

Polyurethane Resin for Composite Application

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Huntsman Polyurethanes

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Outline

- **Introduction**
 - Huntsman Cooperation
 - Polyurethane Chemistry
 - Polyurethane Composite
- RIMLine[®] and Vitrox[®] Resin
 - Thermal Analysis
 - Physical Properties
- Process and Comparison
 - Pultrusion
 - Filament winding
- Conclusion

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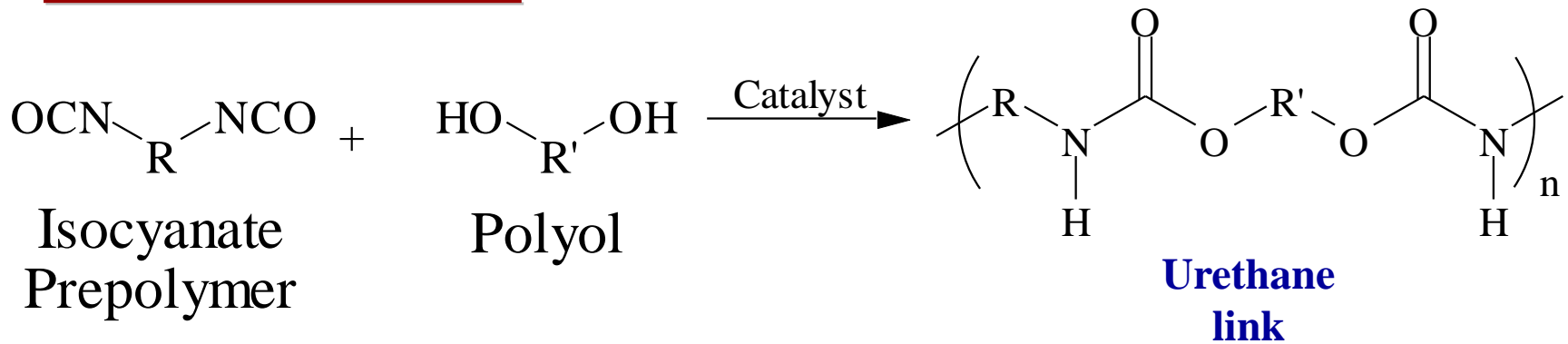
Business Portfolio

| Differentiated | | | | Inorganic |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------|
| Polyurethanes | Advanced Materials | Textile Effects | Performance Products | Pigments |
| Adhesives, Coatings & Elastomers Appliances Automotive Composite Wood Products Footwear Furniture & Bedding Insulation TPU | Formulated Systems Specialty Components Base Resins | Apparel & Home Textiles Specialty Textiles | Amines Carbonates Maleic Anhydride & Licensing Surfactants | Titanium Dioxide Additives |

