MICHELMAN®

IACMI Winter Meeting

Indianapolis

January 30, 2019

CONFIDENTIAL

Our Vision: The Interface Experts

Agenda:

- Michelman Overview
- Fiber Sizing Fundamentals
- Market Challenge
- Application Review
- Research & Product Portfolio Overview
- Active Research Programs

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Company Overview

About Michelman

Purpose: **Innovate** a **sustainable future**

- **Established in 1949**
  - Specialty chemicals
  - Customer focused
  - Family enterprise
- **Today, Michelman is**
  - Global
  - 475+ employees
  - Family owned
  - Professionally managed
- **Key Strengths**
  - Strong Balance Sheet
  - Highly Profitable
  - Historical Track record of Growth





Our Vision: The Interface Experts

Mission:

- To become the **Experts**, delivering new solutions to the Composites Value Chain through new and differentiated technology, proven and validated with industry-standard equipment, testing, and data.

- To optimize the performance between Fibers, Fabrics and Polymers across **all types** of composites, whether Thermoplastic or Thermoset.

- To achieve our Mission, a multi-dimensional **Composites Leadership** strategic approach is being deployed.

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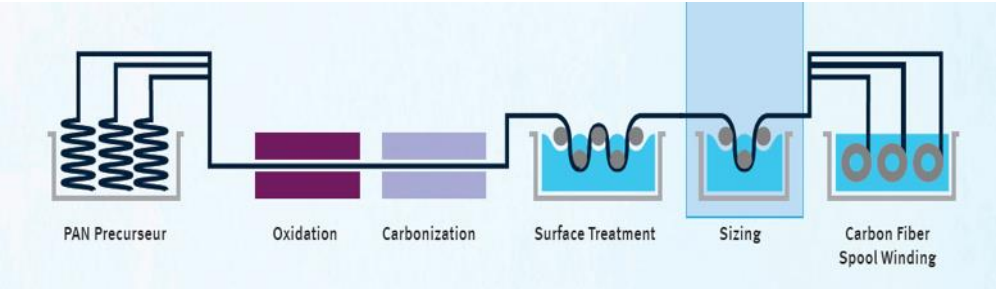
Fiber Sizing Fundamentals

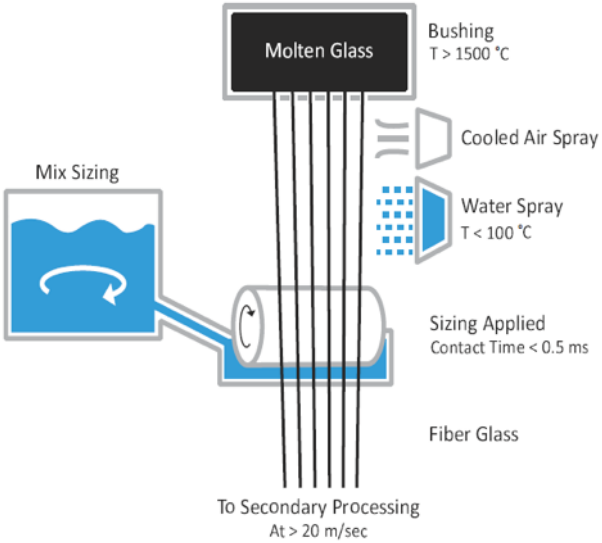
Sizing – The Secret Sauce

?

Sizing Benefits

- **Protect** the freshly formed fiber surface **from abrasion** F/F, F/M
- **Prevent fiber breakage** during forming, processing and post processing
- **Protect** the fiber from the **hydrolytic attack** by water





Sizing Benefits

Changes in sizing can affect the fiber physical characteristics.

Fiber
discoloration
solubility
resin wetting
ease of chopping
reduction of static
FDA compliance
reduction of fuzz
bundle integrity

