Design, fabrication and testing of a triangular carbon fiber truss beam for the AGORA inner tracker

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on behalf of mechanical group

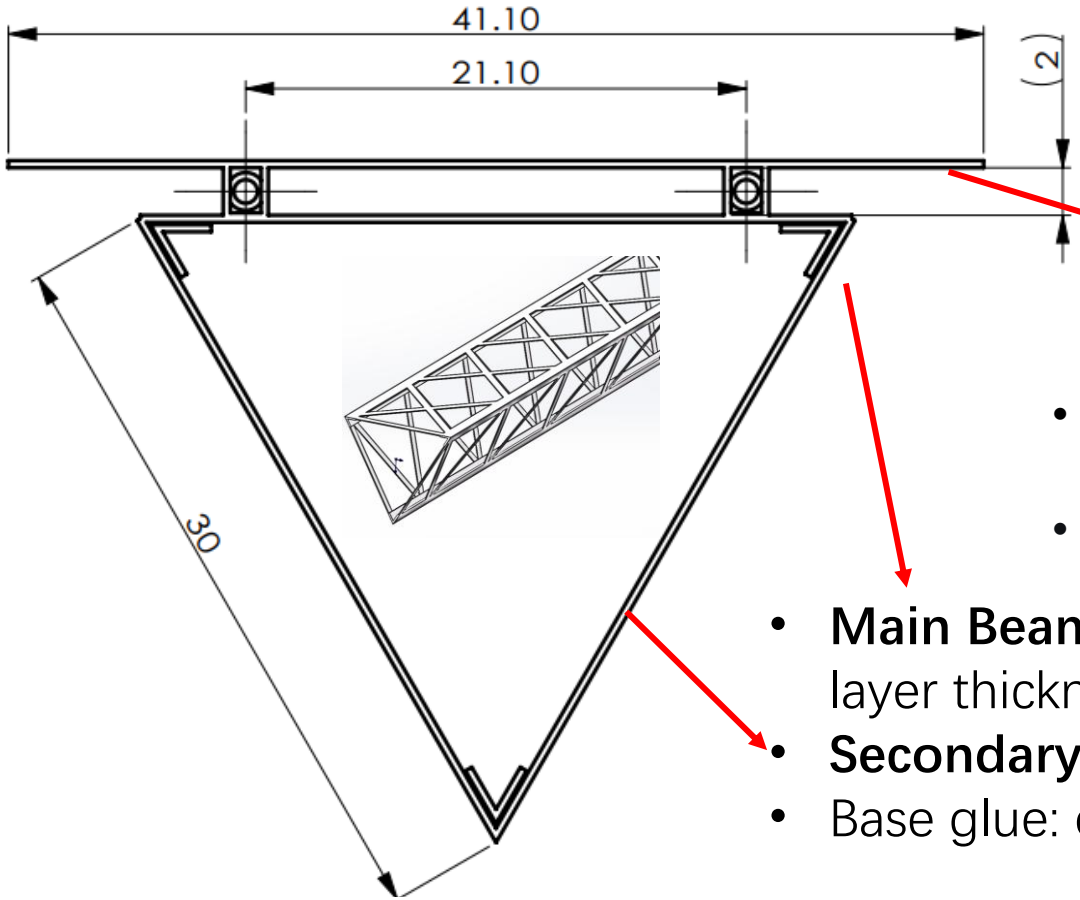
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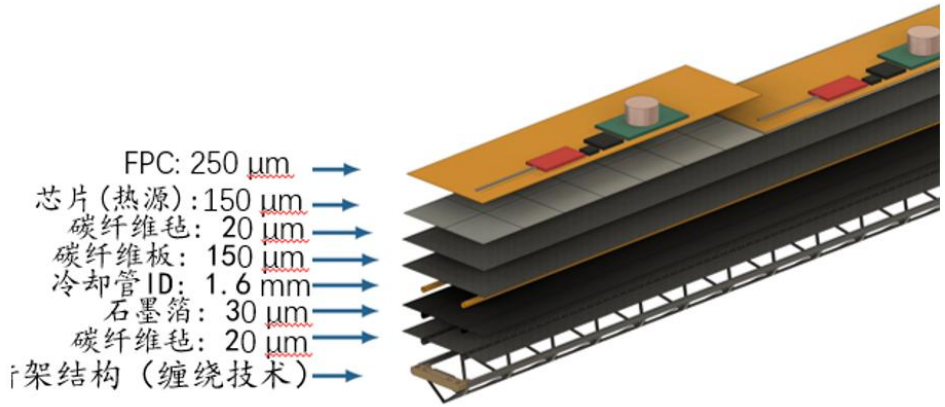
Oct. 2026 @ CEPC day

Content

- Structural design of the triangular CFRP truss beam
- Fabrication process
  - Manufacturing of 500 mm length beam
  - Manufacturing of 1000 mm length beam
- Test
  - Static mechanical test and creeping test
  - Flatness measurement of cold plate
- Conclusion

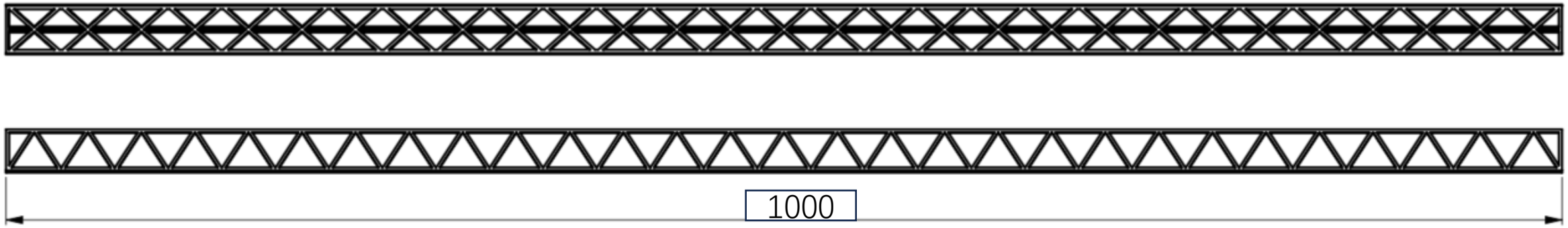
Structure of the triangular truss beam





- In this prototype, the thickness of some layers may be different from the design in TDR.
- **Thickness of cold plate in design is ~ 0.3mm**

- **Main Beam**: Thickness: 0.4mm,width 3X2mm, 0-0-0-90-0-0-0, layer thickness: 0.06mmX7, M40J
- **Secondary beam**: 1X0.4mm, Carbon fiber filament, T700
- Base glue: **epoxy**



