Thermoplastic Composites Conference

Robotic 3D Printing of Continuous Carbon Fiber - PAEK Tape

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TEIJIN CARBON AMERICA, INC.

Ryerson University

American Composites Manufacturers Association

Learning Objectives

At the end of this session - Participants will be able to -

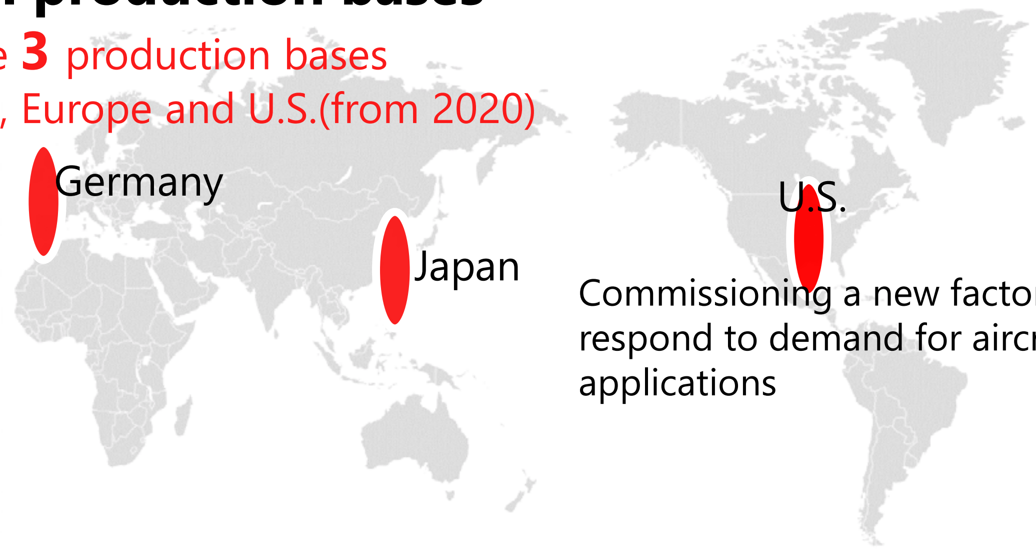
- Understand progress done over to achieve 3D printing of continuous high-performance CF TPC tape
- Have a first understanding of the benefits as well as the limits of the technology
- Get the perspective of next development steps

Details about the Teijin's Carbon Fiber BU

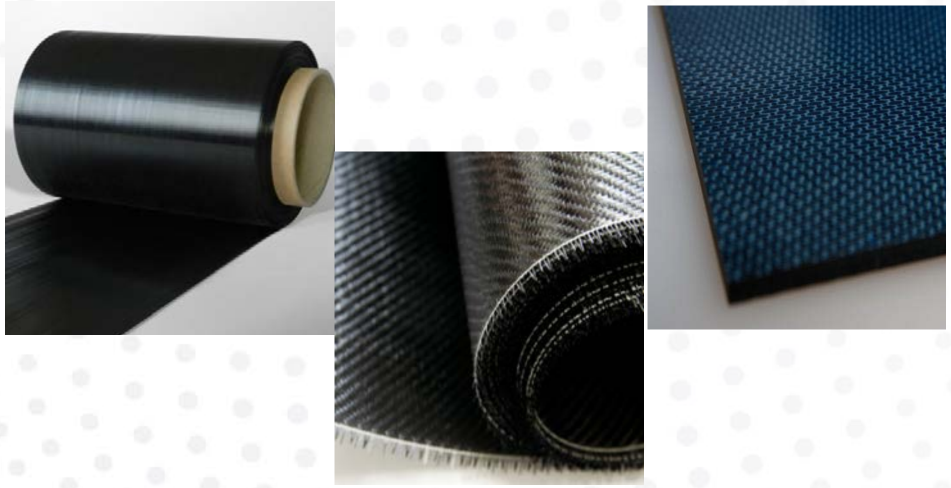
TEIJIN
TEIJIN CARBON AMERICA, INC.

Global production bases

We have **3** production bases
in Japan, Europe and U.S.(from 2020)



Commissioning a new factory to respond to demand for aircraft applications



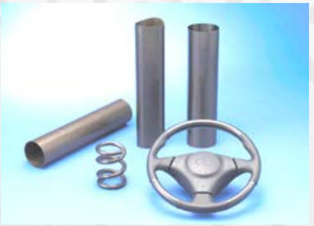
- Keep and increase position as one of the leading company in carbon fiber, its textile and prepreg for aerospace applications with strength of technological superiority

- Aim for annual sales of over $900 million, mainly in aviation industry by 2030

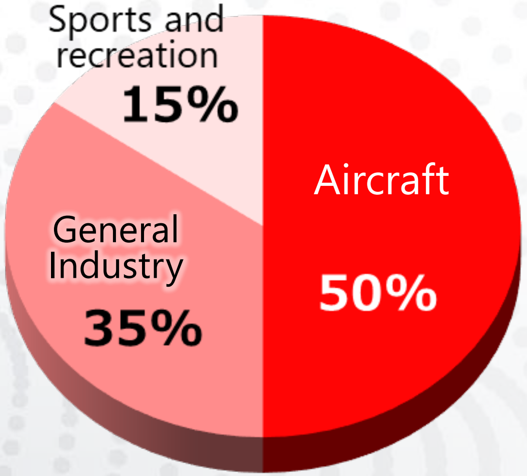
Breakdown of Carbon fibers by applications

(based on our sales in FY2019)