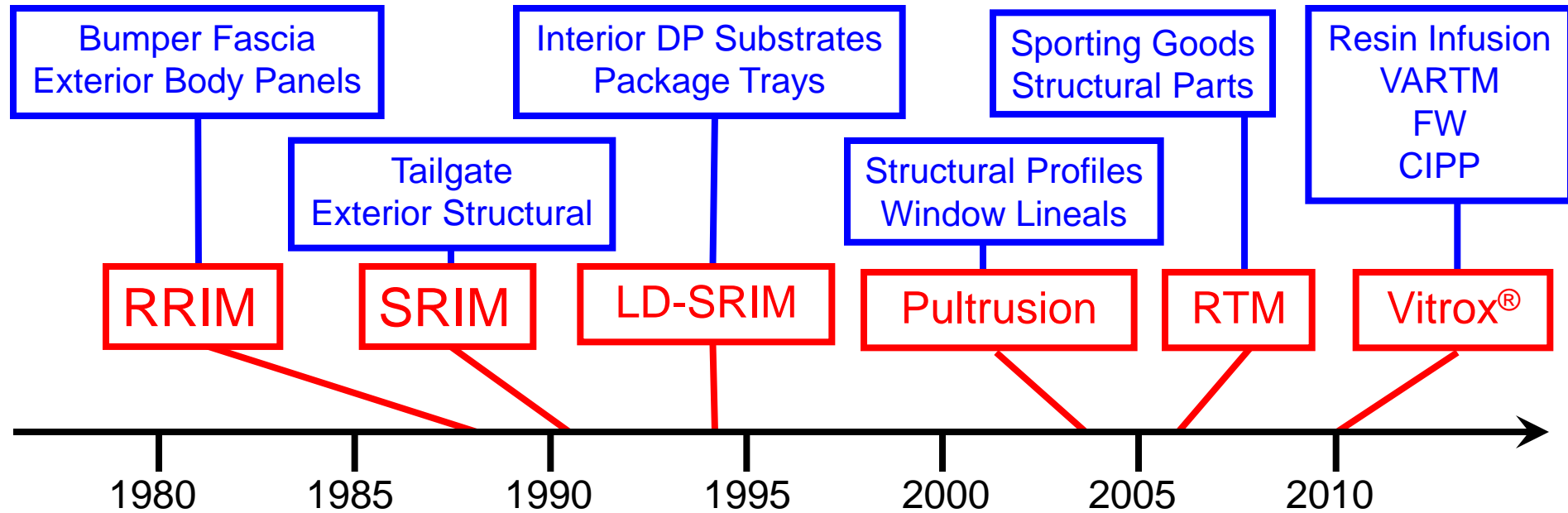


PU Chemistry

POLYURETHANE



PU Composite Innovations

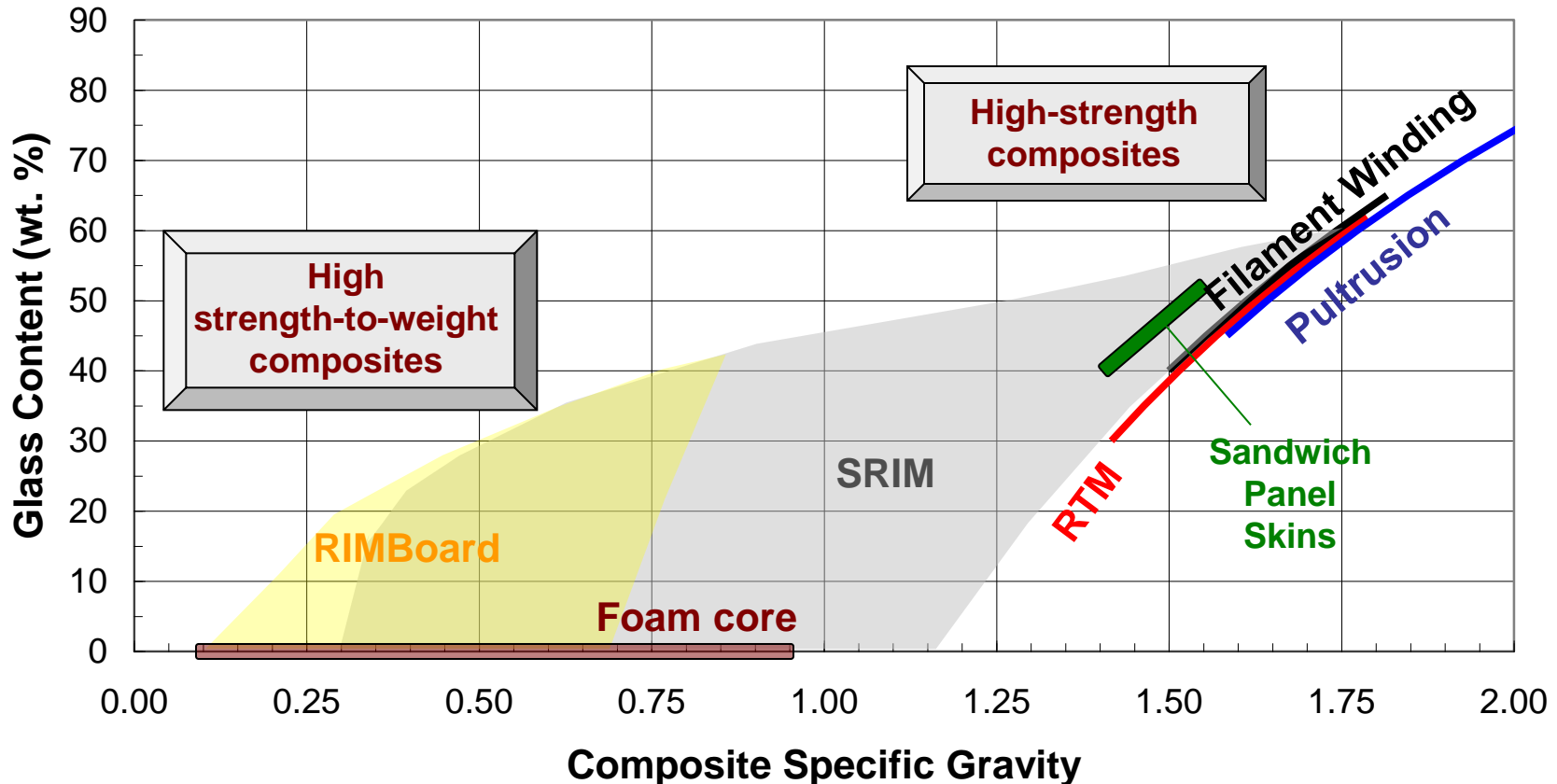


- 20+ year history in automotive and industrial components



PU Composite Technologies

Typical Composite Glass Content and Specific Gravity



- Broad spectrum of chemistry & processing
- PU also plays role as structural adhesive