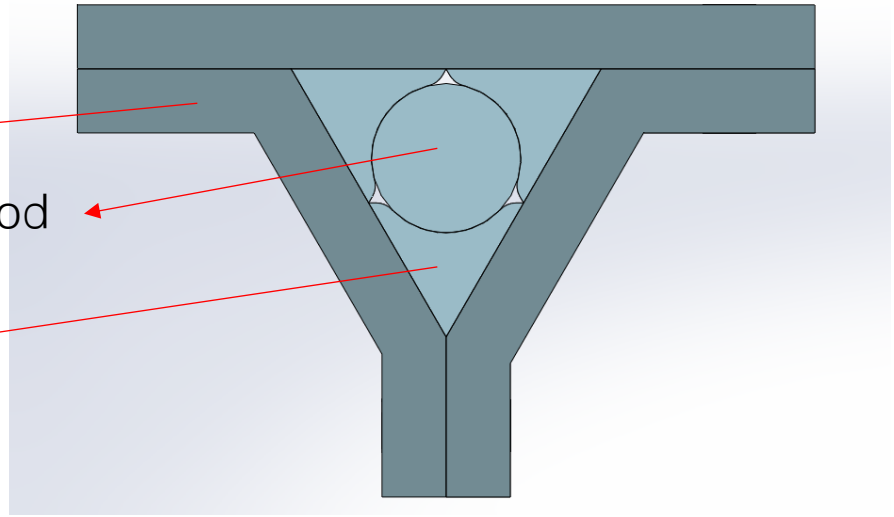
Fabrication process——500mm length beam

Initial mold design: refer to the design of ALICE's tracker mold

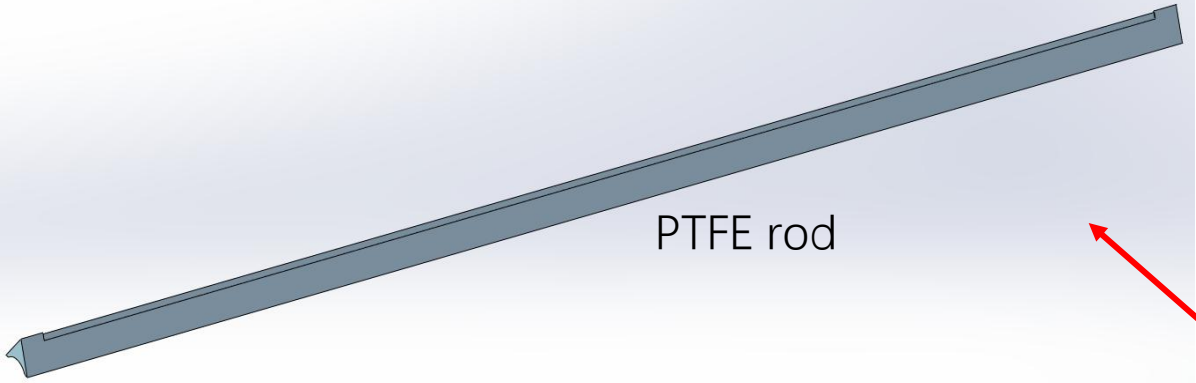


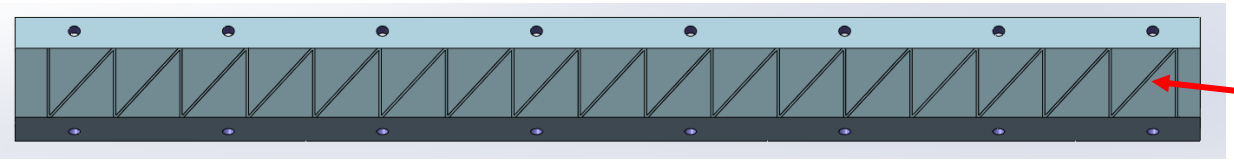
ALICE's tracker mold



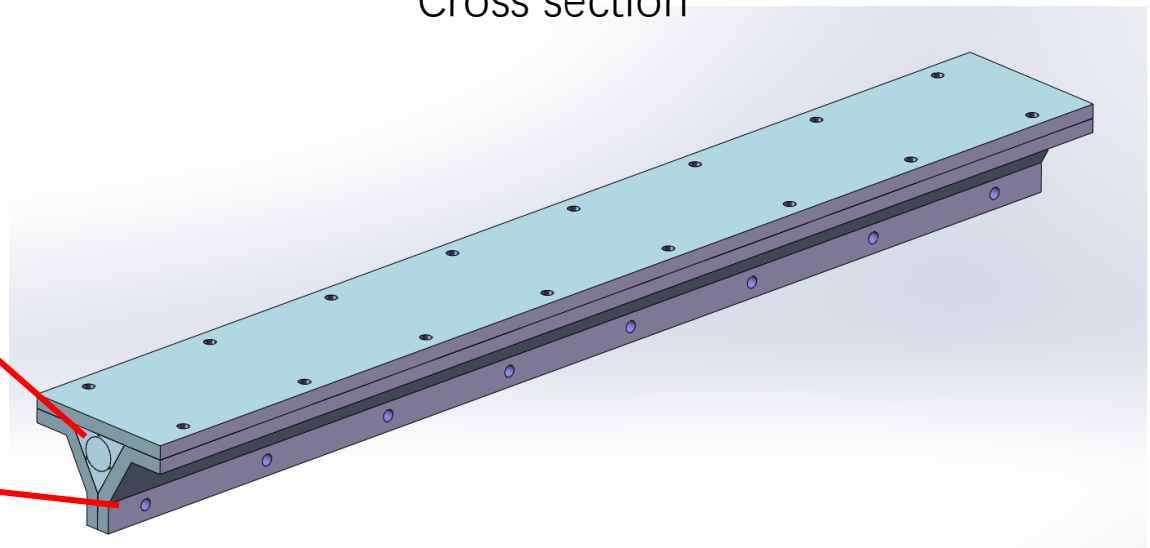


Cross section





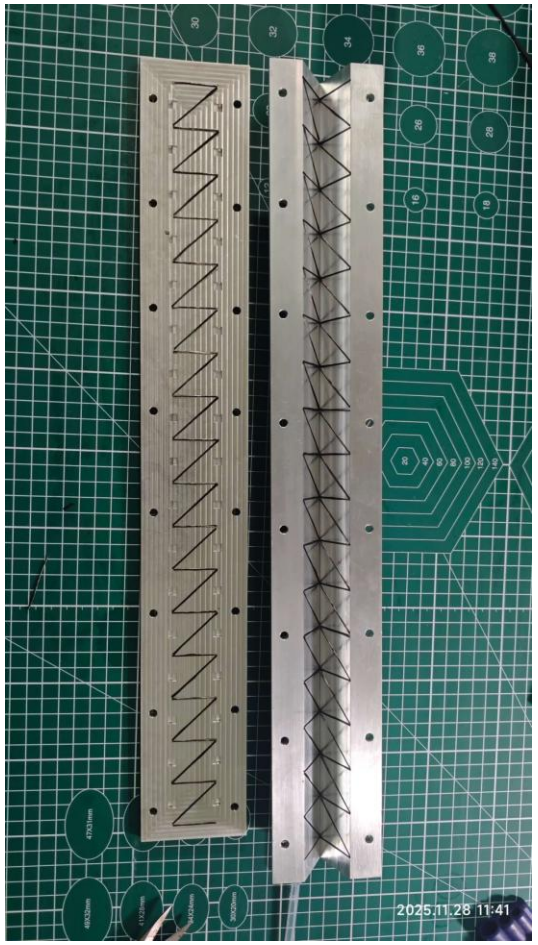
Grooves in outer mold

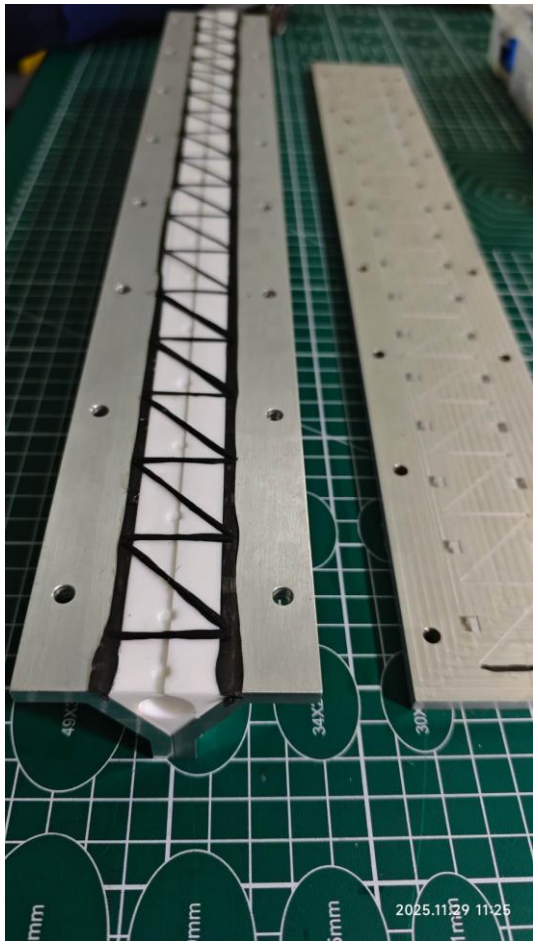


Fabrication process——500mm length beam

Issues

- Carbon fiber of Secondary beam can not be continuous——have to be **separated into lots of short carbon fiber rods**
- Main beams and secondary beams hard to be their position

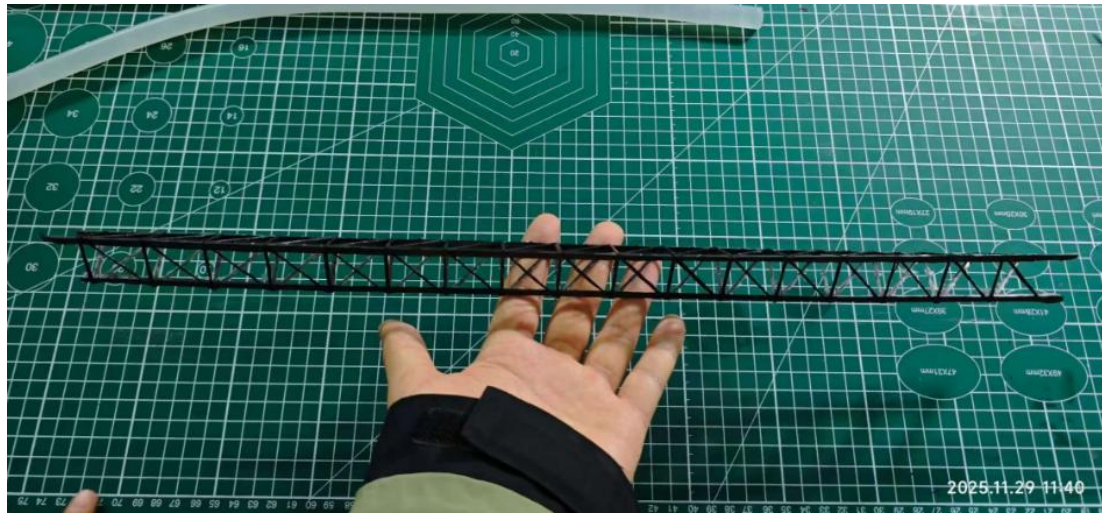




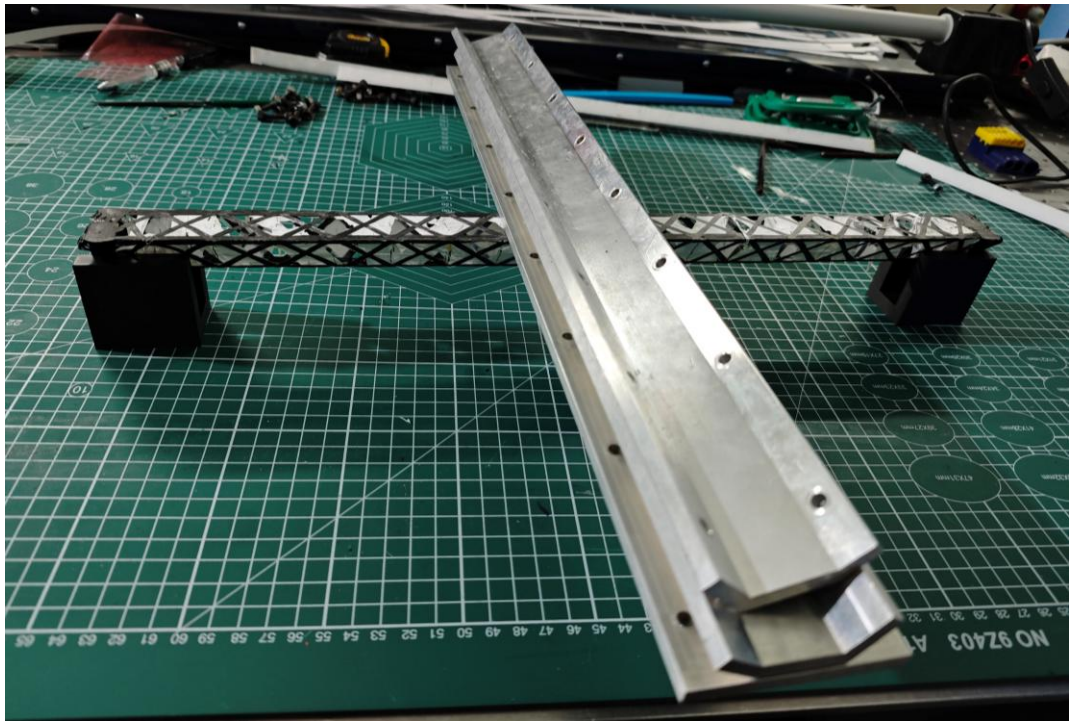


Products of 500 mm length triangular beam









Failure samples (ALICE method)

