Joint Centers of Excellence for Advanced Materials

Development of Process Specification and Quality Assurance of Slit Tape for Automated Fiber Placement

Process Development & Effects of Defects

Waruna Seneviratne, John Tomblin, and Alex Martens

JAMS Technical Review
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Seattle, WA

Wichita State University

Development of Process Spec. and Quality Assurance of Slit Tape for AFP

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BOEING

AFRL
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

FEDERAL AVIATION ADMINISTRATION

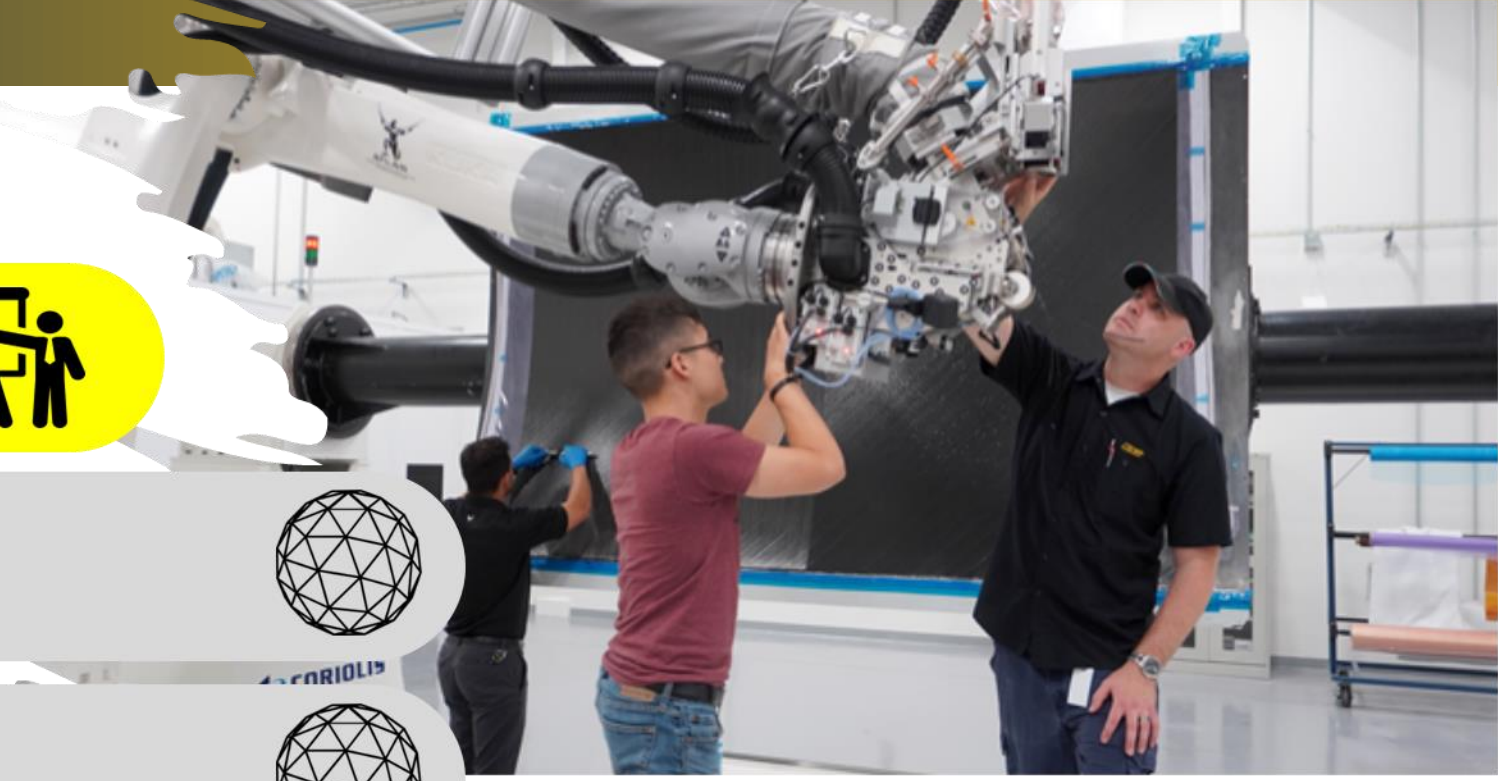
LOCKHEED MARTIN

SOLVAY

victrex

NORTHROP GRUMMAN

SPIRIT AEROSYSTEMS



Program Overview

Material Slitting

Slitting Parameters

Guidance Materials

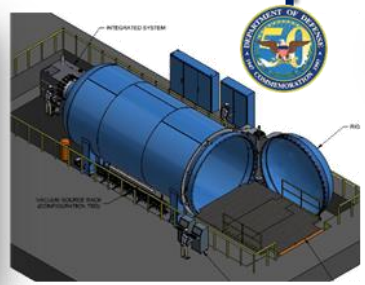
Process Specification

NAR Advanced Technologies Lab for Aerospace Systems (ATLAS)

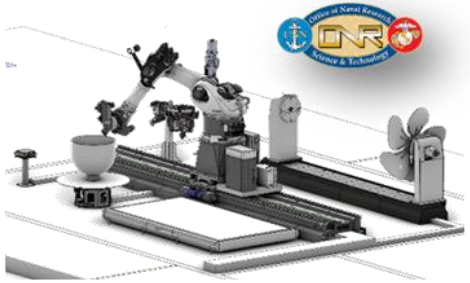
ATLAS
ADVANCED TECHNOLOGIES LAB FOR AEROSPACE SYSTEMS


Coriolis C1 AFP


Mikrosam Slitter


ASC 13'x26' Autoclave


Mikrosam Dual-Robot AFP+ATL


Electroimpact SCRAM+


XCT / UT/ PT/ LS (Sector X)


ElectroImpact AFP+ATL


UT CNC


ENGEL Thermoplastic Press (CM / IM / OM)

HP-RTM


Cevotec Fiber Patch Placement

X — January 2020 — March 2020 — C — July 2020 — E — August 2020 — May 2020 — A — November 2020 — C — February 2021 — A — July 2021 — May 2021 — A — February 2022 — March - December 2022 — A


Sector T


7,200 sq.ft.

3,600 sq.ft.


Sector E
4,700 sq.ft.


Sector A
128,000 sq.ft. (next to Spirit AeroSystems)

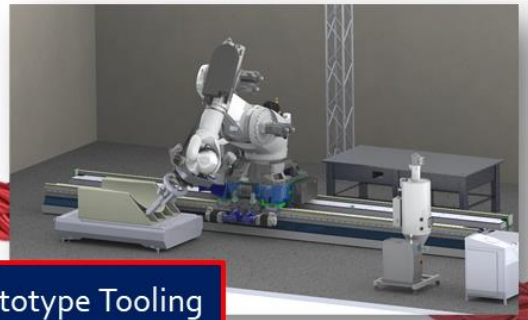
https://www.wichita.edu/research/NIAR/Laboratories/atlas.php

Comprehensive Support for Manufacturing R&D

Prepregging
(Thermoset & Thermoplastic)

Slitting
(Advanced QA)

Processing
(Oven, Autoclave)



Prototype Tooling
(AM + AFP)

Manufacturing
(AFP, ATL, FPP, TF, IM)

Inspections
(XCT, PT, LS, UT, EC)

Manufacturing Simulations
(Optimization & Cure Kinetics)

Testing
(Multi-Scale & Env.)

Background

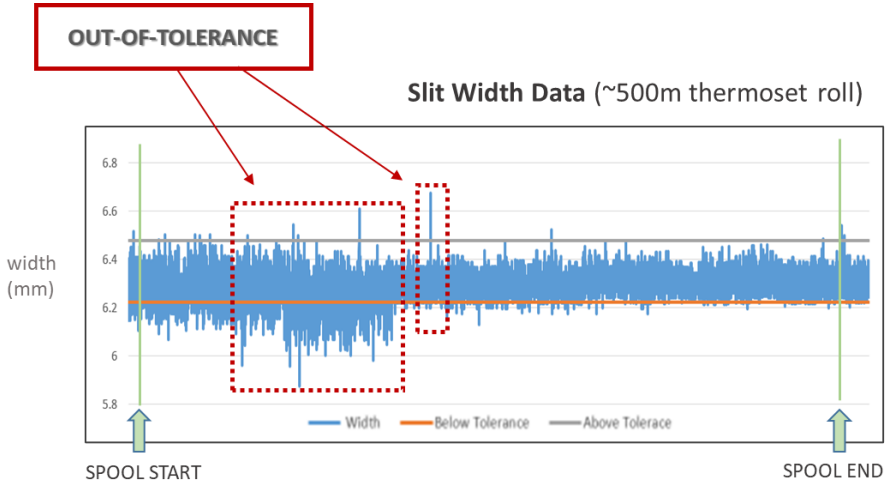
- Automated fiber placement (AFP) and automated tape laying (ATL) of fiber-reinforced composites provide great advantages in terms of production rate compared to traditional manual methods especially in high-volume environments.
  - With the ever-increasing adoption of these technologies comes challenges in material allowables due to intermediate processes that alter the prepreg to be readily acceptable by AFP/ATL machines.
  - Wide rolls of composites materials are slit to appropriate width with an appropriate width tolerance (ex, ± 0.005")
- The quality of slit tape must be maintained within the specified tolerance in order to meet required part quality and the targeted manufacturing rates.
  - Variation in slit tape widths can cause unintentional gaps and overlaps in part resulting localized porous areas or thickness variations that can result in gaps during part assembly.
  - In addition, such variation can cause unplanned maintenance of the AFP/ATL equipment due to shutdown for cleaning layup heads.

Program Goals

- Slitting process from wide roll of materials involves several steps such as unwinding of tape, separation of backing films, precision cutting, spooling, and rewinding.
  - During these steps, material travels through various blades, pulleys, and rollers that may introduce defects such as twisted or folded tows, fuzzballs, foreign object debris (FOD), and broken fibers.
  - Such defects can not only cause layup head malfunctions causing manufacturing delays, but also substandard parts that require repairs or scrap.

