

Effects of Fiber Finish on Mechanical, Low and High Speed Impact of Glass Fiber Reinforced Composites

Ramakrishna Iyer*, Timothy Woo^ξ, John Osterndorf^ξ and Dan Prillaman^ξ

*: US Army, RDECOM - TARDEC, Warren, MI 48397

^ξ: US Army, RDECOM - ARDEC, Picatinny, NJ 07801

Matthew Dabrowski[§], Bill Chen[£], Yong Lei[£] and Jerry Chung[§]

[§]: Novus Technologies Corporation, NY, NY, 10031

[£]: Frontier Performance Polymers Corporation, Dover, NJ 07801

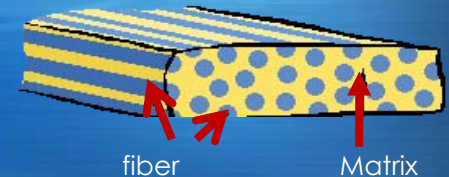
Feridun Delale and Benjamin Liaw

The City College of New York, NY, NY, 10031

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 12 MAY 2011		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Effects of Fiber Finish on Mechanical, Low and High speed Impact of Glass Fiber Reinforced Composites			5a. CONTRACT NUMBER W56HZV-09-C-0569		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) R. Iyer; T. Woo; J. Osterndorf; D. Prillaman M. Dabrowski; B. Chen; Y. Lei; J. Chung; F. Delale; B. Liaw			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army, RDECOM-TARDEC, Warren, MI 48307 US Army. RDECOM-ARDEC, Picatinny, NJ 07801 Novus Technologies Corp. NY, NY 10031 Frontier Performance Polymers Corporation, Dover, NJ 07801 The City College of New York, NY, NY 10031			8. PERFORMING ORGANIZATION REPORT NUMBER 21823		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA			10. SPONSOR/MONITOR'S ACRONYM(S) TACOM/TARDEC/RDECOM		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 21823		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 35	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Polymer Matrix Composites

- Large Variety In Material Type And Cost
 - Matrix: type, cost, properties
 - Reinforcement: shape, material, cost
- Promising Advantages
 - Much lower density than metals
 - Excellent specific strength and stiffness to weight ratio
 - High damping & fatigue endurance
 - Low thermal coefficient
 - Good corrosion resistance
- Potential Application For Lightweight Energy Absorbing Materials



PMC Impact Performance

- Mechanisms For Dissipating Energy

Delamination

↑ Plug punch-out

↑ Resin matrix cracking

↑ Fiber pull-out

↑ Fiber fracture

Interfacial Adhesion Between
Matrix & Reinforcement

Impact Performance

Structural Integrity

Adjustable Interfacial Adhesion

- Matrix
 - Mechanical Properties
 - Chemical Properties
 - Physical Properties
- Reinforcing Fiber
 - Types of Fiber
 - Thickness/count
 - Weave type
 - Finish/sizing



Interfacial Adhesion

Significance Of This Research

- Investigate The Effects Of Four Glass Fiber Finishes On Mechanical Properties And Low/High Speed Impact Performance
 - Greige
 - Heat-burnt
 - Volan
 - Silane
- Correlate The High Speed Impact Properties With Mechanical Properties
- Correlate The High Speed Impact Properties With The Interfacial Adhesion (To be done in the near future)

Part 1

Experimental Procedures

Materials

● Matrix Resins

- Polypropylene Film

- Polyester resin system

- 98.5 wt% Aropol® 7241T-15 (46% styrene)/1.5wt% Methyl ethyl ketone peroxide (MEKP)

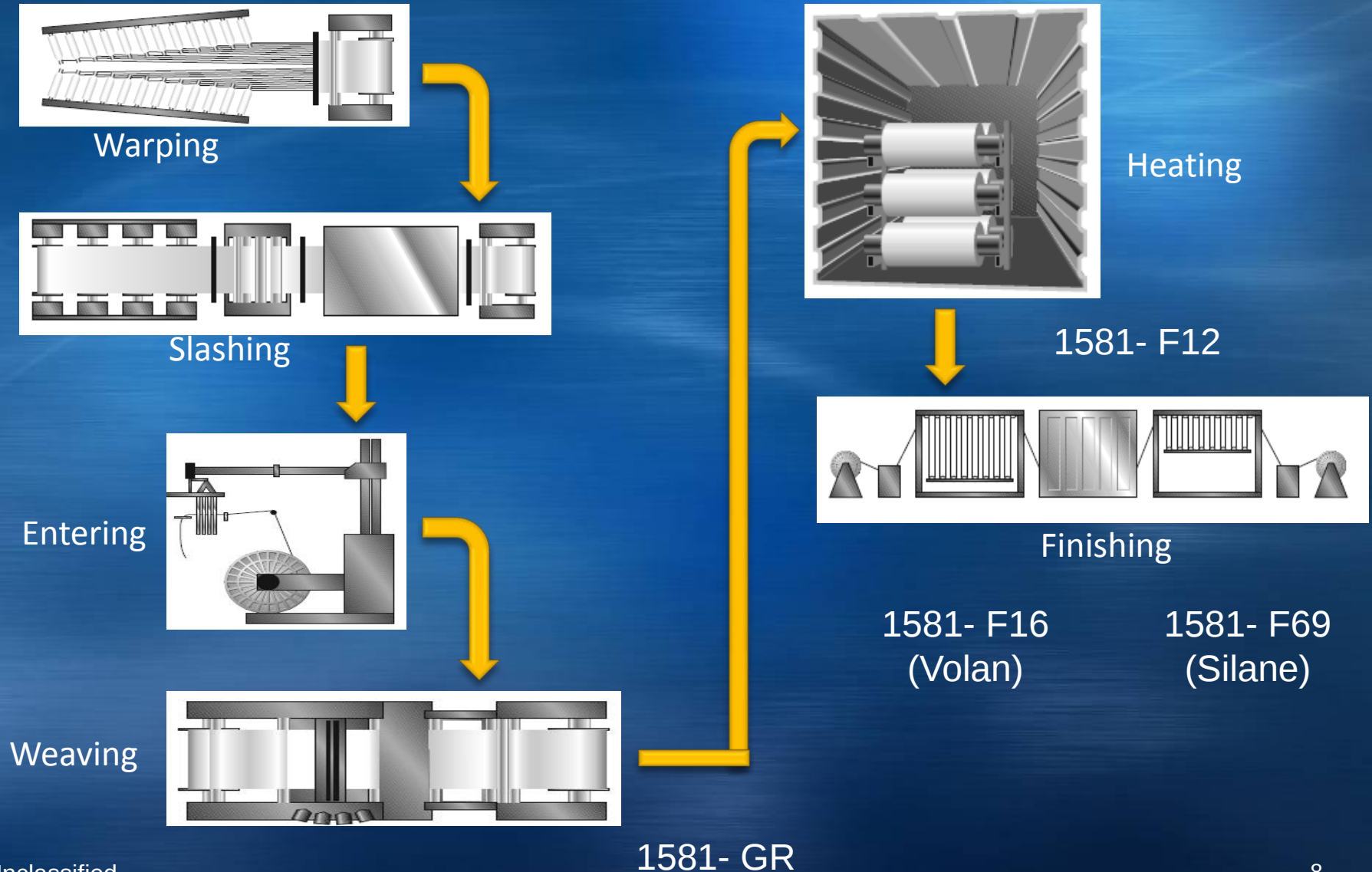
- Vinyl Ester

- 98.12wt% Derakane 411-350/1.5wt% MEKP/0.03wt% 2,4-Pentanedione/0.05wt% dimethylamine/0.3wt% cobalt naphthenate

● Glass Fiber: Hexcel® 1581 Series Glass Fiber Fabrics

Fabric	Finish	Weave	Weight	Thickness
1581-F12	None (Heat-burnt HB)	8H Satin	298 g/m ²	2.16x10 ⁻⁴ m
1581- GR	Greige	8H Satin	298 g/m ²	2.16x10 ⁻⁴ m
1581-F16	Volan	8H Satin	298 g/m ²	2.16x10 ⁻⁴ m
1581-F69	Silane	8H Satin	298 g/m ²	2.16x10 ⁻⁴ m

Glass Fabric Fabrication Process



Compression Molding

For Fabricating PP Composite Specimens

- Vacuum Hot Press
 - Evenly Distribute And Lay Up Fabric Sheets And PP Film Based On The Requirements Of The Thickness And Fiber Content
 - Put Closed Mold Into Compression Press
 - Compression Mold At 235°C Under 1.5 MPa For 70 Min
 - Cool Down And De-mold