Composite Benefits

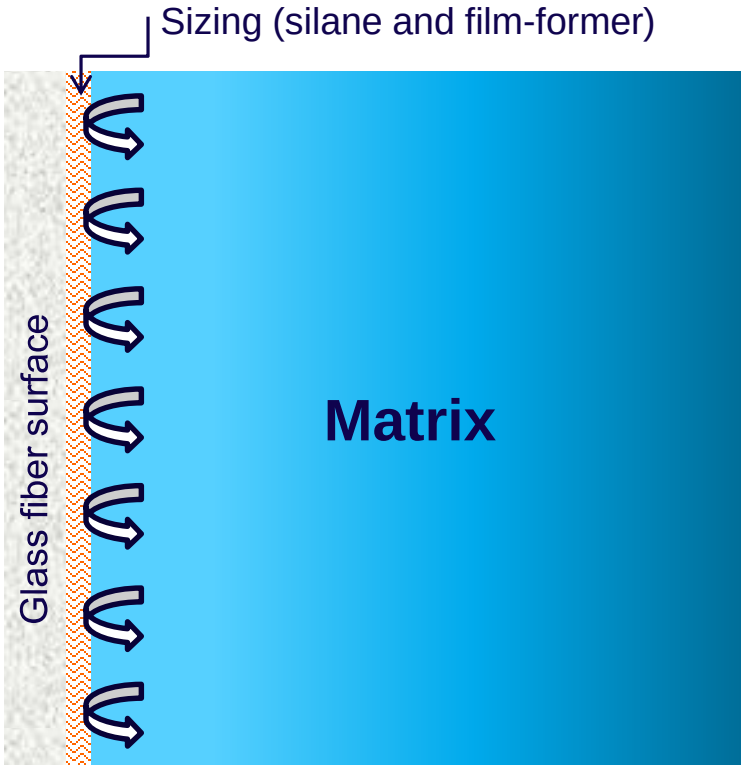
Sizing enhances composite **mechanical** and **chemical** properties due to the role it plays at the interface of the fiber and matrix.

- Thermal and hydrolytic stability
- Corrosion resistance
- Heat and oil resistance
- Impact strength
- Tensile and flexural strengths
- Compressive strength
- Fatigue performance
- Electrical conductivity
- And many others

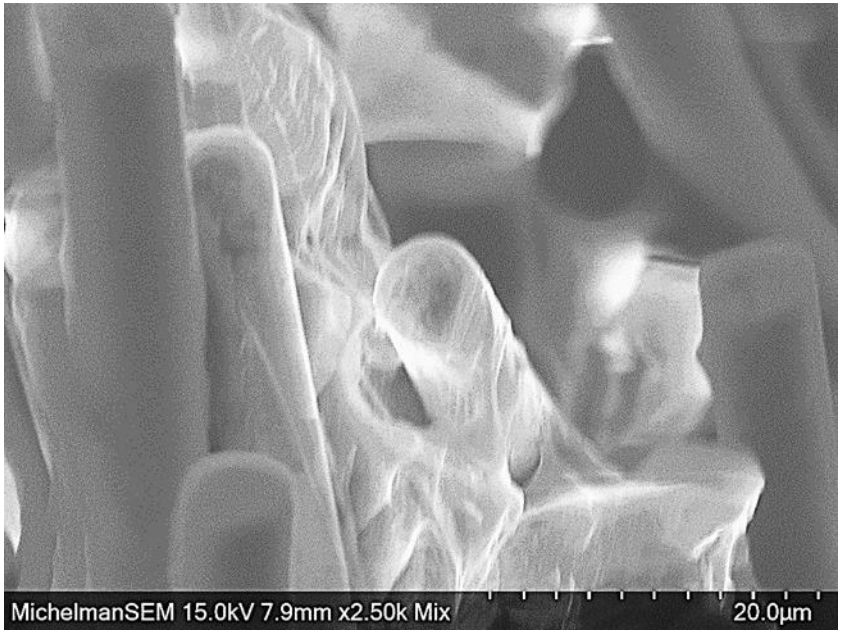
The Interface - Schematic

When the sized fiber is introduced to the resin matrix the sizing becomes the “glue”.

The forces between sizing and matrix can be chemical bonding, hydrogen bonding and Van der Waals interaction.