Tennis rackets

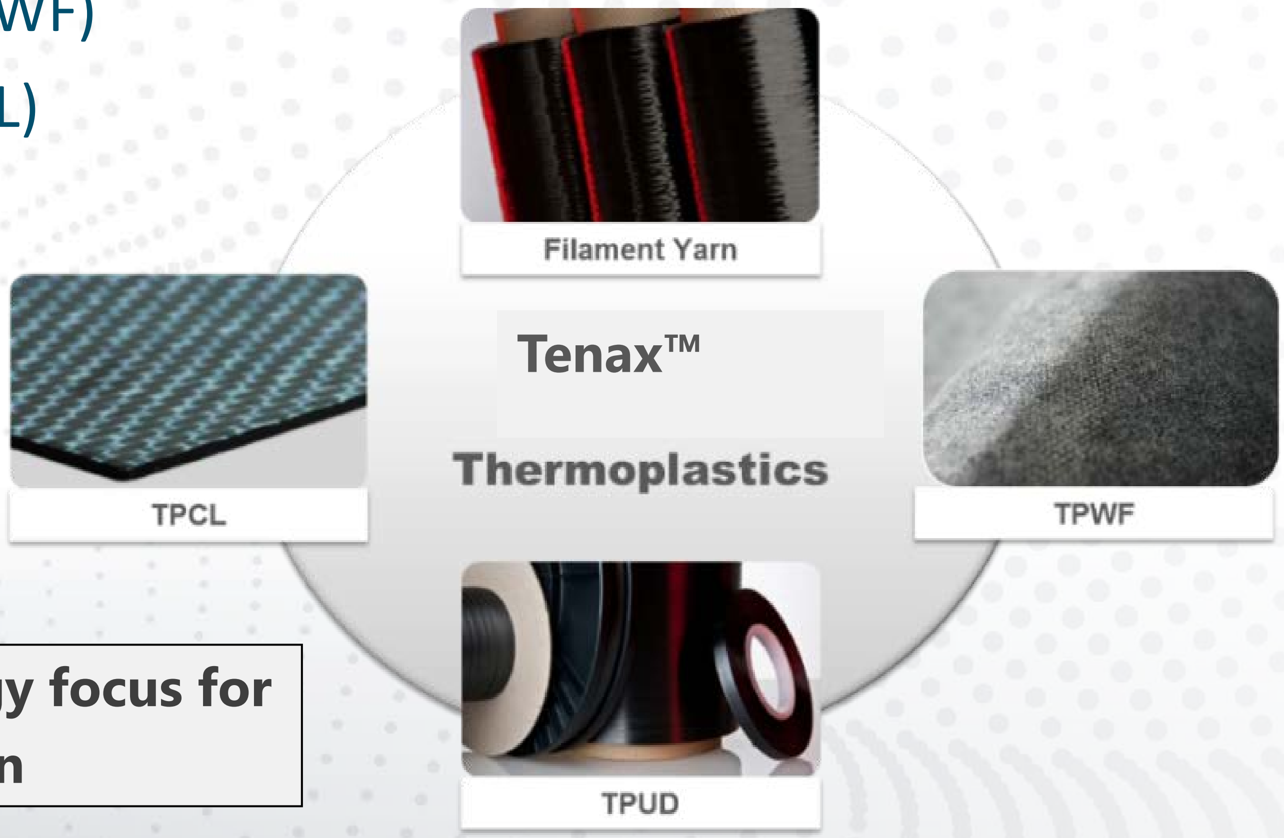


Compounds



Tenax™ ThermoPlastics

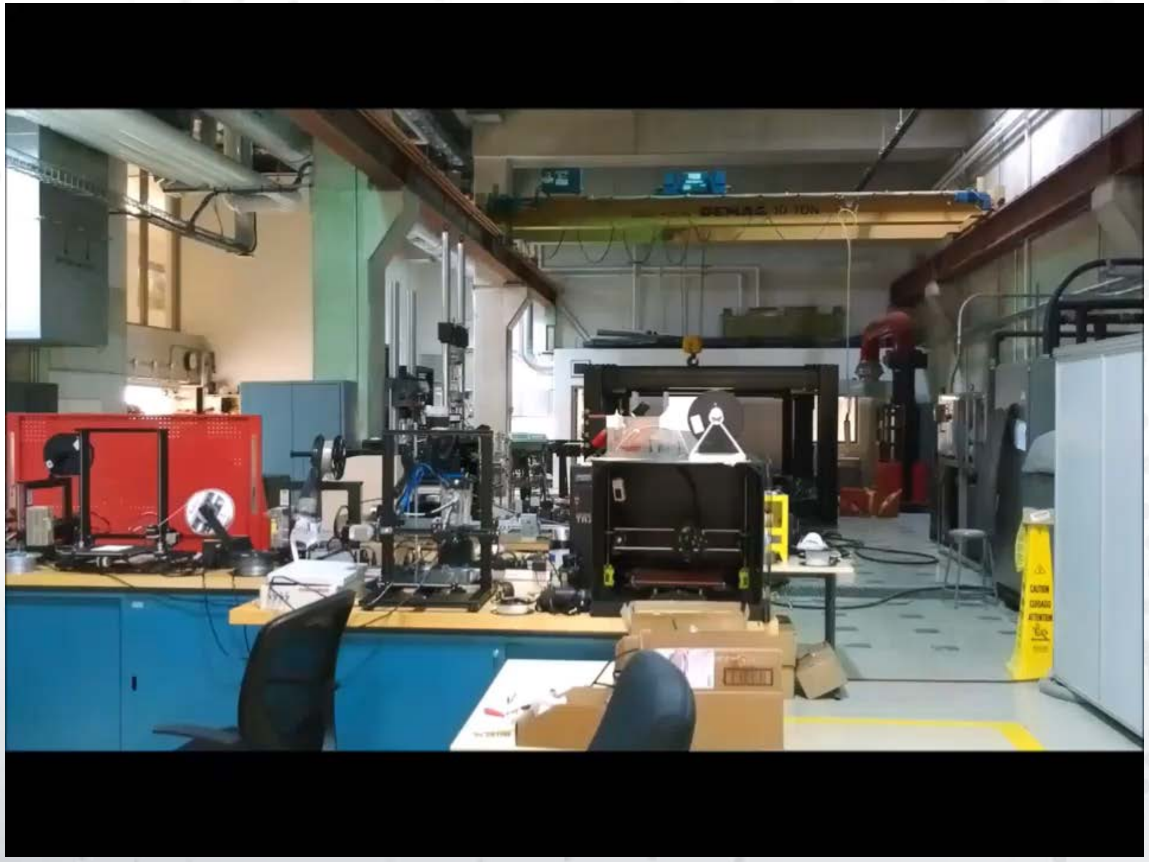
- Carbon fiber with tailored sizing for Thermoplastics polymer (Tenax™ Carbon Fiber)
- 4 millions lbs existing capacity in Germany (+ new SC line 6 Millions lbs/y)
- Powder coated woven fabric (Tenax™ TPWF)
- Pre-consolidated laminates (Tenax™ TPCL)
- Unidirectional (UD) tape (Tenax™ TPUD)
- 2 TPUD lines in Germany (12” and 24”)



