Innovative Composites Manufacturing Solutions

Since 1990

Manufacturing Solutions and Properties of Thermoplastic Composites

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Outline

- Company highlights
- MIKROSAM's thermoplastic manufacturing solutions
- Experimental part
- Conclusion and the future of thermoplastic composite

Company Highlights

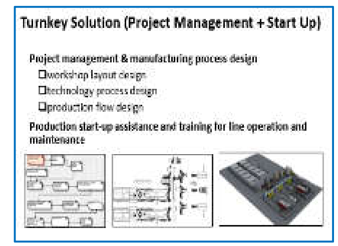



Company established	1990
Synonym for Innovative composites manufacturing solutions:	Specializing in all advanced technologies for manufacturing of composite parts
Technical areas of focus:	❑ Composites production expertise ❑ Motion control and process automation ❑ Specialized software development
Workforce:	❑ Engineers: 58% ❑ Production personnel: 31%
General Activities:	Manufacturing, R&D, Education

R&D Support to Customers

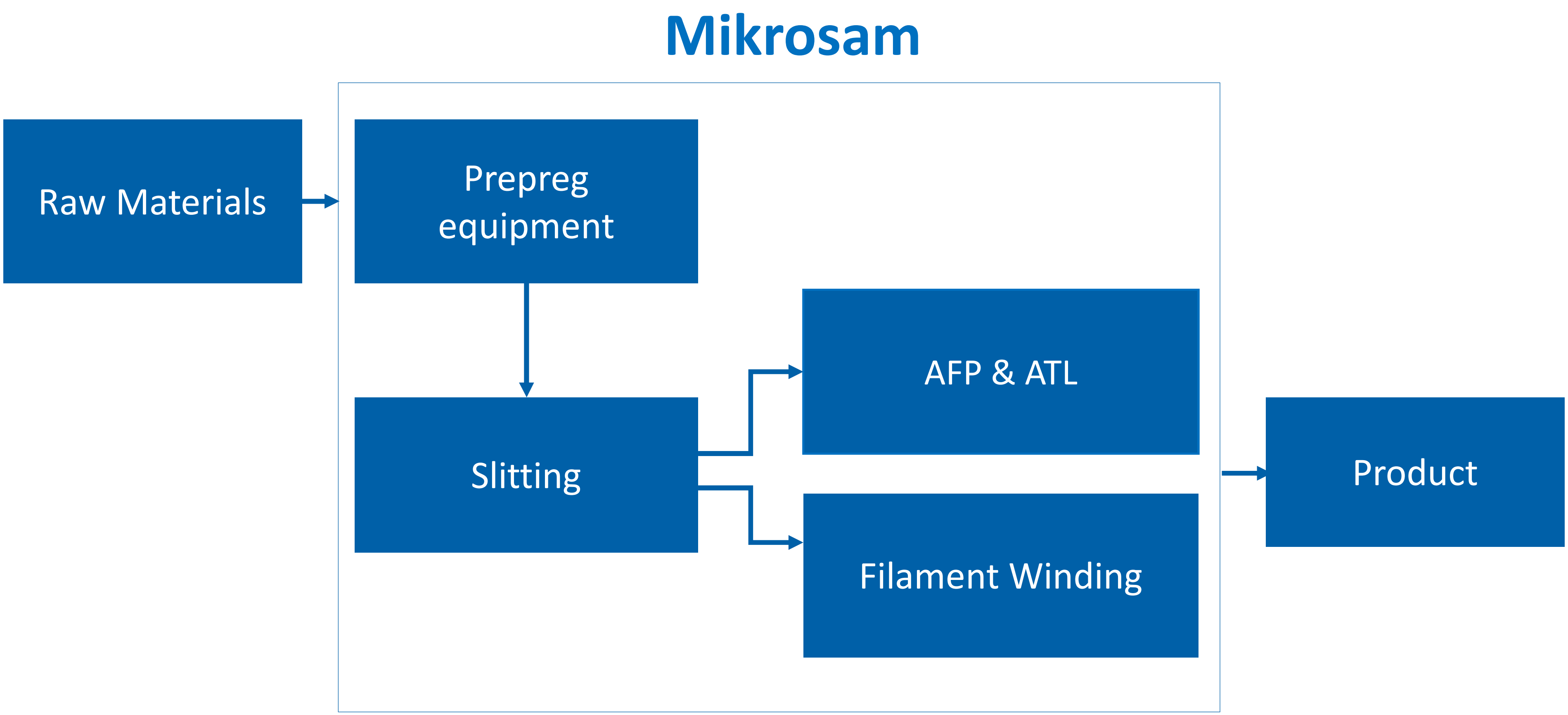
Institute for Advanced Composites and Robotics

- R&D assistance
- Full design and development support
- Technology process testing, manufacturing samples or prototypes
- Services include:
  - new product or technology development
  - testing and supervising
  - equipment and process operation training
  - feasibility reports
  - project management and start-up assistance
  - know-how and technology transfer



MIKROSAM's Thermoplastic Manufacturing Solutions

Mikrosam in the Process of Manufacturing Thermoplastic Composites



Experimental part:

Properties of Thermoplastic Composites

Why Thermoplastic Composites?

Benefits

- Durability
- Fatigue
- Corrosion
- Toughness
- Unique properties
- Vibration dampening
- Light weight
- Potential for low cost
- Shelf life
- Recyclable

Limitations

- Cost
- Materials
- Manufacturing
- Tooling
- Design know-how
- Manufacturing know-how
- Use high temperature

On-Line Consolidation System

In our experiments

- Laser Heating
- Hot Gas Heating
- Infrared Heating

On-Line Consolidation System

Qualitative Comparison of Three Heat Sources

	Hot Gas Torch	Laser Beam	Infrared Light
Energy Efficiency	- -	+	+/-
Response Time	-	++	+/-
Size	+ +	-	+/-
Weight	+ +	-	+
Price	+/-	-	+

Note: + Good; ++ Very good; - Bad; - - Very bad; +/- Average

Main Purpose

- The influence of manufacturing parameters on flexural strength of thermoplastic tape (UD prepreg) samples
- Samples manufactured with LATP technology with different
  - speed
  - pressure of contact roller (compaction force)
  - temperature of laser
- Flexural strength tested on universal testing machine

Materials for Experiment

- LATP 1: UD tape CF/PPS, 0.19 mm thickness
  - fiber volume fraction of 60 ± 3% width 1"(25,4mm)
- LATP 2: UD tape CF/PEEK, 0.19 mm thickness
  - fiber volume fraction of 60 ± 3% width 1"(25,4mm)
- LATP 3: UD tape CF/PEKK, 0.14 mm thickness
  - fiber volume fraction of 60 ± 3% width 1"(25,4mm)




Thermoplastic Unidirectional Prepreg (UD)

Variables in LATP

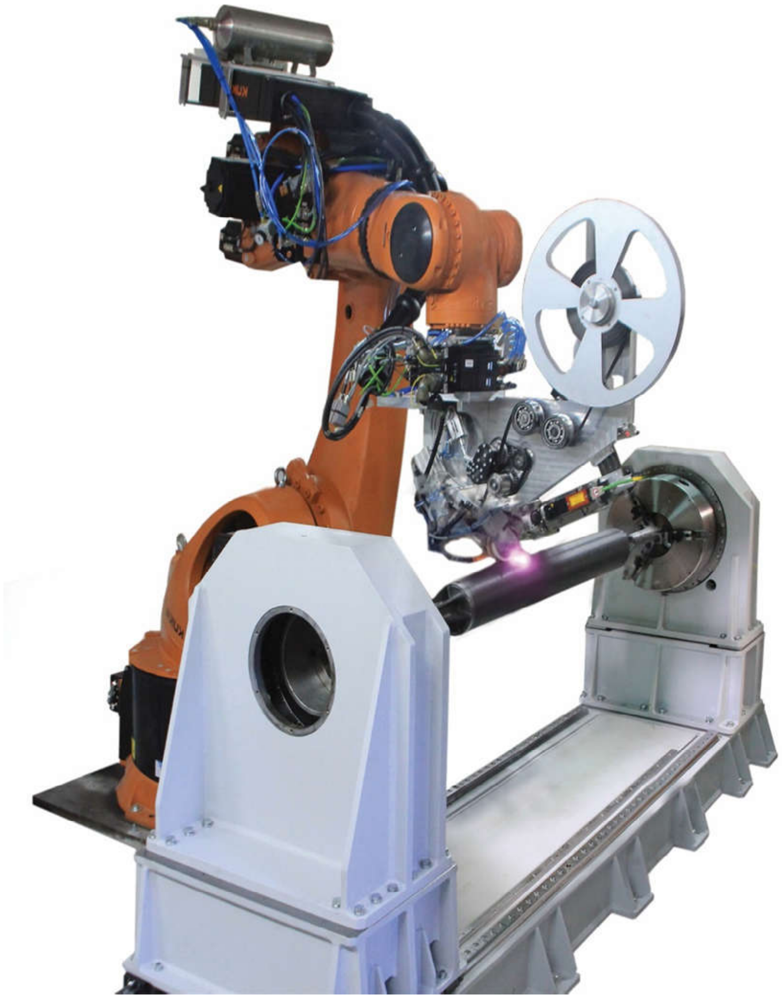
Processing variables controlled in the LATP process include:

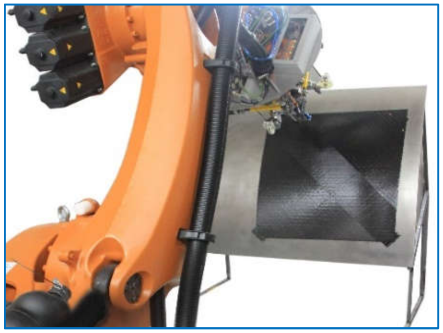
- laser power
- laser angle
- roller pressure
- tool temperature
- lay-down speed and
- roller temperature

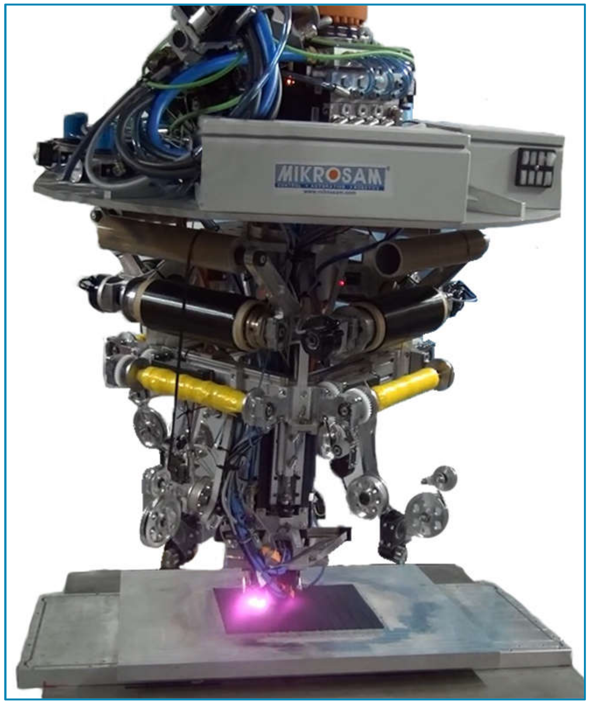
Processing parameters chosen based on a small number of trials performed by the UD tape (Carbon fiber/PPS)

Integrated Solution

AFP/ATL Robotic Cell







Video

Laminates Production - Theoretical Approach

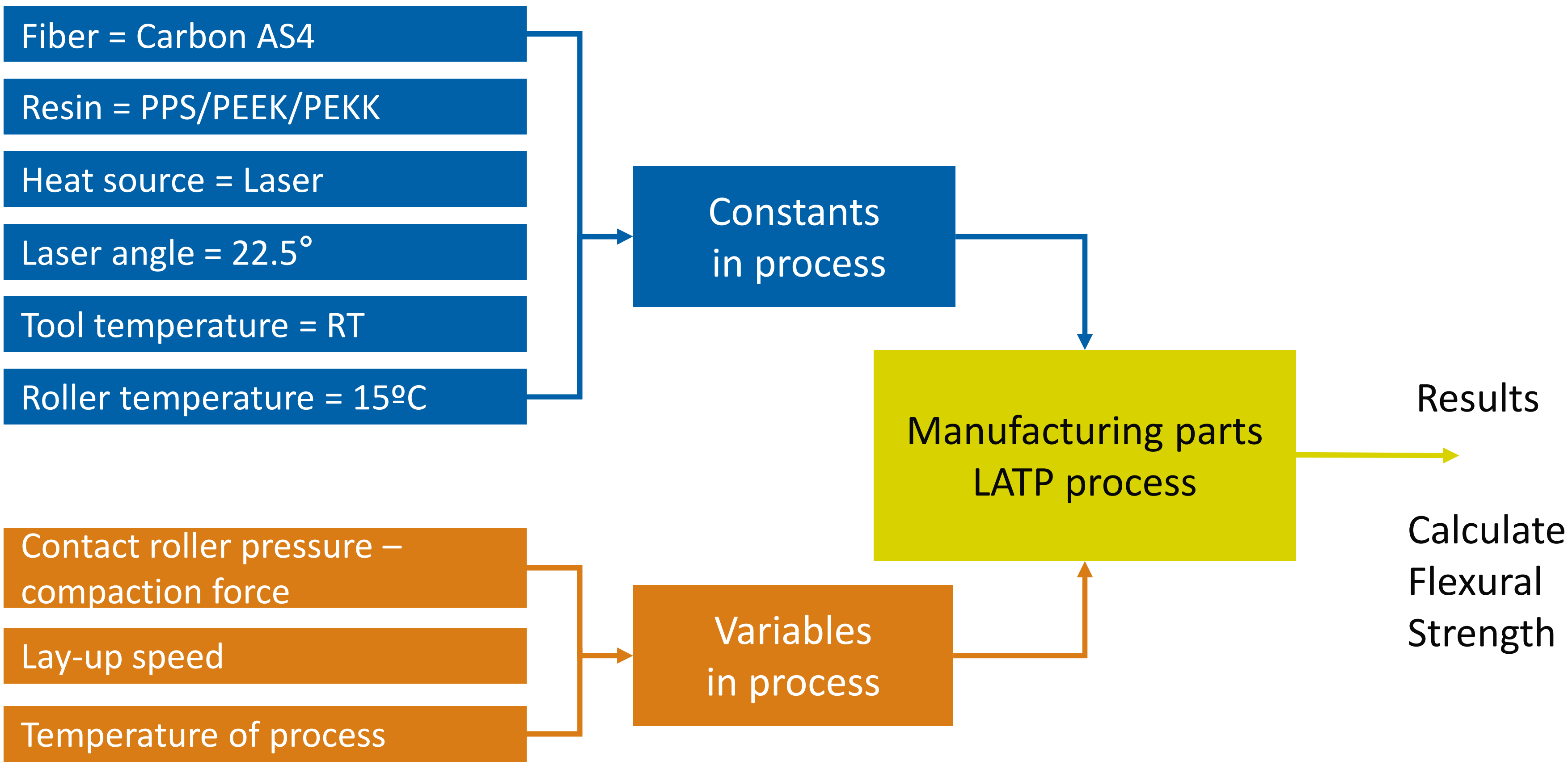
- ❑ Which material UD prepreg will you use?
- ❑ What will be the velocity?
- ❑ What will be the process temperature?
- ❑ What will be the compaction force of contact rollers?
- ❑ e.t.c.

However, there is a better way to get the best combination of variables to make your product

Input Parameters for LATP Tests

- UD thermoplastic prepreg
  - LATP1 PPS/Carbon fiber 25mm
  - LATP2 PEEK/Carbon fiber 25mm
  - LATP3 PEKK/Carbon fiber 25mm
- **Process temperature = T1, T2, (variable)**
- Heat source = laser 3 kW power (constant)
- **Compaction force = F1, F2 (variable)**
- Tool temperature = RT 19-20°C (constant)
- **Speed / velocity = V1, V2 (variable)**
- Laser angle = 22.5° (constant)
- Roller temperature (constant ~ 15°C)
- Laser optical (constant) and other parameters (constants)

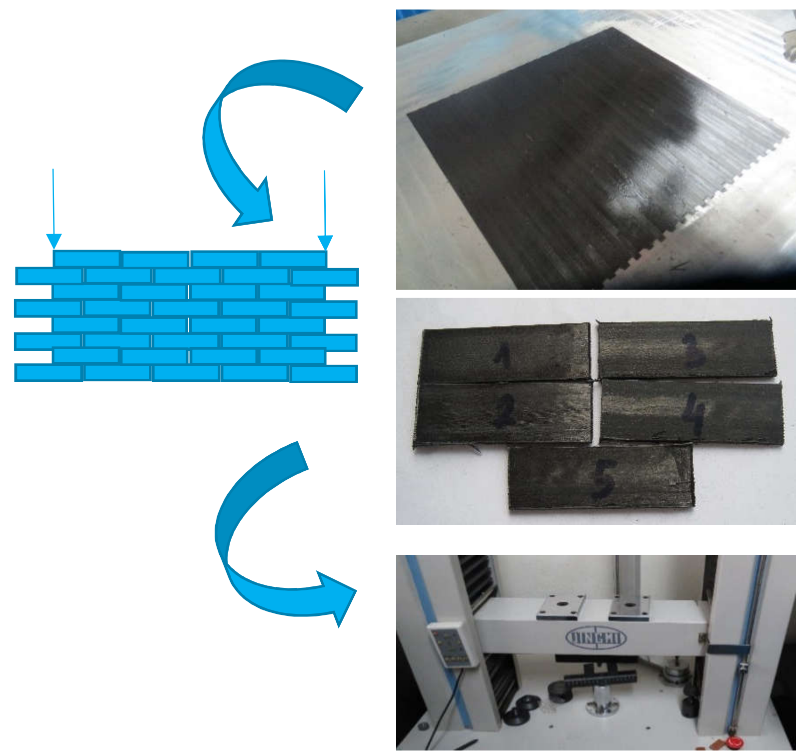
Constants and Variables for LATP Process