- <2 mm bonding length (main beam width 3mm)
- Not continuous of CF makes the **bonding strength between secondary beam and main beam very weak**

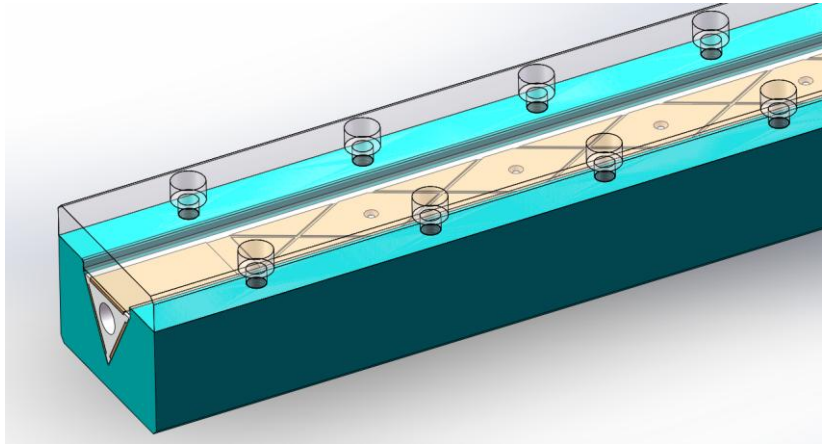
Success samples when change the fabricated process

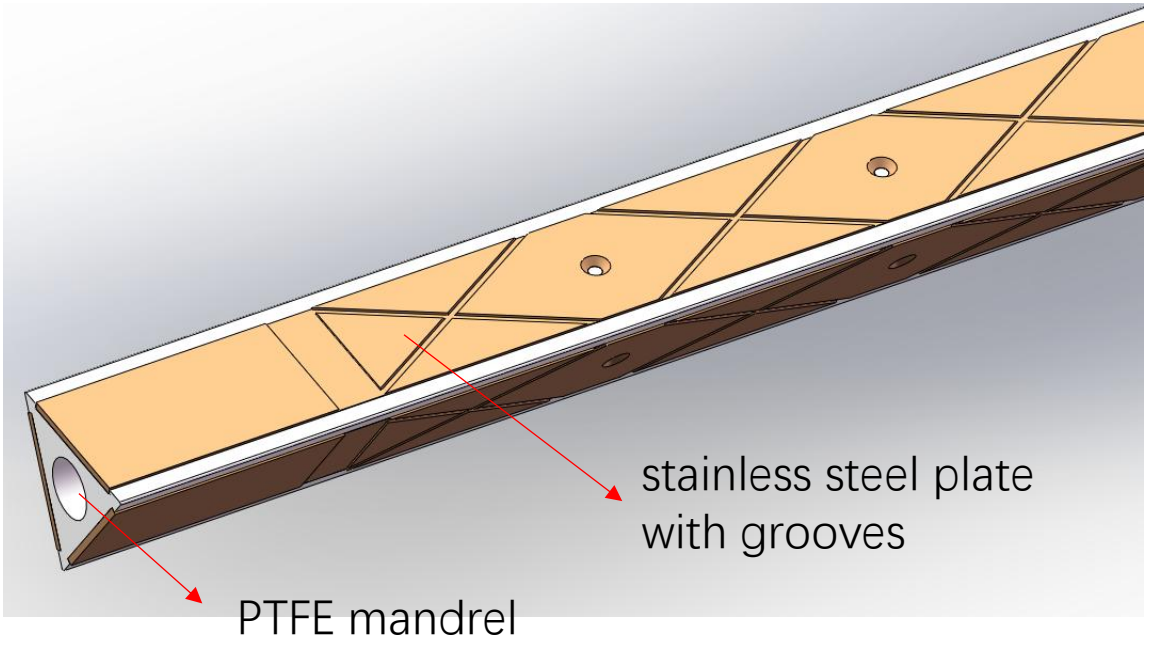
- **Fiber wrapped around the core mold instead of in grooves of outer mold**
- Using a continuous fiber

Fabrication process——1000 mm length beam

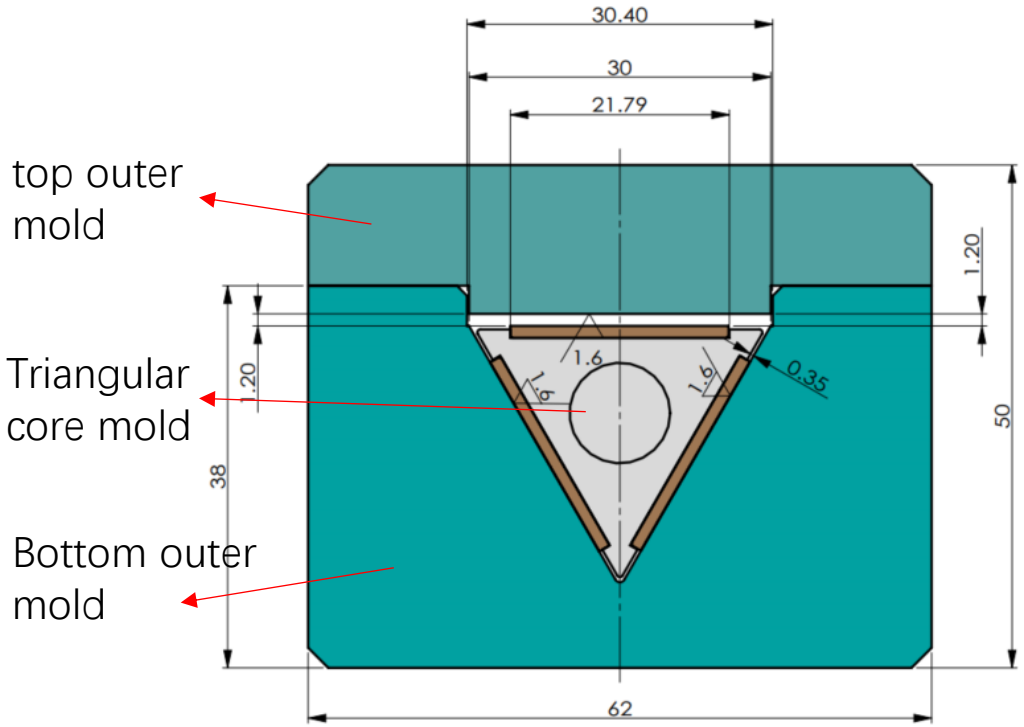
Mold design of Beam:

- Main difference: the grooves in the core mold
- Length of Beam:1000 mm
- Secondary beam use the continuous fibre: total length ~7m
- Material: stainless steel



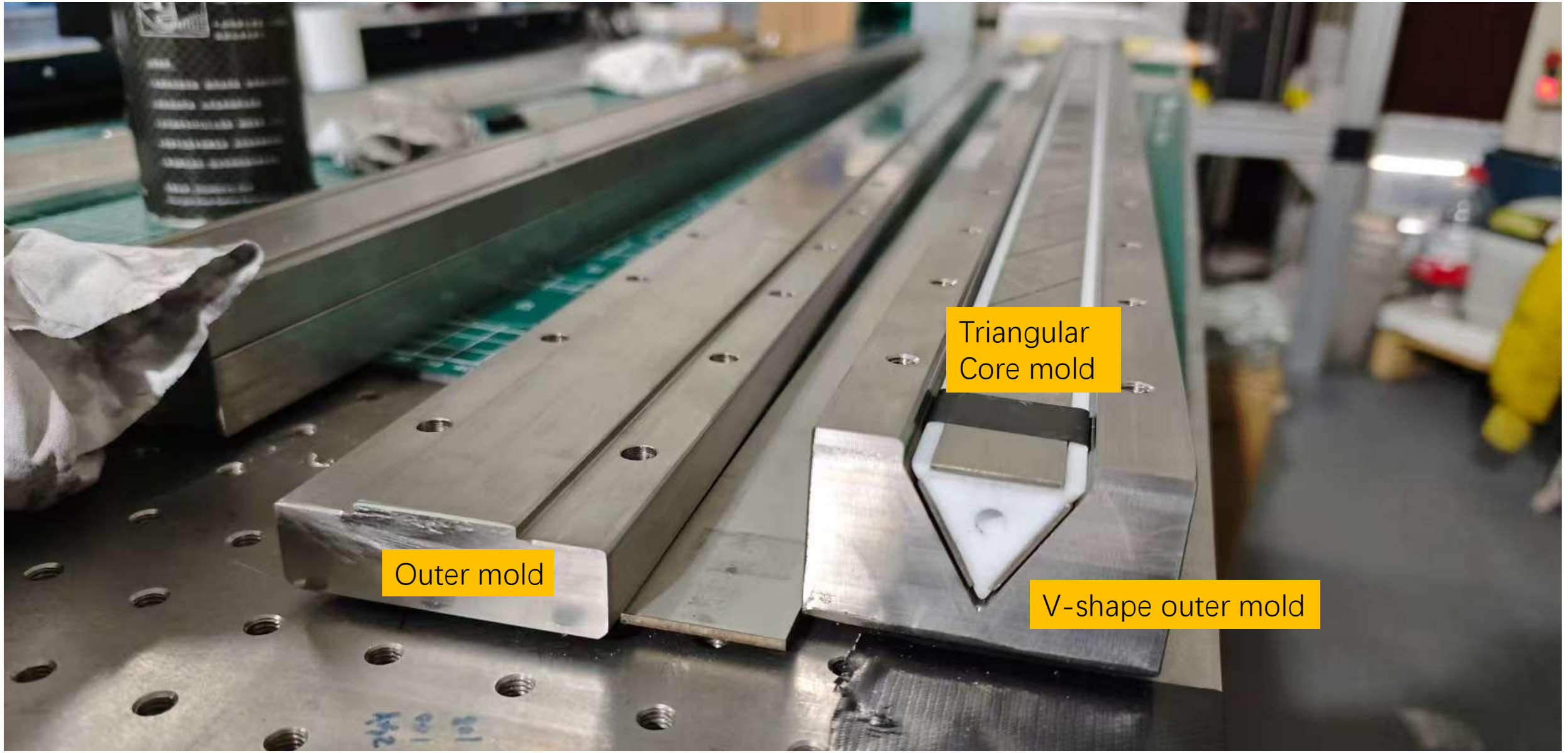


Triangular core mold



Cross section of mold

Photograph of the 1000 mm triangular CFRP truss beam mold



Fabrication process——1000 mm length beam

- **Main beam**： on the three angles of the triangular core mold
- **Secondary beam:** Unidirectional Carbon Fiber Tows wrap around the core mold
- **Weight of the first beam prototype**: 13.9g
- (second and third beam: 15.0g /15.23g)