Key technology focus for Teijin

FRAMES

- Facility for Research on Aerospace Materials and Engineered Structures (FRAMES) at Ryerson University, Toronto, CANADA
- Complete cycle of 3D printing, full-scale mechanical testing, and materials characterization



Ryerson University

FRAMES

3D printing of continuous carbon fiber thermoplastic composites

All started from a shared ‘dream’ of achieving high performance 3D printing of Carbon Fiber TPC

R&D collaboration between Ryerson and Teijin started in 2018 with a focus on:

- **Robotic 3D printing**
- **Continuous** carbon fiber composites
- **High-temperature/High performance** thermoplastics

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Ryerson University

FRAMES

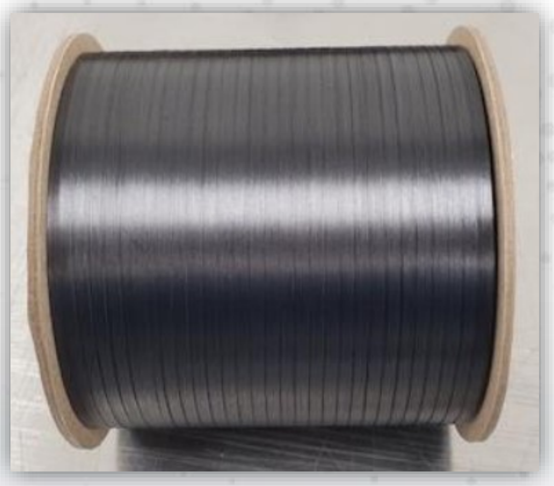
Material development

Type of materials used and developed for this program:

Tenax™-E TPUD **PEEK-HTS45** and Tenax™-E TPUD **PAEK-HTS45**

Focus on ¼” and 1/16” products

1/4”
‘state of the art ‘

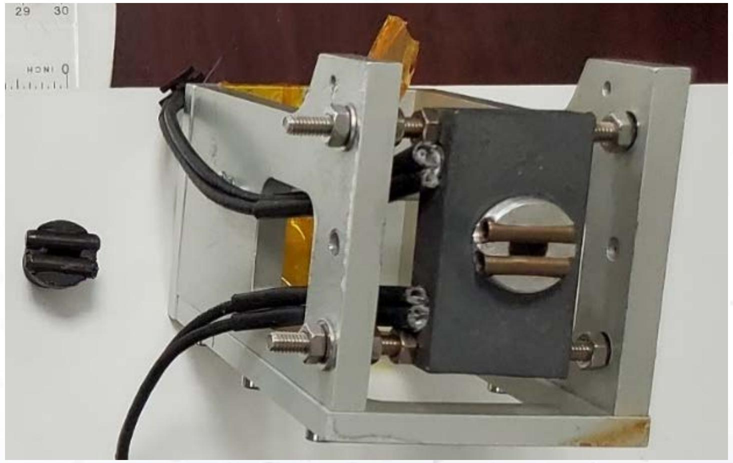


1/8”

1/16”

Evolution of nozzles

- Nozzle width to process different tape widths (1/16" vs 1/4")
- Nozzle geometry (round, slotted, with dowl pins, etc.)



An early version of 3D printing head showing the nozzle

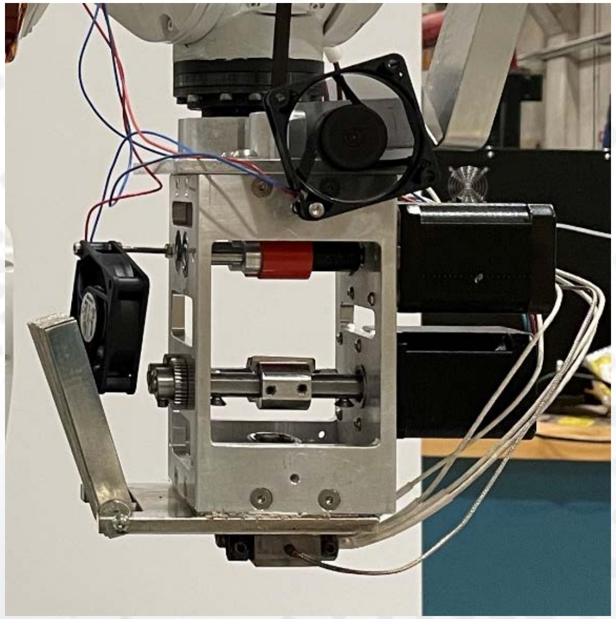
Nozzles investigated since 2018

Evolution of the 3D printing heads

- Without feeding or cutting capability
  - Can work for 1/16" tow width

3D printing head
Without feeding or cutting

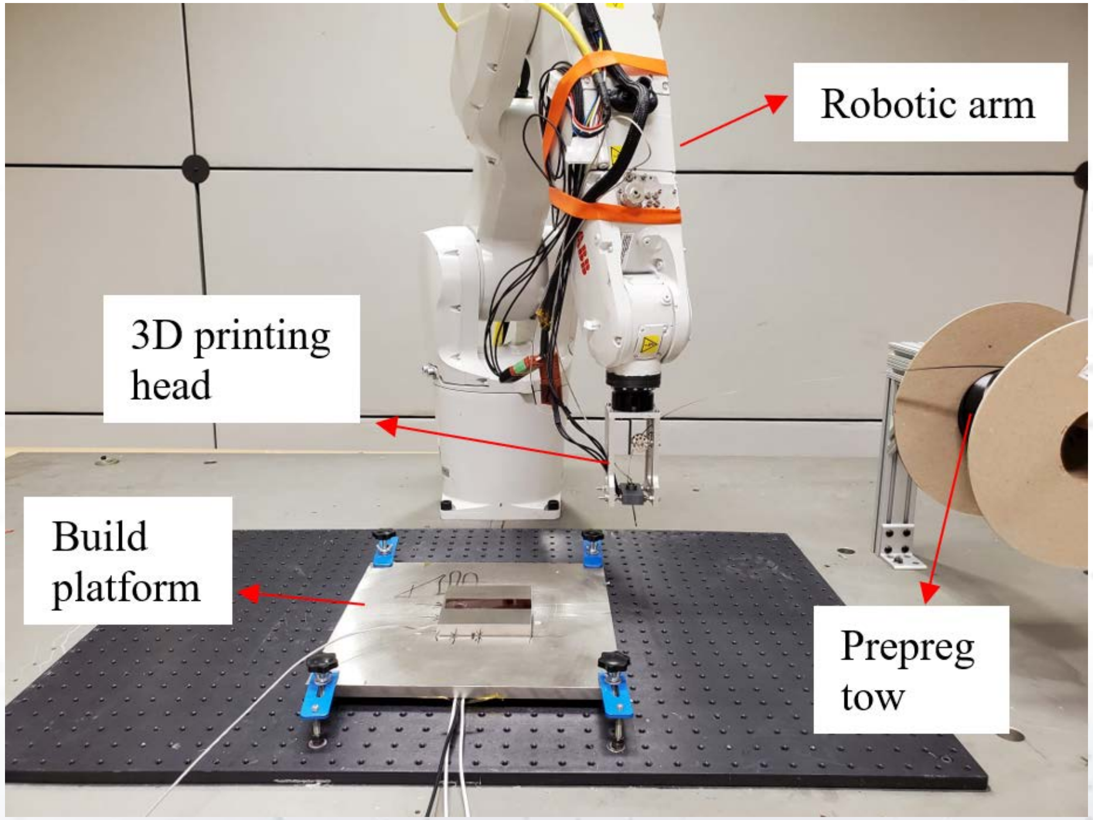
- With feeding and cutting capability
  - Can give more flexibility to the process