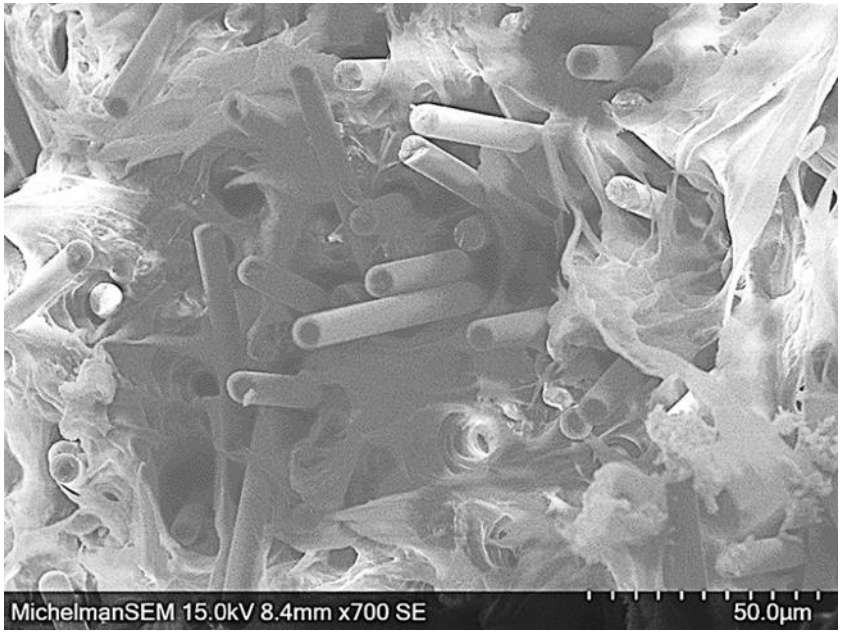


The Interface – Close up



Good Adhesion

(No pull out fibers)



Poor Adhesion

(Fiber slippage)

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Market Challenge

Composite Market – Past & Future

Current State:

- **Compartmentalized**
- **Complex**
- **Inefficient - iterative**
- **Sub-optimized**

IACMI & Michelman – working to change the market

About IACMI

The Institute for Advanced Composites Manufacturing Innovation, IACMI, is a partnership of industry, academic institutions, as well as federal, state, and local governments that are working together to benefit the nation's energy and economic security. This diverse public/private partnership validates manufacturing technologies that respond to private industry's need for faster and more cost, material, and energy-efficient composite manufacturing, including recycling at the end of product life. IACMI's research and development programs are driven by major industry participation with a focus on reducing technical risk and developing a robust supply chain to support a growing advanced composites industry.

IACMI broadly engages educational, economic development, trade, and professional organizations to build the skills and workforce critical to the growth of composite industry companies of all sizes.

IACMI is managed by Collaborative Composite Solutions Corporation (CCS), a not-for-profit organization established by the University of Tennessee Research Foundation.

Organizations of any size can join IACMI through a membership. Once a part of IACMI, members can benefit from participating in projects, networking with other IACMI members, and participating in workforce development opportunities to meet organizational needs.

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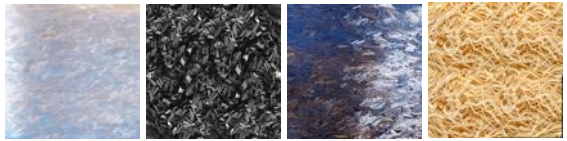
Application Review

Fiber Type

Michelman develops film formers & surface treatments to serve ALL fiber types:

- Glass
- Carbon
- Recycled CF/GF
- Basalt
- Natural
- Synthetic (UHMWPE, etc)



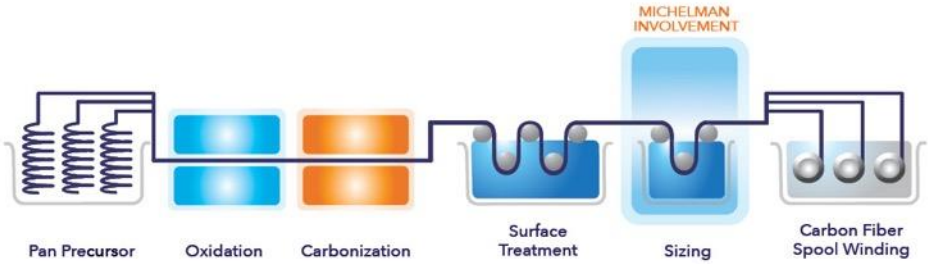
Fiber Format

- Chopped Fiber Bundle
- Roving
- Non Woven
- Woven
- Non Crimp Fabric

Composite Process

Composite Process:

- Pultrusion
- Filament Winding
- Compounding
- Molding
- SMC/BMC
- RIM
- (HP) - RTM
- UD Tapes
- Technical Textiles
- Pre-Pregs