Experiments with LATP Technology

Tape Placement experiments **LATP1/LATP2/LATP3**

- Velocity/lay up speed = V
- Temperature = T (laser power)
- Compaction force = F
- Placement velocity –
  - **V1 = 100mm/s and V2 = 150mm/s**
- Temperature
  - LATP 1 **T1 = 280 and T2 = 400ºC**
  - LATP 2 **T1 = 420 and T2 = 450ºC**
  - LATP 3 **T1 = 400 and T2 = 430ºC**
- Contact roller force **F1 = (270 N) 45 N*mm – F2 = (400 N) 65 N*mm**



Experiments with LATP Technology

120 specimens tested, allowing 5 reproducibility tests on each sample from No.1 to No.8 for LATP1/LATP2 and LATP3

Table 1. Level of process parameters

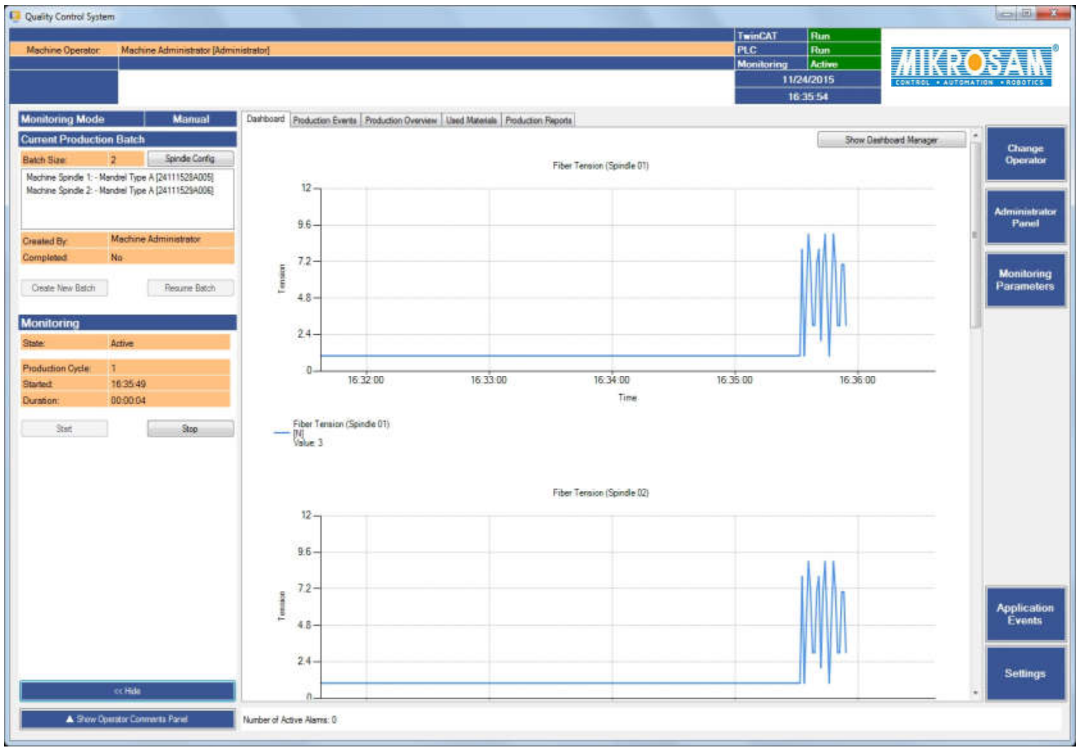
Symbol	Factor	Level	
		-1	+1
A (x_1)	Laser temperature (⁰C)	280 (LATP1) 420 (LATP2) 400 (LATP3)	400 (LATP1) 450 (LATP2) 430 (LATP3)
B (x_2)	Placement rate (mm/s)	100	150
C (x_3)	Roller compaction force (N)	~270	~400

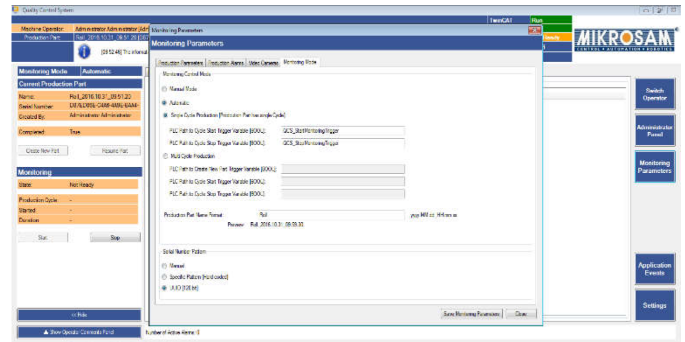
Table 2. Factorial design 2^3

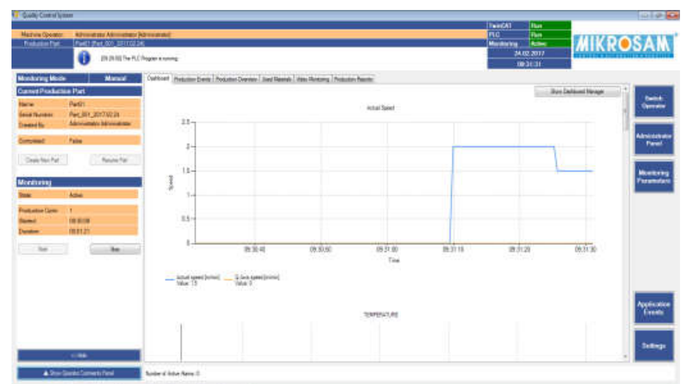
Nº of exp.	Factor				
	A			B	C
	LATP1	LATP2	LATP3		
1	400	450	430	150	400
2	280	420	400	150	400
3	400	450	430	150	270
4	280	420	400	150	270
5	400	450	430	100	400
6	280	420	400	100	400
7	400	450	430	100	270
8	280	420	400	100	270

Monitoring the process parameters

Quality Control System (QCS)



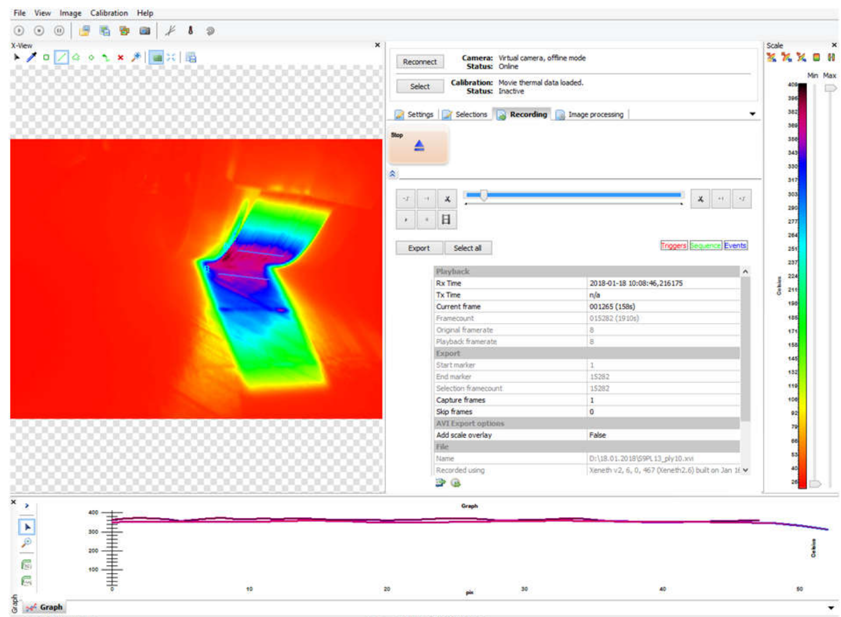




Monitoring the process parameters

Thermal camera

- Mounted on the lay-up head
- Moves along with head and records temperature at the point of lay-up
- Temperature scale showing color spectrum and temperature value



