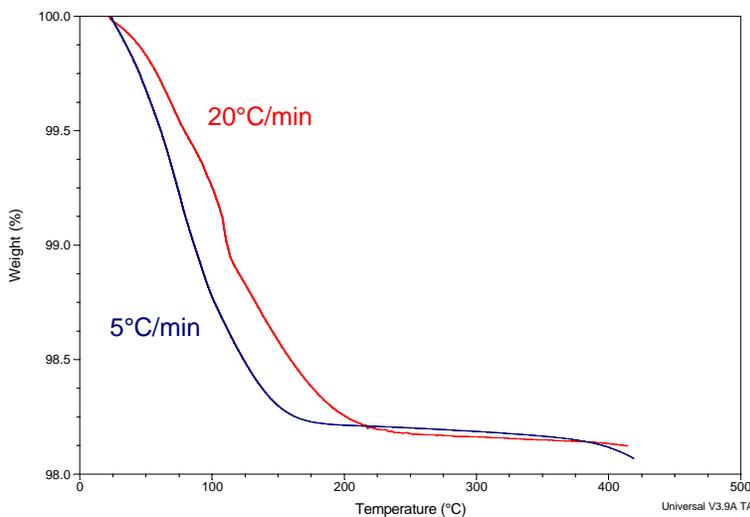
Panel	Condition	T <sub>g</sub> (°C)	
		E''	tan δ
T650-35	control	340	352
	316°C/100h	352	361
S-2	control	361	368
	moisture (5°C/min)	352	360
	moisture (20°C/min)	362	375
	316°C/100h	357	364



**Figure 11:** Representative laminate DMA curves.

As noted from Table III, the initial T<sub>g</sub> of the T650-35 reinforced laminate was lower than the S-2 laminate cured under the same conditions. We have observed this behavior for many other polyimides reinforced with glass and carbon textiles. After environmental aging at 316°C for 100 h, the T650-35 laminate T<sub>g</sub> increased slightly by 12°C via loss modulus but the S-2 laminate T<sub>g</sub> remained approximately the same.

In this effort, an attempt was made to measure the “wet T<sub>g</sub>” of the S-2 laminate by rapid heating (20°C/min) in the DMA. Measurement of the true “wet T<sub>g</sub>” is difficult due to moisture diffusion out of the sample during heating. The value obtained is therefore highly dependent on



**Figure 12:** TGA curves for moisture saturated S-2 laminates at heating rates of 5 and 20°C/min.

reinforcement orientation. Simultaneous TGA scans were performed on the moisture saturated laminate to determine the moisture profile during the DMA experiment. Figure 12 displays two curves at heating rates of 5°C/min and 20°C/min. At 5°C/min, nearly all moisture is removed from the specimen by 200°C, and by 230°C at 20°C/min. Plots of the derivatives revealed that at a heating rate of 5°C/min, the maximum moisture diffusion rate occurs at 76.4°C with a value of 0.11%/min. At the higher heating rate, the values are higher: 109°C and 0.64%/min,

respectively. Therefore, within instrument limitations, a “wet  $T_g$ ” cannot be determined for the 16781 10-ply laminates. Better approximations of the “wet  $T_g$ ” can be determined on thick unidirectional laminates that have more restrictions to moisture diffusion.

### 3.2.3 Laminate Mechanical Properties

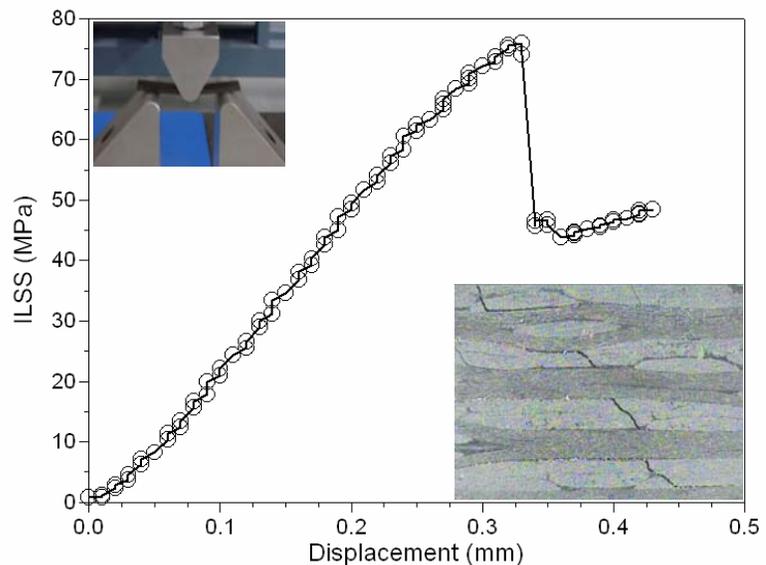
Interlaminar shear and flexural testing was performed at room temperature for control and conditioned laminates. The test results are summarized in Table IV. Due to the poor quality of the aged S-2 laminates, no direct correlations can be made with regard to the control laminate.