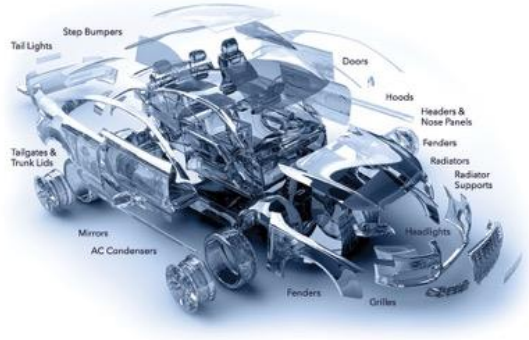
Fiber/Fabric Requirements

- Spreadability
- Wettability
- Dispersion
- Interfacial Adhesion
- Feadability
- Aspect Ratio/Fiber Length

Application Requirements

Targeted Applications:

- Automotive – UTH
- Automotive – Interiors
- Automotive – (Semi) – structural
- Construction
- Aerospace
- Appliances
- Sporting Goods
- Infrastructure



Application Requirements

- Thermal Stability
- Chemical Resistance
- Fatigue
- Dimensional Control
- Cost
- Stiffness/Strength
- Impact Resistance

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Research & Product Portfolio Overview

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Current Portfolio Overview

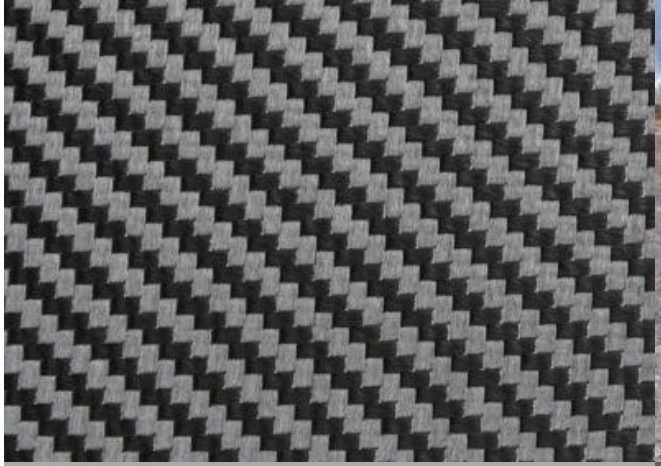
Product Overview

Applications

Sizing – glass fiber, carbon fiber, etc.

Binder – UD tapes, laminates, organo sheets, etc.

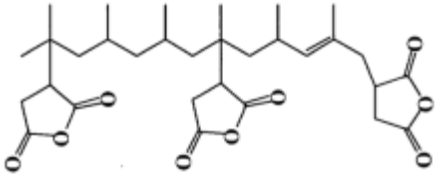
Lubricant/Process Aid – spreadability, weavability, etc.

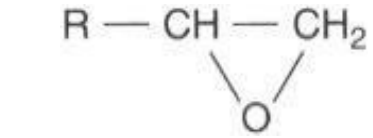


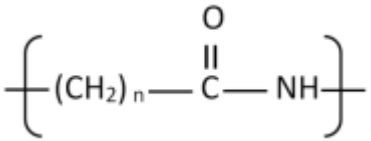
Products tailored for Matrix Resin

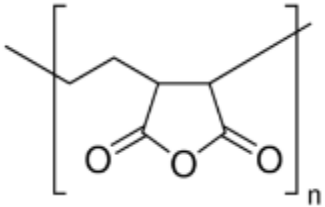
Products are designed for use in the following matrix resins :

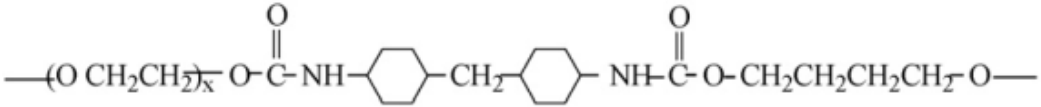
- Polypropylene (PP)
- Polyethylene (PE)
- Polyamide (PA)
- Polyether Imide (PEI)
- Polyether Ether Ketone (PEEK)
- Polyphenylene Sulfide (PPS)
- Thermoplastic Polyurethane (TPU)
- Polyester, (Un)saturated
- Vinylester
- Epoxy
- Products tailored to meet the specific applications, environmental footprint











Polypropylene Matrix

Michelman offers an extensive line of emulsions made to fit PP composite properties.