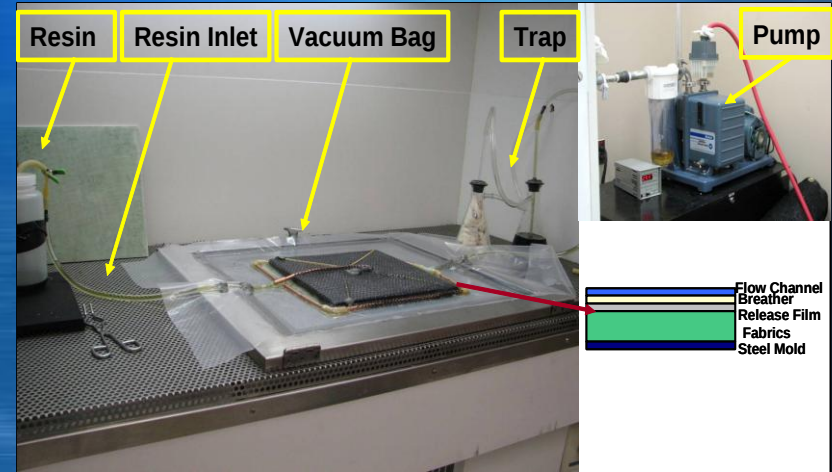


Vacuum Infusion

For Producing Polyester Or Vinyl Ester Composite Specimens

● Process

- Lay down glass fiber, peel ply, and flow channel
- Place vacuum conduit around mold, hook conduit end to vacuum pump
- Seal the set-up and resin inlet
- Turn on pump (achieve >1 torr vacuum)
- Formulate resin and connect resin inlet to resin mixture
- Start resin infusion
- Stop the pump when the infusion is completed



Tensile Property Testing

- Universal Tensile Tester
 - 200KN Capacity
- Standard
 - ASTM D3039



Flexural Property Testing

- Universal Tensile Tester
 - 10KN Capacity
- Standard
 - ASTM D790



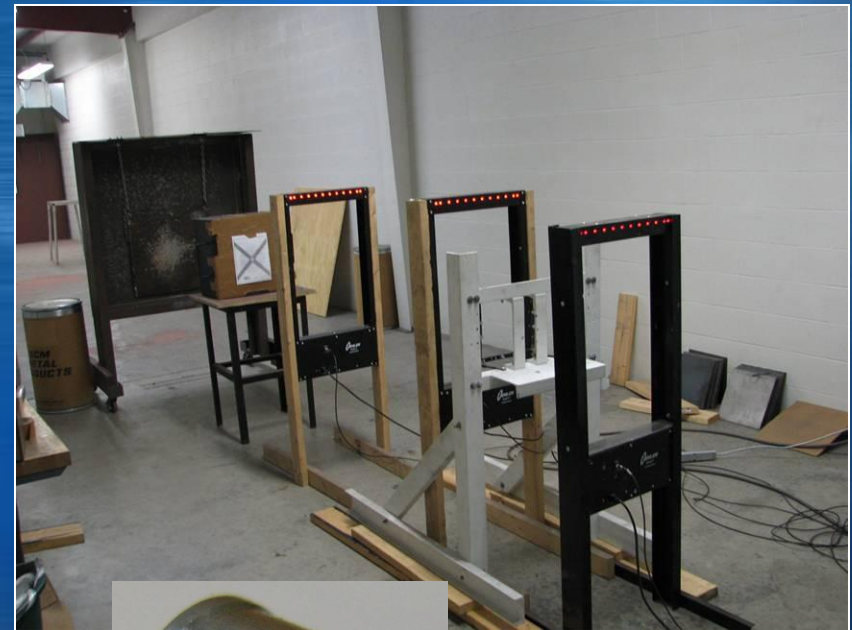
Low Speed Impact Testing

- Sample: ¼" panels
- Instrumented Impact Tester
 - Speed up to 10 ft/s
- Standard
 - ASTM D3763
- Tup
 - A custom designed impact tup



High Speed Impact Testing

- Sample: 1/8" panels
- Standard
 - Mil-STD-662F
- High Speed Impact Projectiles As Per Mil-STD-662F
- Data Collection
 - Velocity (V_{50}) and Impact Energy at 50% probability of penetration
 - Impact Energy Absorption



Part 2

Experimental Results

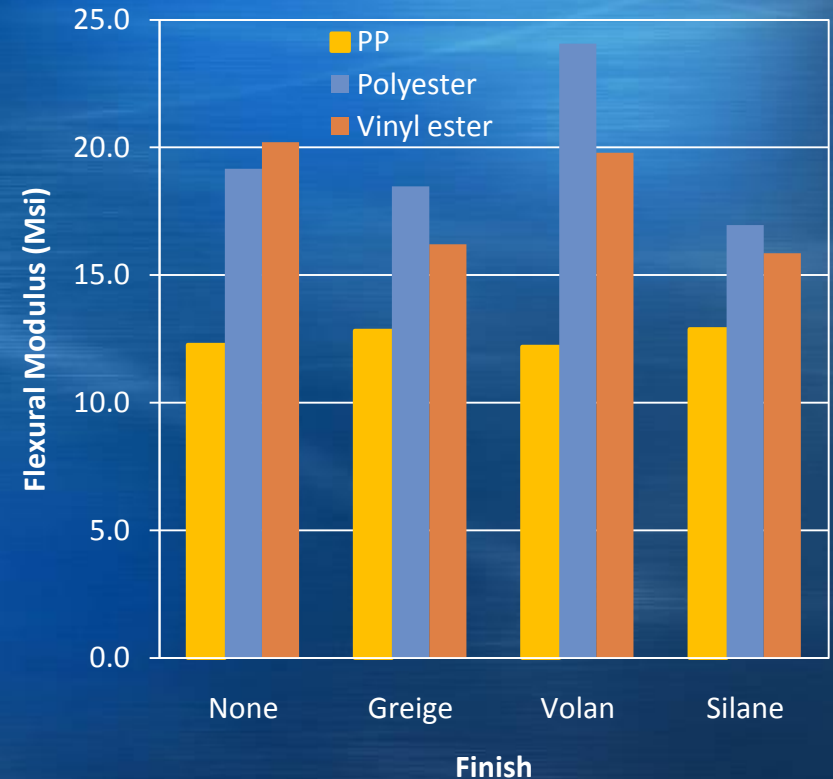
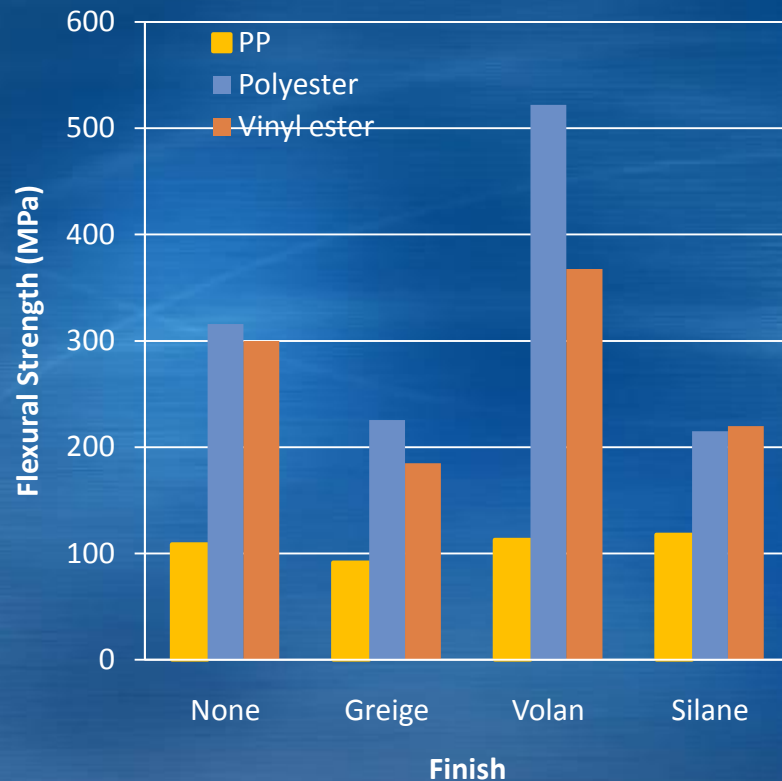
Areal Density And Fiber Content

3.2mm Thick Composite Specimens

Reinforcement	Finish	Matrix	Fiber Content (%)
Hexcel 1581-F12	Heat Burnt (No Finish)	PP	71.0
		Polyester	70.0
		Vinyl ester	66.2
Hexcel 1581-GR	Greige (Starch and Oils)	PP	67.0
		Polyester	65.6
		Vinyl ester	71.2
Hexcel 1581-F16	Volan	PP	64.0
		Polyester	69.0
		Vinyl ester	65.2
Hexcel 1581-F69	Silane	PP	70.0
		Polyester	64.7
		Vinyl ester	66.2