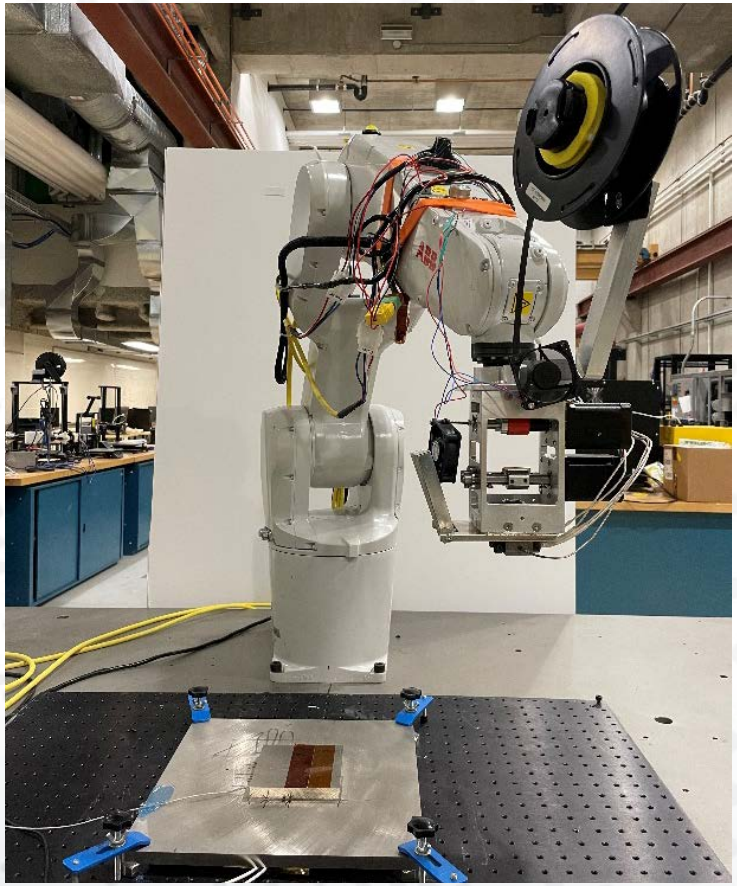
3D printing head
With feeding and cutting

The complete 3D printing set-up

- Stainless steel build platform



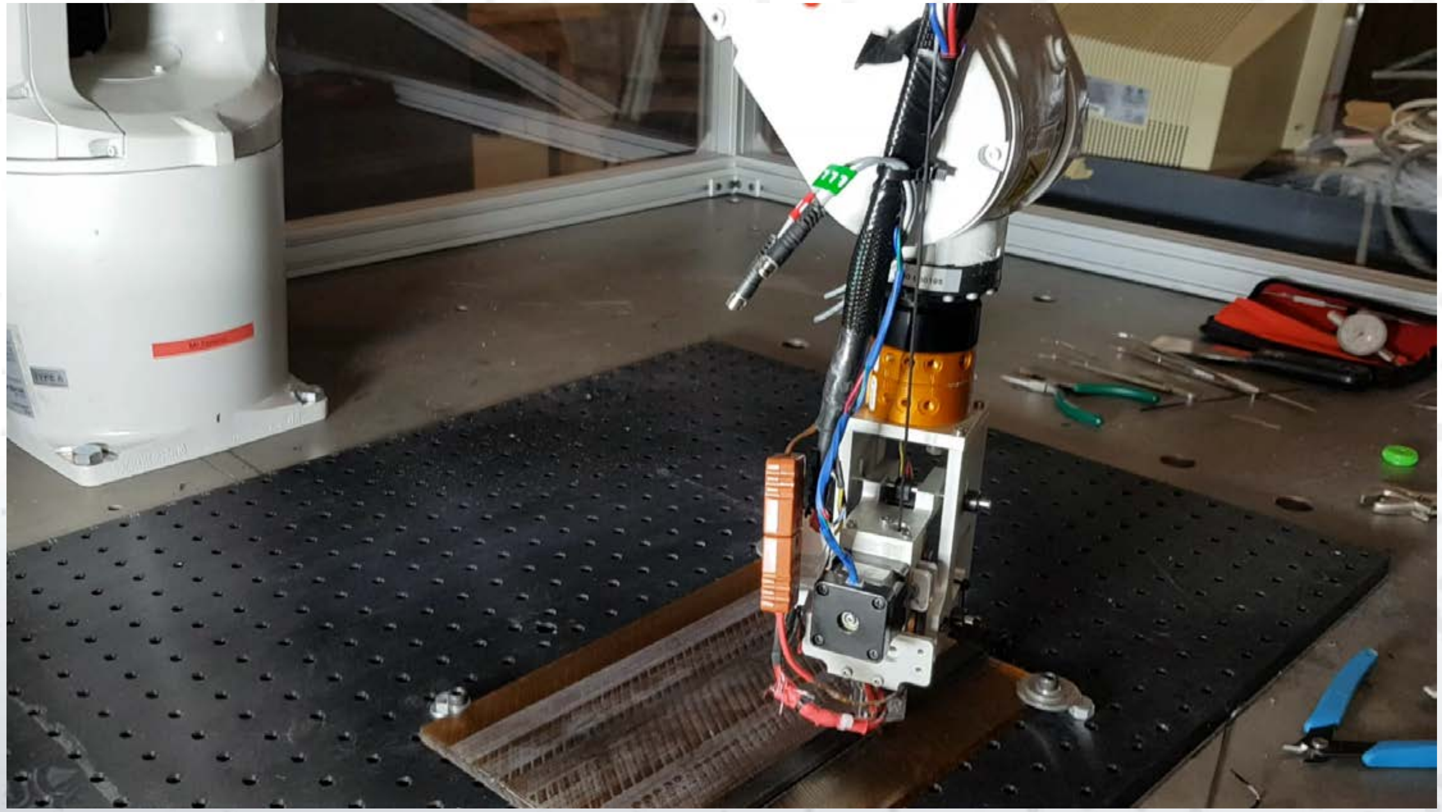
The preliminary set-up with
an early-version 3D printing head