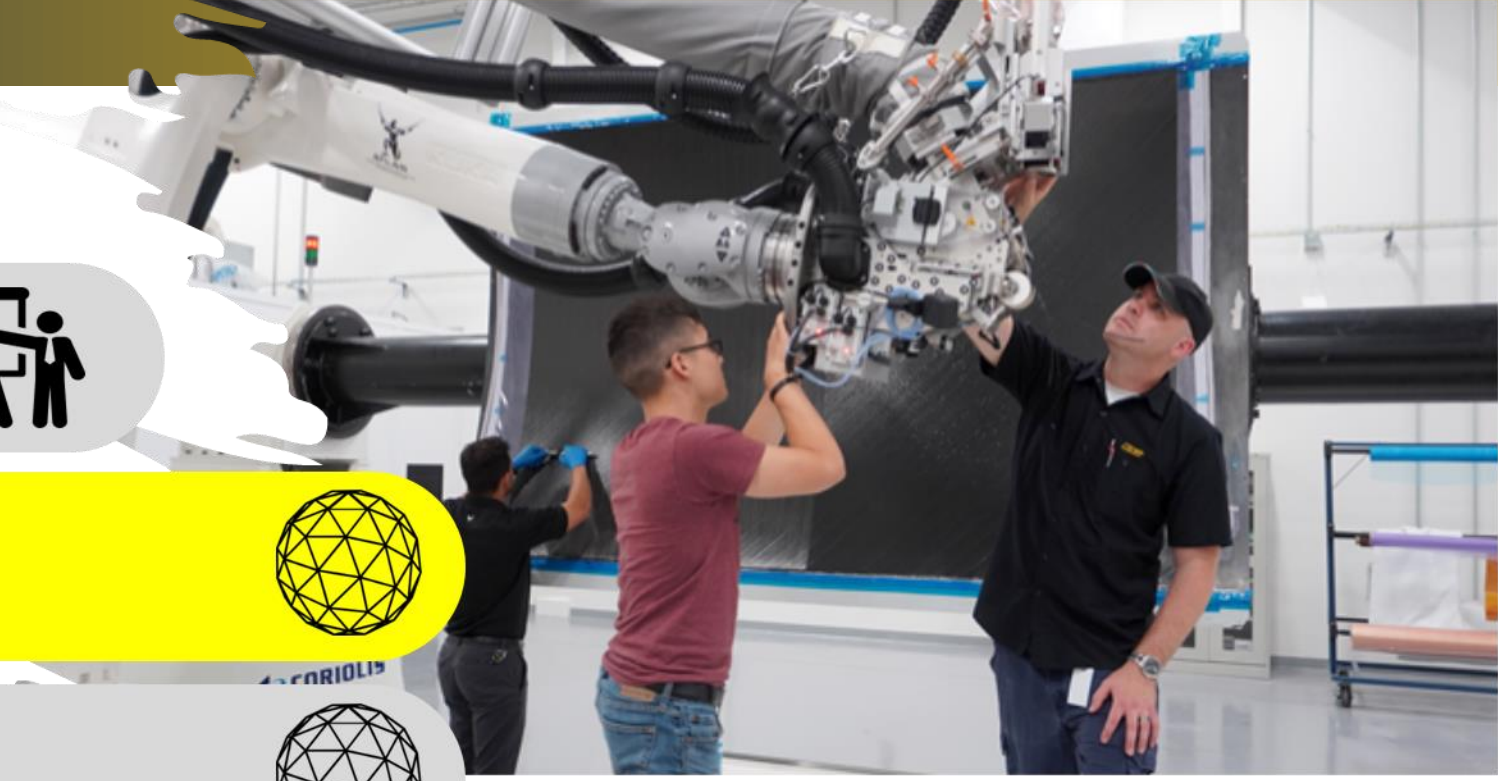
The primary goal of this research is to develop process specification and quality assurance methodologies for slitting materials for Automated Fiber Placement.

Secondary goals include an investigation into the state-of-the-art for slitting and in-process inspections and an investigation of the effects of defects or sub-standards slit tape quality on part performance.



Technical Approach

- In order to produce aerospace quality AFP/ATL parts and maintain required manufacturing rates without unscheduled maintenance and repair of equipment, it is important to control all aspects of materials and process including the quality of slit tape materials.
- Key enablers for ensuring the quality of slit tape are the in-process inspection system integrated to slitting machine along with a machine-learning algorithm for detecting manufacturing defects as well as acquiring key measurements required for quality control.
- The investigation includes the following three tasks:
  - Investigation of state-of-the-art (SOA) equipment for slitting and in-process inspections.
  - Development of an industry-standard process specification for slitting thermoset, thermoplastic, and dry fiber materials for AFP and ATL.
  - Investigate the effects of slit tape quality on the manufacturing quality of AFP/ATL parts.



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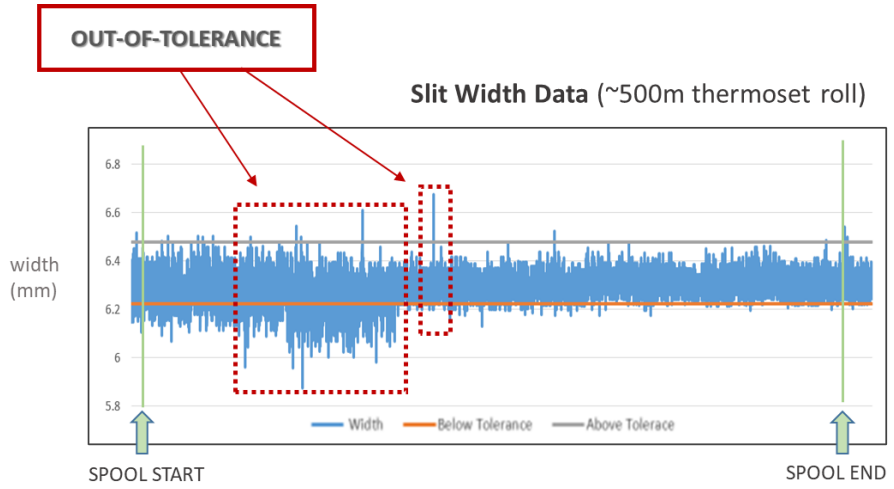
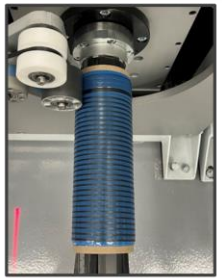
Quality Assurance of Automated Fiber Placement

Inspections are carried out after every layer to ensure quality

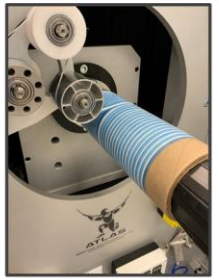
Prepreg Slitting at NIAR ATLAS

- Wide Tape Slitting (up to 24-inch)
  - Single or double backing film/paper removal
- Narrow Tape Slitting (12-inch or less)
  - Direct Slitting of ½" and ¼" tape to 8 winded spools
  - Transverse winding and spool customization
- Thermal and pressure splicing
- IPLIS (In-Process Laser Inspection System)
  - Detect: Fuzzballs, FOD, Splice, Twist, Out of tolerance
- Quality Management System



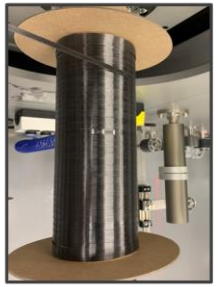


THERMOSET



CMC

WEAVE/FABRIC



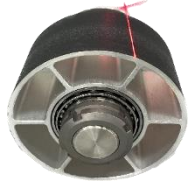
THERMOPLASTIC

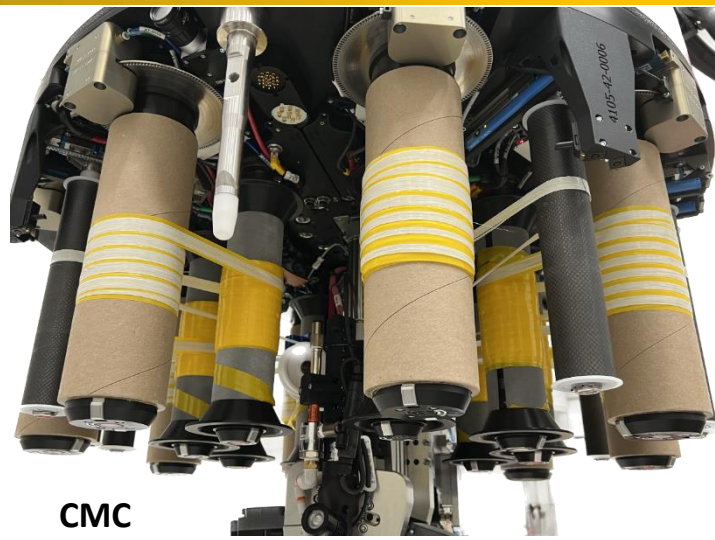
Capabilities

THERMOPLASTIC

IPLIS

(In-Process Laser Inspection System)