Flexural Strength And Modulus

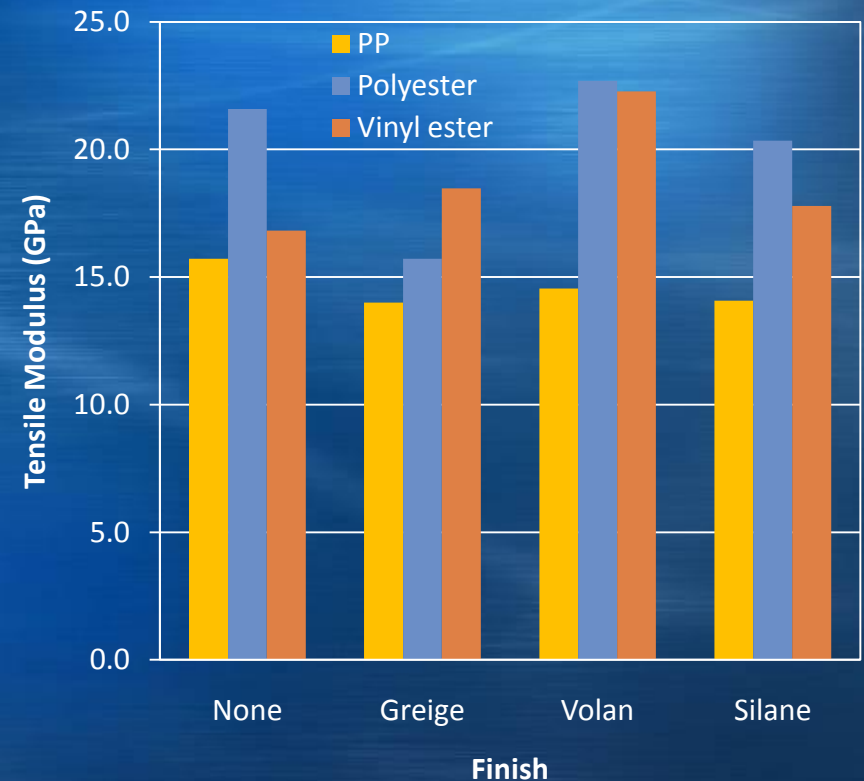
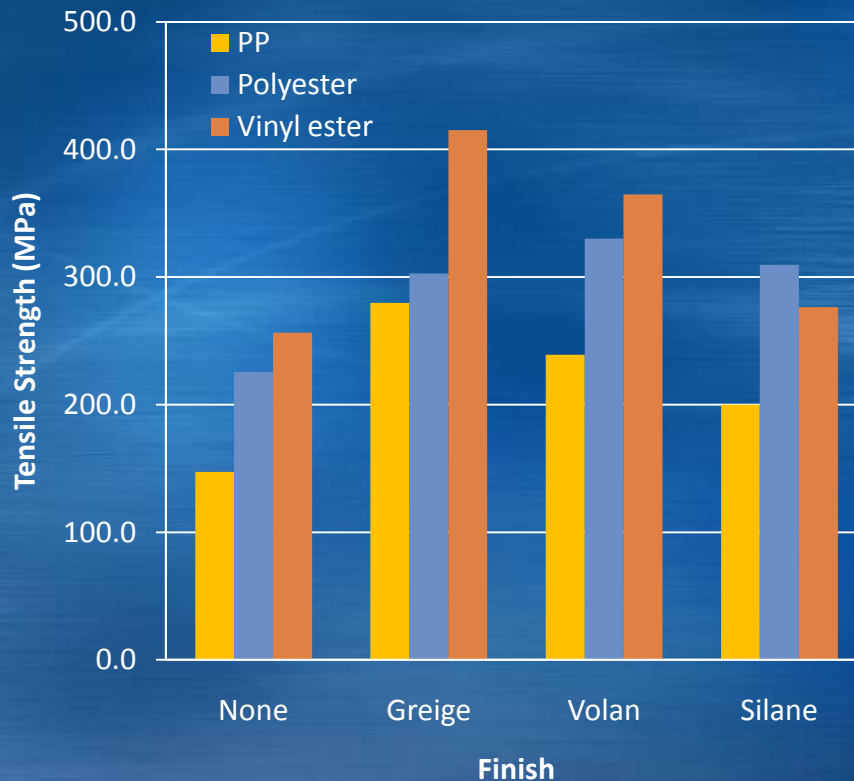
Effects of Matrix Resins And Glass Surface Finishes



- PP Has Significantly Lower Flexural Properties
- Volan Finish Has Highest Flexural Properties

Tensile Strength And Modulus

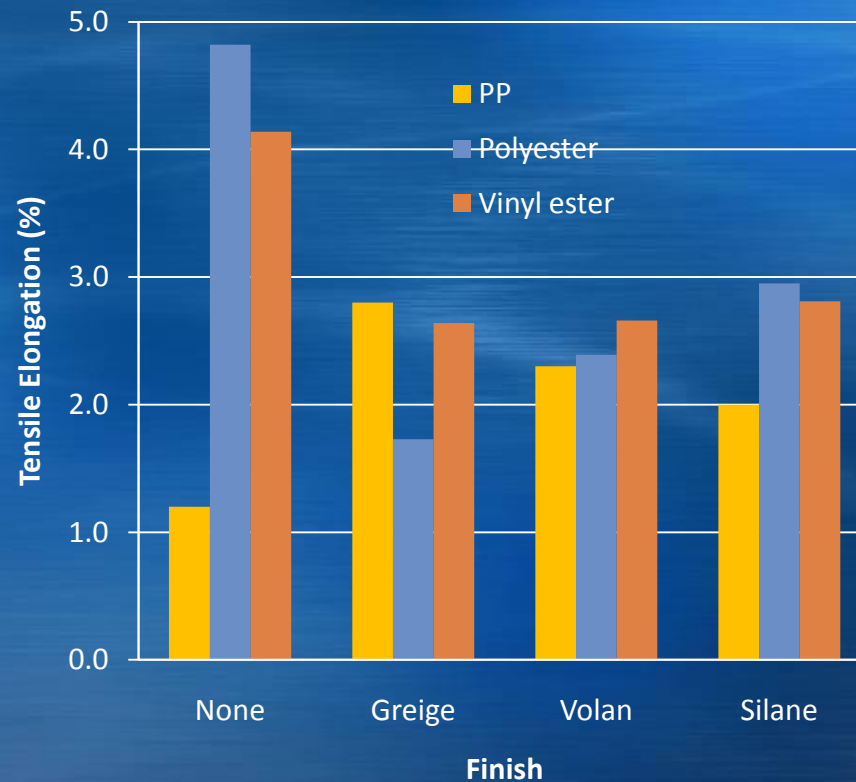
Effects of Matrix Resins And Glass Surface Finishes



- PP Has Slightly Lower Tensile Strength and Modulus
- Volan Finish Has Better Overall Tensile Properties

Tensile Elongation

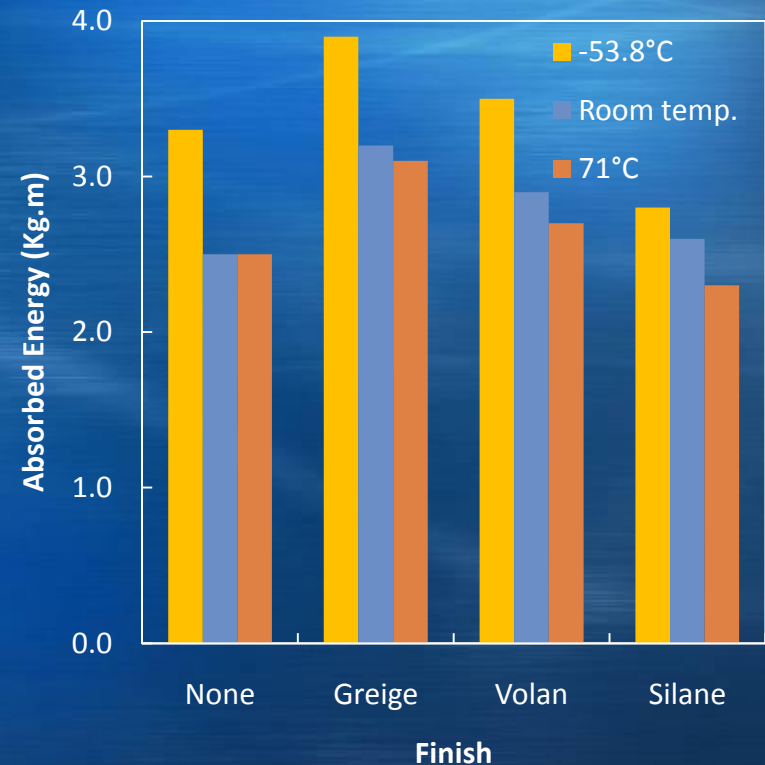
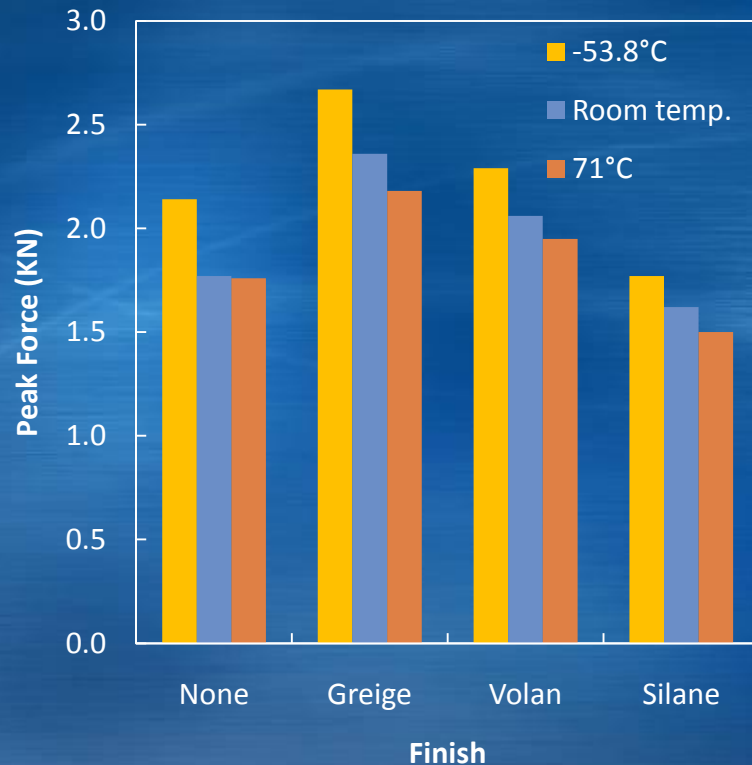
Effects of Matrix Resins And Glass Surface Finishes