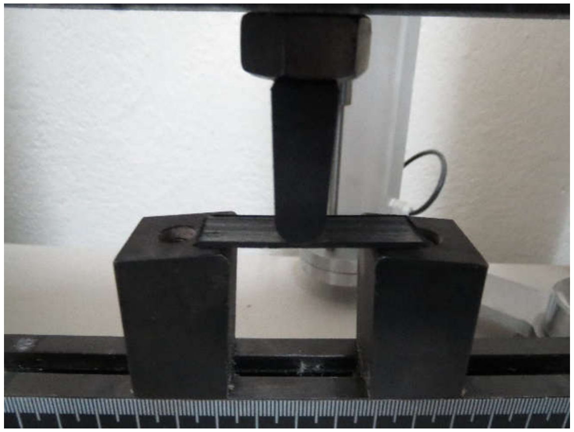
Samples Testing

- ASTM D790 (ISO 14125) standard
- Micrometer used to measure dimensions and thicknesses of specimens
- Room temperature
- CNC testing machine, speed of 5 mm/min
- Force (load) and time recorded by an automatic data acquisition system for the samples

Samples Testing

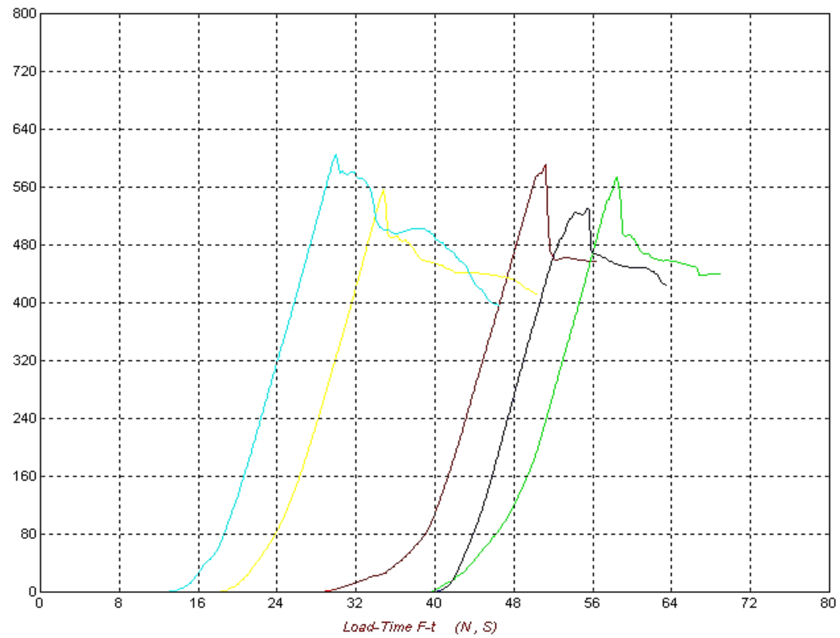
Samples No.6 (x5) for LATP 1

Universal Testing machine



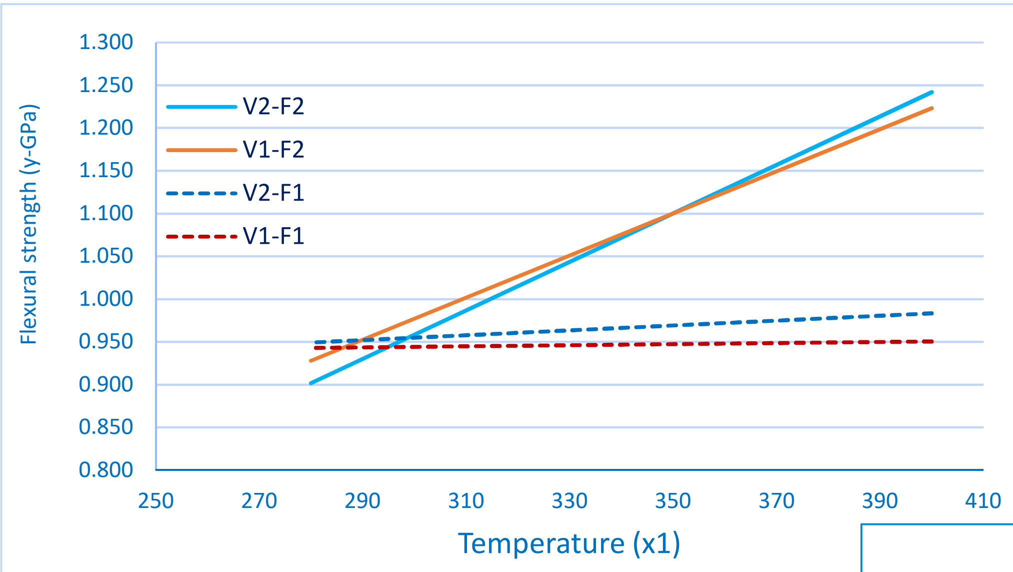
Specimens mounted on two cylindrical supports

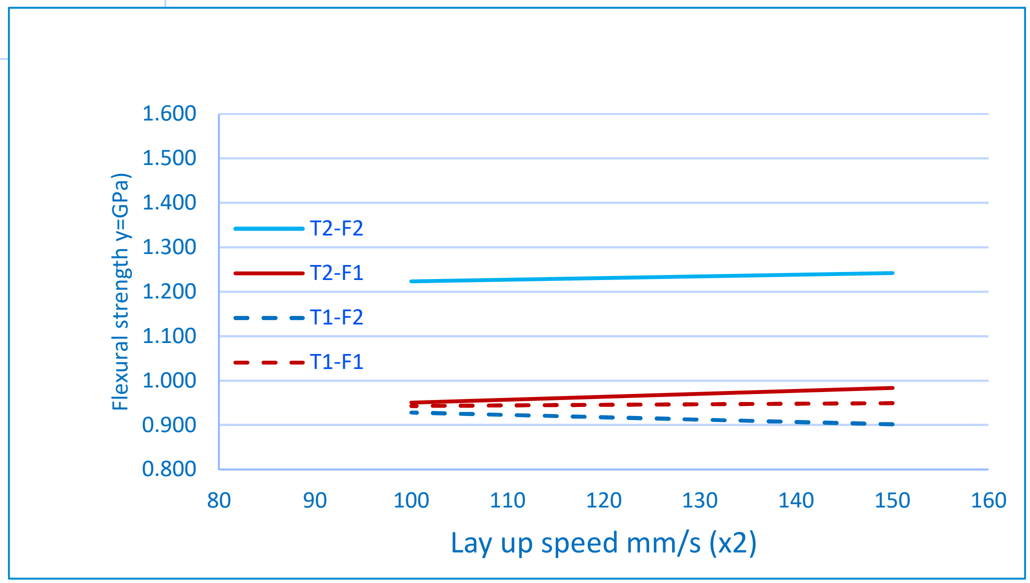
Flexural strength measurement method



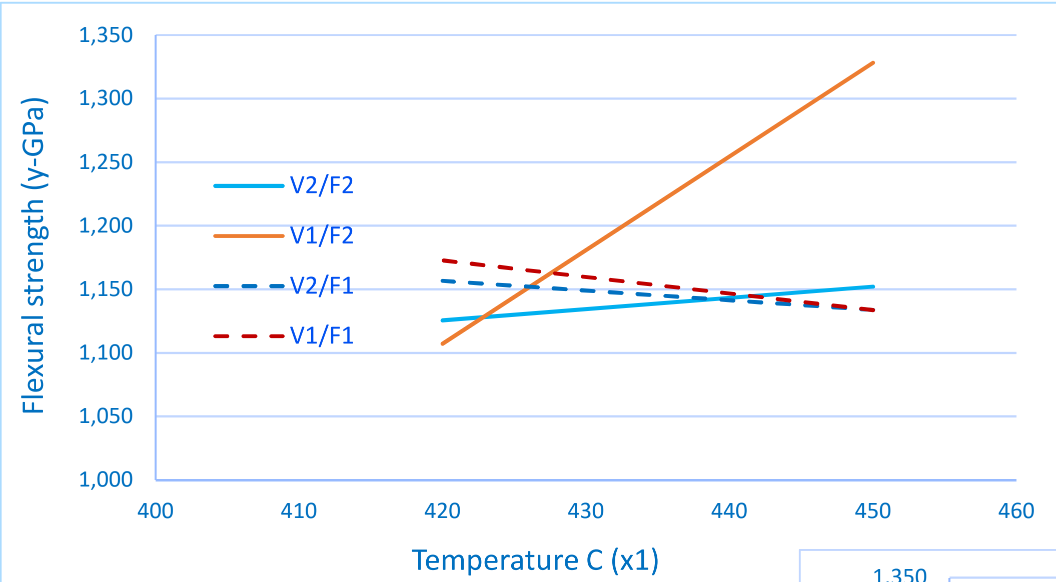
Force-time diagram of No.6 sample for LATP 1