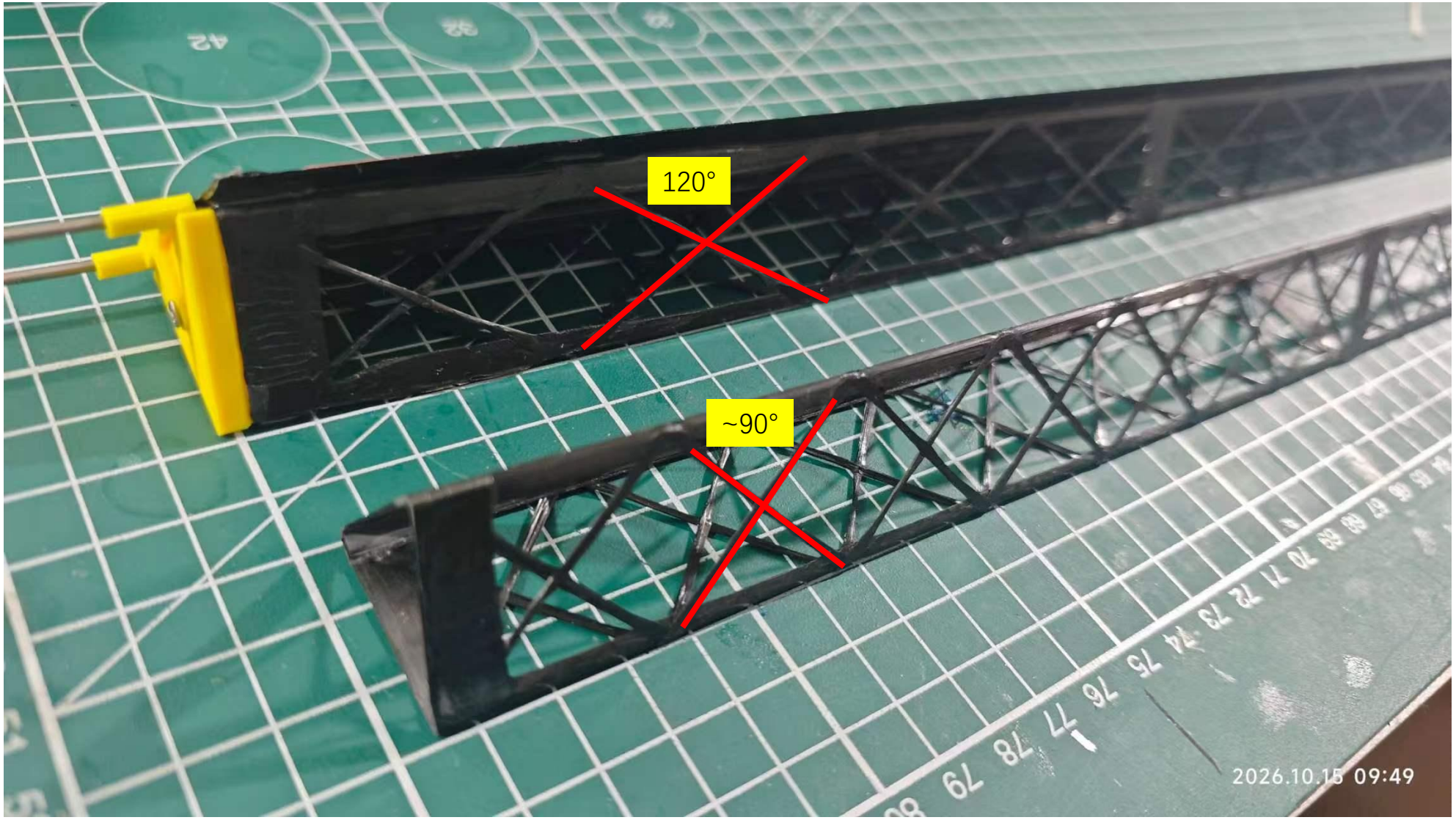
Fiber wrapped around the core mold in the lab



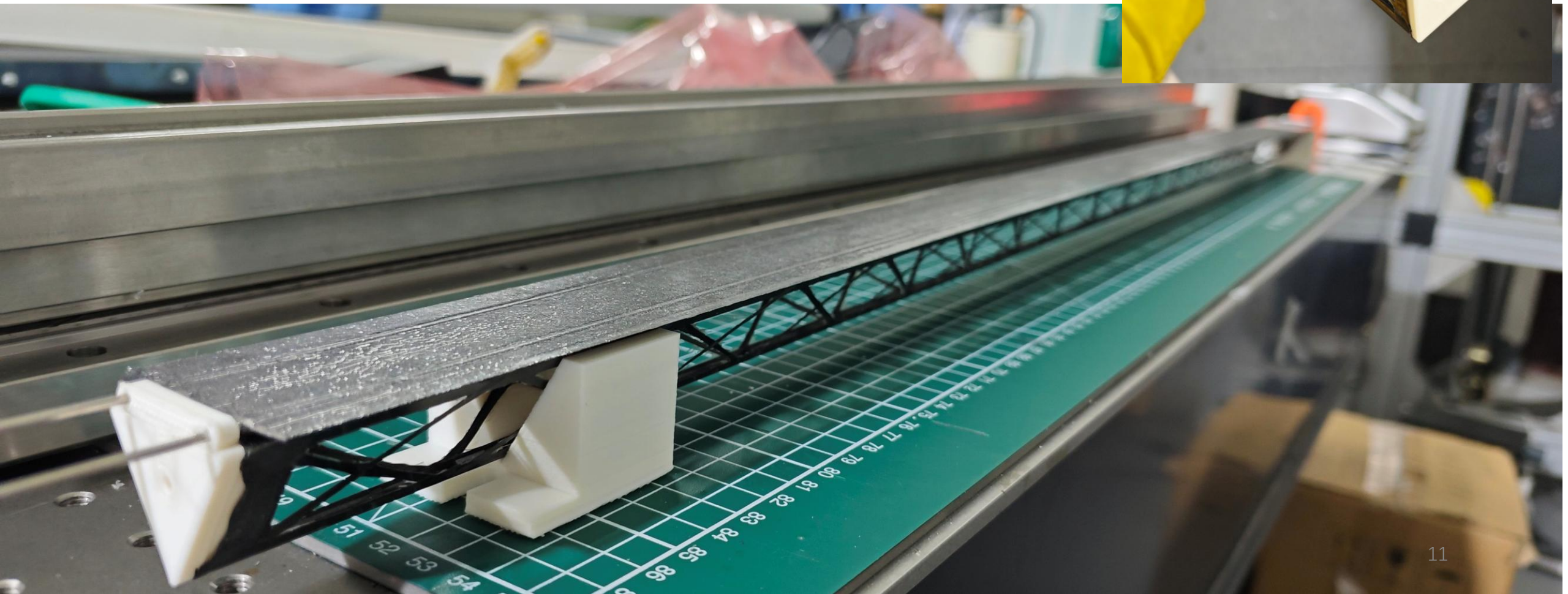
First beam

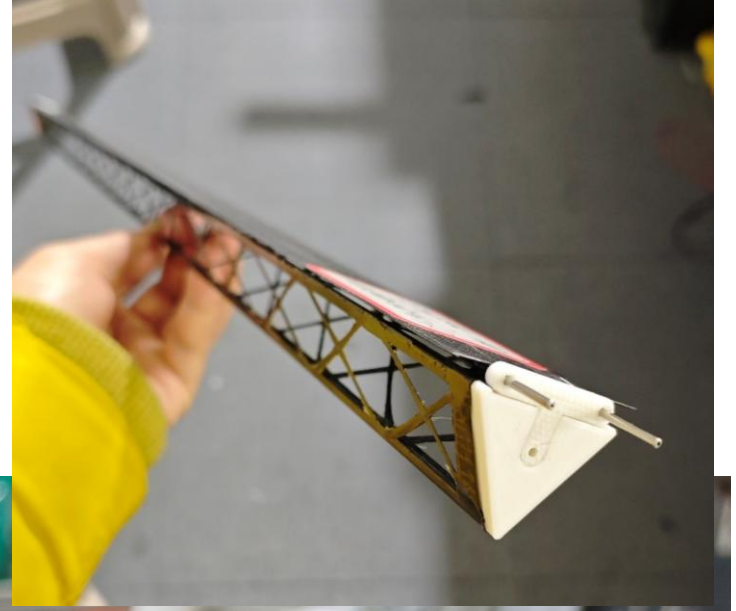
Fabrication process——1000 mm length beam

- Optimize the angle of secondary beam to make the beam more rigid
- The weight of beam increasing ~ 1g