- Heat Burnt Finish Has Highest Tensile Elongation

Low Speed Impact Performance

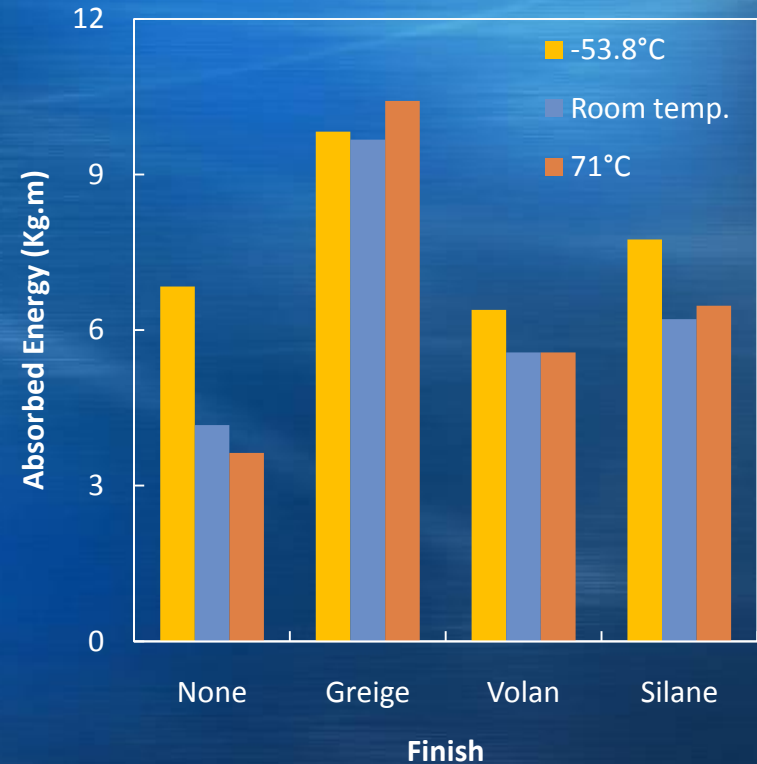
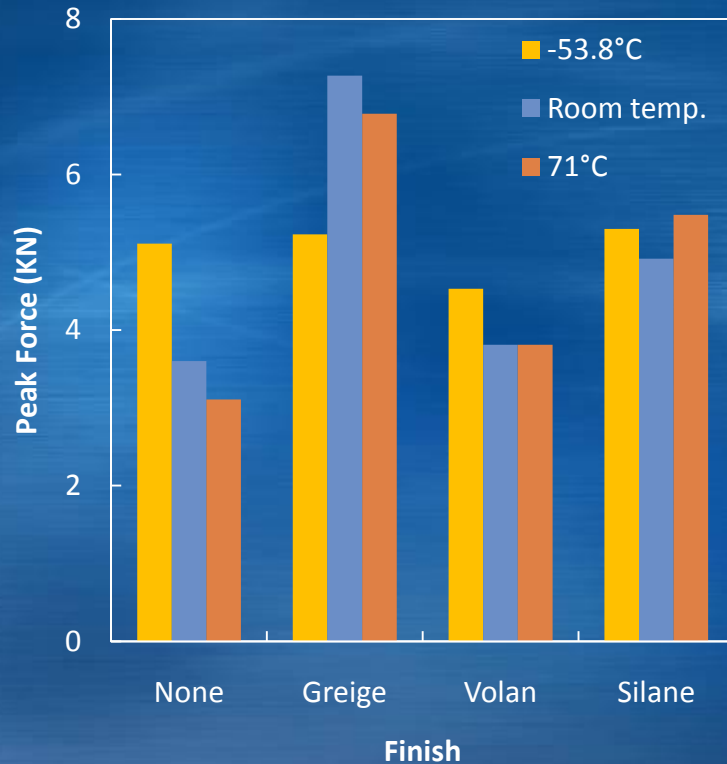
Effects of Temperatures On PP Composites



- Greige Finish Has Best Low-Speed Impact Performance
- Impact Performance Decreases With Increase In Temperature

Low Speed Impact Performance

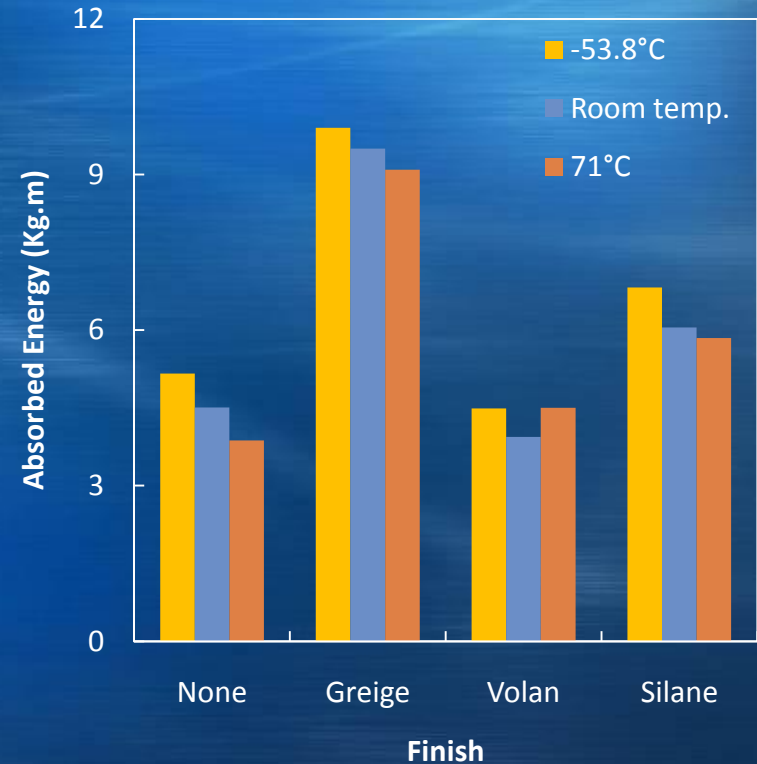
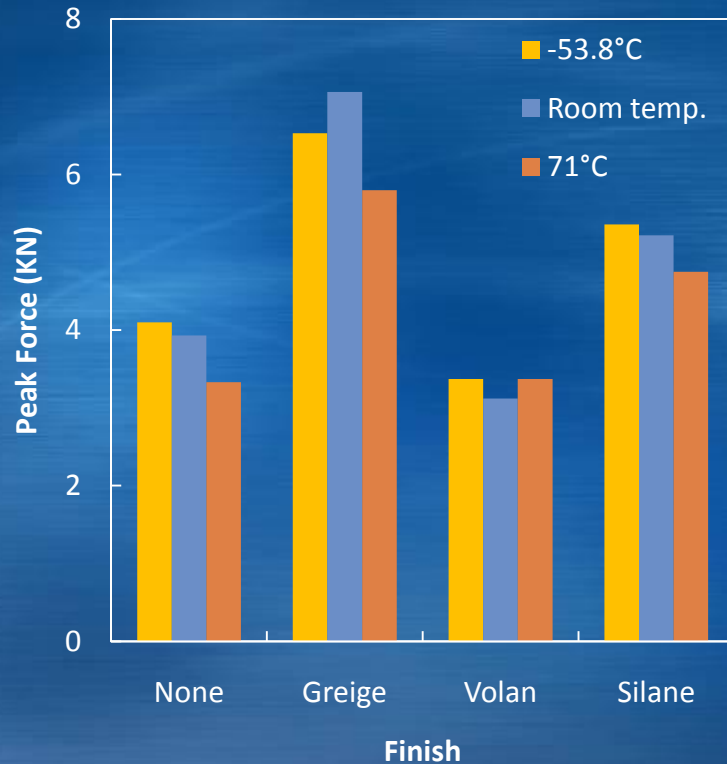
Effects of Temperatures On Polyester Composites