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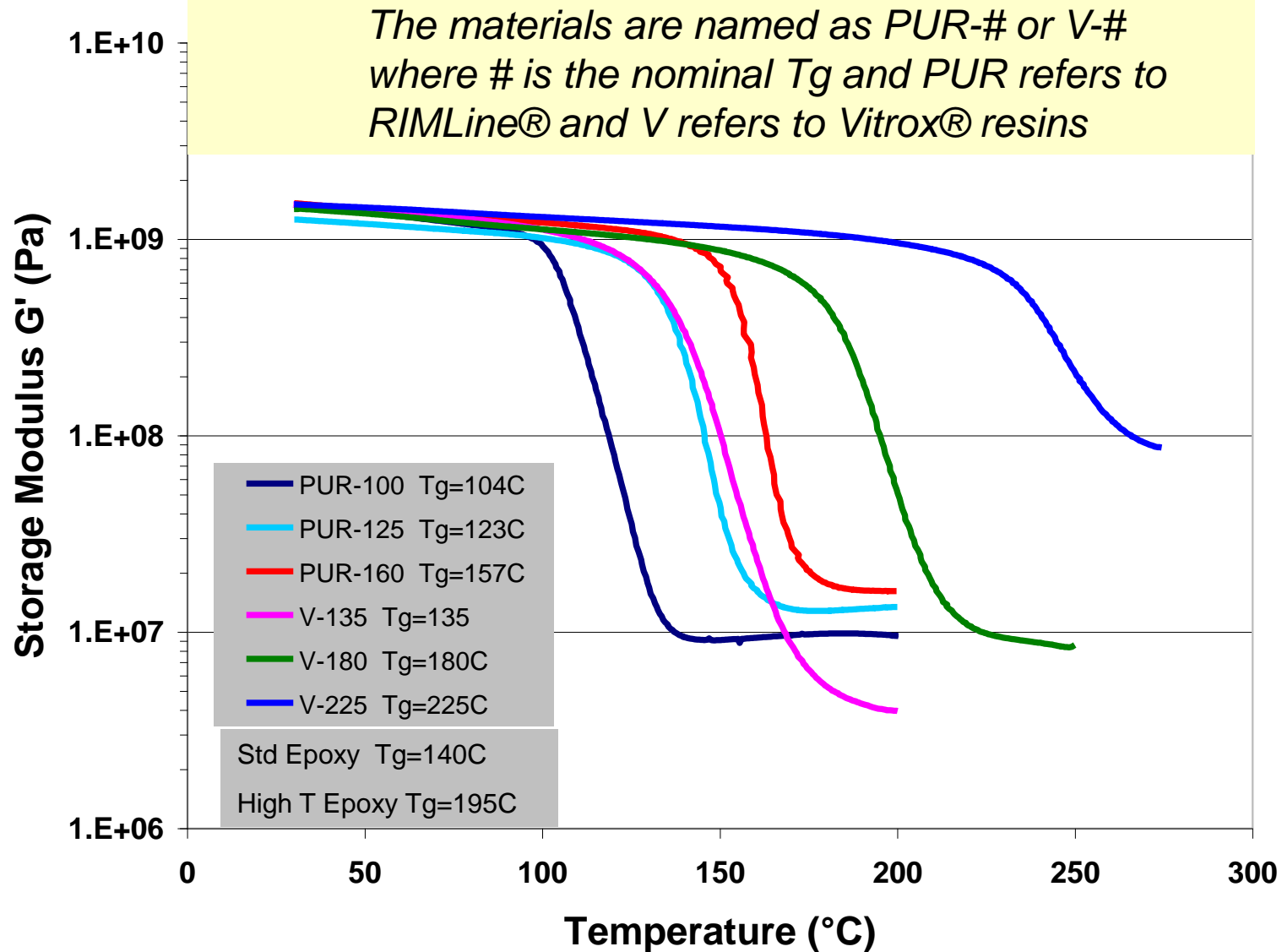
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HPU Composite Platform

- Base Resin Systems:
 - RIMLine[®] standard PUR systems
 - Vitrox[®] systems
- Each base resin system can be modified for a variety of applications or processing methods
 - Cure time
 - Viscosity
 - Pot-life
- The key defining feature of the six systems is the nominal Tg of the cured resin