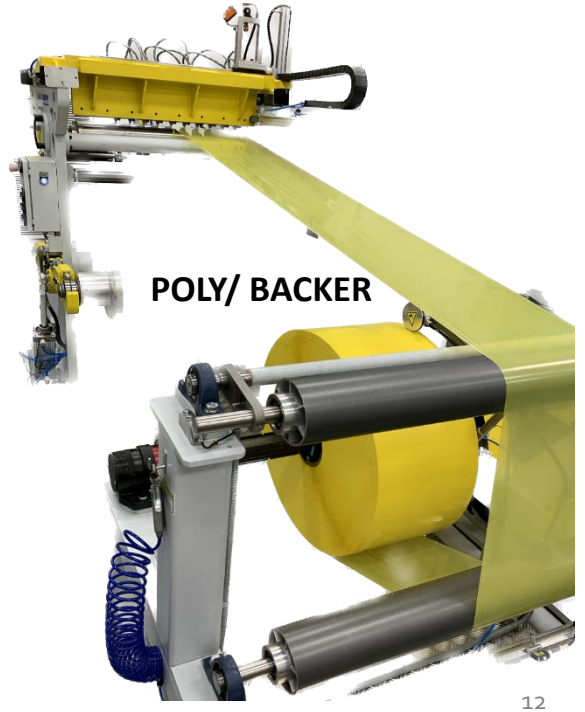


CMC

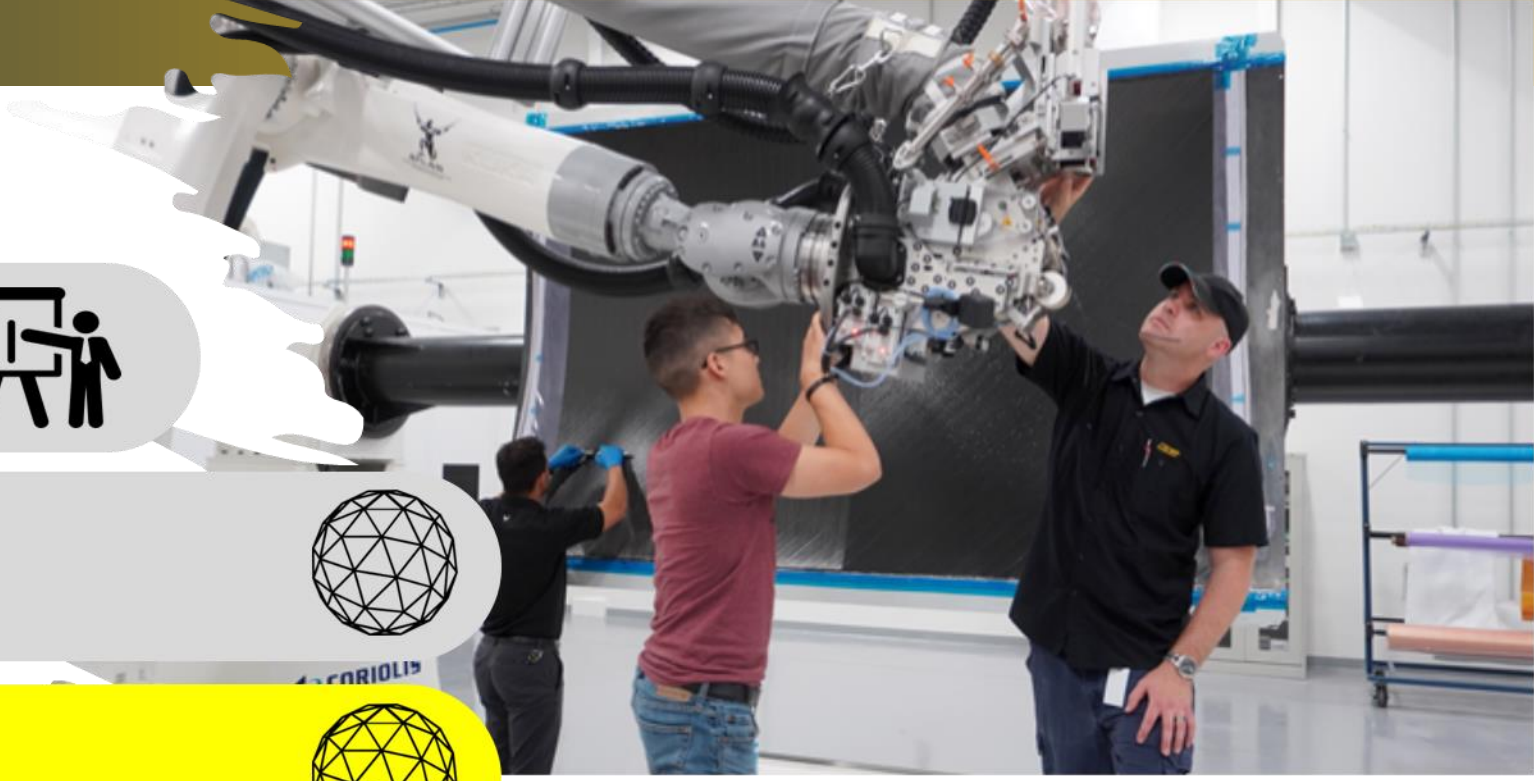
WEAVE

THERMOSET

FIBER PATCH PLACEMENT



POLY/ BACKER



Program Overview

Material Slitting

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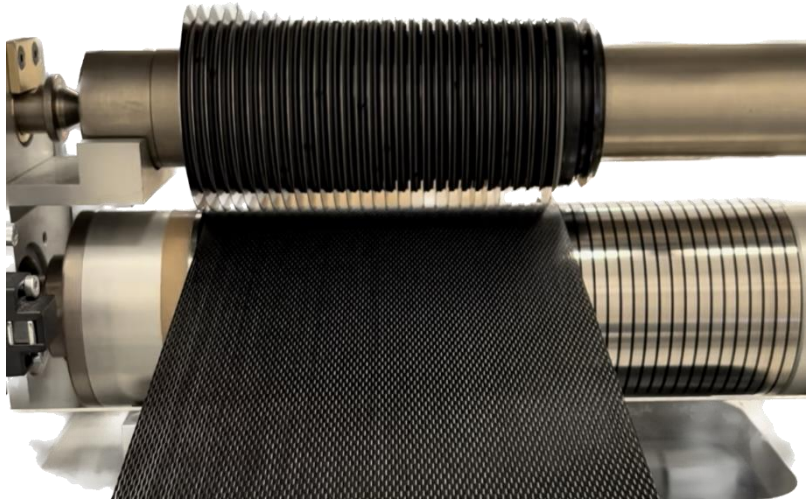
Process Specification

Development of Process Specification for AFP Tape Slitting

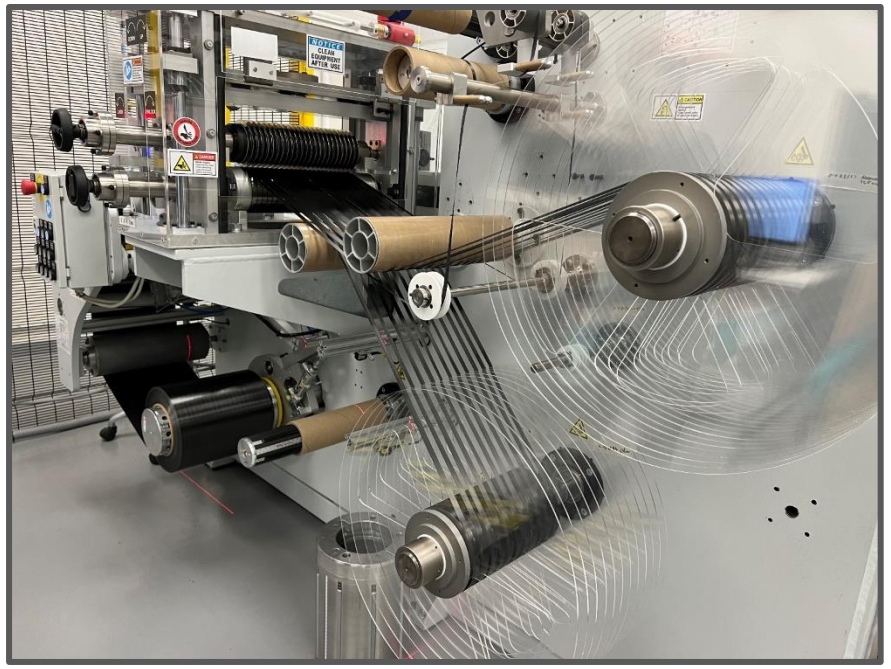
Scope	Work Instructions	Personnel Requirements	Materials	Facilities	Equipment Calibration	Preventative Maintenance	Manufacturing Control	Post-Slit Operations	Inspection and QA Requirements
- Specification Overview. What is this document looking to accomplish?	- Required information before operation. - Required equipment/ environmental conditions before operation.	- Suitable # of operators. - Physical requirements - Required training	- Suitable materials for slitting. - Optimal machine settings for thermosets, thermoplastics and CMC's.	- Environmental requirements - Emergency Response. Loss of power, shop air, Temp/humidity	- Tension, load cell, edge/prox sensor calibration - Blade assembly alignment	- Machine maintenance plan - Cleaning practices	- Requirements to ensure safe/smooth operation. - Scrap prevention.	-Proper bagging/storage - Standardized labeling - Proper handling, transport and storage practices.	- IPLIS config+calib - Keyence TM-065 - Minimum inspection guidelines

WHAT IS REQUIRED FOR AN EFFICIENT SLITTING OPERATION?

Personnel Requirements



Material Compatibility



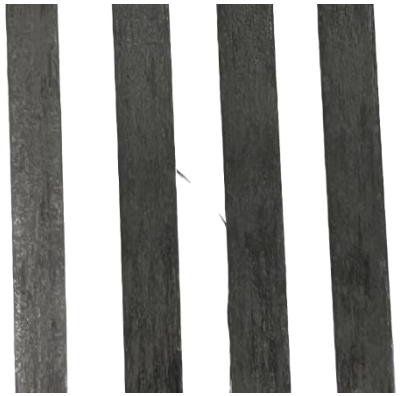
Facilities & Preventative Maintenance

Guideline Document for AFP Tape Slitting

DEFECT TOLERANCE GUIDELINES

Spools/Cores	Splicing	Winding Parameters	Backer/ Carrier	Splice	Slit-Width	FOD/ Fuzzballs	Edge Quality/ Stringers
- Standardized spool dimensions - Spool formatting * Designs * Materials - Standardized Flanges *Adhesion	- Overlap Length - Frequency - Temperature - Pressure - Standard Markings *color/spacing - In-line Tension	TAPER vs LEVEL - Winding Length - Taper Angle - Tow Spacing - 1/4in vs 1/2in vs - Max Weight/Dimension	- Backer Thickness - Backer Width vs Material Width - Release Level - Stretch Factor - Centering/Alignment	- Overlap Length - Frequency - Temperature - Pressure - Standard Markings - In-line Tension	- Allowable Over/Under Tolerance - Prevention - Corrective Action	-Allowable Size/ Frequency - Prevention - Corrective Action	- Allowable Length/ Frequency - Prevention - Corrective Action

WHAT IS REQUIRED FOR OPTIMAL OUTPUT?