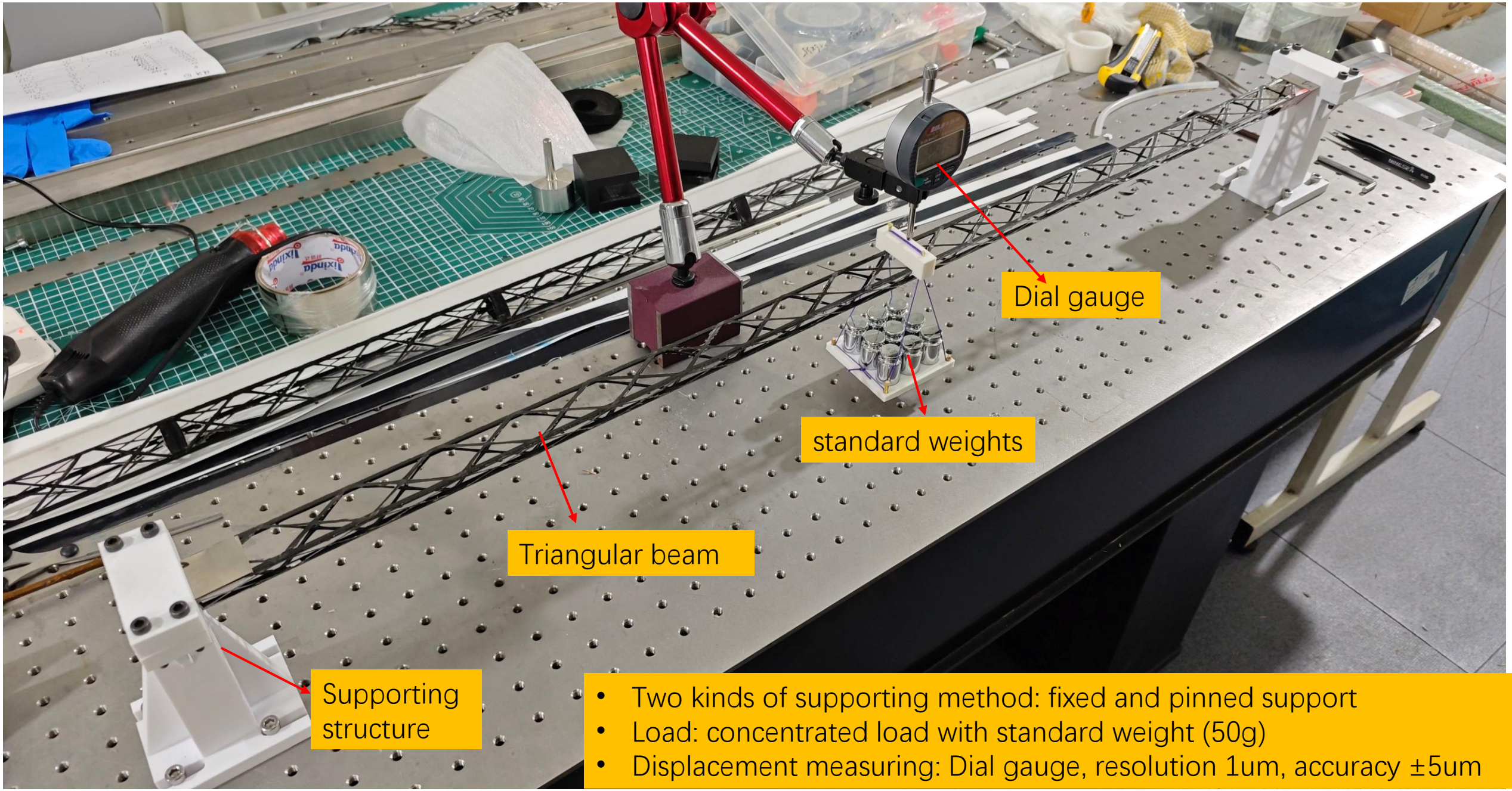


Assembly of cold plate and triangular beam





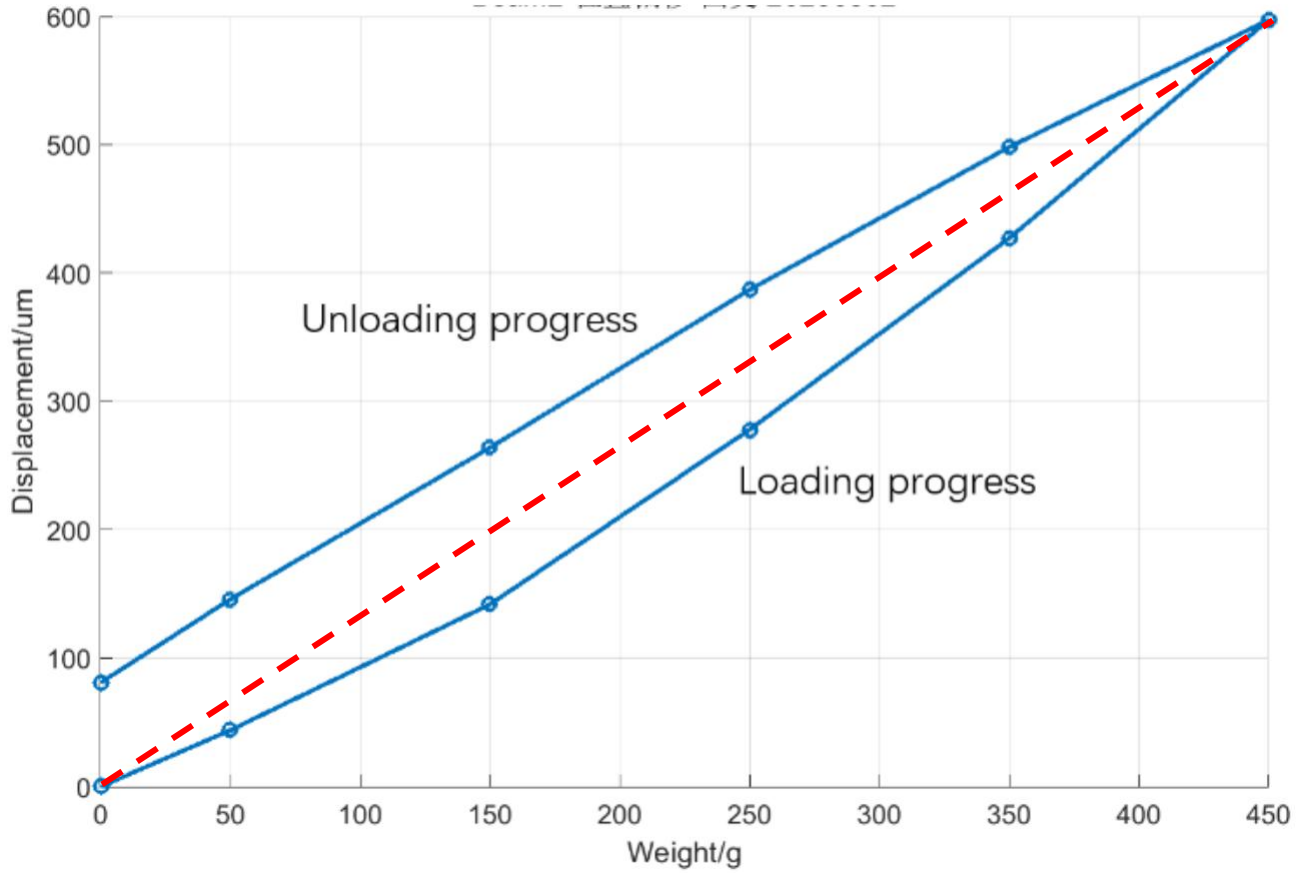
Static mechanical test of triangular beam



- Two kinds of supporting method: fixed and pinned support
- Load: concentrated load with standard weight (50g)
- Displacement measuring: Dial gauge, resolution 1um, accuracy ±5um

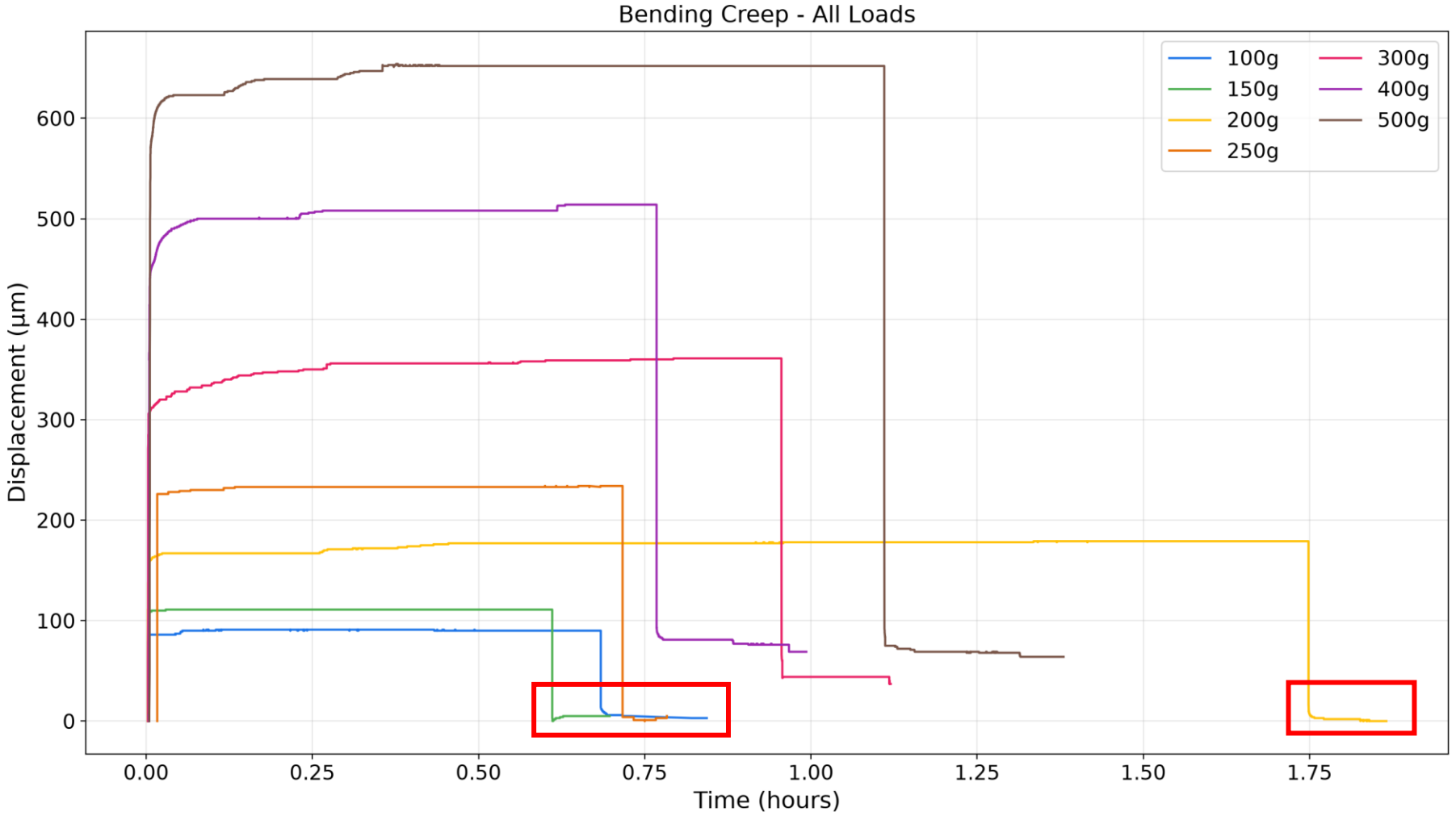
Displacement measurement of beam

- ➢ Load: 0~450g
- ➢ Displacement is not linear with the load increasing: not elastic deflection
- ➢ **Loading and unloading curves are not matched together**
- ✓ Creeping is obvious under high load
- ✓ Minor cracks may occur under high load