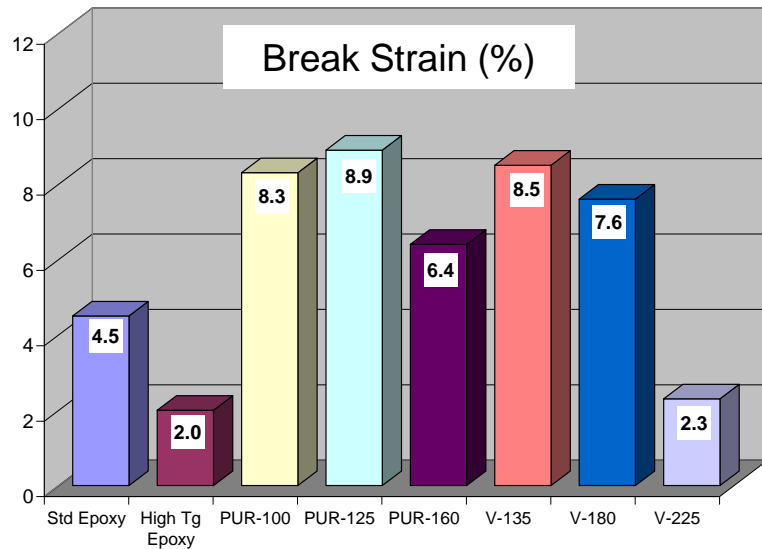
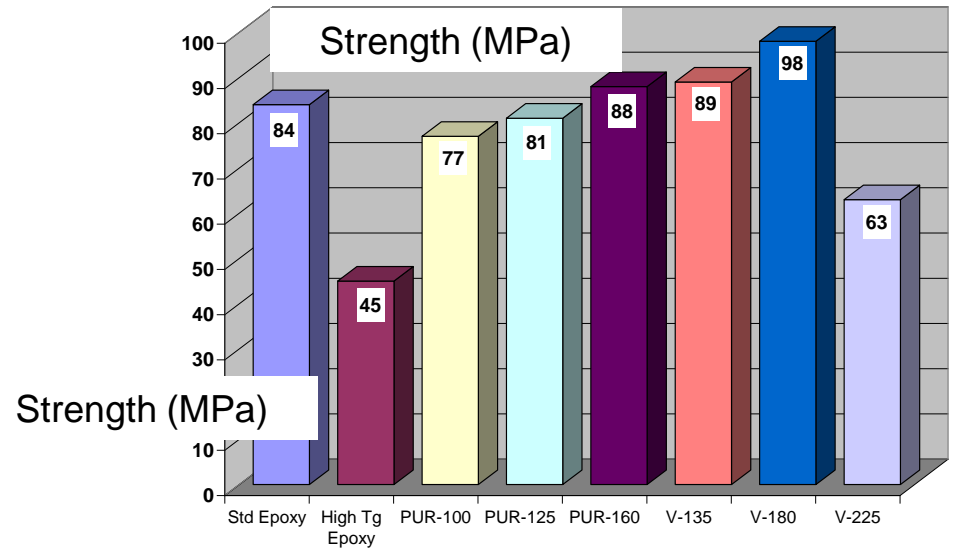
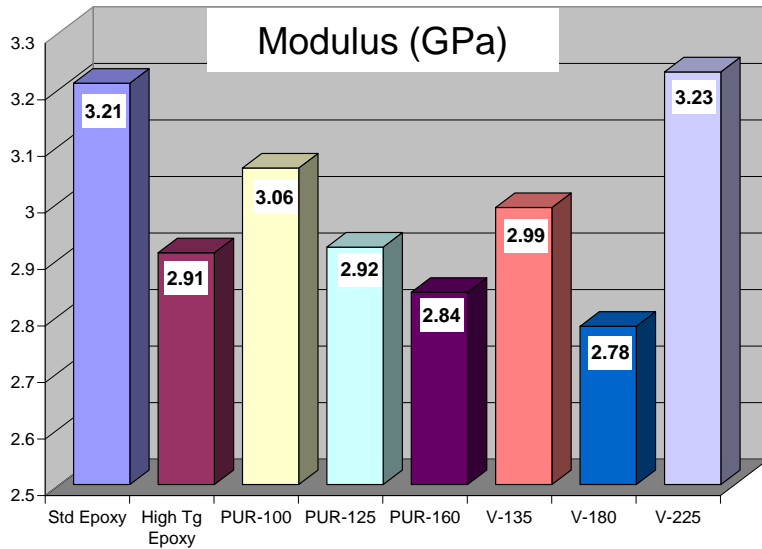
Thermal Analysis by DMA