The final set-up with
a second-version head

Tenax™-E TPUD PEEK-HTS45 (1/16")

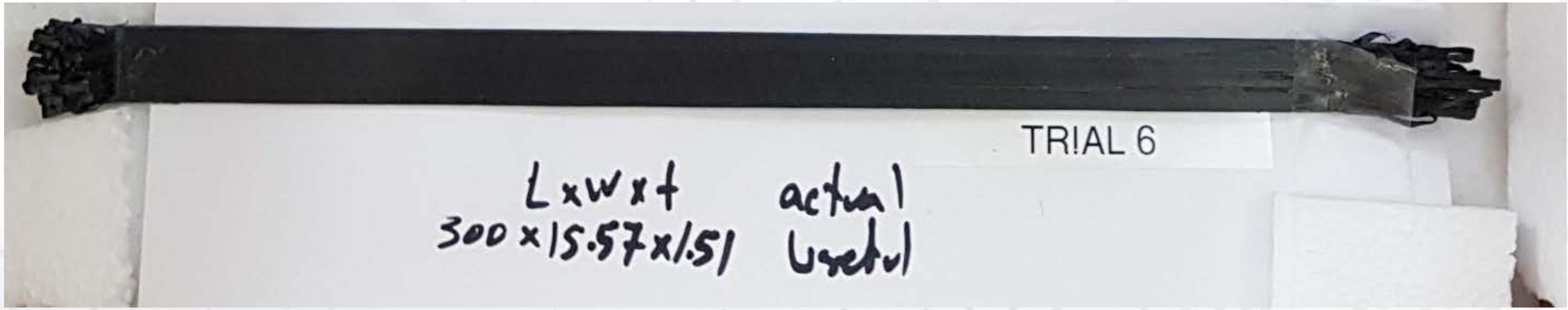
- Tensile specimens on a PEI build platform
- 0 deg fiber orientation with a speed of 10 mm/s (23.6”/min)
- Circular nozzle, no feeding or cutting
- Nozzle temperature of 380, 390, and 410 ºC, (716, 734, 770 ºF) and room temp bed



Tensile testing results

Results per ASTM D3039 for specimen #6:

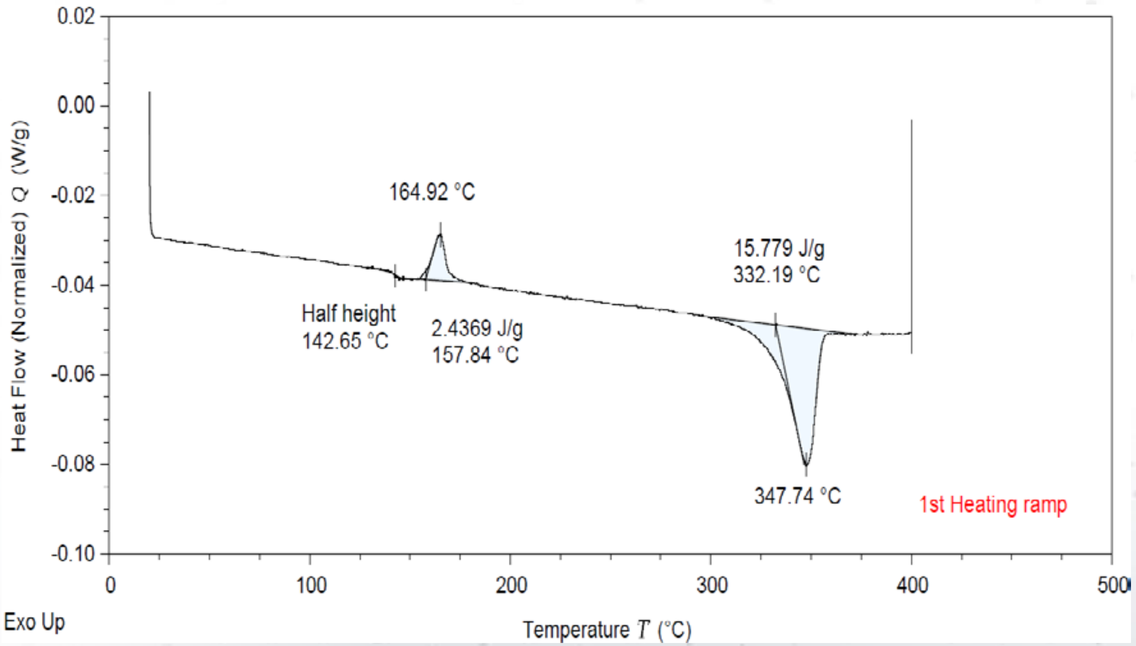
- Tensile strength: 1159 MPa (168 ksi)
- Tensile Modulus: 108 GPa (15.6 msi)
- Failure strain: 17583 µm/m
- Failure mode: XGM (explosive at midpoint of the gauge length)