- Greige Finish Has Best Low Speed Impact Performance

Low Speed Impact Performance

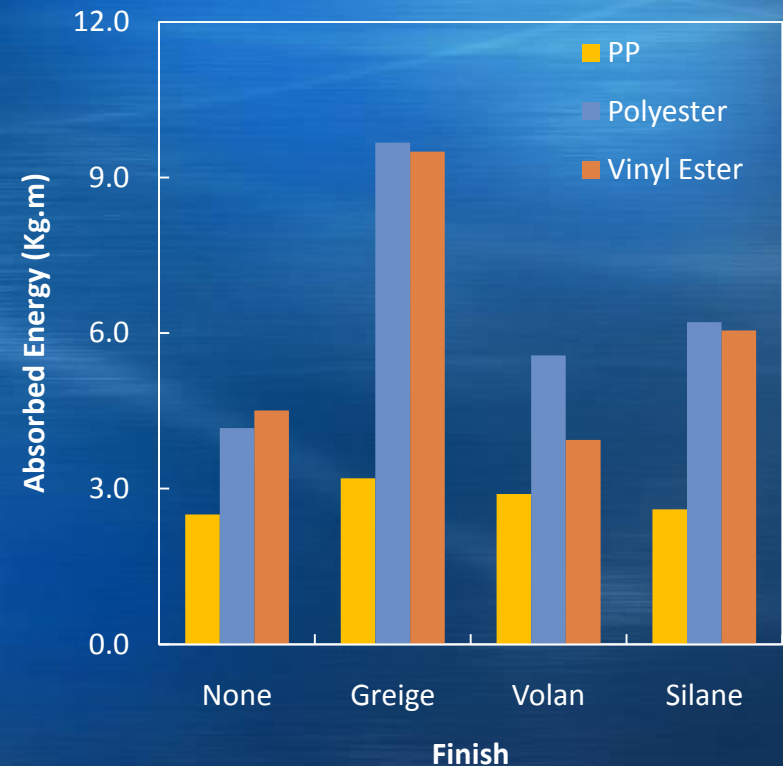
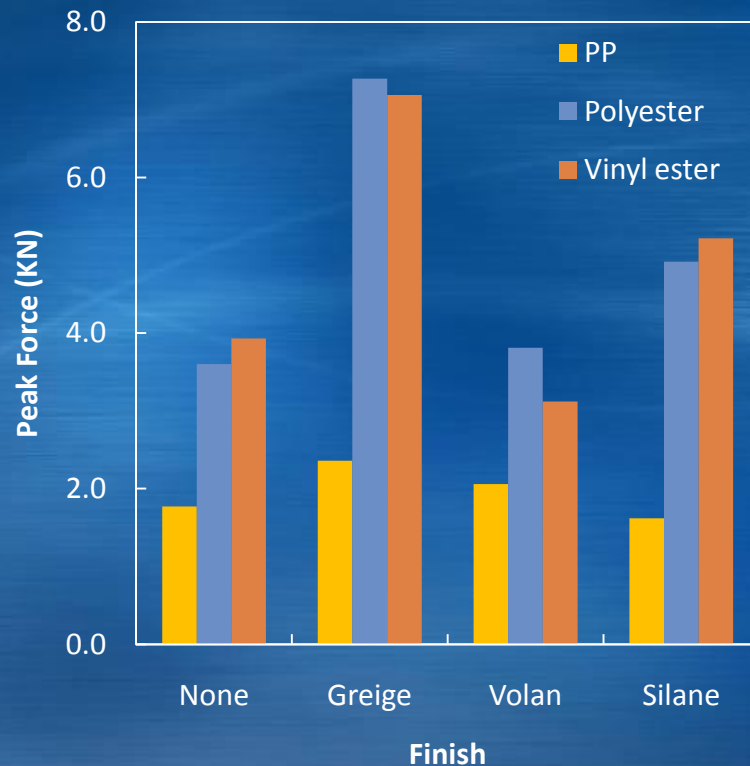
Effects of Temperatures On Vinyl Ester Composites



- Greige Finish has Best Low Speed Impact Performance

Effects Of Resins And Fiber Finishes

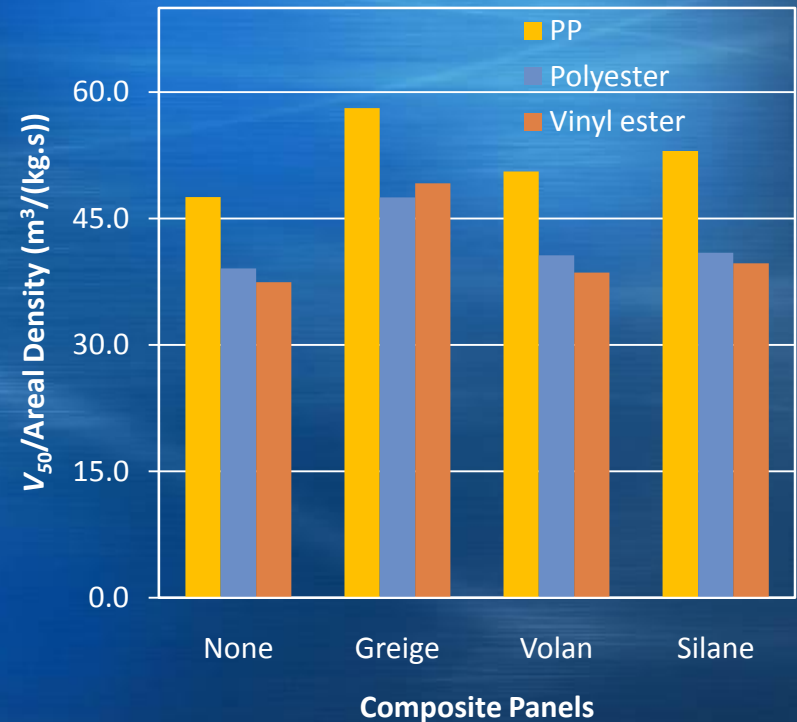
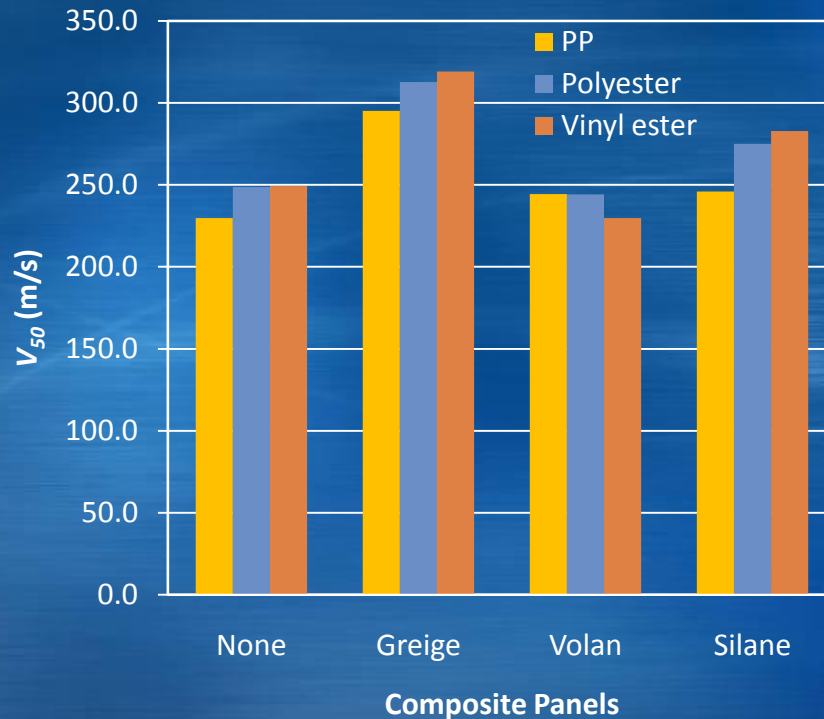
Low Speed Impact Performance At Ambient