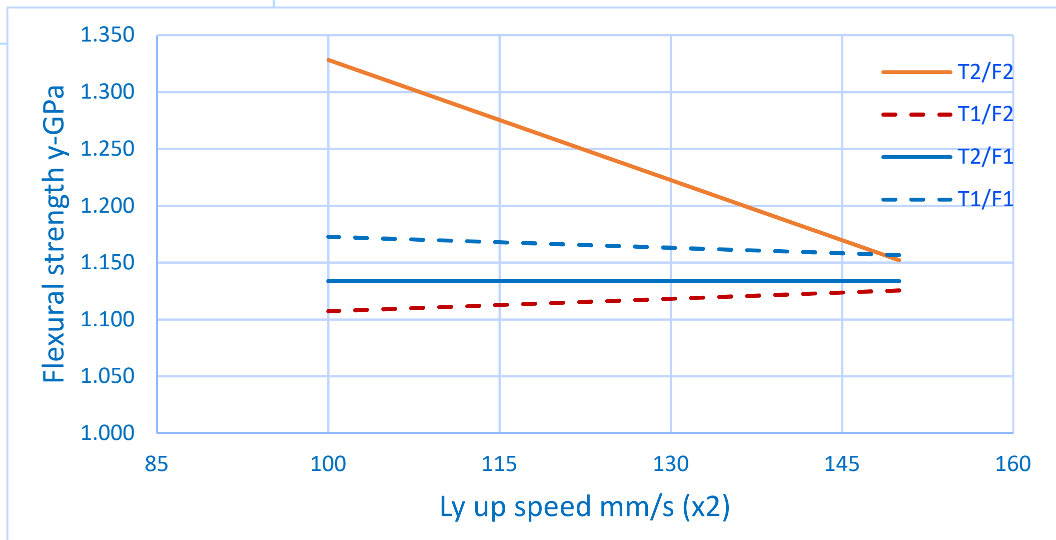
Experimental Results LATP1



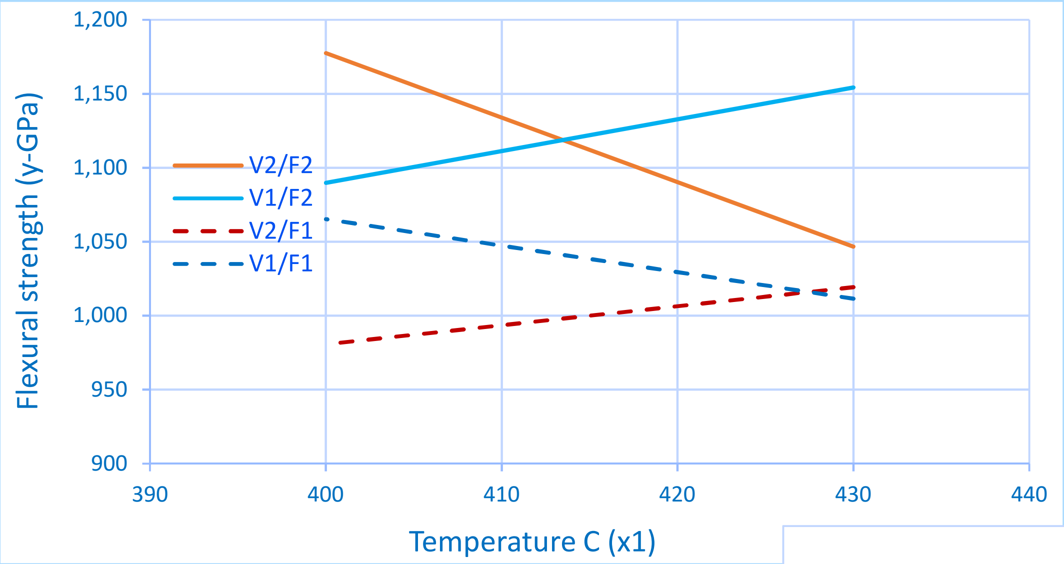


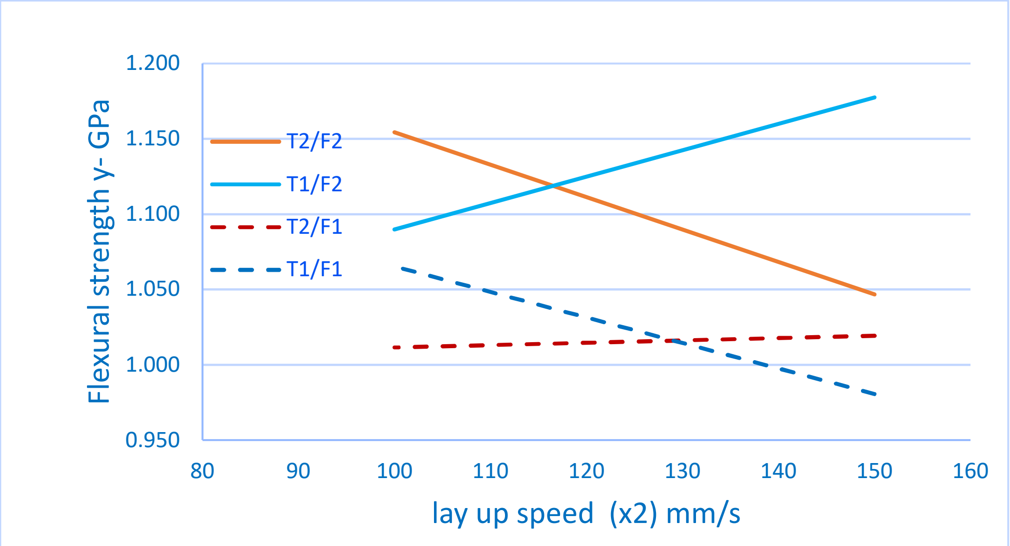
Experimental Results LATP2





Experimental Results LATP3





DOE Calculation of Flexural Strength σf (Y) with T (X_1), F (X_2) and V (X_3)

X_1 - Temperature (^{0}C)

X_2 - Lay up speed (mm/s)

X_3 - Compact force of rollers (N)

Y = 1015.085 + 84.663 x1 + 58.608 x3 + 74.22 x1x3...............(1) LATP1

Y = 1003.858 + 73.436 x1 + 47.381 x3 + 62.993 x1x3........... (2) LATP2

Y = 990.683 + 60.26 x1 + 34.205x3 + 49.818 x1x3 - 30.262 x1x2x3......(3) LATP3

Cochran (G cal) and Fisher (F cal) criteria calculated from design 2^3, fulfilling the rule G cal < G tab and F cal < F tab

- Hypothesis acceptable with 5% mistake for all samples

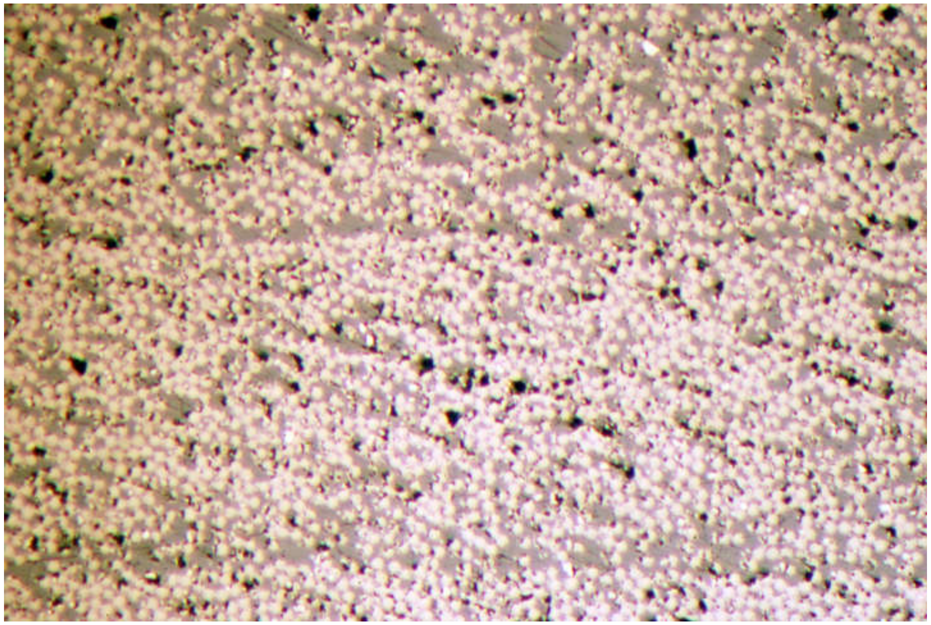
Void Content at Laminates Manufactured with LATP