Neat Resin Physical Properties

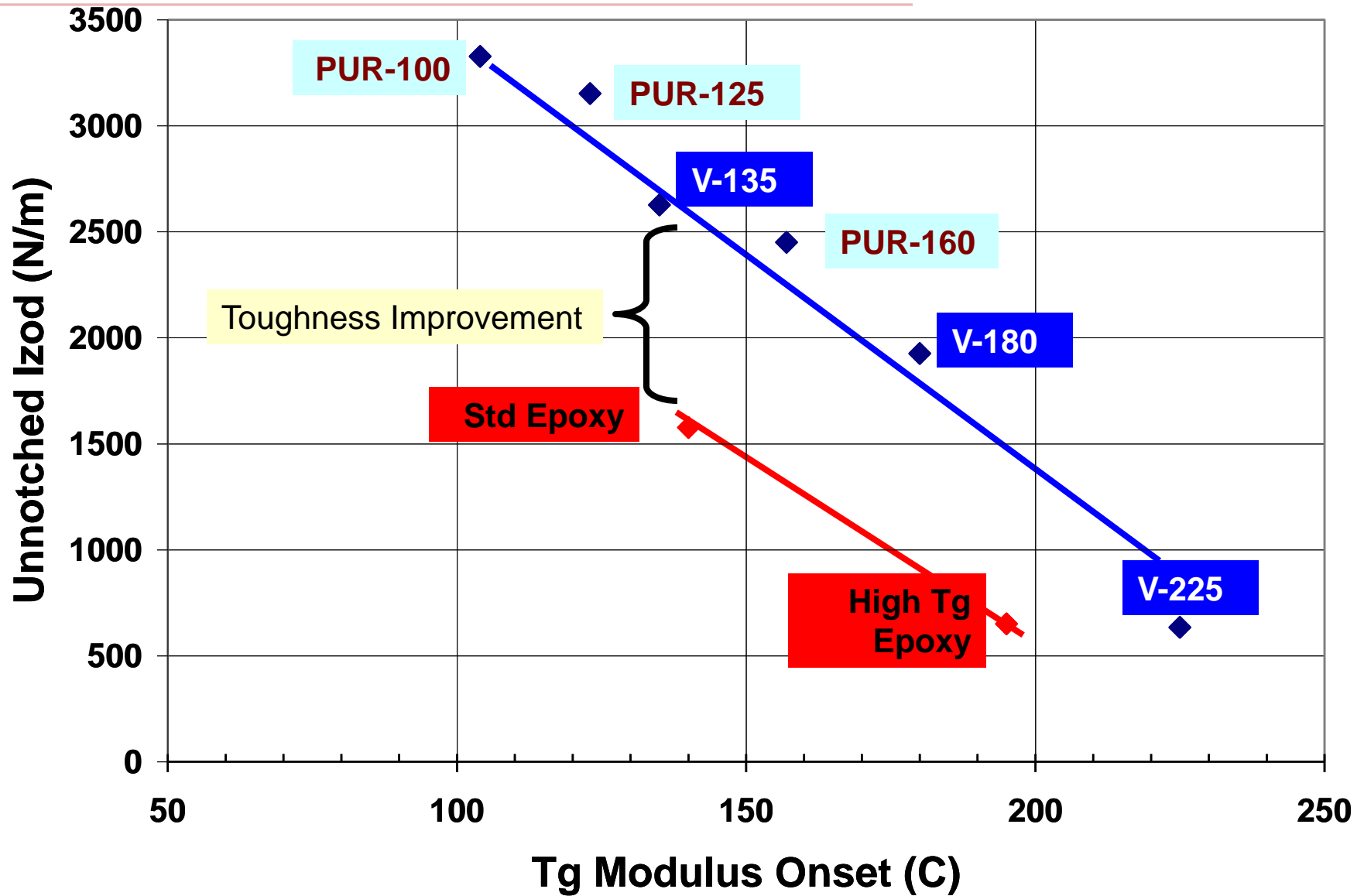
| Description | Definition | Standard Epoxy | High Tg Epoxy | PUR-100 | PUR-125 | PUR-160 | V-135 | V-180 | V-225 |
|-----------------------------------------------------|-------------------------------|----------------|-----------------|----------|----------|----------|----------|----------|-----------------|
| Cure Cycle | Cure Temperature (°C) | 180 | 180 | 120 | 150 | 180 | 180 | 180 | 180 |
| | Cure Time (min) | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | Post Cure | ----- | 200 C 60 min | ----- | ----- | ----- | ----- | ----- | 220 C 30 min |
| Neat Resin Tensile Properties (ASTM D638) | Tensile Modulus (GPa) | 3.21 | 2.91 | 3.06 | 2.92 | 2.84 | 2.99 | 2.78 | 3.23 |
| | Tensile Yield Strength (MPa) | No Yield | No Yield | 89 | 83 | 92 | No Yield | No Yield | No Yield |
| | Tensile Yield Strain (%) | No Yield | No Yield | 5.5 | 6.7 | 5.5 | No Yield | No Yield | No Yield |
| | Tensile Break Strength (MPa) | 84 | 45 | 77 | 81 | 88 | 89 | 98 | 63 |
| | Tensile Break Strain (%) | 4.5 | 2.0 | 8.3 | 8.9 | 6.4 | 8.5 | 7.6 | 2.3 |
| Neat Resin Flexural Properties (ASTM D790) | Flexural Modulus (GPa) | 3.14 | 2.82 | 3.18 | 2.85 | 2.9 | 3.19 | 2.89 | 3.08 |
| | Flexural Yield Strength (MPa) | No Yield | No Yield | 127 | 105 | 119 | No Yield | No Yield | No Yield |
| | Flexural Yield Strain (%) | No Yield | No Yield | 6.4 | 7.1 | 7.1 | No Yield | No Yield | No Yield |
| | Flexural Break Strength (MPa) | 129 | 126 | No Break | No Break | No Break | 137 | 102 | 144 |
| | Flexural Break Strain (%) | 7.4 | 6.8 | No Break | No Break | No Break | 9.5 | 14.2 | 6.1 |
| Unnotched Izod (ASTM D256) | (N/m) | 1576 | 650 | 3327 | 3152 | 2450 | 2626 | 1926 | 634 |

Tensile Properties



- Good combination of modulus, strength, and break strain leads to a high toughness for the urethane systems.

Toughness Comparison



Processing Recommendations

| Process | PUR-100 | PUR-125 | PUR-160 | V-135 | V-180 | V-225 |
|------------------|-------------|-------------|-----------------|-------------|-------------|-----------------|
| Filament Winding | Potential | Potential | Not Recommended | Potential | Potential | Recommended |
| HP-RTM / SRIM | Recommended | Recommended | Recommended | Potential | Potential | Not Recommended |
| RTM / RTM Lite | Recommended | Recommended | Not Recommended | Recommended | Potential | Recommended |
| Pultrusion | Potential | Recommended | Recommended | Potential | Potential | Potential |
| Vacuum Infusion | Recommended | Recommended | Not Recommended | Recommended | Recommended | Recommended |

Recommended

Potential

Not Recommended

- The choice of resin depends upon
 - Proposed processing method and conditions
 - Open time, cure rate, viscosity
 - Final product material specifications