PRODUCT	MECHANICAL PERFORMANCE	DETERGENT RESISTANCE	COLOR	MW	GRAFTING LEVEL	CHOPPED STRAND	LONG FIBER REINFORCED THERMOPLASTIC	ODOR PERFORMANCE
FGLASS™ X48	○	●	●	●	●	○	●	
Hydrosize® PP-201	●	●	●	○	●	○	●	●
Hydrosize® PP-247	●	●	●	●	●	●	○	○
Hydrosize® PP-286	●	●	●	●	○	●	●	
Michem® Emulsion 91735	●	●	●	●	○	●	●	

○ Good performance

● Better performance

● Best performance

Products listed are illustrative – for complete portfolio, please contact a Michelman representative

Polyamide Matrix

Polyurethane dispersions have been the sizing of choice for polyamide (PA) reinforced composites. Polyurethanes are tough materials with good adhesion to PA6 and PA66. We **design** our own polyurethanes to meet our customer needs by changing the chemistry to modify flexibility, toughness, Tg, chemical resistance, mechanical properties, etc.

PRODUCT	MECHANICAL PERFORMANCE	GLYCOL RESISTANCE	THERMAL RESISTANCE	LONG FIBER REINFORNCED THERMOPLASTIC	STRAND INTEGRITY	CHOPPED STRAND	EU FOOD COMPLIANCE
Hydrosize® U2023	●	●	●	●	●	●	YES
Hydrosize® U5-01	●	●	●	○	●	●	
Hydrosize® U5-02	●	●	●	●	●	●	YES
Hydrosize® U6-01	●	●	●	●	●	●	
Hydrosize® U8-02	●	●	●	●	●	●	YES
Hydrosize® LINK U470	●	●	●	○	●	●	
Hydrosize® LINK U480	●	●	●	●	●	●	

○ Good performance

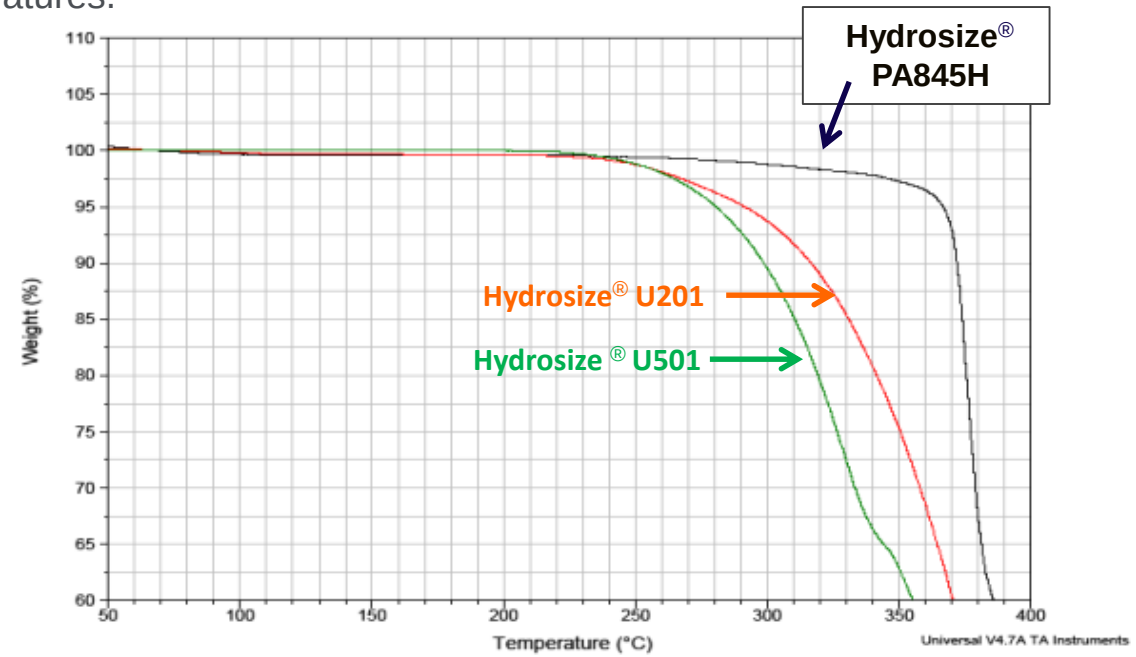
● Better performance

● Best performance

Products listed are illustrative – for complete portfolio, please contact a Michelman representative

Polyamide – High Temperature

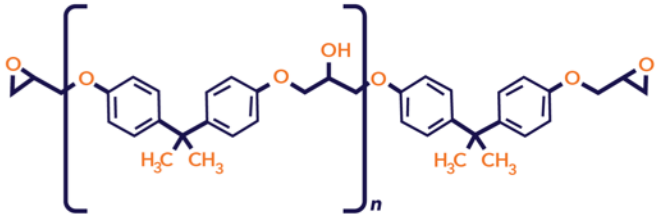
We use a proprietary technology to make polyamide dispersions. These products are designed with thermal resistance in mind. Compared to polyurethanes, polyamide (Hydrosize® PA845H) dispersions can withstand higher processing & end-use temperatures.

