



Composite Prepregs that Display Fire Resistance and Adhesive Properties

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Introduction

- The use of composite prepregs to make commercial aircraft interior parts has been in place for more than 30 years.
- Epoxies are used in situations where only vertical burn (12 second, 60 second) and/or 45 degree burn are required.
- Phenolics are used where more stringent FST (Flame/Smoke/Toxicity) requirements are in place.
- In most cases the composite prepreg is expected to co-cure to a sandwich core material in order to produce a lightweight structure with reasonable strength and stiffness (usually aramid honeycomb).

Introduction

- Epoxies themselves are not inherently flame retardant but instead require additives or grafting of a fire resistant component directly to the molecule.
- Typically, epoxies need some sort of toughening mechanism to improve adhesion to aramid honeycomb and when highly modified will be self adhesive to aluminum honeycomb as well.
- Typical unmodified phenolics are inherently fire resistant and yield very good FST (Flame/Smoke/Toxicity) performance but also yield poor bond (e.g. via climbing Drum Peel) to honeycomb core.
- This poor bond was initially overcome by incorporating the “Crushed Core” Process (in a press) which yielded more surface area of the aramid honeycomb core to bond to resulting in increased peel performance even with lower resin content (e.g. ~ 32%).

Introduction

- The crushed core process is still widely used but toughened phenolic resins have also been developed that are self bonding to core without crushing the core via processing in a press or vacuum bag.
- In order to improve adhesion in non-crushed core applications, toughening phenolic resin improves adhesion to honeycomb but will contribute to higher Peak and Total OSU Heat Release but because of the inherently good FST properties of the phenolic resin they typically are still able to meet the 65/65 maximum requirement with acceptably low smoke density/toxicity.

Introduction

- There is a need for more flexibility in decorative materials, particularly for single ply thin core constructions, which calls for even lower OSU Heat Release resin systems.
- Also, snap curing self adhesive, fire resistant composite systems, both phenolic and epoxy can offer the added value of increased throughput.
- Barrday Composite Solutions offers both epoxy and phenolic solutions suitable for the interiors market.

Introduction

- LC799 is a polyvinyl butryal modified phenolic that is used in ballistic armor applications such as helmets, chest plates and vehicle armor.
- PSR133 is a resole phenolic capable of meeting the stringent requirements of MIL-R-9299, grade B. It is used in vehicle armor, carbon-carbon applications and ablatives.
- LC193 is an accelerated resole phenolic used in shipboard interiors with good flame, smoke and toxicity properties.
- LC194 is a modified resole phenolic that is used in aircraft and shipboard interiors. LC194 has excellent flame, smoke and toxicity properties while displaying excellent adhesion to aramid honeycomb. LC194 is capable of being molded in flat panels in a press and vacuum bag molded for complex parts.

Barrday Phenolic Resin Systems

- LC195 is a snap curing resole phenolic that is capable of cure cycles less than 20 minutes and is used in interiors applications such as crushed core molding. LC195 is not modified for improved adhesion to aramid honeycomb.
- LC196 is a snap curing resole phenolic that is capable of cure cycles less than 20 minutes and is used in interiors applications such as crushed core molding and compression molding of flat panels.

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- LC294 is a modified resole phenolic that is modified with a fire retardant package that allows extremely low heat release rate values. LC294 is capable of being molded in flat panels in a press and vacuum bag molded for complex parts.
 - LC296 is a modified snap curing resole phenolic that is modified with a fire retardant package that allows extremely low heat release values and is capable of cure cycles less than 20 minutes and is used in interiors applications such as crushed core molding and compression molding of flat panels.

Current Barrday Phenolic Prepregs for Commercial Aircraft Interiors

- LC194 is a toughened phenolic resin system that can be supplied as a vacuum bag (moderate tack & drape) and a press (low tack and drape) grade prepreg.
 - Cures in 45 to 60 minutes @ 235 to 250°F.
 - Self adhesive to core.
 - Yields excellent surface quality in parts.

Current Barrday Phenolic Prepregs for Commercial Aircraft Interiors

- LC195 is a snap curing, though not modified phenolic system.
 - Can be snap cured in 15 minutes at 275°F.
 - Suitable for Crushed Core Process.
 - Not self adhesive in Nature.