Allowable Defects

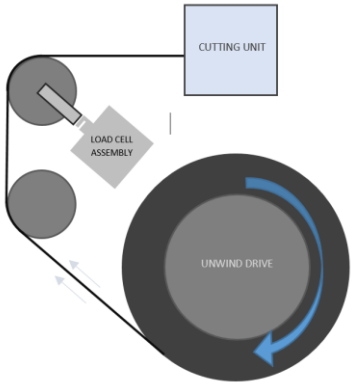
Spool Format

Packaging & Labeling

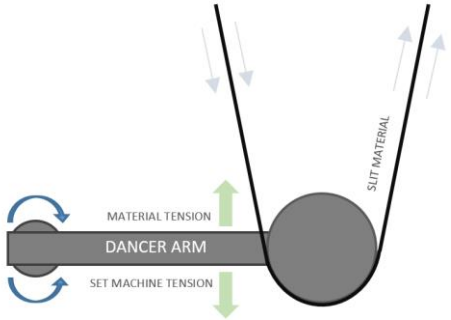
Shipping Requirements

Slitting Parameters

TENSION MONITORING

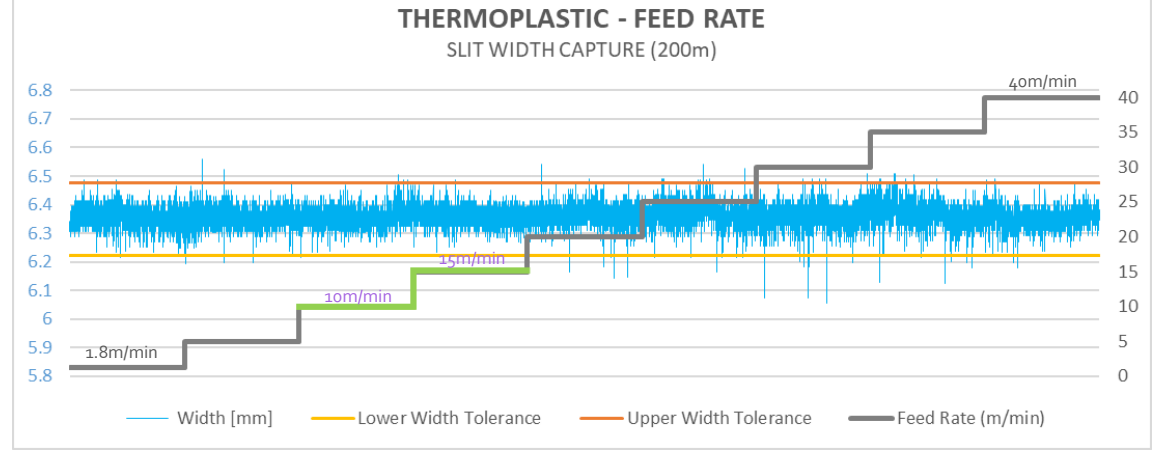


Before Blades

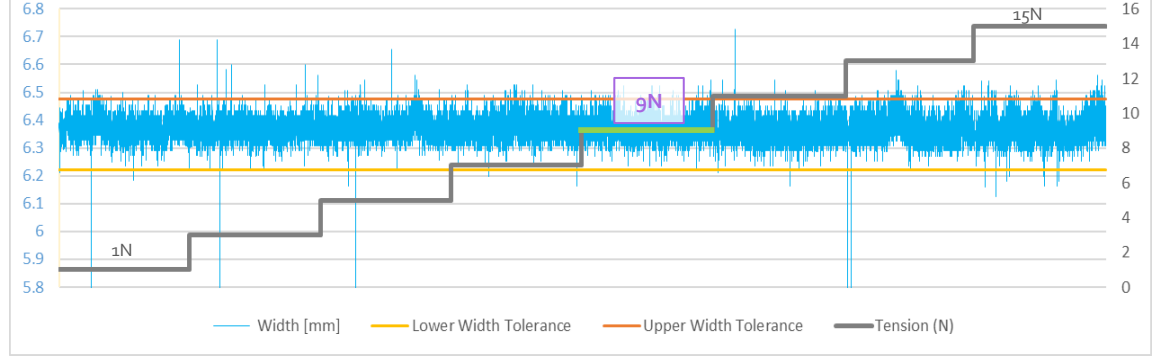


Before Finished Spool

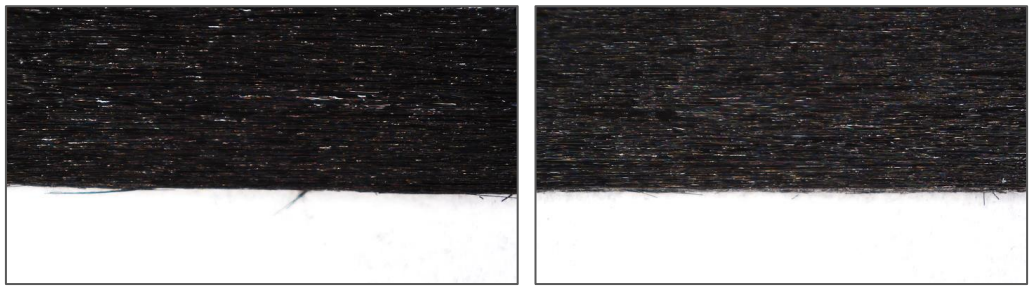
	Length of Roll									
	0m-20m	21m-40m	41m-60m	61m-80m	81m-100m	101m-120m	121m-140m	141m-160m	161m-180m	181m-200m
Feed Rate	MIN	5m/min	10m/min	15m/min	20m/min	25m/min	30m/min	35m/min	40m/min	-



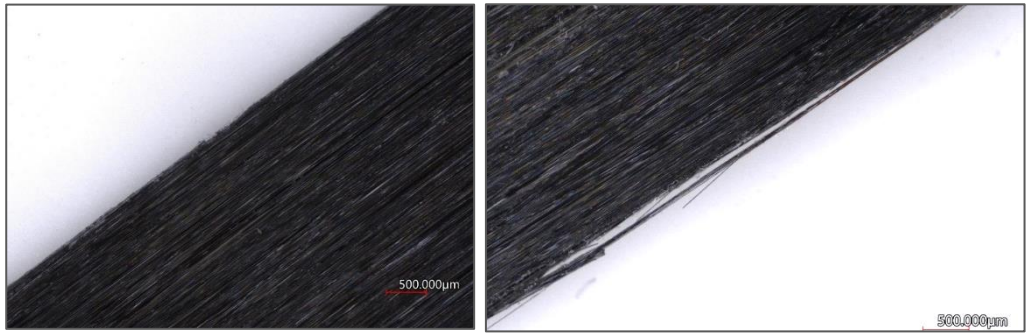
	Length of Roll									
	0m-20m	21m-40m	41m-60m	61m-80m	81m-100m	101m-120m	121m-140m	141m-160m	161m-180m	181m-200m
Tension	1N	3N	5N	7N	9N	11N	13N	15N	17N	20N



Slitting Parameters

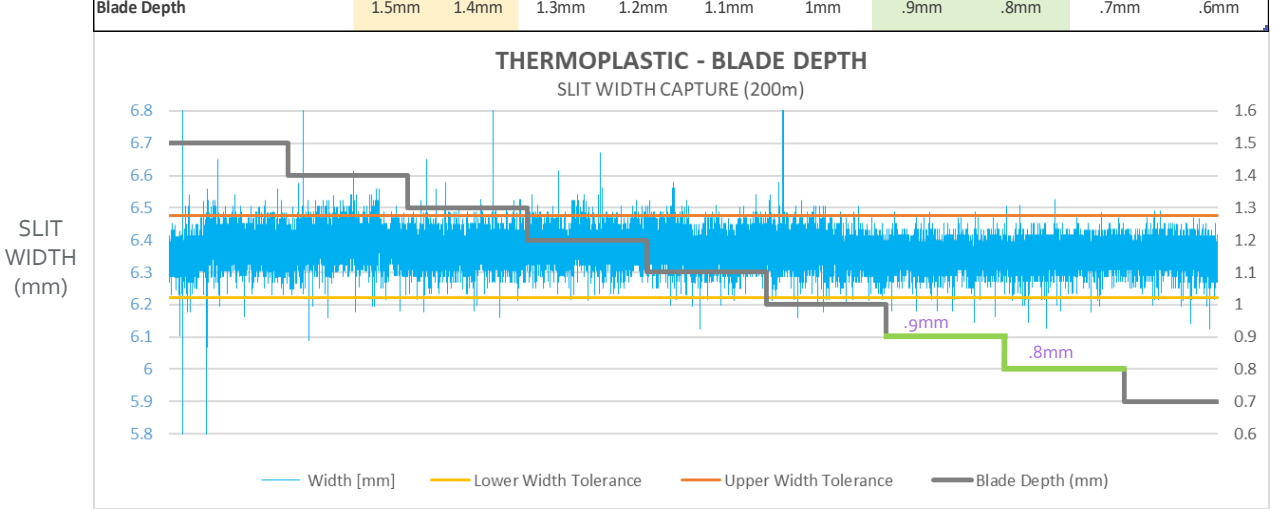


Thermoplastic Blade Depth Trials – 1.5mm (left) vs .7mm (right).