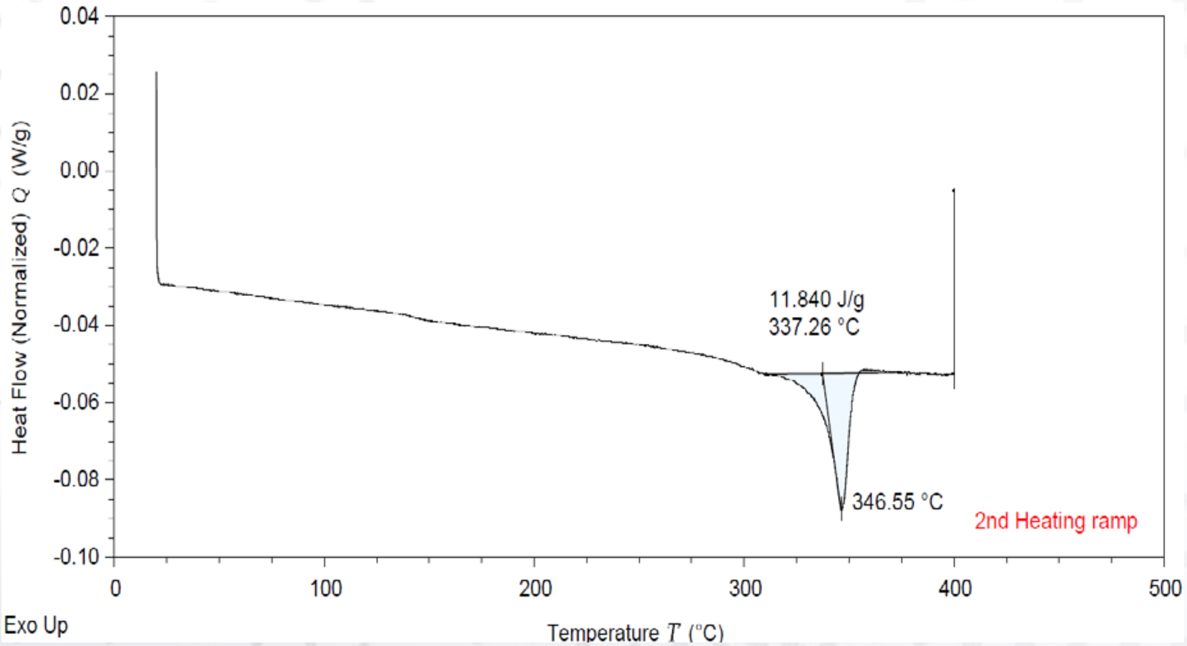
Tensile specimen used for testing

Thermal testing results per ASTM D3418-15

- Differential Scanning Calorimetry (DSC) testing
- Glass transition temperature (T_g) of 142.7 ºC (288.9 ºF).
- Melting temperature of 347.7 ºC (657.9 ºF).
- Cold crystallization was observed.



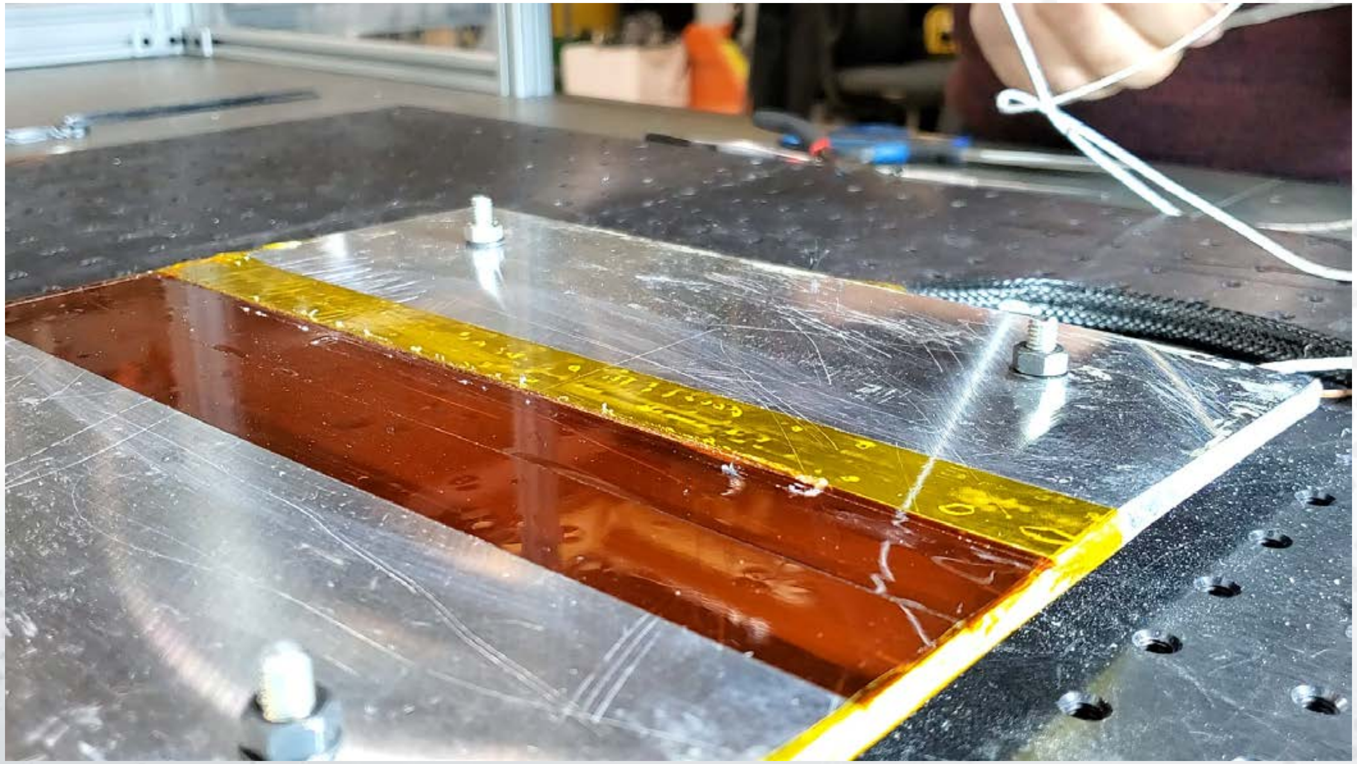
Thermal history for 1st Heating ramp



Thermal history for 2nd Heating ramp

Tenax™-E TPUD PEEK-HTS45 (1/4")