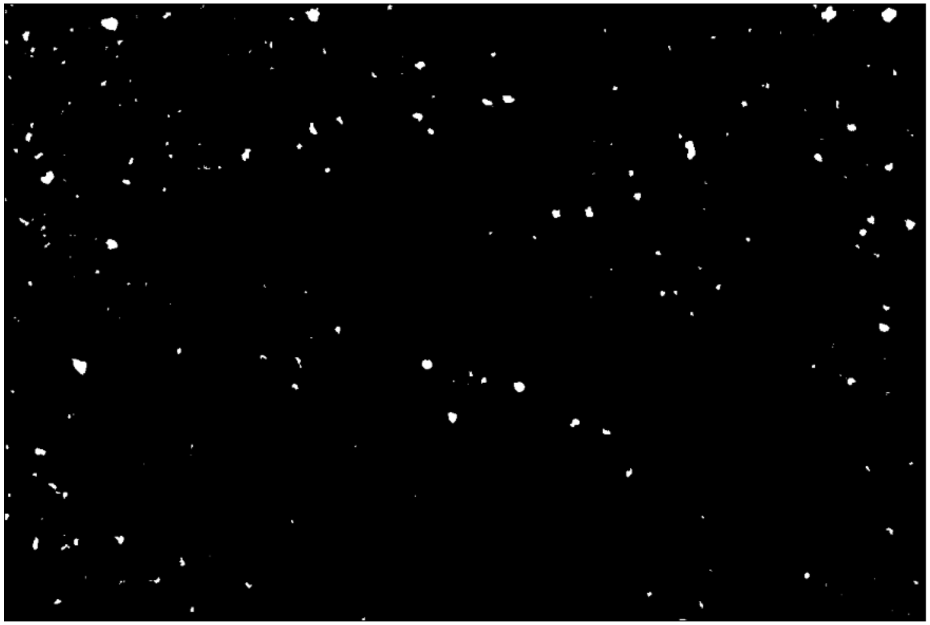
Flat plate

- Material: UD tape CF/PPS, 0.19 mm thickness
- Design: $[0°]_8$
- Number of layers: 8
- Pressure: 4 bar
- Temperature: 400°C
- Lay-up speed: 150 m/min
- Programmed gap: 1 mm
- Laser angle: 22.5°

Void Content at Laminates Manufactured with LATP

Expansion x 100 and calculation of the void percentage





Void percentage: 0.79 %

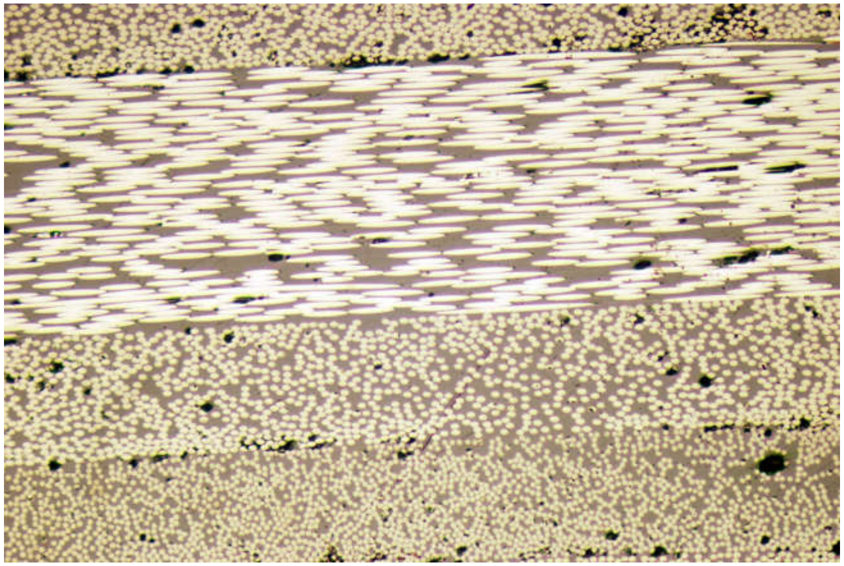
Void Content at Laminates Manufactured with LATP

Flat plate

- ❑Material: UD tape CF/PEKK, 0.14 mm thickness
- ❑Design: 45°/0°/-45°/90°/45°/0°/-45°/90°/45°/0°/-45°/90°/45°/0°/-45°/90°/90°/-45°/0°/45°/90°/-45°/0°/45°/90°/-45°/0°/45°/90°/-45°/0°/45°
- ❑Number of layers: 32
- ❑Pressure: 3 bar
- ❑Temperature: 480°C
- ❑Lay-up speed: 18 m/min
- ❑Programmed gap: 1 mm
- ❑Laser angle: 22.5°
- ❑Laser optics: 250 mm

Void Content at Laminates Manufactured with LATP

Expansion x 100 and calculation of the void percentage

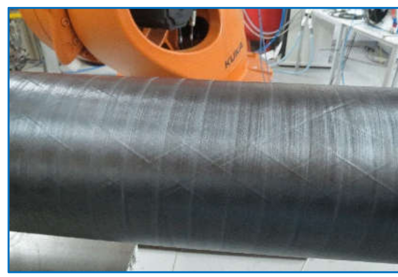


Void percentage: 1.21 %

Void Content at Laminates Manufactured with LATP

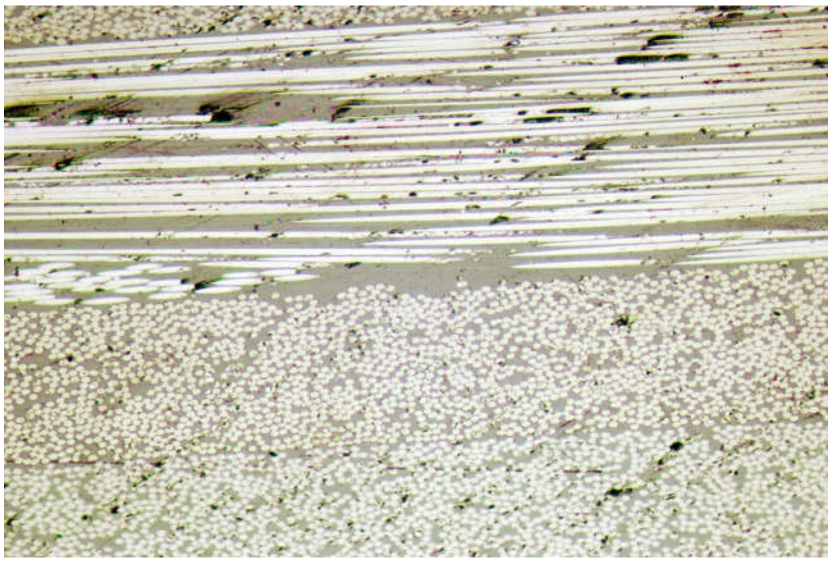
Pipe 1

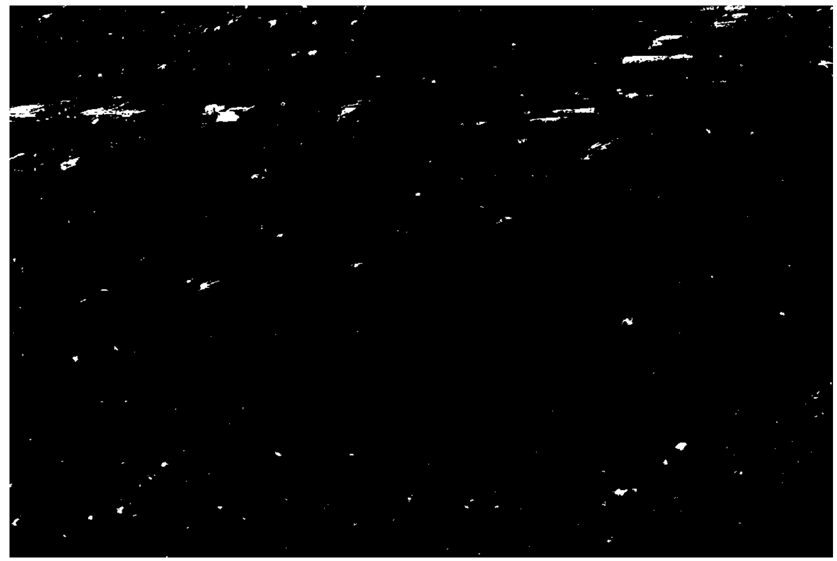
- Material: UD tape CF/PPS, 0.19 mm thickness
- Design: 88°/44.4°/-44.4°/92.9°/44.4°/-44.4°/87.1°/92.9°/44.4° /-44.4°/87.1°/92.9°/44.4°/-44.4°/87.1°/44.4°/-44.4°/92.9°/87.1°
- Number of layers: 19
- Pressure: 3 bar
- Temperature: 450°C
- Lay-up speed: 18 m/min
- Programmed gap: 1 mm
- Laser angle: 22,5°
- Laser optics: 250 mm