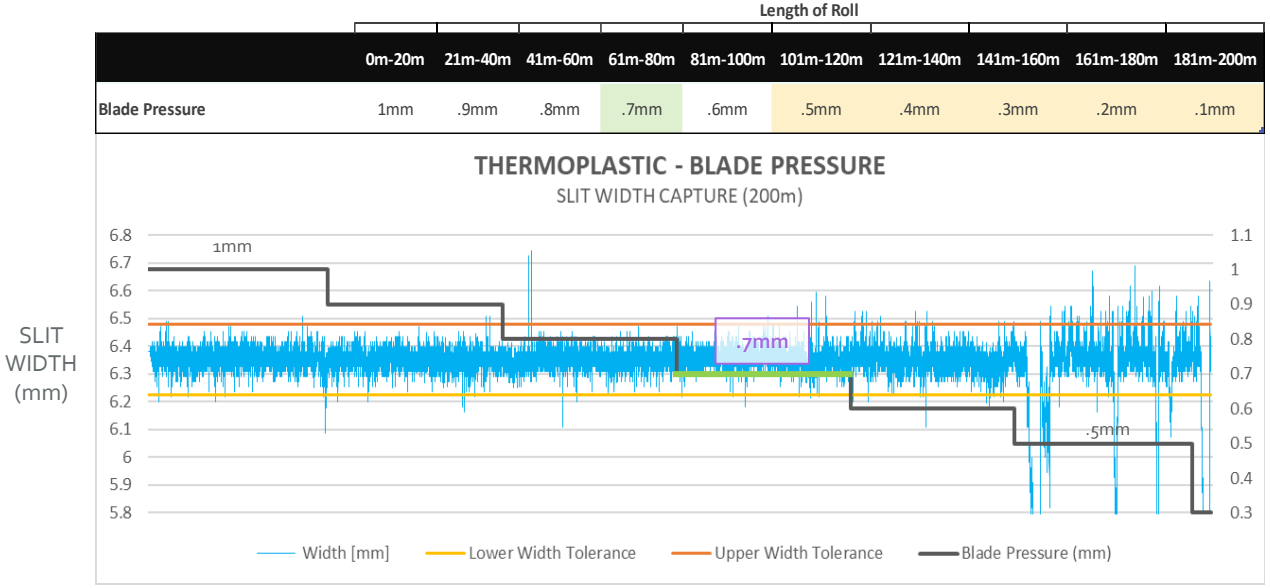


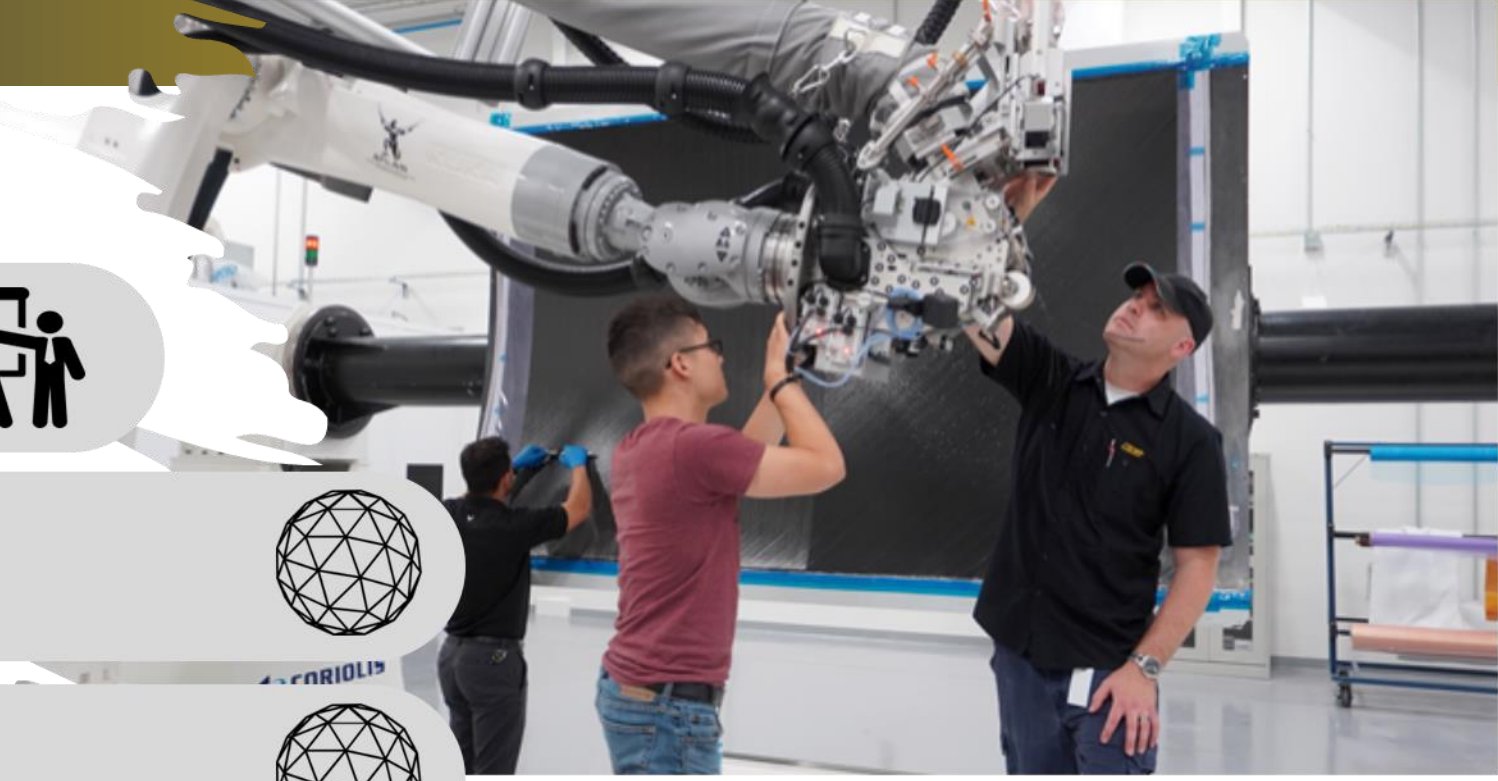
Thermoplastic Blade Pressure Trials - 1mm (left) vs 4mm (right).

	Length of Roll									
	0m-20m	21m-40m	41m-60m	61m-80m	81m-100m	101m-120m	121m-140m	141m-160m	161m-180m	181m-200m
Blade Depth	1.5mm	1.4mm	1.3mm	1.2mm	1.1mm	1mm	.9mm	.8mm	.7mm	.6mm



	Length of Roll									
	0m-20m	21m-40m	41m-60m	61m-80m	81m-100m	101m-120m	121m-140m	141m-160m	161m-180m	181m-200m
Blade Pressure	1mm	.9mm	.8mm	.7mm	.6mm	.5mm	.4mm	.3mm	.2mm	.1mm





Program Overview

Material Slitting

Slitting Parameters

Guidance Materials

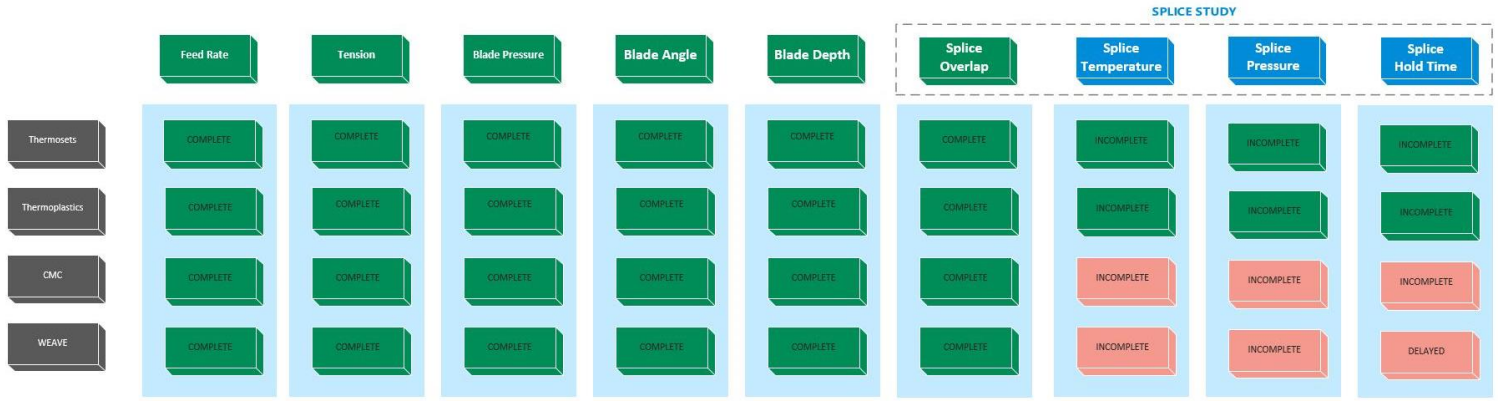
Process Specification

Slitting Parameter Study

- Feed rate
- Tension
- Blade Pressure
- Blade angle
- Splice Overlap
- Splice Temperature
- Splice Pressure
- Splice Hold Time

Splicing Study

- Materials
  - Thermoset
  - Thermoplastic
  - CMC
  - Weave



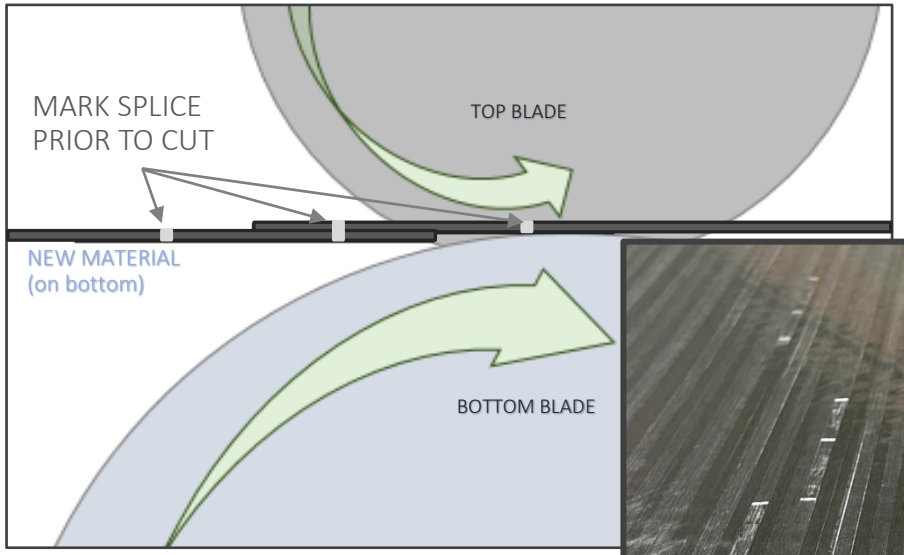
Splice Overlap

Splice overlap is a critical measurement when adhering two ends of material into one continuous tow. Too much overlap can cause issues over tight-radius rollers and too little overlap can result in a broken splice. Zero overlap, where the material edges are aligned, is considered a butt-splice which requires tape. Most often, tape is avoided for AFP layup due to the damage on the end part. Replacing this with an overlap thermal splice will avoid this issue and help maintain smooth layup during AFP stages.