**Table IV:** 23°C mechanical properties of T650-35 and S-2 glass reinforced P<sup>2</sup>SI 635LM.

Reinforcement	Aging Condition	Flexural Strength (MPa)	Flexural Modulus (GPa)	Apparent ILSS (MPa)
T650-35 8 HS	control	935 ± 55	57.1 ± 3.1	83.5 ± 11
	316°C/100 h	799 ± 47	58.0 ± 2.3	71.2 ± 4.2
16781 S-2	control	873 ± 26	31.2 ± 1.2	67.5 ± 5.7
	moisture	452 ± 38	22.0 ± 0.5	27.8 ± 1.5
	316°C/100 h	429 ± 32	26.0 ± 0.6	50.7 ± 2.1

With respect to the T650-35 composites, significant mechanical property retention was observed after aging: 86% of flexural strength, 100% flexural modulus, and 85% of the initial interlaminar shear strength. More aggressive thermo-oxidative aging must be performed in the future to further assess the TOS of this material. Mechanical testing revealed good flexural and shear failures for both deformation modes. For example, Figure 13 displays a typical short beam shear stress versus displacement curve with a micrograph of the shear failure mode in the inset for a T650-35 specimen. Also shown in the figure inset is a 3-point flexural deformation.

In the case of the S-2 glass laminates, some useful qualitative information may be obtained from the data, despite the poor laminate quality of the aged materials. For example, since the moisture saturated and thermally aged specimens were obtained from the same initial panel the values of their flexural strengths suggest that only minor knockdowns in properties should be expected after thermal aging and moisture conditioning. Lower values for flexural modulus and ILSS are consistent with matrix plasticization, which is likely more severe in this case due to the high laminate void content. Also, the stress-strain curves for flexural and shear testing exhibited more plastic deformation and higher failure strains than the “dry” materials. Mechanical test results obtained for the T650-35 composite laminates after thermo-oxidative aging, as well as limited

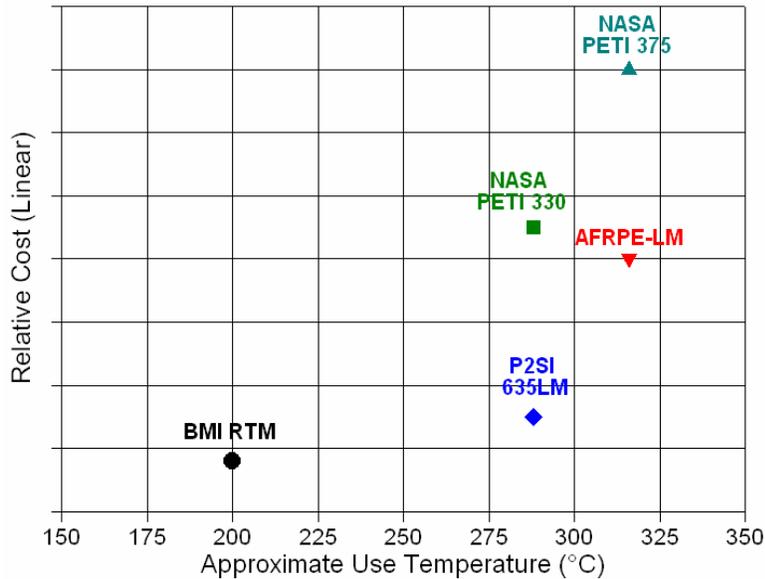


**Figure 13:** Short beam shear stress-displacement curve, showing a typical flexural test and shear failure mode.

qualitative information derived from the S-2 results demonstrate that the P<sup>2</sup>SI 635LM polyimide exhibits good mechanical performance, durability, toughness, and TOS.

### 3.3 P<sup>2</sup>SI 635LM Composite Affordability

Certainly, many polyimides have been developed and exist commercially that exhibit mechanical performance and thermo-oxidative stability superior to P<sup>2</sup>SI 635LM. For liquid molding resins, the choices are fewer. What sets this novel system apart from other commercial systems is the



balance of performance, versatility, and cost. P<sup>2</sup>SI 635LM bridges the cost-performance gap between RTM processable bismaleimides and high cost RTM processable polyimides. Figure 14 provides a qualitative assessment of some commercially available RTM resins with respect to relative cost and estimated realistic use temperature. These values are based on current commercial pricing for these materials.

**Figure 14:** RTM processable polyimide affordability.

We have demonstrated under this research effort that it is possible to achieve quality melt processable polyimides by implementation of commercially

available, low cost, commodity raw materials. Unlike most research efforts undertaken to develop state-of-the-art materials based solely on performance, our approach was based on affordability.

## 4. CONCLUSIONS

Preliminary results on a newly developed, affordable polyimide liquid molding resin system were presented for neat, 16781 S-2 glass, and T650-35 carbon fiber reinforced laminates. The initial data presented here suggests that this new resin system provides a good balance of toughness, durability, processing versatility, and cost, and has potential for applications requiring a thermally stable, melt processable resin matrix. Additional characterization is underway in our laboratory, including hygrothermal cycling, cure cycle optimization, additional long-term thermo-oxidative aging, and elevated temperature mechanical property measurements. Additional testing and characterization is required to validate the performance characteristics and determine the limitations of this material.

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