Void Content at Laminates Manufactured with LATP

Expansion x 100 and calculation of the void percentage





Void percentage: 0.728 %

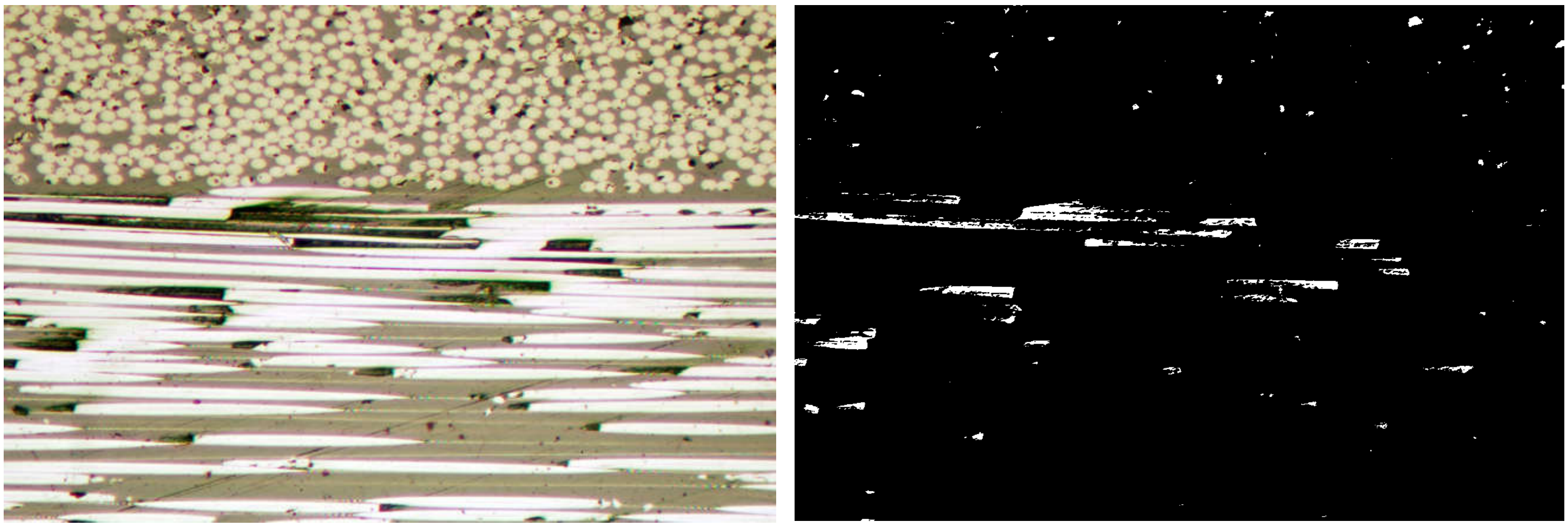
Void Content at Laminates Manufactured with LATP

Pipe 2

- Material: UD tape CF/PEEK, 0.19 mm thickness
- Design: 88°/44.4°/-44.4°/92.9°/44.4°/-44.4°/87.1°/92.9°/44.4°/-44.4°/87.1°/92.9°/44.4°/-44.4°/87.1°/44.4°/-44.4°/92.9°/87.1°
- Number of layers: 19
- Pressure: 3.8 bar
- Temperature: 320°C
- Lay-up speed: 18 m/min
- Programmed gap: 1 mm
- Laser angle: 22,5°
- Laser optics: 250 mm

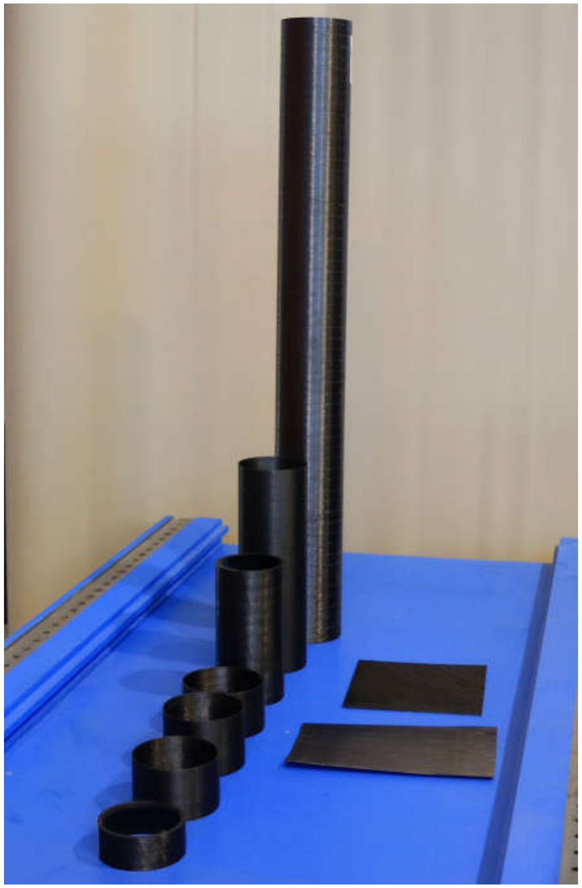
Void Content at Laminates Manufactured with LATP

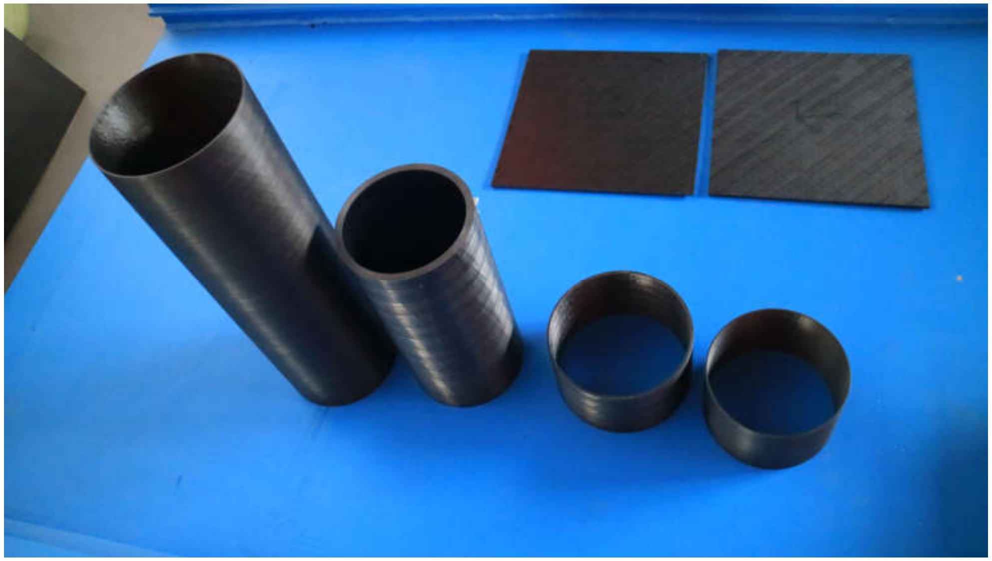
Expansion x 200 and calculation of the void percentage