- Greige Finish: Highest Low Speed Impact Performance

High Speed Impact Performance

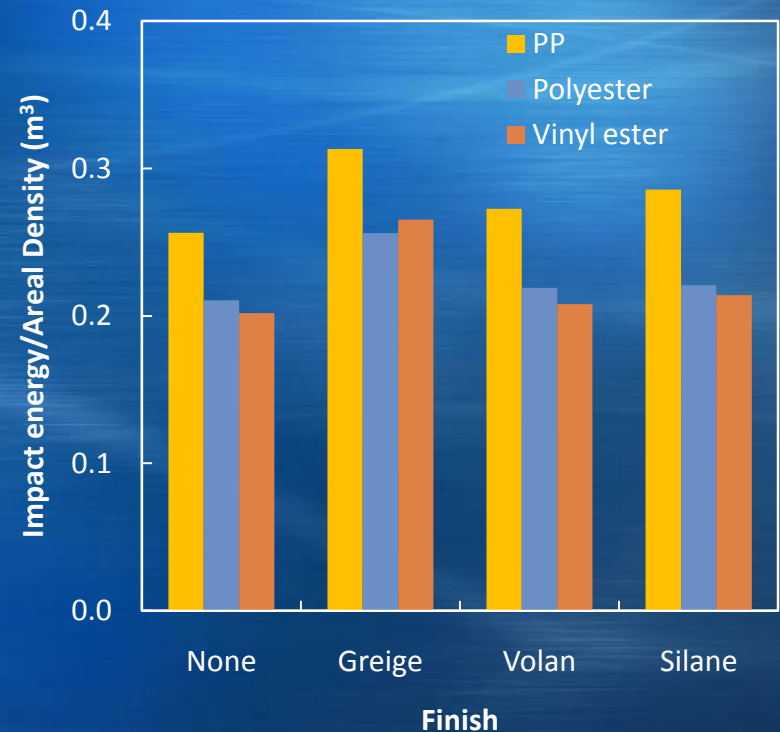
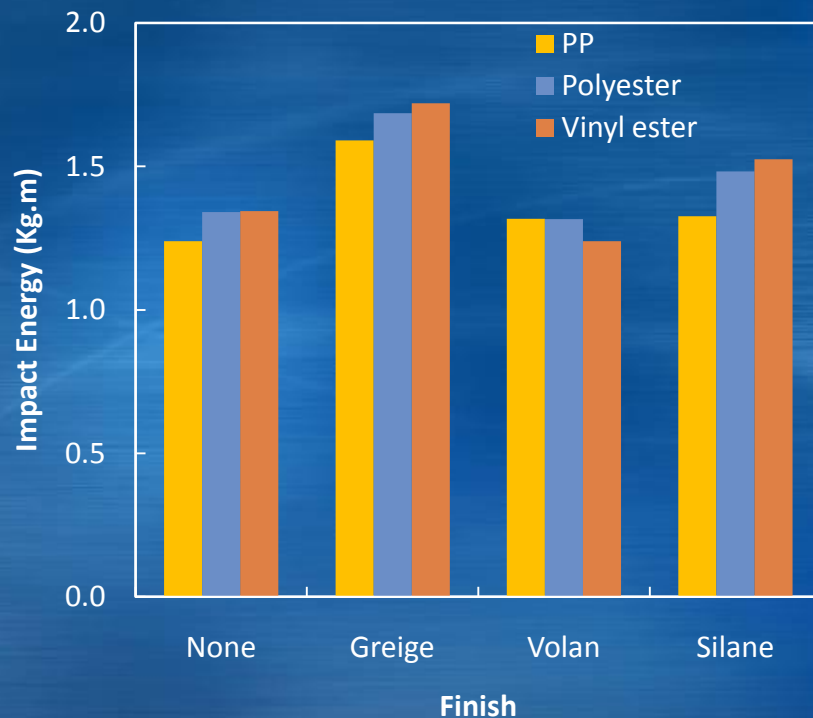
V_{50} And $V_{50}/\text{Areal Density}$ for 3.2mm Samples



- Greige Finish Has Highest High Speed Impact Performance
- PP Composite Has Highest High-Speed Impact Efficient

High Speed Impact Performance

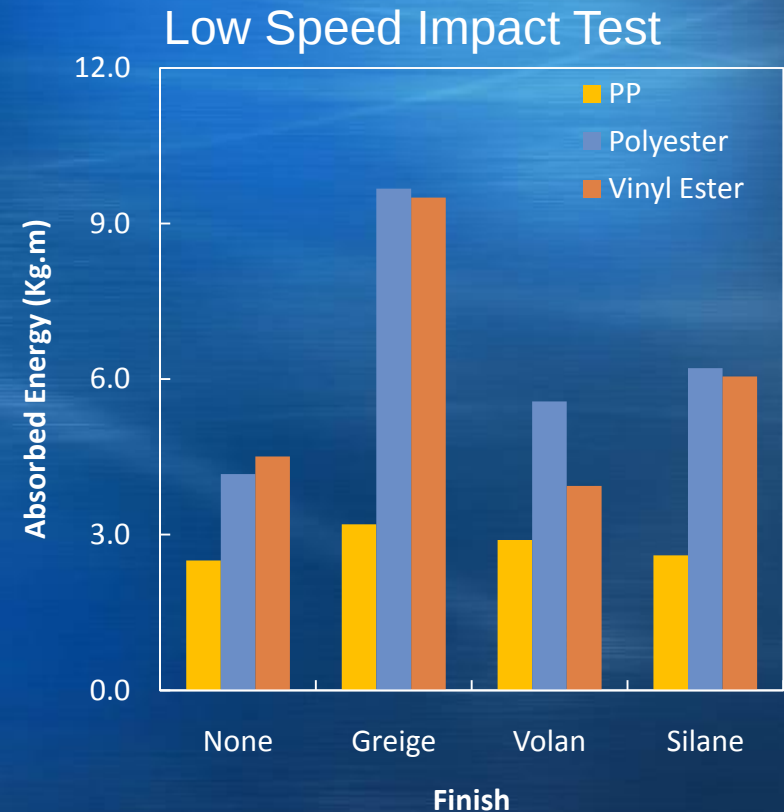
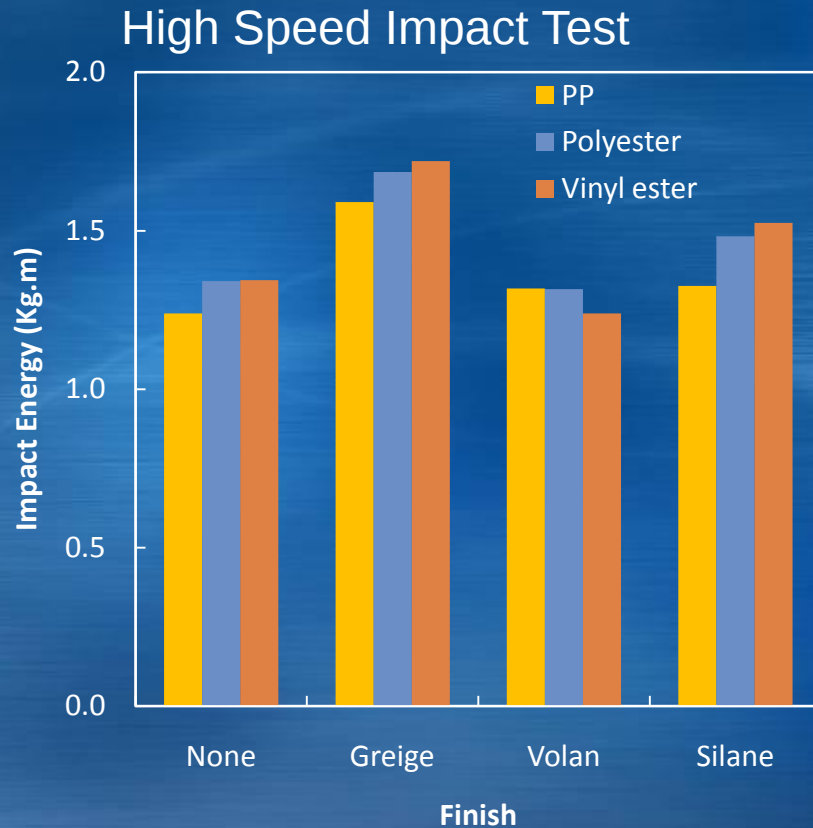
Impact Energy And Impact Energy Per Areal Density for 3.2mm Samples



- Greige Finish Has Highest High Speed Impact Performance
- PP Composite Has Highest High-Speed Impact Efficient