THERMAL SPLICE

BUTT-SPLICE

OVERLAP ORIENTATION



THERMOPLASTICS
(TC1225 LM PAEK, T700GC 24K)

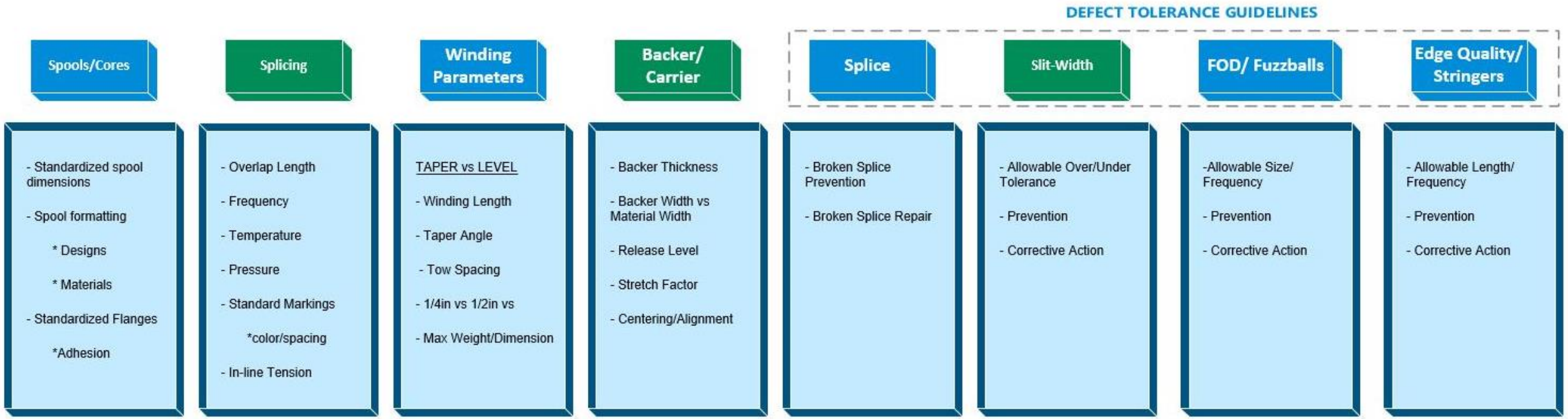
Splice Overlap - Through Blades (7N)	.25in	.5in	.75in	1in	1.25in	1.5in	1.75in	2in
	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Splice Overlap - Through Rollers (7N)	.25in	.5in	.75in	1in	1.25in	1.5in	1.75in	2in
	PASS	PASS	PASS	PASS	FAIL	PASS	PASS	FAIL

THERMOSETS
(T800 24K 3900G)

Splice Overlap - Through Blades (7N)	.25in	.5in	.75in	1in	1.25in	1.5in	1.75in	2in
	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
Splice Overlap - Through Rollers (7N)	.25in	.5in	.75in	1in	1.25in	1.5in	1.75in	2in
	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS

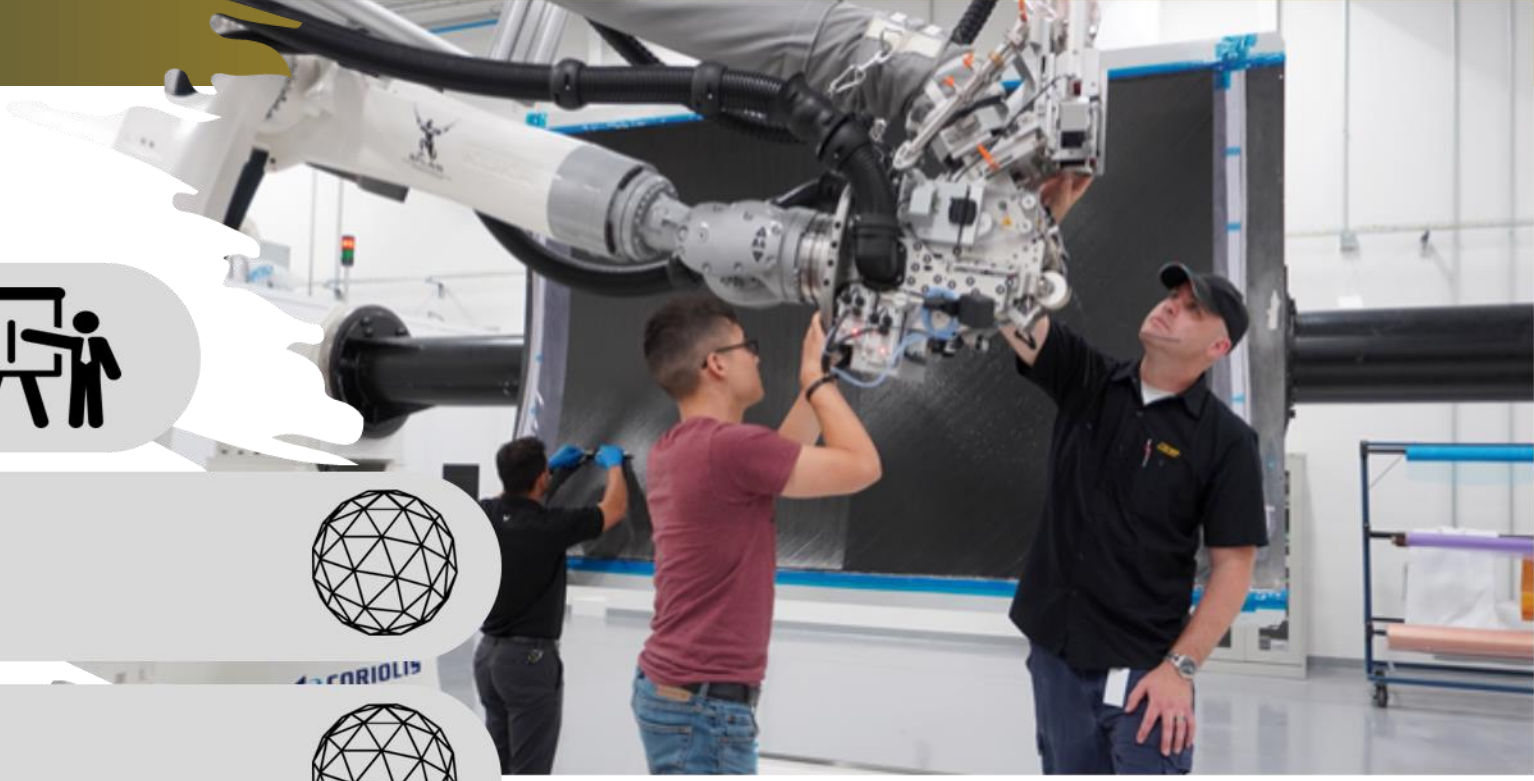
STATUS	COLOR
Optimal	
Operational	
Issues Occurred	
Error	

Guideline Document



Effects of Defects

Efficiency Performance			vs.	Mechanical Performance			
Backing (Width, Tension,Compatability)	Winding Parameters	Stringers (Time Trial)		Splicing	Fuzzballs/FOD	Twisted Tows	Slit Width
Thermosets	Thermosets	Thermosets		Thermosets	Thermosets	Thermosets	Thermosets
CMC	Thermoplastics	Thermoplastics		Thermoplastics	Thermoplastics		Thermoplastics
	CMC						



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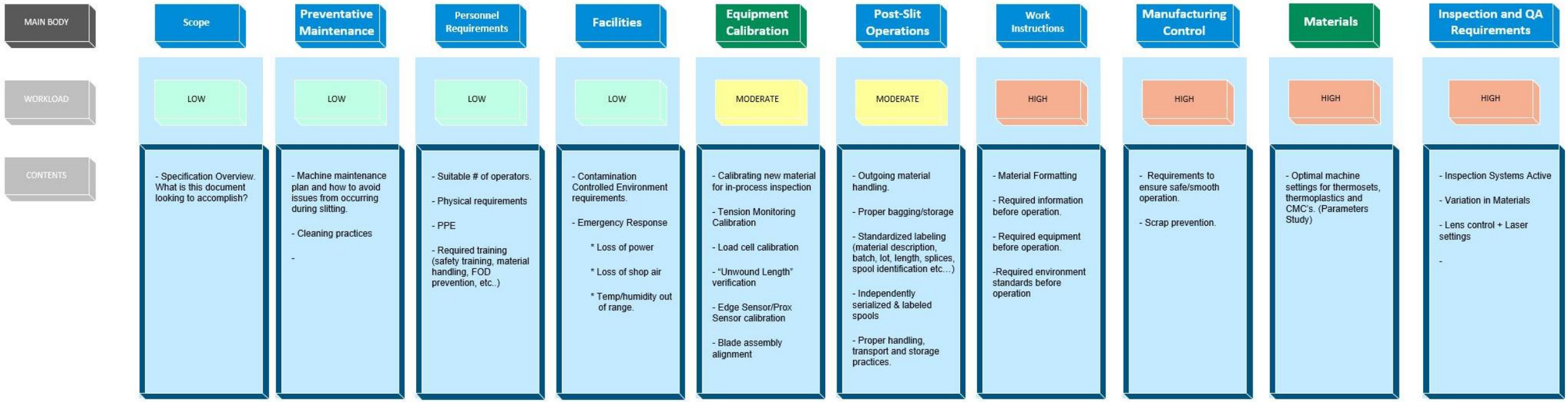
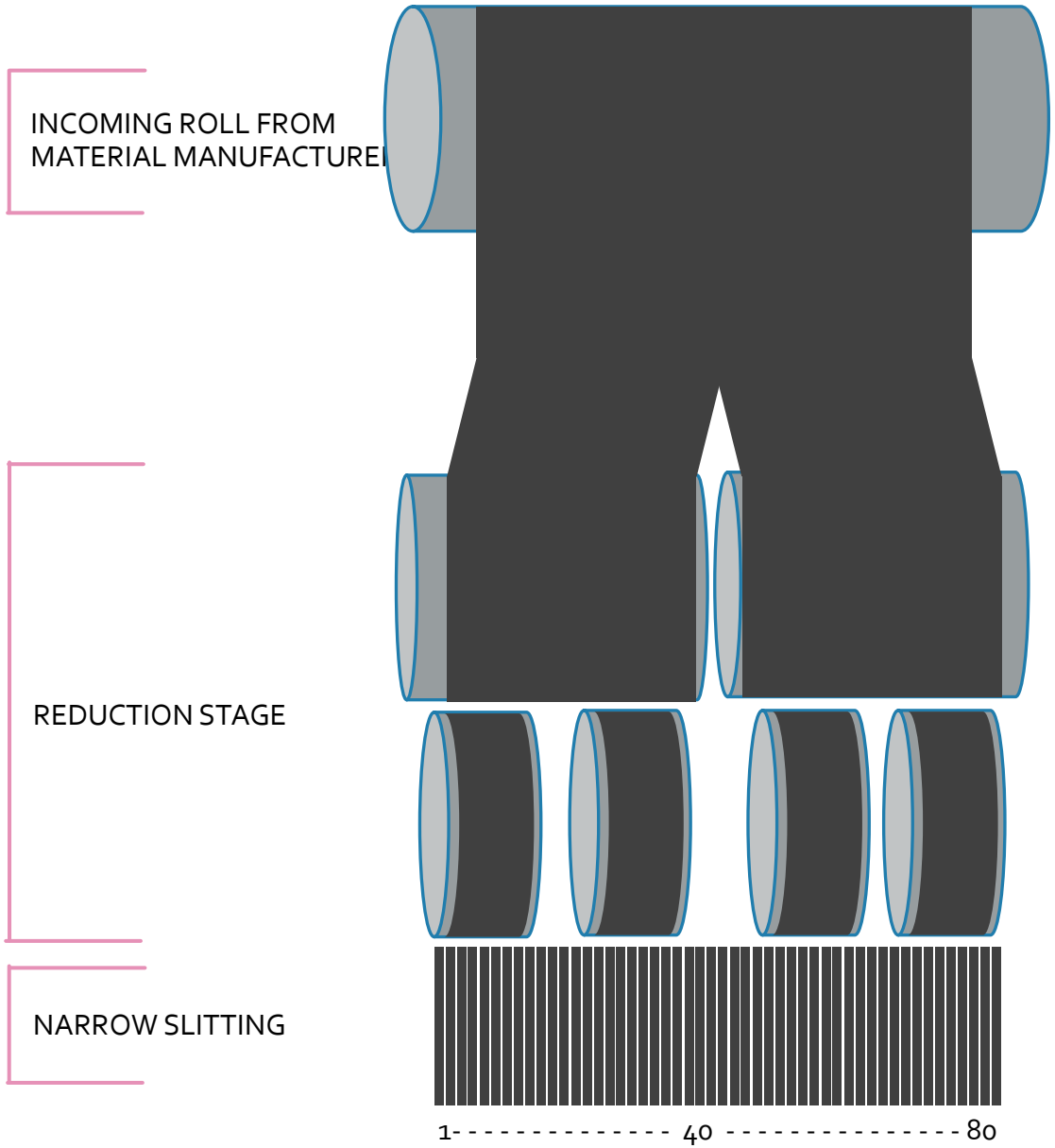
Process Specification