Void percentage: 1.753 %

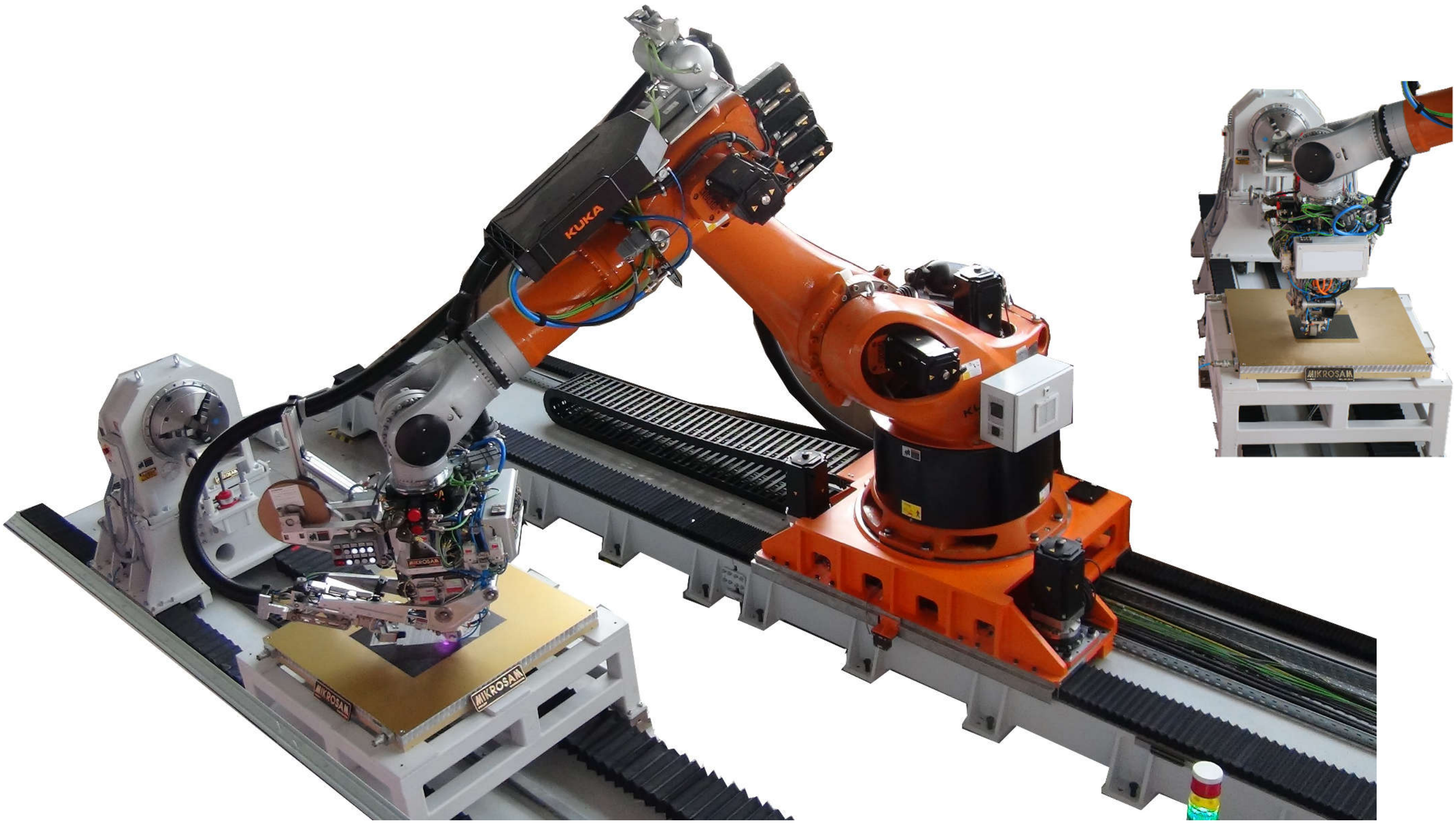
Thermoplastic Products Manufactured with Mikrosam's LATP Technology



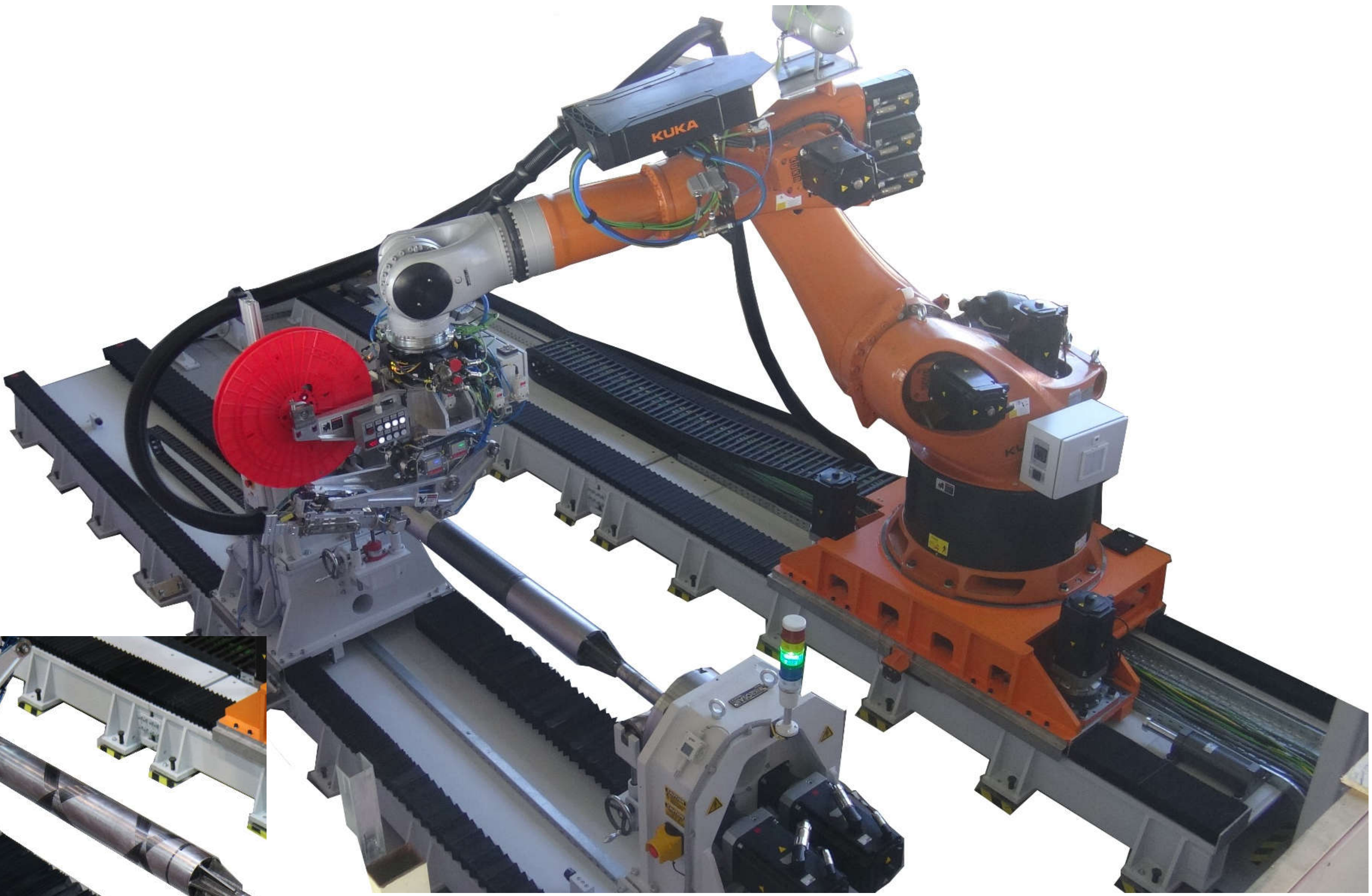


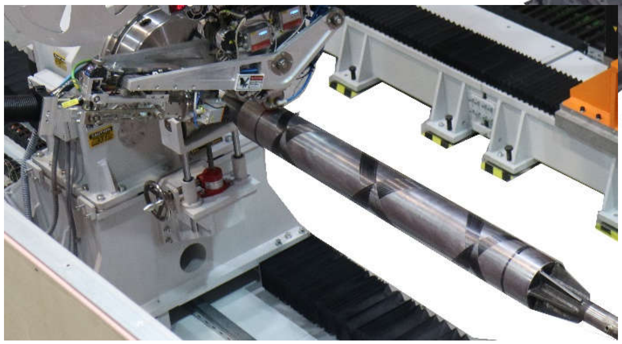
Thermoplastic Products Manufactured with Mikrosam's ATP Technology

Preparation of Flat Specimens



Preparation of Tube Specimens





Conclusion and the Future of Thermoplastic Composite

Conclusion from Experiments

- Best results in flexural strength for each experiment obtained from
  - Higher values of T and F
  - Temperatures above 400°C and pressure of ~ 400 N
  - In bonding of layers at higher temperature for all thermoplastic matrixes (PPS/PEEK/PEKK)

- Percentage of voids on optical microscope images for all products tested are below 2%
  - Best result obtained for pipe 1 from PPS thermoplastic material

The Future of Thermoplastic Composites

- Expected to undergo substantial growth over the next 10 years
- Low-cost production techniques are the current trend to lower overall part costs
- Focuse on producing parts utilizing processes without an autoclave
- Composites reinforced with thermoplastic polymers provide a variety of processes that make parts rapid and reliable
- Main advantage compared to thermosetting composite is the ability to re-melt
- Must be accompanied by the development of new innovative technologies
- With recent developments in automation, these thermoplastic composites will be useful in more applications

Thank you for your attention!

Innovative Composites Manufacturing Solutions

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