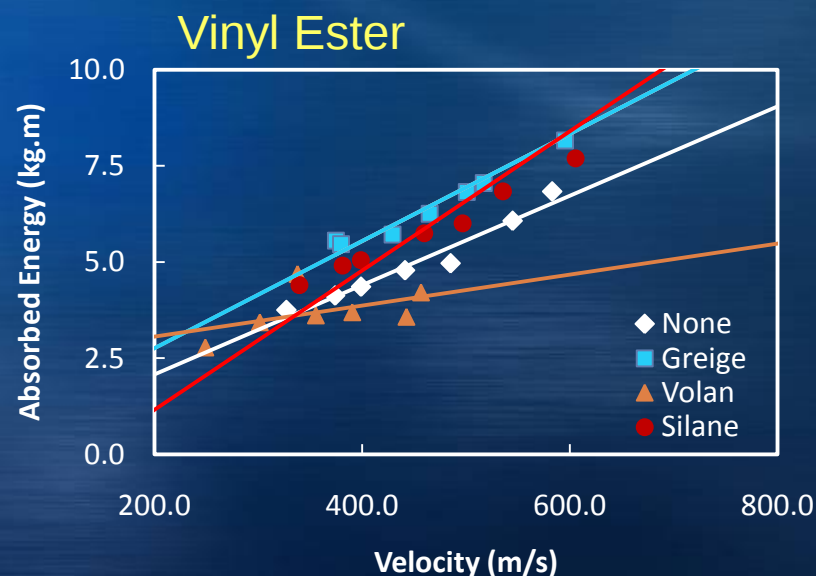
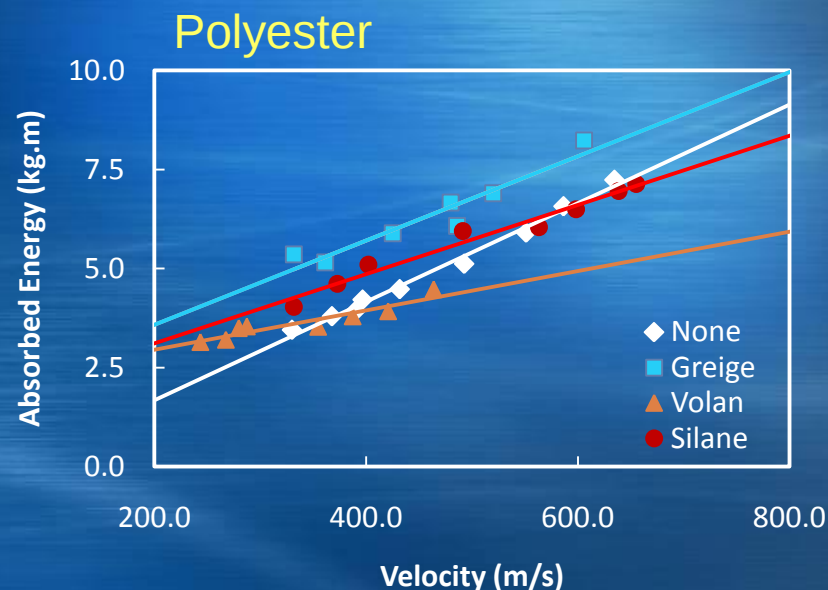
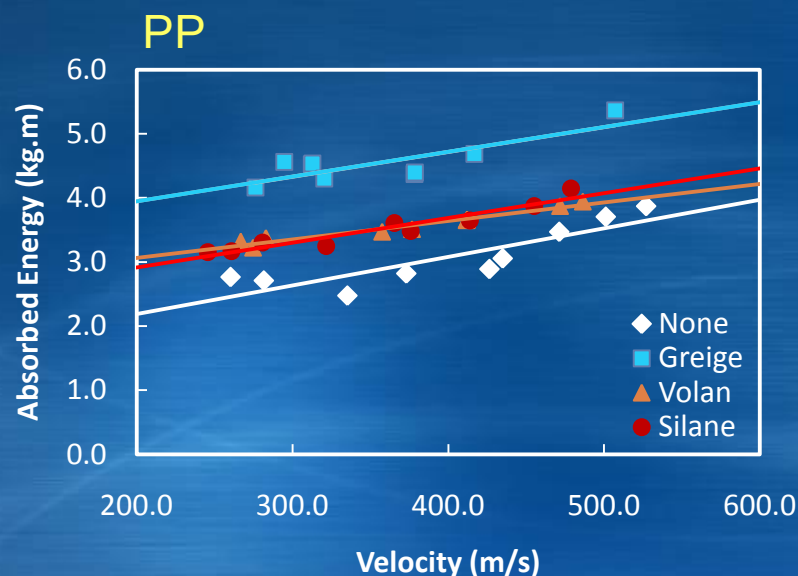
High Vs. Low Speed Impact

Impact Energy Comparison at Ambient for 3.2mm Samples



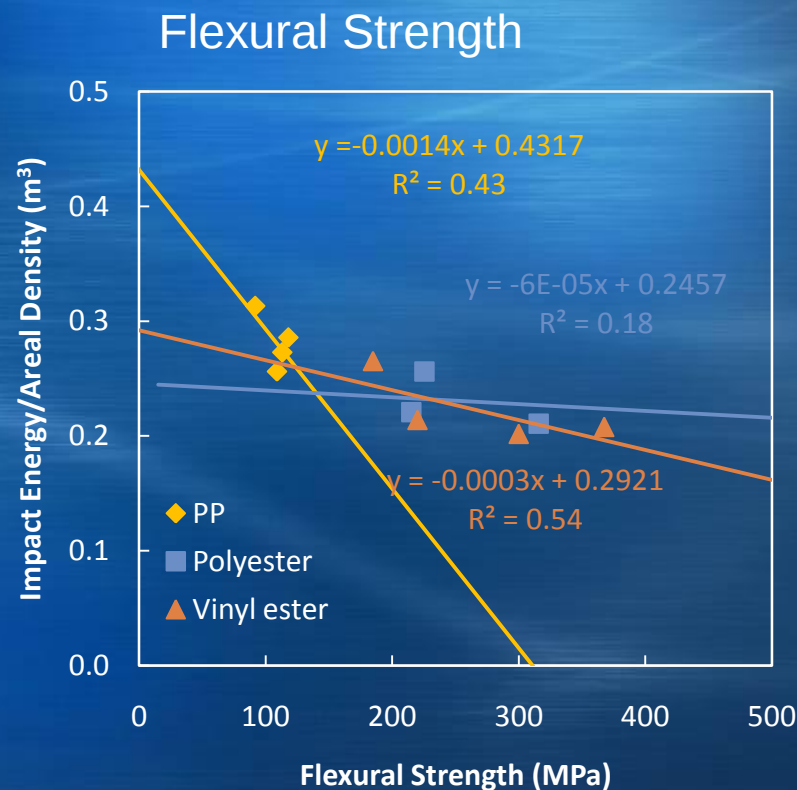
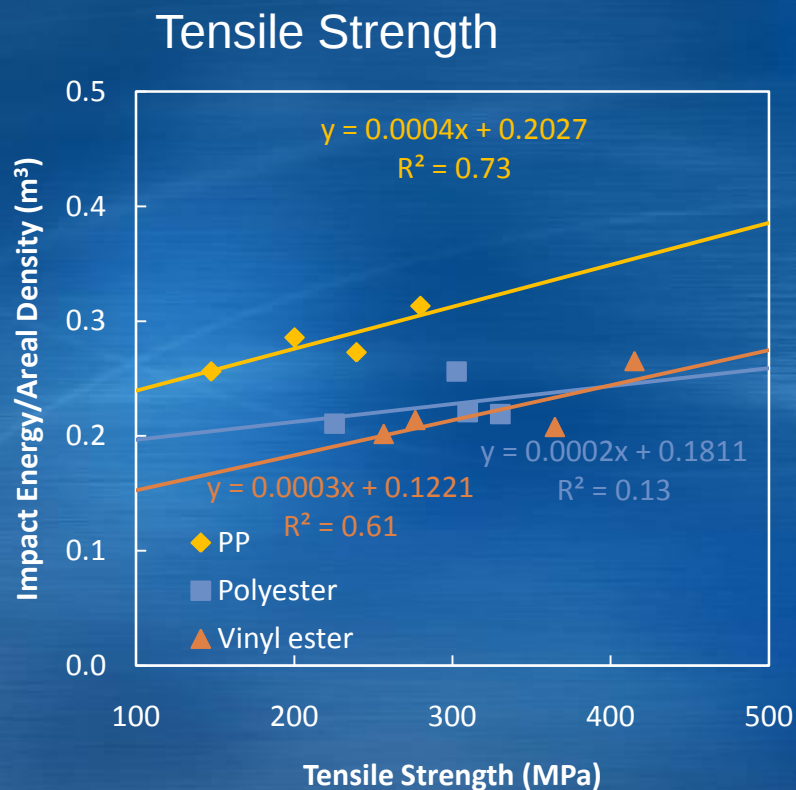
- Results From Low Speed Impact Can Not Predict High Speed Impact Performance Between Different Resin Systems

Impact Energy Absorption



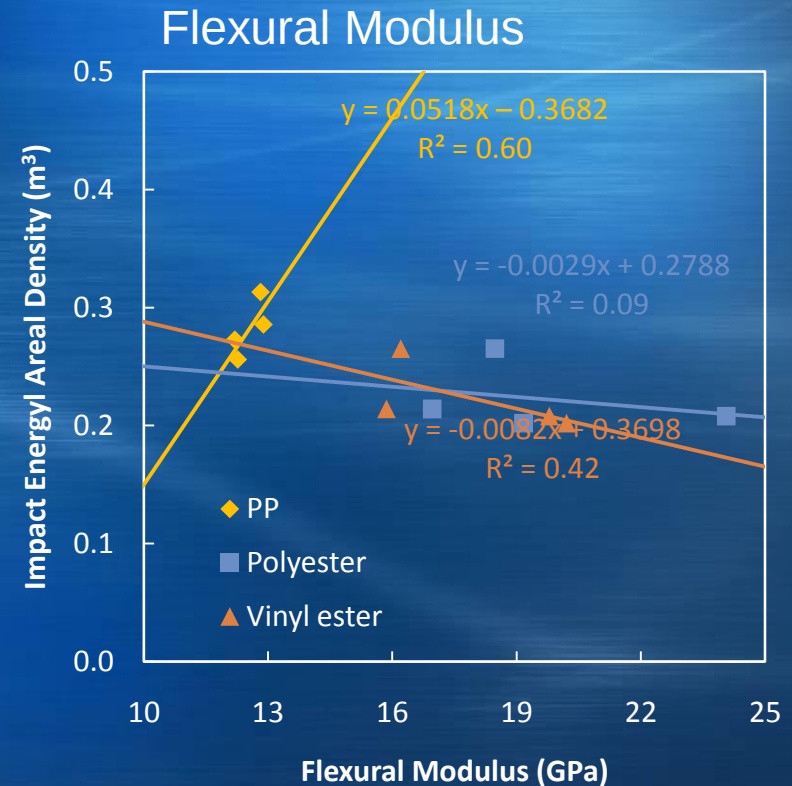
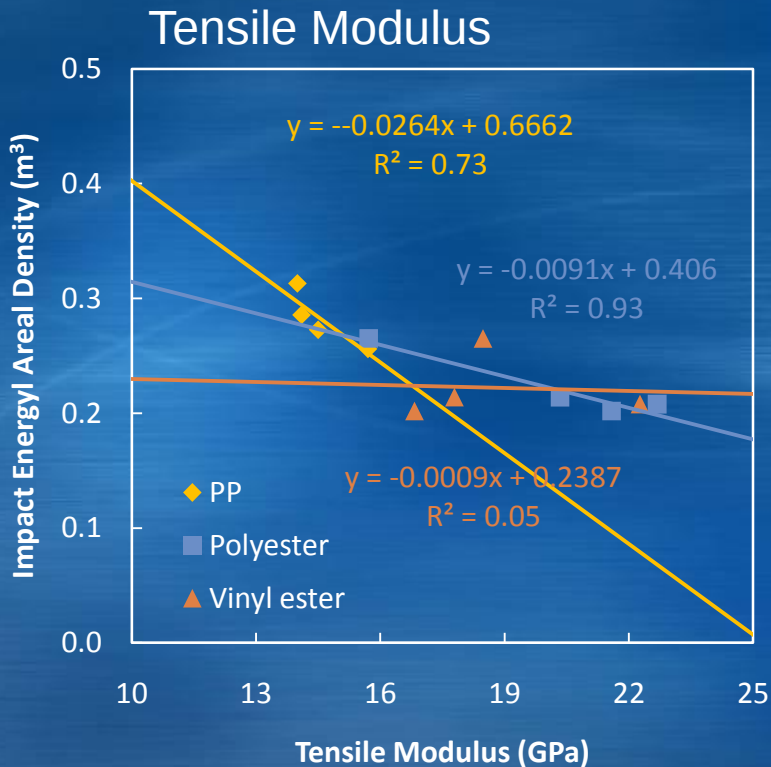
- Impact Energy Absorption Increases With Projectile Velocity
- Greige Finish Has Higher Impact Energy Absorption
- PP Resin Has Lower Impact Energy Absorption