- 3D printing on an aluminum build platform
- 0 deg orientation with a total width of 31.75 mm (1.25”)
- Warping was observed with room-temp. and 165 ºC (329 ºF) bed

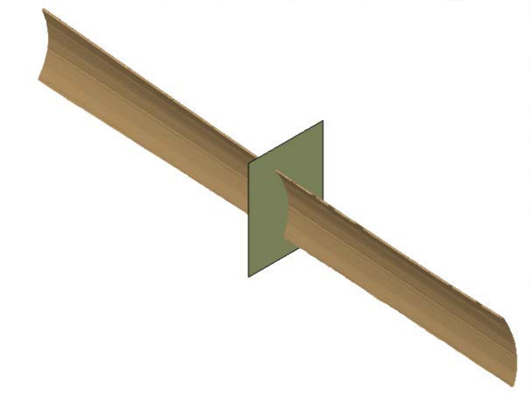


3D printing of 0º specimen on an aluminum build platform

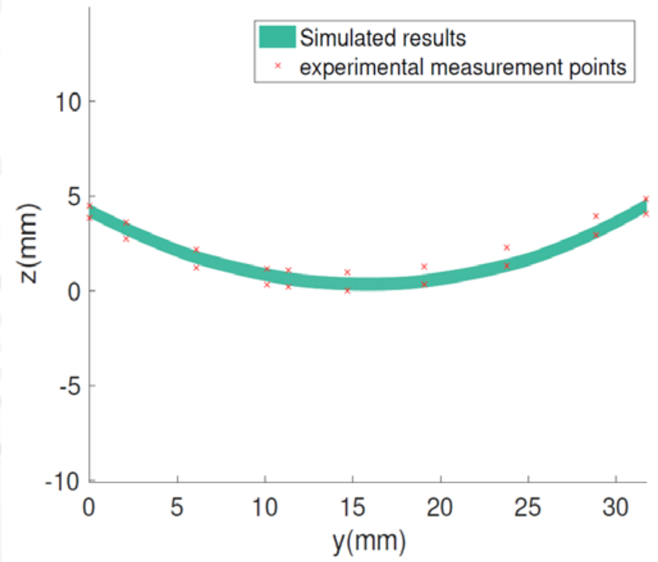
Tenax^{TM}-E TPUD PEEK-HTS45 (1/4")

- A laser-based 3D scanner created the 3D model of the warped specimen
- A simulation model was used to predict the deformed shape

3D printed specimen
Length: 250 mm (9.8”)



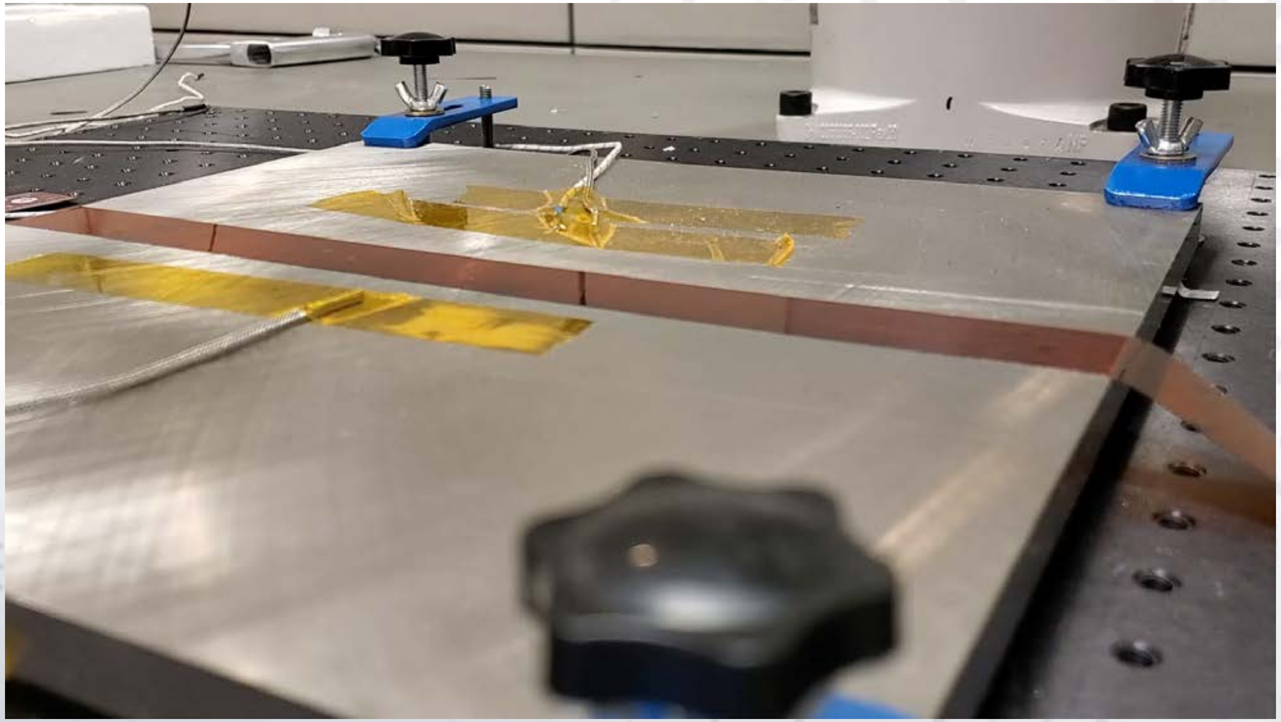
3D model from
the scan



Numerical vs experimental
Cross-section displacement

Tenax^{TM}-E TPUD PAEK-HTS45 (1/4")

- Tensile specimens on a stainless steel build platform
- 0 deg fiber orientation with a speed of 10 mm/s (23.6”/min)
- Nozzle with two dowel pins, no feeding or cutting
- Nozzle temperature of 380 ºC (716ºF) with room-temp and 165 ºC (329ºF) bed



3D printing of 0º specimen on a stainless steel build platform

Tenax™-E TPUD PAEK-HTS45 (1/4")

Tensile testing

- Specimen set #7: room temperature build platform
- Specimen set #8: 165 ºC (329 ºF) build platform