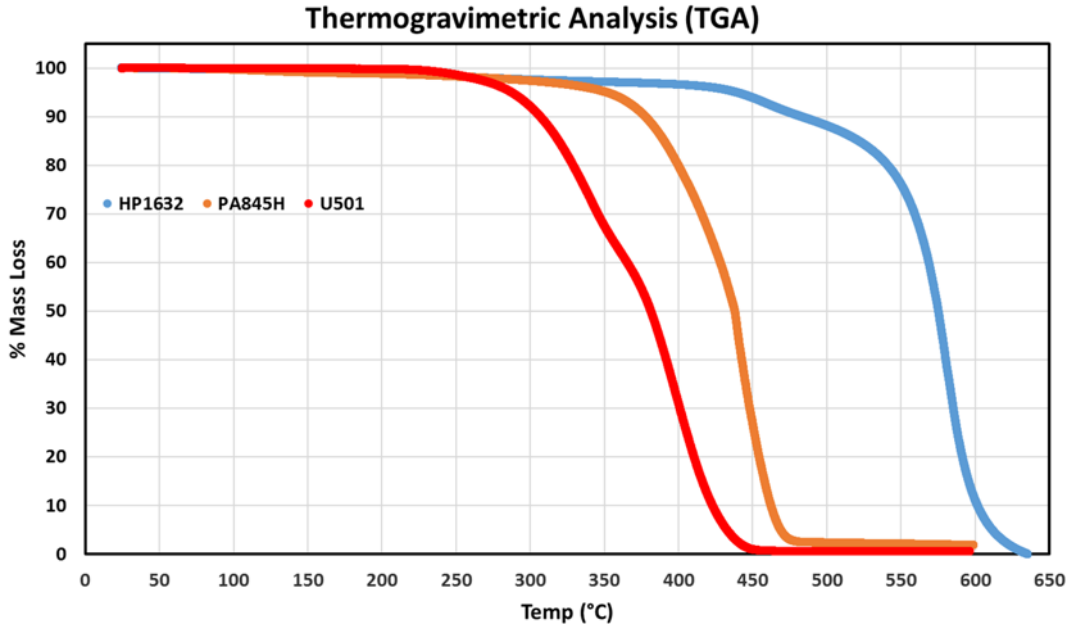


High Temperature Sizing

Our Hydrosize® HP-1632 is specially designed for materials and applications that require extreme thermal resistance

PRODUCT	PEEK	PEI	PPS	PPA
Hydrosize® HP-1632	•	•	•	
Hydrosize® PA845H	•			•
Hydrosize® U5-01	•		•	•





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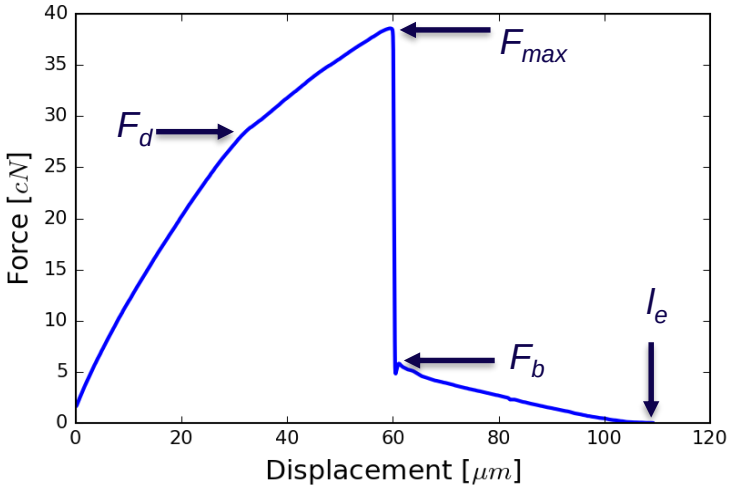
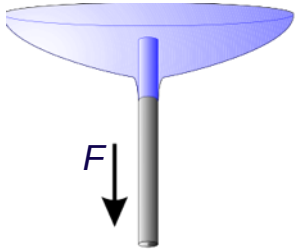
Research Activity Overview