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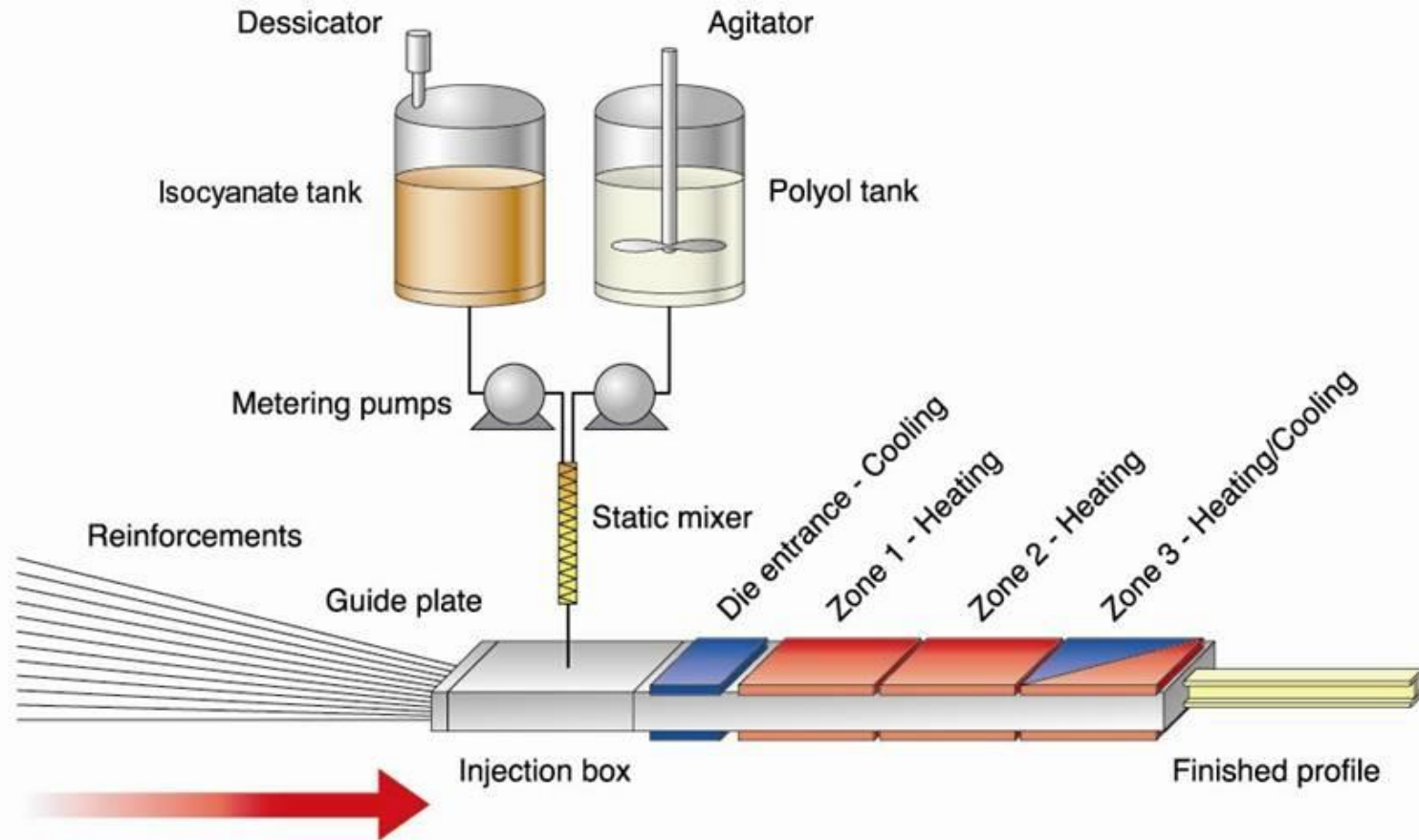
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Resin Comparison

| Resin | Advantages | Disadvantages |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Unsaturated Polyesters | <ul style="list-style-type: none"> Easy to use Cheapest resin | <ul style="list-style-type: none"> Moderate mechanical properties High styrene emissions High shrinkage on curing Only moderate env./chem resistance |
| Vinyl Esters | <ul style="list-style-type: none"> High chemical & environmental resistance Higher mechanical properties than polyesters | <ul style="list-style-type: none"> Generally requires postcure for high properties High styrene content More expensive than UPE (double) High shrinkage on curing |
| Epoxies | <ul style="list-style-type: none"> High mechanical & thermal properties High water resistance Long open (working) times possible Temperature resistance up to 140°C wet & 220°C dry Low shrinkage on curing | <ul style="list-style-type: none"> Significantly more expensive than VE Requires excellent mixing & stoichiometry More EHS requirements for handling (hardener can be corrosive) |
| Phenolic | <ul style="list-style-type: none"> High Tg – dimensional stability Inherent FR properties Corrosion resistance | <ul style="list-style-type: none"> Difficult to process High void content due to H₂O generation Very brittle |
| Polyurethane | <ul style="list-style-type: none"> Strength Toughness Impact resistance Abrasion resistance Low shrinkage | <ul style="list-style-type: none"> Short Pot life Sensitive to moisture (i.e., foaming) Requirement for 2K metering unit |