	Young modulus		Strength		Failure strain	
Specimen set	Mean (GPa)	CV (%)	Mean (MPa)	CV (%)	Mean (%)	CV (%)
7	111.9	4.7%	1282.1	4.6%	1.8	7.7%
8	108.1	6.9%	1237.7	12.5%	1.7	22.2%

Specimens after trimming

Tenax^{TM}-E TPUD PAEK-HTS45 (1/4")

Tensile specimens after testing

- Failure mode for all specimens:
  - SMC (long-splitting, multiple areas, various)

Specimens after esting

Tenax™-E TPUD PAEK-HTS45 (1/4")

Thermal testing results :

- Differential Scanning Calorimetry (DSC) testing
- Specimen set 7: room-temperature be
- Specimen set 8: 165 ºC bed (329 ºF)

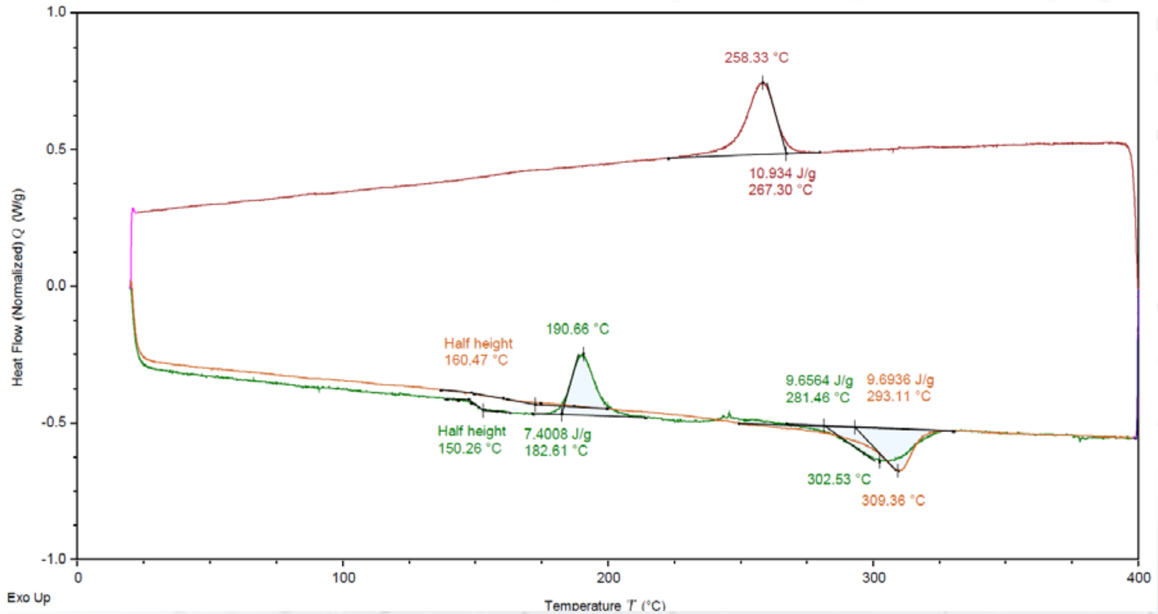
Parameter	**Specimen 7-1**	**Specimen 8-2**
First heating ramp		
Glass transition temperature (°C)	150.26	154.79
Crystallization extrapolated onset temperature (°C)	182.61	N/A
Crystallization peak temperature (°C)	190.66	N/A
Melting extrapolated onset temperature (°C)	281.46	283.37
Melting peak temperature (°C)	302.53	305.12
Enthalpy of fusion (J/g)	9.6564	8.9101
Cold crystallization	Yes	No

Tenax^{TM}-E TPUD PAEK-HTS45 (1/4")

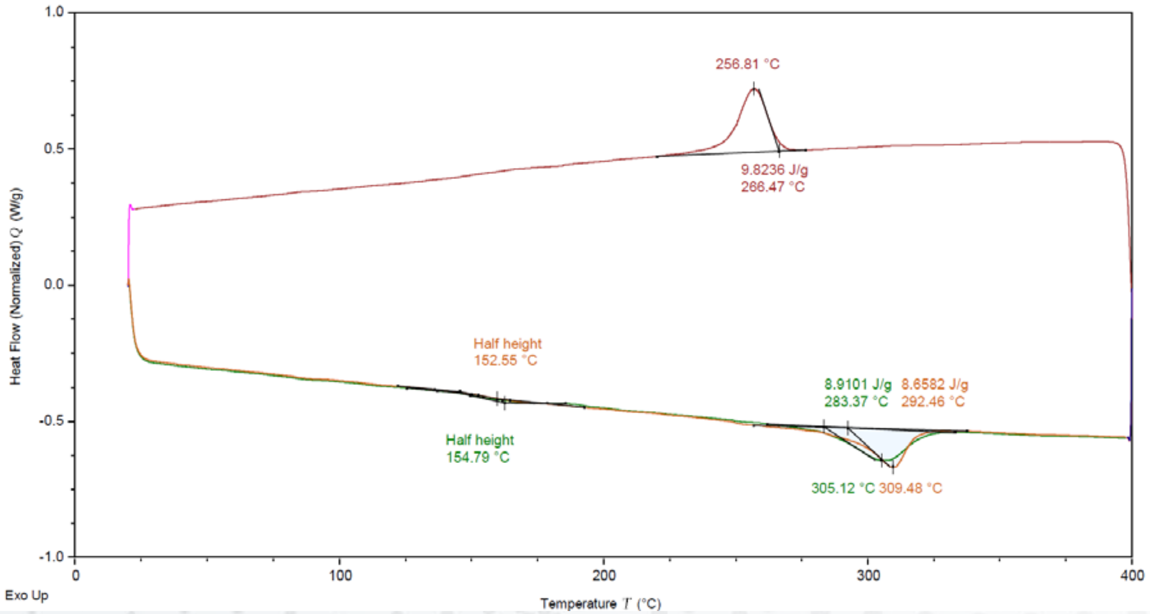
Thermal testing results :

- DSC Graph

the first heating (green), cooling (red), and second heating ramps (orange)



DSC graph (specimen set 7)



DSC graph (specimen set 8)

Future work

- The new 3D printing head with feeding and cutting is robust
  - Maintaining the nozzle and bed temperature
  - Feeding and cutting the material properly

- Minimum turning radius is under investigation

- Short beam strength (SBS) or Isopescu specimens

Questions?