Current Barrday Phenolic Prepregs for Commercial Aircraft Interiors

- LC196 is a toughened phenolic resin system that can be supplied as a press and a crushed core (both with low tack and drape) grade prepreg.
 - Can be “Snap” Cured in 15 to 17-min @ 265°F.
 - Self adhesive to core without crushing the core.
 - Very good bond to core using the crushed core process.
 - Yields excellent surface quality in parts.

Development of Next Generation Prepregs for Commercial Aircraft Interiors

- Significant screening experiments were conducted to identify a flame retardant package for both LC194 and LC196 that would:
 - Significantly reduce the Peak and Total OSU Heat Release performance.
 - Not significantly increase smoke density.
 - Maintain the excellent FST performance.
 - Display good mechanical performance in regards to adhesion to honeycomb.
 - Maintain the excellent surface quality of the parts.

Development of Next Generation Prepregs for Commercial Aircraft Interiors

- Two specifications of a target customer were identified and products were tailored to meet these requirements.
- LC296 (LC196 with the identified FR package) was a good candidate for one of the specifications.
- LC194 with the identified FR package did not fully meet the other customer specification's requirements and required the following modifications:
 - Modify the reactivity to perform well with the required cure cycle (straight ramp to 260°F, 60 minute hold in a vacuum bag).
 - Toughness (Climbing Drum Peel) needed to be further improved.
 - Process characteristics needed to be optimized to translate good bond to core.

LC294-7781 Press Grade

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Physical Properties

Prepreg Property	Initial	Aged*
Resin Solids, %	39.9	39.4
Flow, %	10.3	8.8
Volatiles, %	2.9	2.7
Gel Time @ 265°F, sec	75	59

Cured Mechanical Properties

Sandwich Panel Property	Test Method	Initial	Aged*	Target
Climbing Drum Peel, in-lbs/3-in width	SAE-AMS-STD-401	14.9	14.8	≥ 7.5
Long Beam Flexural Strength, ksi	SAE-AMS-STD-401	29.9	30.2	≥ 22
Flatwise Tensile Strength, psi	SAE-AMS-STD-401	186	180	≥ 163
Laminate Property				
Tensile Strength, ksi	ASTM-D-638	64.9	64.6	≥ 42.5
Tensile Modulus, msi	ASTM-D-638	2.9	3.0	≥ 2.7
Interlaminar Shear, ksi	ASTM-D-2344	6.4	6.7	≥ 2.5

Note: Average of three production lots

* Aged 10.4-days at 75°F

LC294-7781 Press Grade

Barrday Composite Solutions

Cured Flammability Properties

Sandwich Panel Property	Test Method	Initial	Aged*	Target
30 Second, 45° Burn, Extinguish Time, sec	FAR25.853	0	0	≤ 5
30 Second, 45° Burn, Afterglow, sec	FAR25.853	0	0	≤ 5
30 Second, 45° Burn, Flame Penetration	FAR25.853	None	None	None
Peak Heat Release Rate, kW/m ²	FAR25.853	20.4	17.9	≤ 30
Total Heat Release, two minute total, kW-min/m ²	FAR25.853	26.9	21.0	≤ 30
Smoke Density, Ds	FAR25.853	6.1	9.9	≤ 25
Laminate (3-ply) Property				
60 Second Vertical Burn, Extinguish Time, sec	FAR25.853	0	0	≤ 5
60 Second Vertical Burn, Burn Length, in	FAR25.853	2.5	2.6	≤ 4
60 Second Vertical Burn, Drip Extinguish Time, sec	FAR25.853	No Drip	No Drip	≤ 1

Note: Average of three production lots

* Aged 10.4-days at 75°F

LC294-7781 Vacuum Bag Grade

Barrday Composite Solutions

Physical Properties

Prepreg Property	Initial	Aged*
Resin Solids, %	40.0	40.0
Flow, %	19.1	17.6
Volatiles, %	4.5	4.0
Gel Time @ 265°F, sec	100	82

Cured Mechanical Properties

Sandwich Panel Property	Test Method	Initial	Aged*	Target
Climbing Drum Peel, in-lbs/3-in width	SAE-AMS-STD-401	8.5	10.0	≥ 7.5
Long Beam Flexural Strength, ksi	SAE-AMS-STD-401	32.1	28.4	≥ 22
Flatwise Tensile Strength, psi	SAE-AMS-STD-401	200	190	≥ 163
Laminate Property				
Tensile Strength, ksi	ASTM-D-638	69.3	68.5	≥ 42.5
Tensile Modulus, msi	ASTM-D-638	3.1	3.1	≥ 2.7
Interlaminar Shear, ksi	ASTM-D-2344	6.3	6.8	≥ 2.5