Creeping test of triangular beam

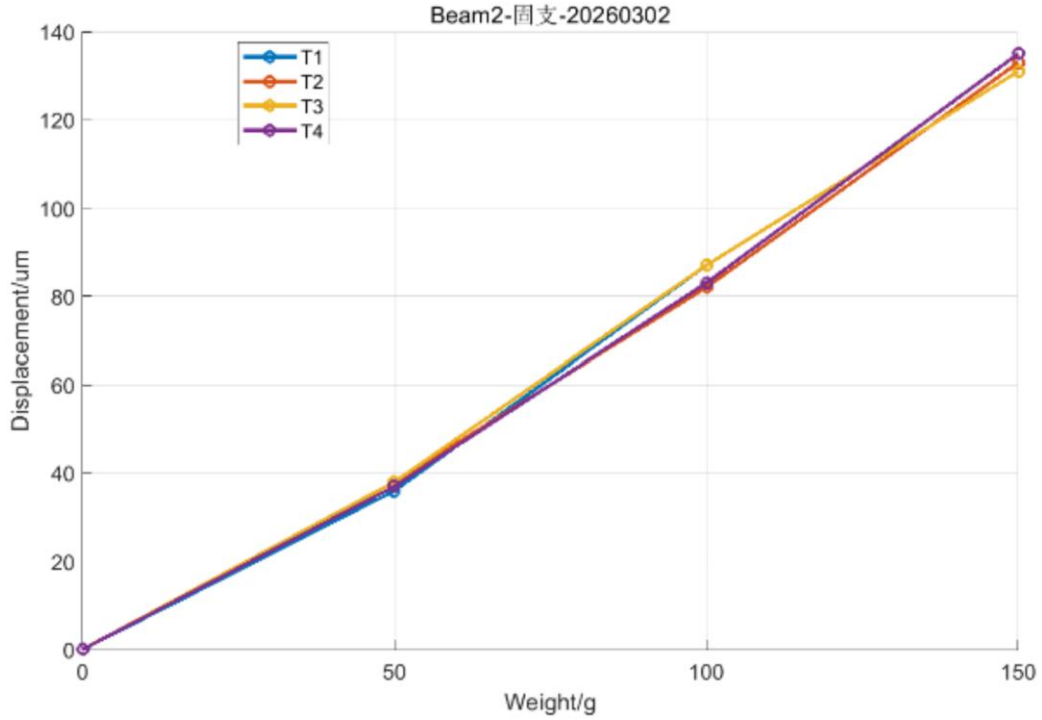
- Test duration: <2 hours —— the temperature could influent the test
- Deformation returns to 0 um after unloading for a while when the load is below 250g —— there is no crack appeared
- Some high loads (>300g) can not return to 0——maybe needs more time or maybe appears minor cracks
- Creeping still exists under light load—— happened at beginning of loading (~half hours)

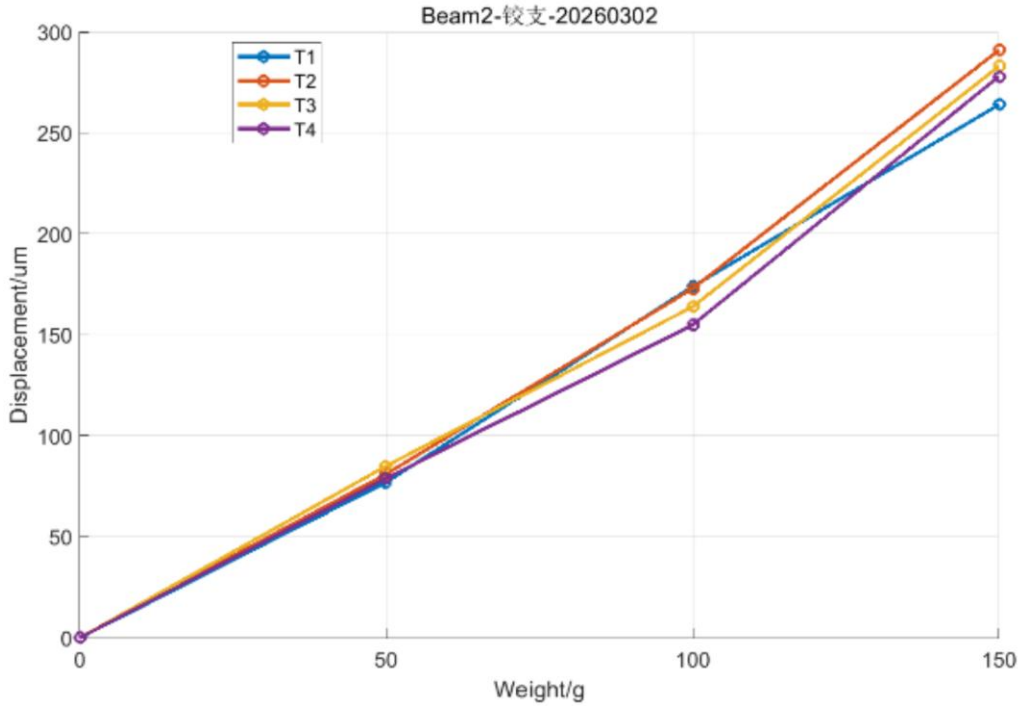


Static mechanical test of triangular beam

Displacement measurement of Beam

- Reduce the load to minimize the creeping: 0~150g





Fixed support boundary:

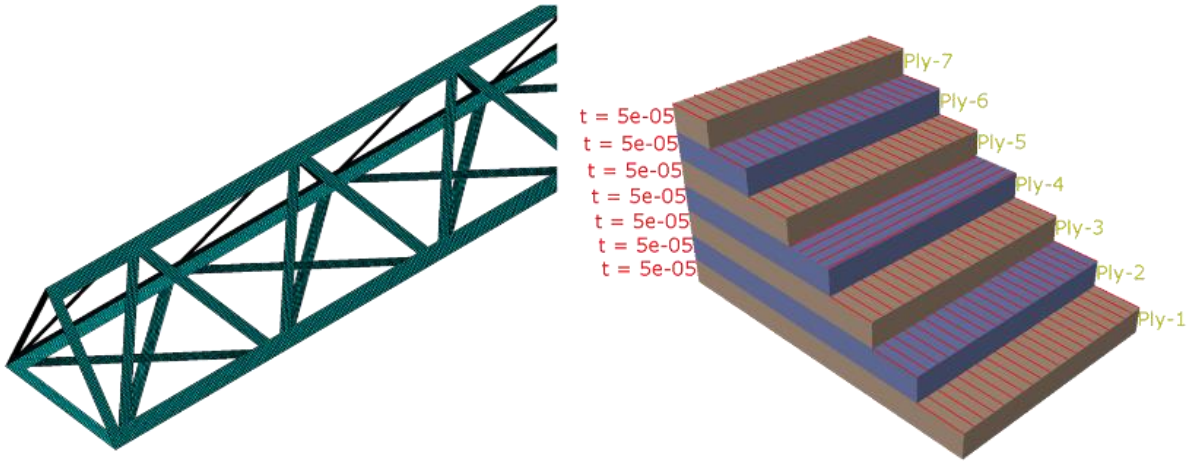
- 50g: 37.25 ± 0.96 um
- 100g: 84.75 ± 2.63 um
- 150g: 132.50 ± 1.91 um

Pinned support boundary:

- 50g: 80.50 ± 3.42 um
- 100g: 166.50 ± 8.89 um
- 150g: 279.00 ± 11.34 um

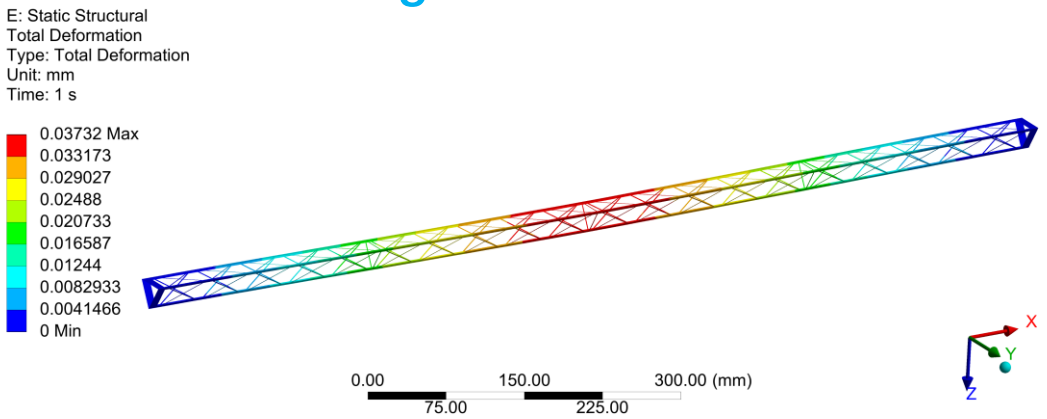
FEA of test beams

FEA model

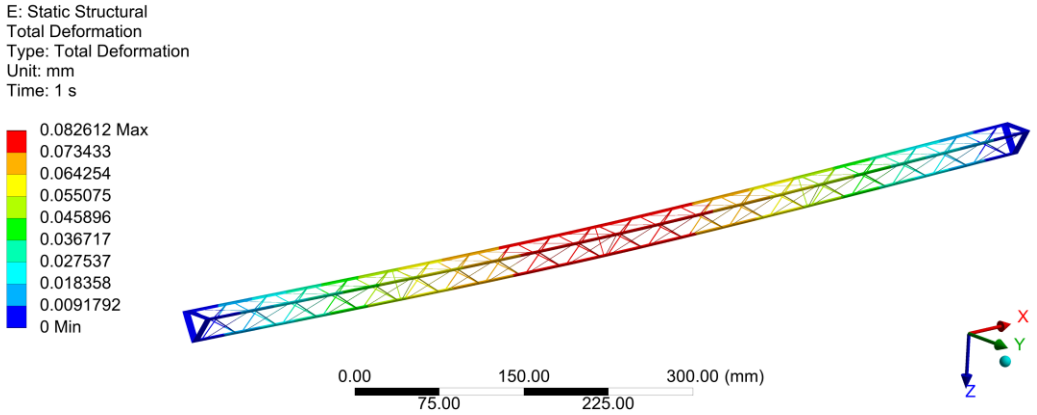


FE mesh of the triangular CFRP truss beam and definition of main beam layup

- load：50g—concentrated load



Deformation under fixed support boundary: 37um
Main beam part: 36um



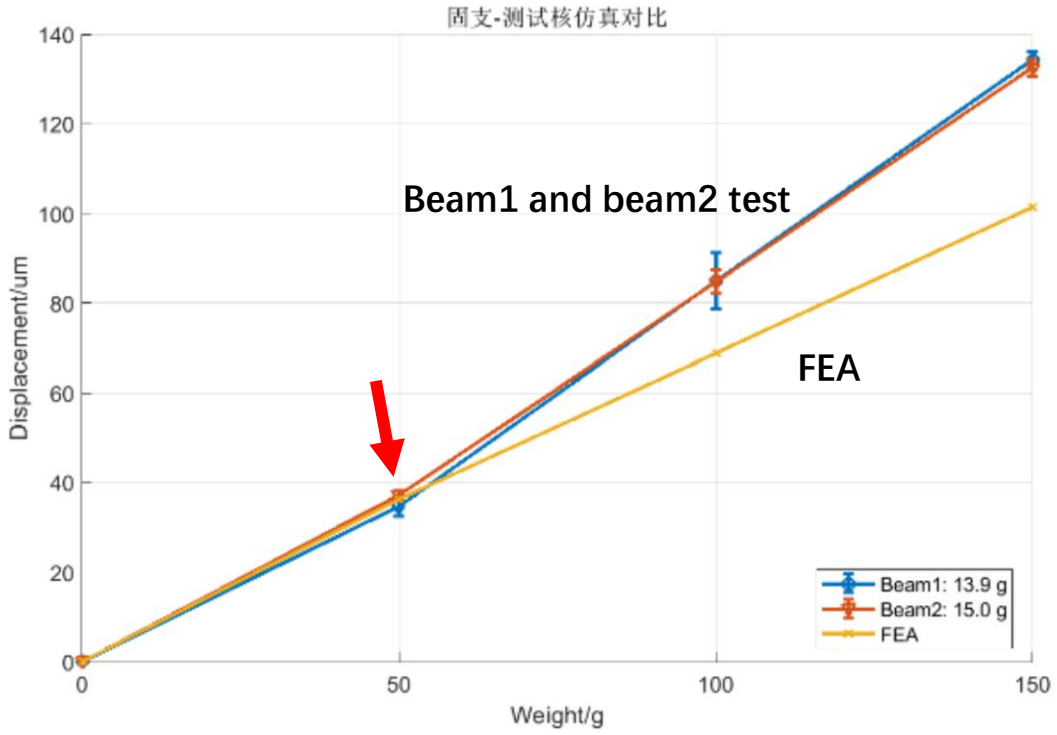
Deformation under pinned support boundary: 83um
Main beam part: 81um

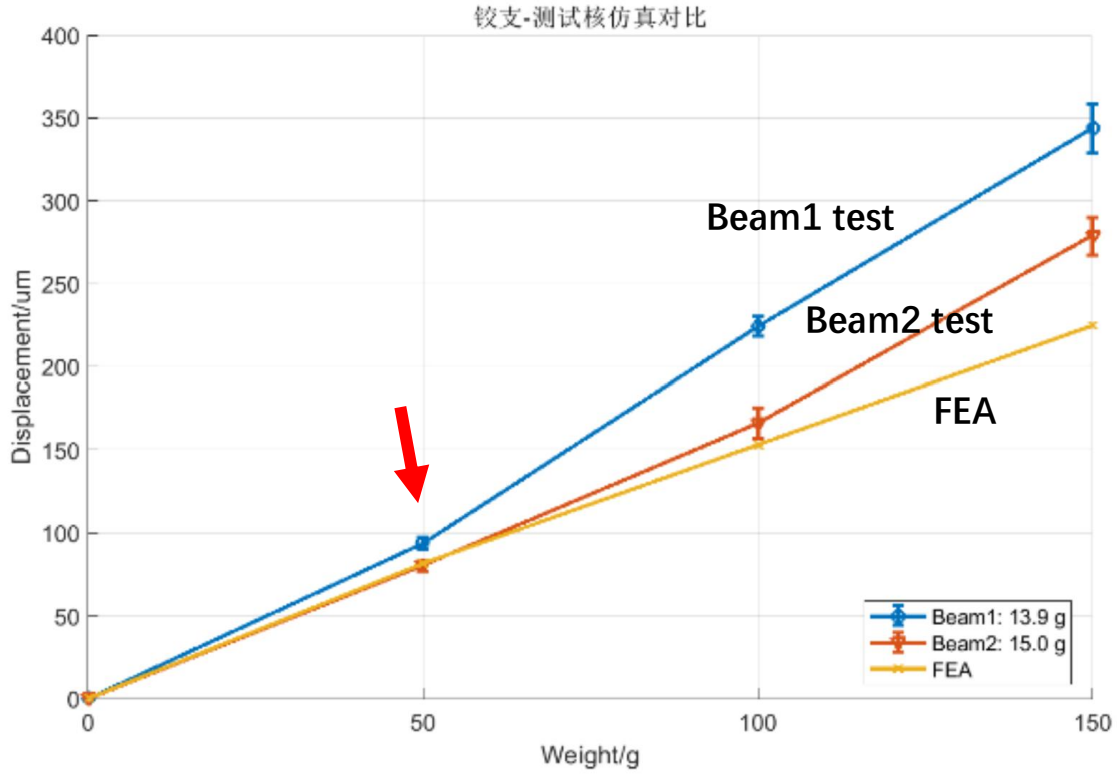
Table 3 Material properties of the CFRP plies used in the FE model.

Material	Density (kg/m³)	E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	ν_{12}	ν_{13}	ν_{23}	G_{12} (GPa)	G_{13} (GPa)	G_{23} (GPa)
M40J	1600	203	10	10	0.3	0.3	0.35	4	4	2.7
T700	1558	123	7.9	7.9	0.3	0.3	0.35	3	3	2.9

Compare between FEA of measurement result

- Under 50g load, the results can be matched very well between FEA and measurement
  - **Verify the correctness of the FEA result under light load**
- Creeping still exist under 100g and 150g load





Table：Comparison under 50 g concentrated load

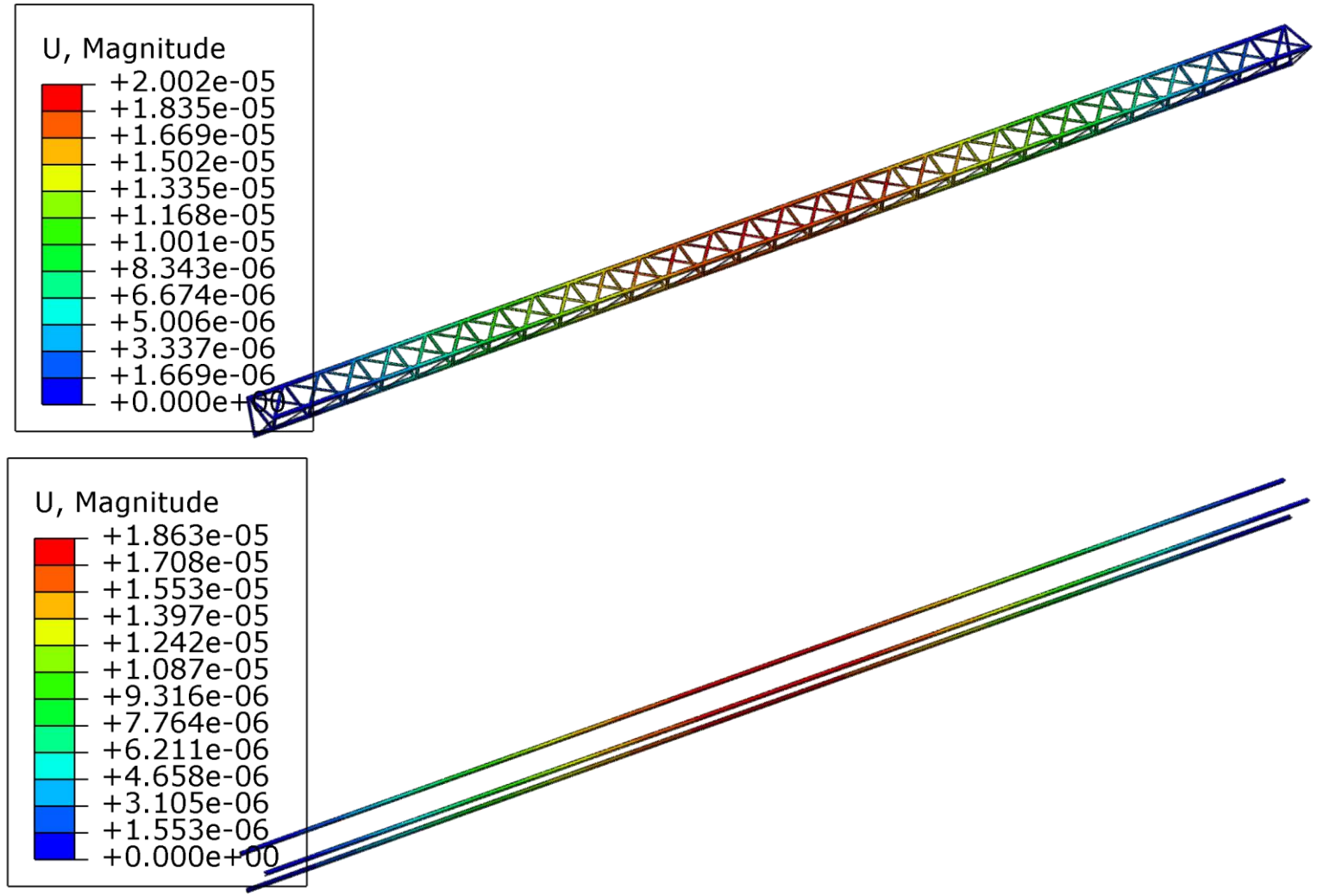
Boundary condition	FEA (μm)	Measured (μm)	Absolute deviation (μm)	Relative deviation (%)
Fixed support	36.32	37.25 ± 0.96	+0.93	2.6
Pinned support	81.49	80.50 ± 3.42	−0.99	1.2