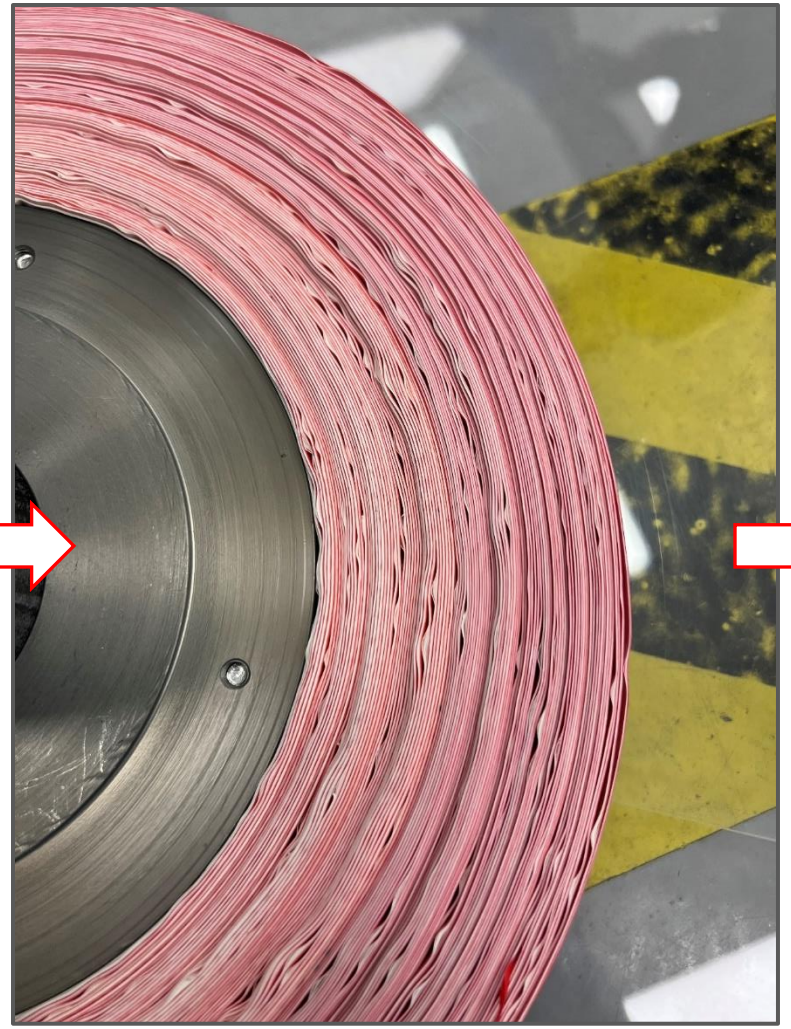


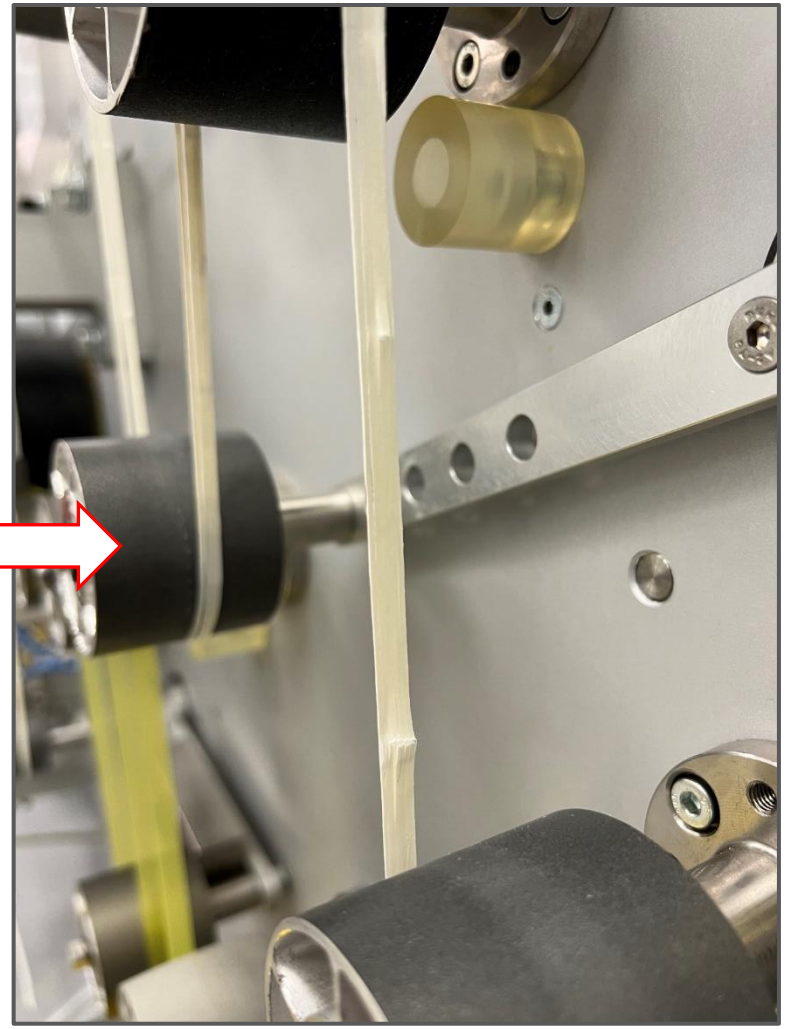
Traceability



- Developing traceability methods to account for and track every portion of an incoming roll front to back and left to right. If a material manufacturer has concerns for dry or heavy resin areas on their roll, fuzzballs, splits, etc..
- We can relay where those defects occurred on the width and length.
- Feedback to improve the prepregging process for higher quality material while reducing outgoing defects and scrap at the user end.
- Expanding this strategy and track those individually categorized tows into the layup stage of AFP.
- Each outgoing spool is serialized and tied to individually serialized slit tows. This ensure the entirety of the role is accounted for and recorded.

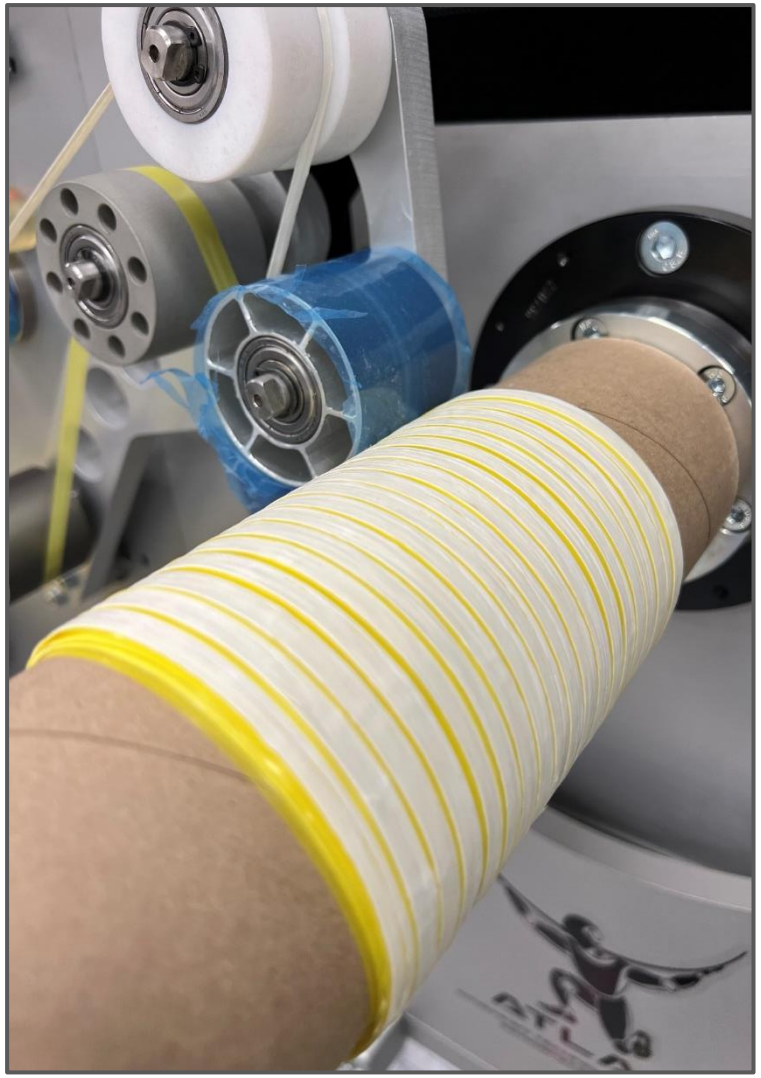
Effects of Waviness in the Carrier on CMC