Note Average of three production lots

* Aged 10.4-days at 75°F

LC294-7781 Vacuum Bag Grade

Barrday Composite Solutions

Cured Flammability Properties

Sandwich Panel Property	Test Method	Initial	Aged*	Target
30 Second, 45° Burn, Extinguish Time, sec	FAR25.853	0	0	≤ 5
30 Second, 45° Burn, Afterglow, sec	FAR25.853	0	0	≤ 5
30 Second, 45° Burn, Flame Penetration	FAR25.853	None	None	None
Peak Heat Release Rate, kW/m ²	FAR25.853	21.8	19.6	≤ 30
Total Heat Release, two minute total, kW-min/m ²	FAR25.853	24.8	26.3	≤ 30
Smoke Density, Ds	FAR25.853	8.6	8.1	≤ 25
Laminate (3-ply) Property				
60 Second Vertical Burn, Extinguish Time, sec	FAR25.853	0	0	≤ 5
60 Second Vertical Burn, Burn Length, in	FAR25.853	2.7	2.8	≤ 4
60 Second Vertical Burn, Drip Extinguish Time, sec	FAR25.853	No Drip	No Drip	≤ 1

Note: Average of three production lots

* Aged 10.4-days at 75°F

LC296-7781 Crushed Core Grade

Barrday Composite Solutions

Physical Properties

Prepreg Property	Initial	Aged*
Resin Solids, %	32.6	32.6
Flow, %	13.3	10.8
Volatiles, %	4.6	4.3
Gel Time @ 320°F, sec	45	40

Cured Mechanical Properties

Sandwich Panel Property	Test Method	Initial	Aged*	Target
Climbing Drum Peel, in-lbs/3-in width	SAE-AMS-STD-401	44.7	36.4	≥ 7.5
Long Beam Flexural Strength, ksi	SAE-AMS-STD-401	27.1	26.2	≥ 22
Flatwise Tensile Strength, psi	SAE-AMS-STD-401	252	336	≥ 163
Laminate Property				
Tensile Strength, ksi	ASTM-D-638	70.9	71.4	≥ 42.5
Tensile Modulus, msi	ASTM-D-638	3.3	3.2	≥ 2.7
Interlaminar Shear, ksi	ASTM-D-2344	6.4	6.9	≥ 2.5

Note: Average of three production lots

* Aged 5-days at 75°F

LC296-7781 Crushed Core Grade

Barrday Composite Solutions

Cured Flammability Properties

Sandwich Panel Property	Test Method	Initial	Aged*	Target
30 Second, 45° Burn, Extinguish Time, sec	FAR25.853	0	0	≤ 5
30 Second, 45° Burn, Afterglow, sec	FAR25.853	0	0	≤ 5
30 Second, 45° Burn, Flame Penetration	FAR25.853	None	None	None
Peak Heat Release Rate, kW/m ²	FAR25.853	21.6	28.9	≤ 50
Total Heat Release, two minute total, kW-min/m ²	FAR25.853	25.2	29.9	≤ 50
Smoke Density, Ds	FAR25.853	3.1	2.9	≤ 20
Laminate (3-ply) Property				
60 Second Vertical Burn, Extinguish Time, sec	FAR25.853	0	0	≤ 5
60 Second Vertical Burn, Burn Length, in	FAR25.853	2.6	2.9	≤ 4
60 Second Vertical Burn, Drip Extinguish Time, sec	FAR25.853	No Drip	No Drip	≤ 1

Note:: Average of three production lots

* Aged 5-days at 75°F

Comparative Smoke Density Testing on 7781 E-Glass, 2 ply on 3/8", 3 pcf, Aramid Honeycomb Core per ASTM E662, Flaming Mode.

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Ds	Limits	LC194	LC196	LC294	LC296
@1.5 minutes	100 max	1	0	4	2
@4.0 minutes	200 max	1	2	8	5
@20.0 minutes	200 max	7	8	11	5

Comparative Toxicity Testing on 7781 E-Glass, 2 ply on 3/8", 3 pcf, Aramid Honeycomb Core per BSS 7239.