Single Fiber Pullout Test

Typical curve for pullout test





F_d : crack is initiated

F_{max} : crack reaches tip of fibre

F_b : no bonding left, only frictional forces

- The FIMATEST analysis software automatically determines the relevant parameters from the force-displacement curve, F_d, F_{max}, F_b, l_e etc. …
- …and calculates the sought-after quantities τ_f, τ_{app}, τ_d and G_{ic}

Fiber Pullout Test

Calculated parameters

- Apparent interfacial shear strength…….. τ_{app} [MPa]
- Local interfacial shear strength…….. τ_{d} [MPa]
- Interfacial frictional stress…….. τ_{f} [MPa]
- Critical interfacial energy release rate…….. G_{ic} [J/m^2]

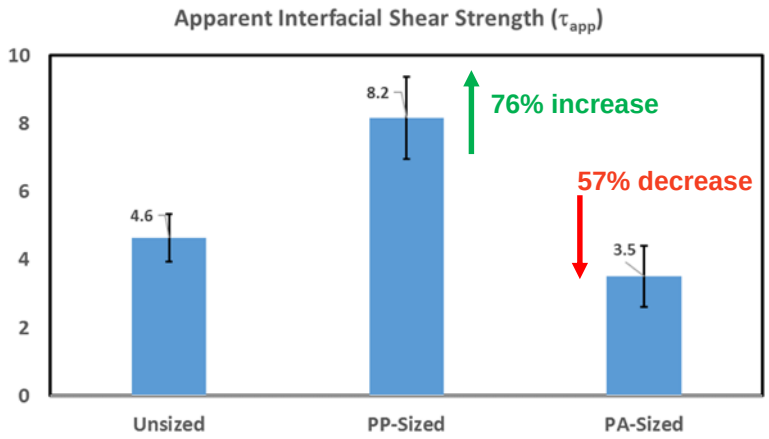
Significance of the Important parameters:

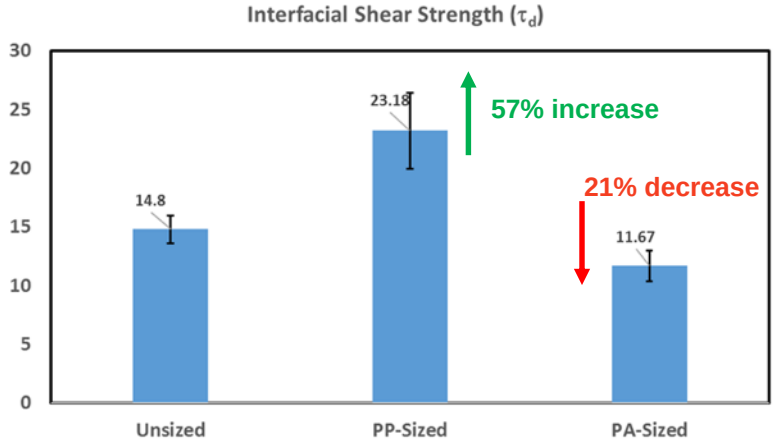
- τ_{app} : based on the maximum force F_{max}.
  Good for a first relative comparison of the fibre-to-maxtrix adhesion (influence of fibre-to-matrix friction)
- τ_{d} : based on the debonding force F_{d}.
  Absolute measure of the fibre-to-matrix adhesion, independent from friction
  and corrected for deformation of fibre and matrix during the pull-out test
- G_{ic} : Describes the energy required to debond the fibre
  per unit contact surface area.

Research Initiatives

Problem Statement: Investigate effect and improvement of interfacial properties of compatible sizing versus un-sized and incompatible sized fiber in ***carbon fiber reinforced polypropylene composites***

Michelman activity: Evaluation of polypropylene compatible sizing compared to incompatible sizing and un-sized carbon fiber using Single Fiber Pullout test