Composite Processing: *Pultrusion*



Profile with Mat

2.41mm Flat sheet with 2*230g/m2 CFM

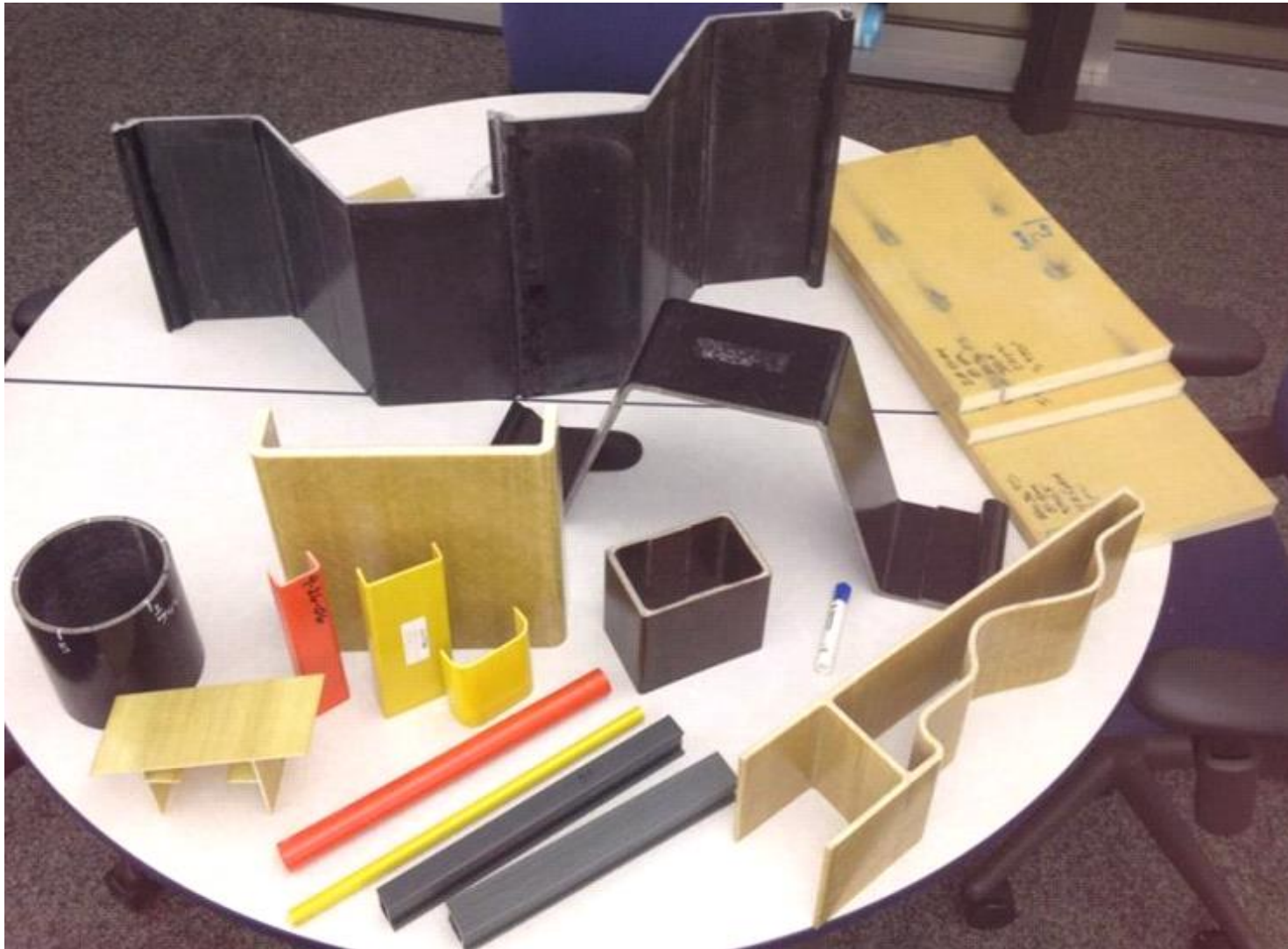
| Properties | Unit | ASTM method | PARA | PERP |
|-------------------|-------|-------------|------|------|
| Tensile Modulus | Gpa | D-638 | 36.4 | 13.3 |
| Tensile Strength | Mpa | | 776 | 78 |
| Tensile Strain | % | | 2.2 | 1.9 |
| Flexural Modulus | Gpa | D-790 | 23 | 10 |
| Flexural Strength | Mpa | | 945 | 131 |
| Flexural Strain | % | | 4.8 | 1.6 |
| Max Load | Kg | D-3763 | 420 | |
| Max Energy | J | | 24.8 | |
| Total Energy | J | | 38.4 | |
| Fiber content | Wt% | D-2584 | 68.2 | |
| Density | g/cm3 | D-792 | 1.9 | |

All Roving Profile

153*2.28mm Flat sheet

| Properties | Unit | ASTM method | PARA | PERP |
|-------------------|-------|-------------|------|------|
| Tensile Modulus | Gpa | D-638 | 52.6 | 14.3 |
| Tensile Strength | Mpa | | 897 | 45.5 |
| Tensile Strain | % | | 1.00 | 0.35 |
| Flexural Modulus | Gpa | D-790 | 54.8 | 15.4 |
| Flexural Strength | Mpa | | 1572 | 117 |
| Flexural Strain | % | | 3.00 | 0.90 |
| Shear Strength | Mpa | D-2344 | 75.3 | |
| Max Load | Kg | D-3763 | 444 | |
| Max Energy | J | | 17.6 | |
| Total Energy | J | | 33.2 | |
| Fiber content | Wt% | D-2584 | 81.1 | |
| Density | g/cm3 | D-792 | 2.13 | |