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Gasses	Limits @ 4 Min	LC194	LC196	LC294	LC296
HCN	150 PPM	<1	<1	<1	<1
CO	3500 PPM	238	138	375	188
NO/NO ²	100 PPM	7	5	6	9
SO ²	100 PPM	<1	<1	<1	<1
HF	200 PPM	2	5	5	5
HCL	500 PPM	5	7	9	9

Current Barrday Epoxy Prepregs for Commercial Aircraft Interiors

- EP255 is a 121°C (250°F) curing system that is self adhesive to aramid honeycomb and meets vertical burn requirements. Cure time ranges from 60 to 90 minutes.
- EP2052 is a new 135°C (275°F) snap curing system that is capable of curing in 20 minutes in a press molding operation and is self adhesive to both aramid and aluminum honeycomb.

Selected Mechanical Properties of EP255 7781

Property	Test Method	Result
Tensile Strength	ASTM D 638	434 MPa (63000 psi)
Tensile Modulus	ASTM D 638	25 GPa (3,650,000 psi)
Flexural Strength	ASTM D 790	648 MPa (94000 psi)
Flexural Modulus	ASTM D790	23 GPa (3,300,000 psi)
Compressive Strength	ASTM D695	414 MPa (60,000 psi)
Compressive Modulus	ASTM D 695	27 MPa (3,900,000 psi)
Short Beam Shear	ASTM D 2344	59 MPa (8,600 psi)
Climbing Drum Peel, Single Ply, Aramid	ASTM D 1781	7 in-lb/in