Impact Energy Vs. Strength



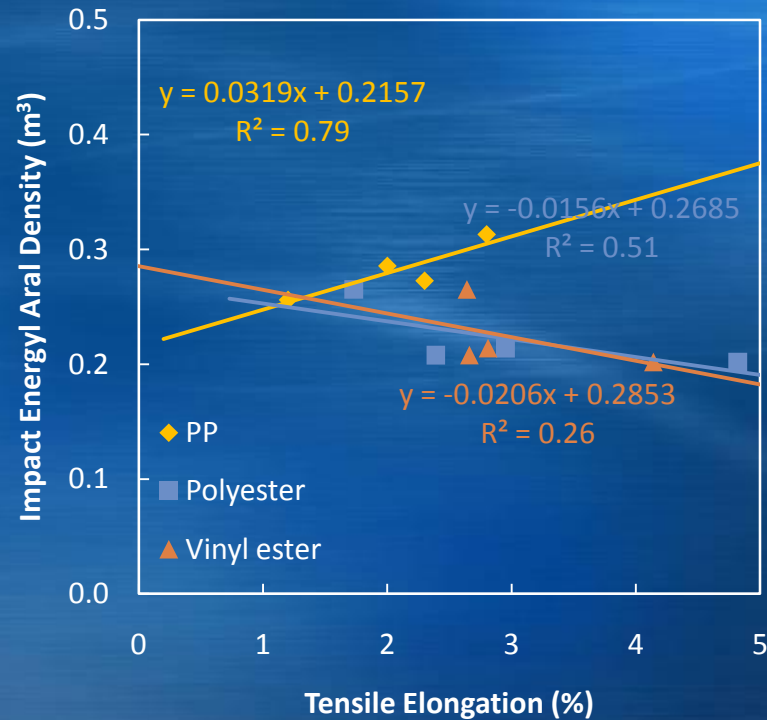
- Impact Energy Is Nearly Proportional To Tensile Strength

Impact Energy Vs. Modulus



- No Obvious Correlation With Tensile Or Flexural Modulus

Impact Energy Vs. Elongation



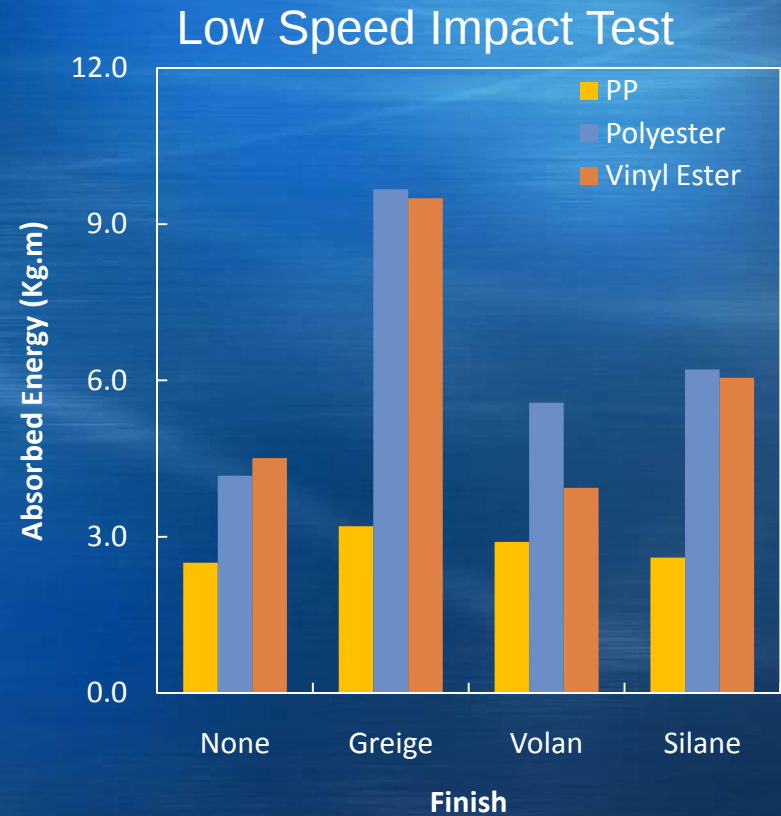
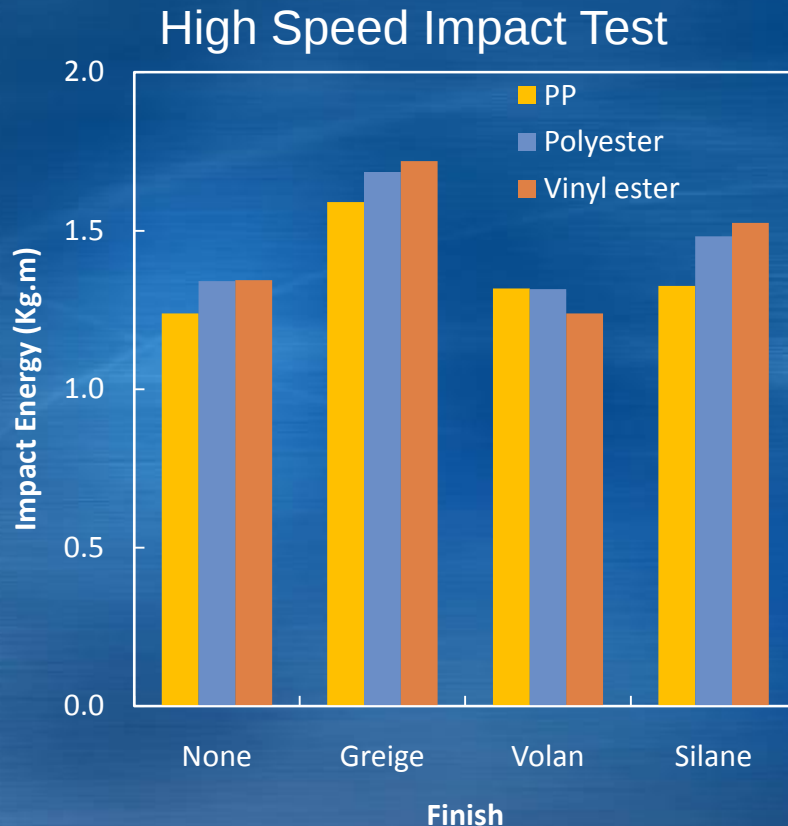
- No Obvious Correlation Observed

Part 3

Conclusion

High Vs. Low Speed Impact

Impact Energy Comparison at Ambient



- Results From Low Speed Impact Can Not Predict High Speed Impact Performance Between Different Resin Systems

Summary And Conclusion

- Surface Finish On Glass Fiber Fabrics Affects Mechanical Properties As Well As Impact Performance Of Resulted Composites
- GR Finish Results In Higher Impact Resistance
- Despite its Low Mechanical Properties, PP Composite Has Better Impact Resistance
- Tensile Strength May Be A Critical Factor For Attaining High Impact Resistance

Acknowledgements

- ❑ **RDECOM-TARDEC:** US Army's Tank Automotive Research, Development & Engineering Center
 - ❑ Contract Number: W56HZV-09-C-0569
- ❑ **RDECOM-ARDEC:** US Army's Armament Research, Development & Engineering Center
 - ❑ Contract Number: W15QKN-08-C-0533



THANK YOU

Any Questions?