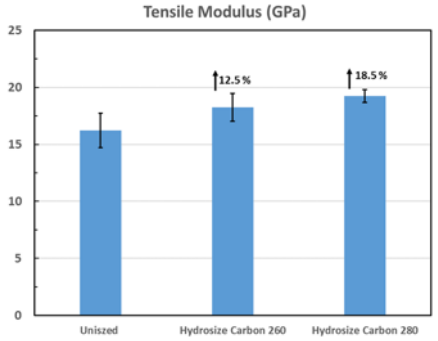


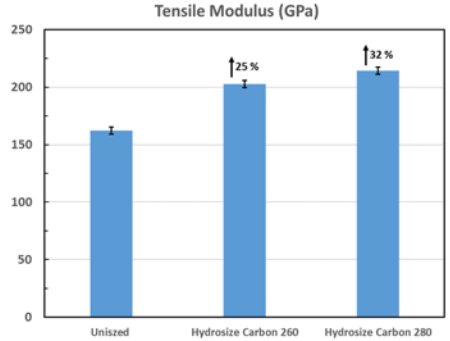


Research Initiatives

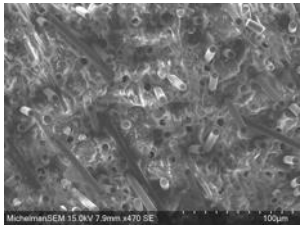
Problem Statement: Evaluate nylon compatible sizing and its effect on ***carbon fiber reinforced nylon composites***

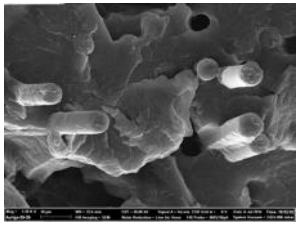
Michelman activity: Initiate micro-compounding and molding evaluation of nylon compatible sizing in carbon fiber reinforced nylon composites (30% fiber loading)

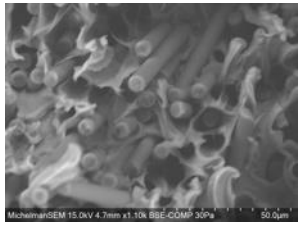


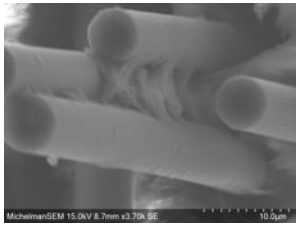


- Up to 18.5 % improvement in Tensile Modulus
- Up to 32 % improvement in Tensile Strength









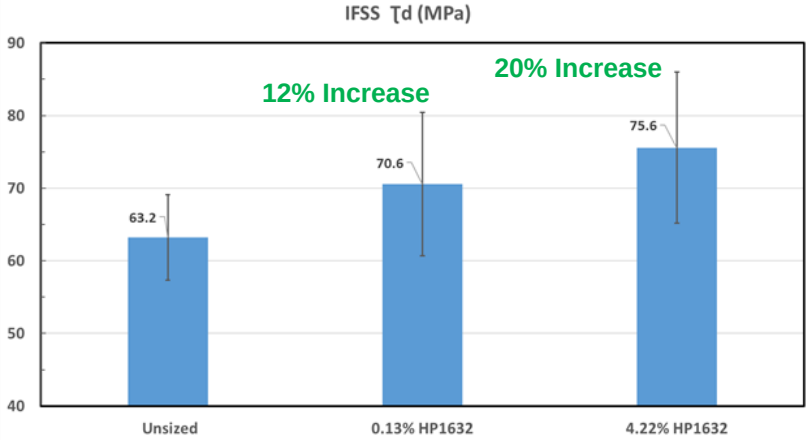
Un-sized Fiber

Sized Fiber

Research Initiatives

Problem Statement: Determine effect of thermally stable sizing on interfacial performance of ***carbon fiber reinforced PEKK composites***

Michelman activity: Initiate single fiber pullout evaluation of thermally stable sizing in PEKK composite compared to conventional sized carbon fiber



Fibers	% Improvement in Interfacial Properties after Sizing		
	Apparent IFSS	Cr. Energy Release Rate	IFSS
	Tapp	Gic	Td
	MPa	J/m²	MPa
CF-0.13% Sizing	7.92	29.01	11.61
CF-4.2% Sizing	19.87	29.48	19.53

Active Research Programs

- **IACMI – Closing the Loop on Automotive Carbon Fiber Prepreg Manufacturing Scrap – Project Lead: Vartega**
- **IACMI – Low Cost Basalt Fiber for Automotive Applications Project Lead: Michelman**
- **IACMI – Silicone-free Spin Finish for PAN Precursor Fiber Project Lead: Michelman**
- **IACMI – SMC Reinforced by Recycled or Textile Based Carbon Fibers Project Lead: CCS Corp(IACMI)**
- **ACMA/IACMI – Glass Fiber/Carbon Fiber Recycling**
- **ITA Aachen – In Situ Polymerization Caprolactum Carbon Fiber Composites**

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Thank You