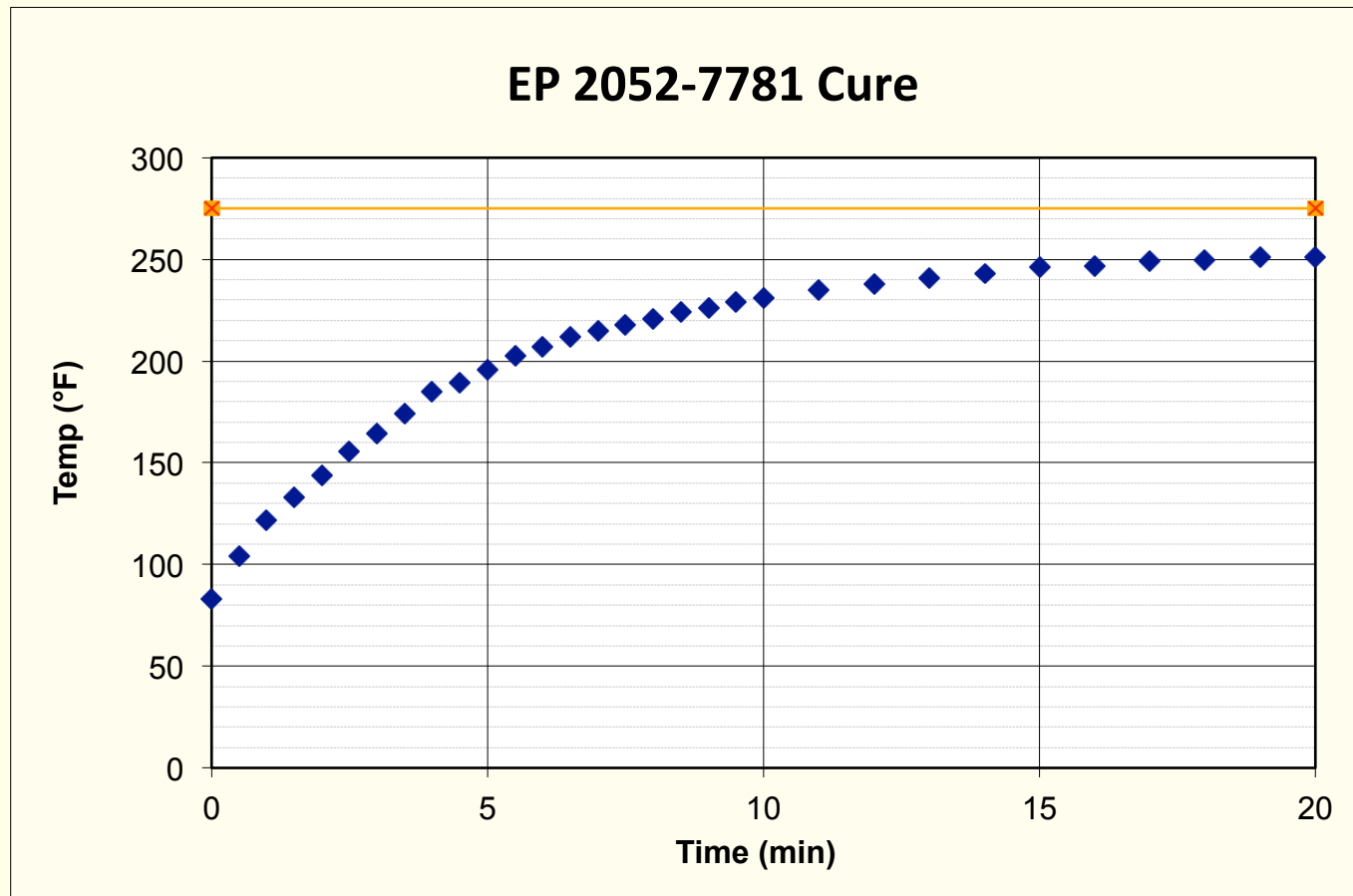
EP255 3K PW Vertical Burn Testing

	60 second	12 second
Laminate Thickness	0.50"	0.50"
Burning Time (seconds)	0	0
Burning Length (inches)	3.7	0.9
Longest Burning Particles (seconds)	None	None
Laminate Thickness	0.100"	0.100"
Burning Time (seconds)	0	0
Burning Length (inches)	3.0	0.4
Longest Burning Particles (seconds)	None	None
Laminate Thickness	0.175"	0.175"
Burning Time (seconds)	0	0
Burning Length (inches)	2.6	0.2
Longest Burning Particles (seconds)	None	None
Laminate Thickness	0.265"	0.265"
Burning Time (seconds)	0	0
Burning Length (inches)	0.1	1.6
Longest Burning Particles (seconds)	None	None

Selected Mechanical Properties of EP2052 7781

Property	Test Method	Result
Tensile Strength	ASTM D 638	462 MPa (67,000 psi)
Tensile Modulus	ASTM D 638	21.3 GPa (3,100,000 psi)
Flexural Strength	ASTM D 790	696 MPa (101,000 psi)
Flexural Modulus	ASTM D790	21.7 GPa (3,150,000 psi)
Compressive Strength	ASTM D695	414 MPa (60,000 psi)
Compressive Modulus	ASTM D 695	26.2 GPa (3,800,000 psi)
Short Beam Shear	ASTM D 2344	54 MPa (7,800 psi)
Climbing Drum Peel, Single Ply, Aramid	ASTM D 1781	10 in-lb/in
Climbing Drum Peel, Single Ply, Aluminum	ASTM D 1781	8 in-lb/in

Press Curing Profile of EP2052 7781



Vertical Burn Results of EP2052 7781

60 Second Vertical Ignition per FAR 25-853 (a), Appendix F, Part I, (a), 1, (i): 60 second	
Solid Laminate Thickness (inches)	0.140
Burning Time (seconds)	0
Burning Length (inches)	3.4
Longest Burning Particles (seconds)	None
12 Second Vertical Ignition per FAR 25-853 (a), Appendix F, Part I, (a), 1, (ii): 12 second	
Solid Laminate Thickness (inches)	0.140
Burning Time (seconds)	0
Burning Length (inches)	0.4
Longest Burning Particles (seconds)	None

Conclusions

- The LC294 7781 Press Grade and Vacuum Bag Grade met all of the customer requirements as listed in this presentation and is a viable candidate for interior applications where very low contribution to OSU Heat Release Peak and Total are required.
- The LC296 7781 Crushed Core Grade met all of the customer requirements as listed in this presentation and is a viable candidate for interior applications where very low contribution to OSU Heat Release Peak and Total are required and has demonstrated rapid cure capability.
- Both systems offer improved surface quality versus other phenolic systems.

Conclusions

- Both the EP255 Epoxy and EP2052 Epoxy provide acceptable adhesive performance to aramid honeycomb.
- The EP2052 provides acceptable adhesive performance to both aramid and aluminum honeycomb.
- The EP255 is highly flame resistant as evidenced by the 60 second and 12 second vertical burn results.
- The EP2052 is flame resistant as evidenced by the 60 second and 12 second vertical burn results.
- The EP2052 offers molders the additional advantage of a snap cure.