Pultrusion Samples



Polyurethane Systems for Structural Composites, Huntsman Polyurethanes

Pultrusion Samples



RIMLINE®

Composite Processing: *Filament Winding*

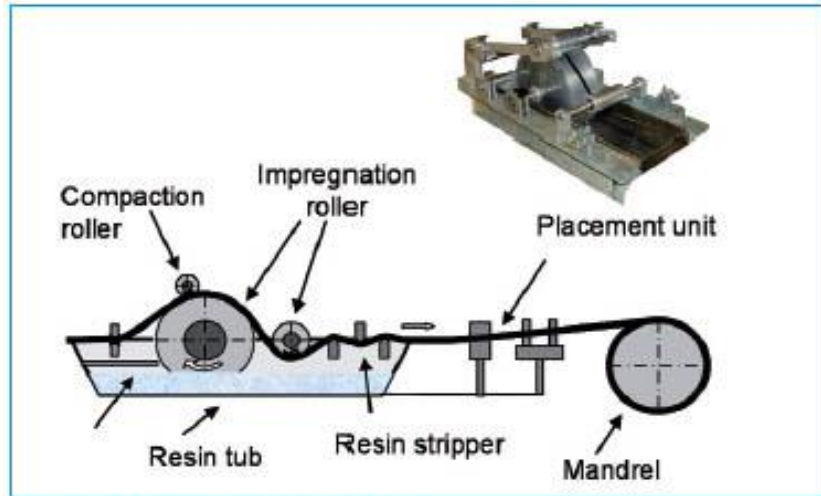


Fig. 1: Typical drum-type resin bath



snap_cure_VITROX.mp4 - Shortcut.Ink



winding_bath_open.MOV - Shortcut.Ink

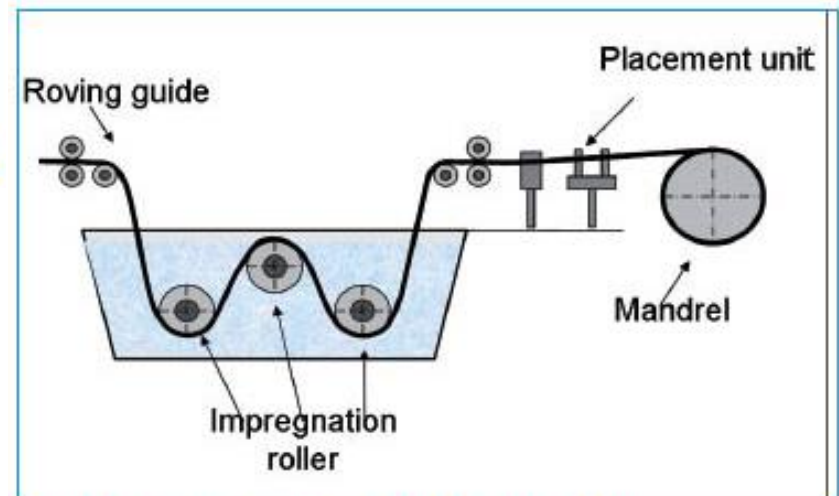
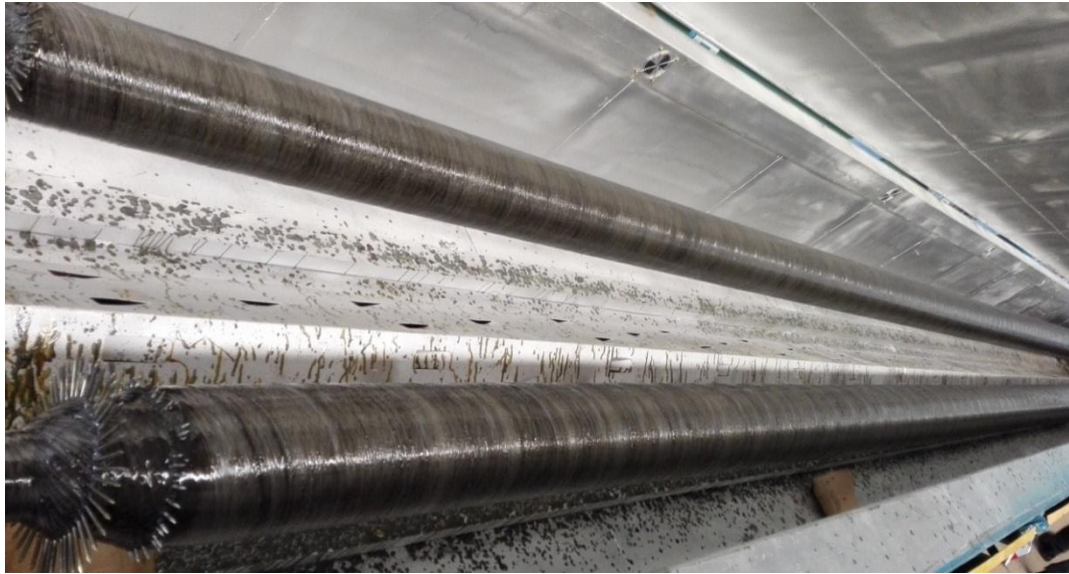


Fig. 2: Schematic representation of a dip-type resin bath

Composite Processing: *Filament Winding*



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Conclusions

- PU resins are suitable for a wide variety of composite processing methods and applications
- PU resins have demonstrated strong physical property performance with outstanding impact strength for a given resin Tg
- Low viscosity values result in easy impregnation of fibers

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