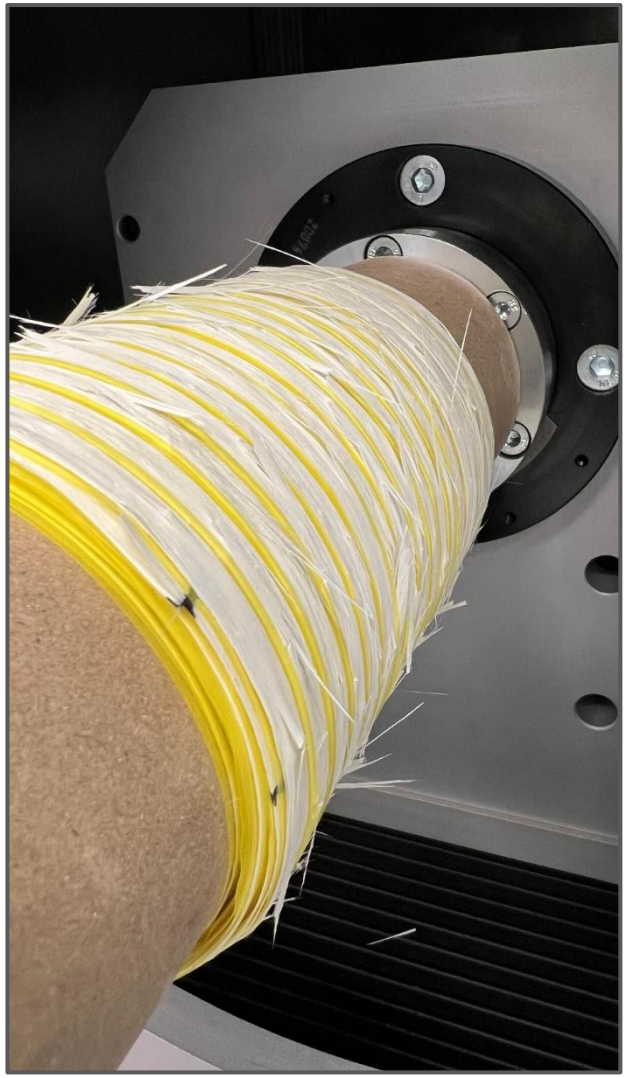
Waves caused by the carrier on the parent roll resulted in broken fibers later on during rewinding.

Inconsistent Tack Level



Proper resin/tack level

Same roll
~4om apart

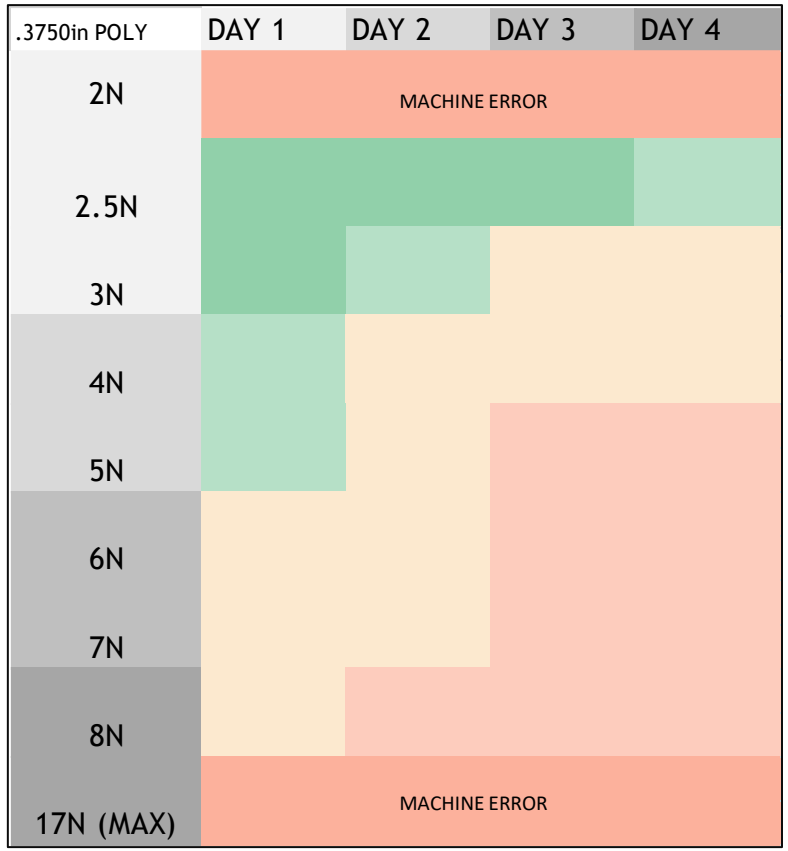


Dry material causing fray

Various levels of tack within a roll can cause issues while rewinding. Too much tack can cause issues with blade buildup and material dryness can cause excessive fray. With the radius of the rollers and finished spool, the material would fray and break causing non-conforming sections of the spool.

Poly Carries Tension

POLY CARRIER PARAMETERS STUDY
TENSION OVER TIME



Poly tension optimal and aligned with material

Higher poly tension caused material bubbling

MATERIAL SYSTEM: Toray T800-3900
CARRIER MATERIAL: .3750in width x 2mil thickness poly
TOTAL CUT LENGTH: ~2,600ft

DESCRIPTION: NIAR conducted a parameters study focusing on the tension of poly carrier during the rewinding process. With an incremental adjustment in tension to the carrier only, we analyzed the rewind quality and the stretching/retraction impact over a four-day period. We found that the lower the tension the better as long as the carrier aligns with the material on the finished spool.

RESULTS: Not enough tension causes slack in the poly and steers away from the center of the tow during rewinding. Too much tension causes stretching/retracting in the poly over time resulting in non-conforming material and bubbling.

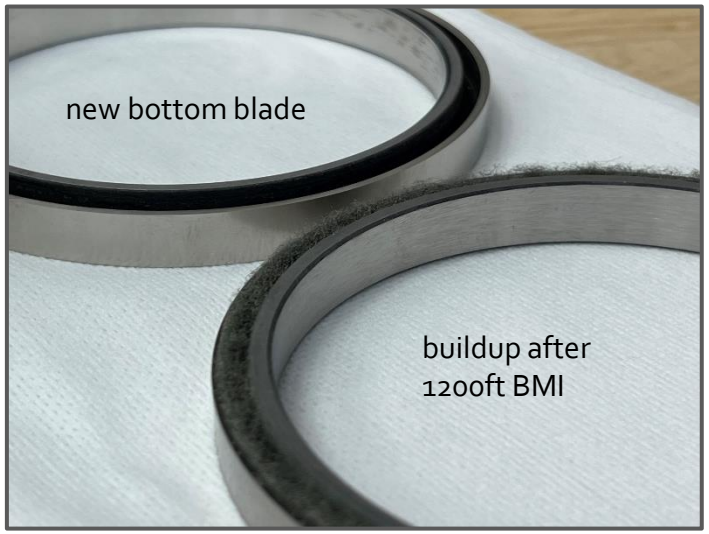
BMI Trials

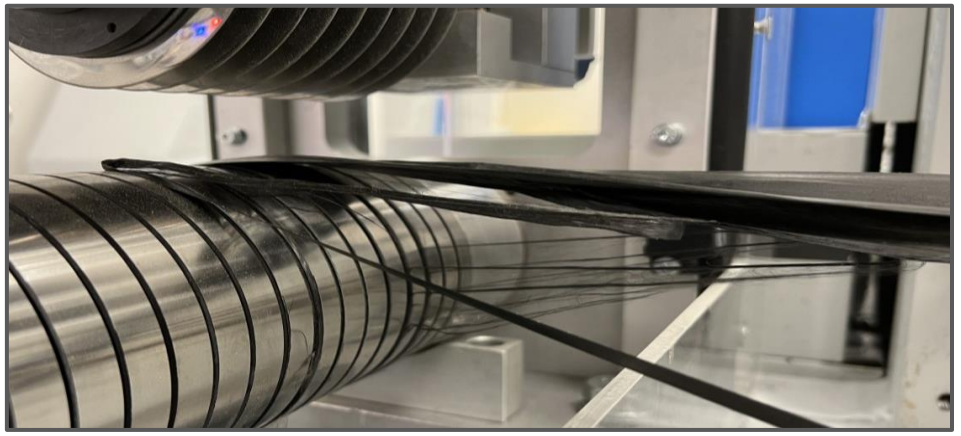
WIDE-TAPE

Removing poly pre-cut results in fiber pull

Removing poly post-cut prevents error

NARROW-TAPE





64,908ft of .5in slit tow

Processed through ElectroImpact

Shear style blades on the narrow-tape unit performed better than crush cut blades on the wide-tape. Cut quality was in-tolerance with minimal edge fray. Blade buildup caused issues after ~1000ft continuous. Standard rewinding parameters applied.

Summary

- In order to meet the quality requirements associated with AFP/ATL process, it is imperative that the slitting process produce slit tape to meet required specifications, which includes dimensional tolerances and requirements for defects-free slit tape.
- Several key in-process inspections and machine-learning algorithms for detecting defects during slitting and develop slitting specifications for thermoset, thermoplastic, and CMC will be evaluated for slitting and automated fiber placement.
- Calibration and verification procedures for in-process inspection systems will be developed for quality assurance and traceability.
- Guidance materials will be developed for determining acceptance limits
  - Effects of slit tape quality
  - Effects of slit tape quality on AFP operational efficiency

Looking Forward / Future Work

- Benefit to Aviation
  - Industry standard process specification and quality assurance methodologies for slitting materials for automated fiber placement.
  - An investigation into the state-of-the-art for slitting and in-process inspections
  - Investigation of the effects of slit tape quality on part performance
  - Identification of critical slitting parameters impacting the slit tape quality
- Next Steps:
  - Complete slitting parameter evaluation
  - Develop manufacturing and test plan for effects of slit tape defects on AFP part quality
  - Develop guidance materials and slitting specification