FEA of beam under the real sensor weight

- Fixed support boundary
- Sensor weight: ~80g—**uniformly distributed load**
- **Deformation is ~20um, smaller than that of concentrated load of 50g （36 um）**
- Buckling coefficient: 36.5, the structure will not lose stability

Index	Description		
0	Increment	0: Base State	
1	Mode	1: EigenValue =	36.501
2	Mode	2: EigenValue =	36.502
3	Mode	3: EigenValue =	39.667
4	Mode	4: EigenValue =	39.668

Buckling coefficient: 36.5



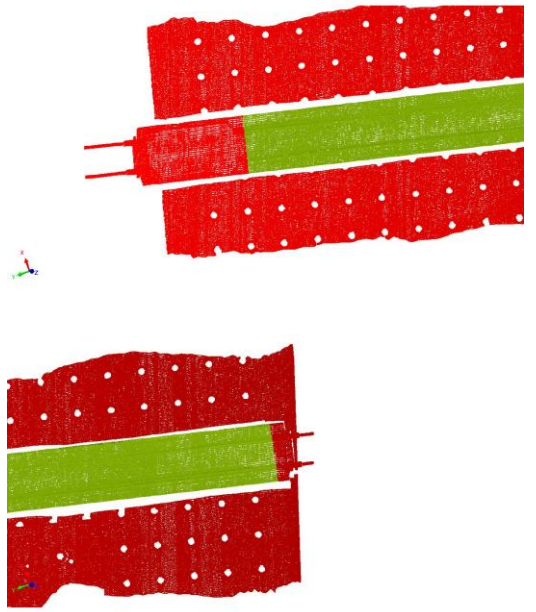
FEA deformation under operational sensor load (80 g uniformly distributed load, fixed support)

Flatness measurement of cold plate

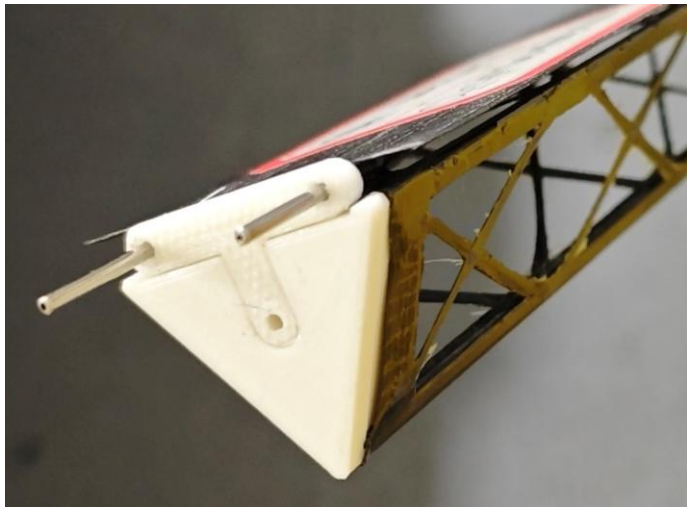
- Measurement accuracy: 50um
- Higher at the both end of plate —— Assembly reasons
- Lower at the edge of plate
- Flatness: ±0.5mm
- Measure the flatness of mold



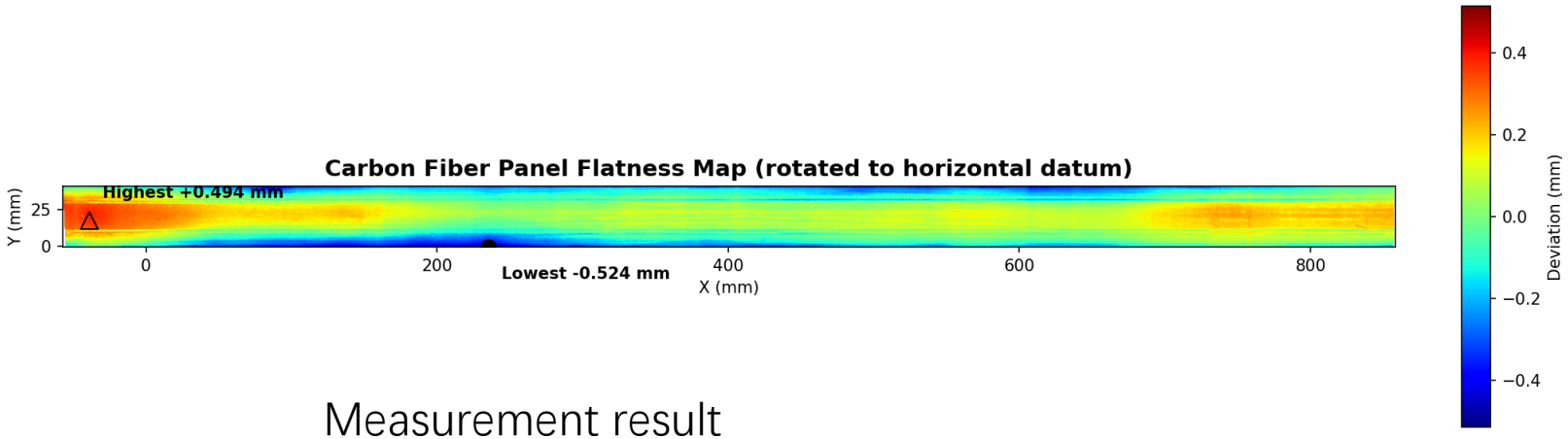
3d scanning measurement



Data cloud



Assemble parts at the end of plate



Measurement result

Summary

- **Successfully fabricated** a 1000 mm triangular CF truss beam; mass ~15 g.
- **FEA vs test**: under 50 g concentrated load—**fixed support 37.25** ± 0.96 μm **vs FEA 36.32 μm** (2.6% deviation); pinned support 80.50 ± 3.42 μm vs FEA 81.49 μm (1.2% deviation).
- **Operational load**: **80 g uniformly distributed load gives ~20 μm deformation**; first-order buckling coefficient 36.5, showing ample safety margin. Deformation **smaller than that of under 50g concentrated load**.
- **Creep behavior**: noticeable above 150 g concentrated load; little impact under normal ~80 g operational load;
- **Crack** will not happen under 80 g operational load, more than 5 times of safety coefficient (250/50)
- **Next plan:** manufacture 10 sample staves for cooling test and flatness improvement

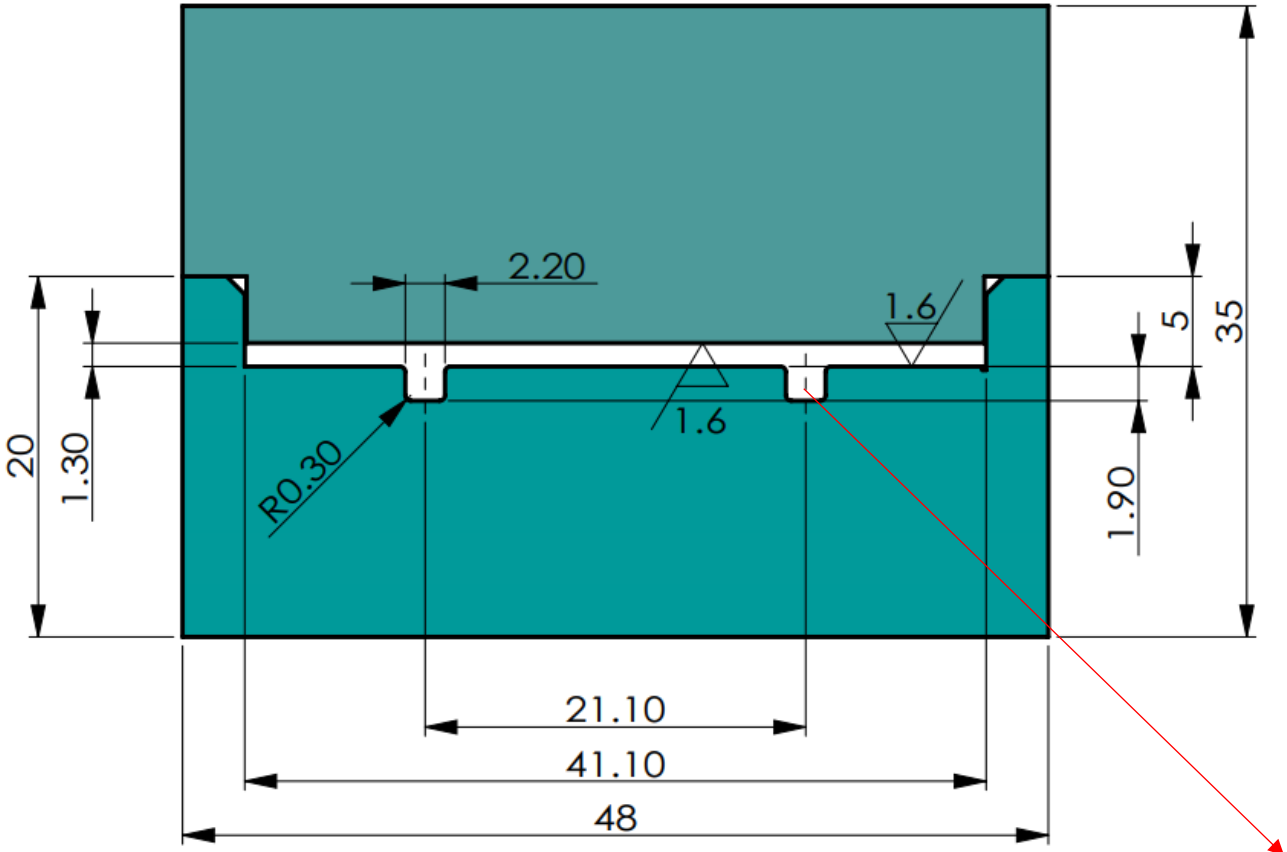
Thanks!

Back up

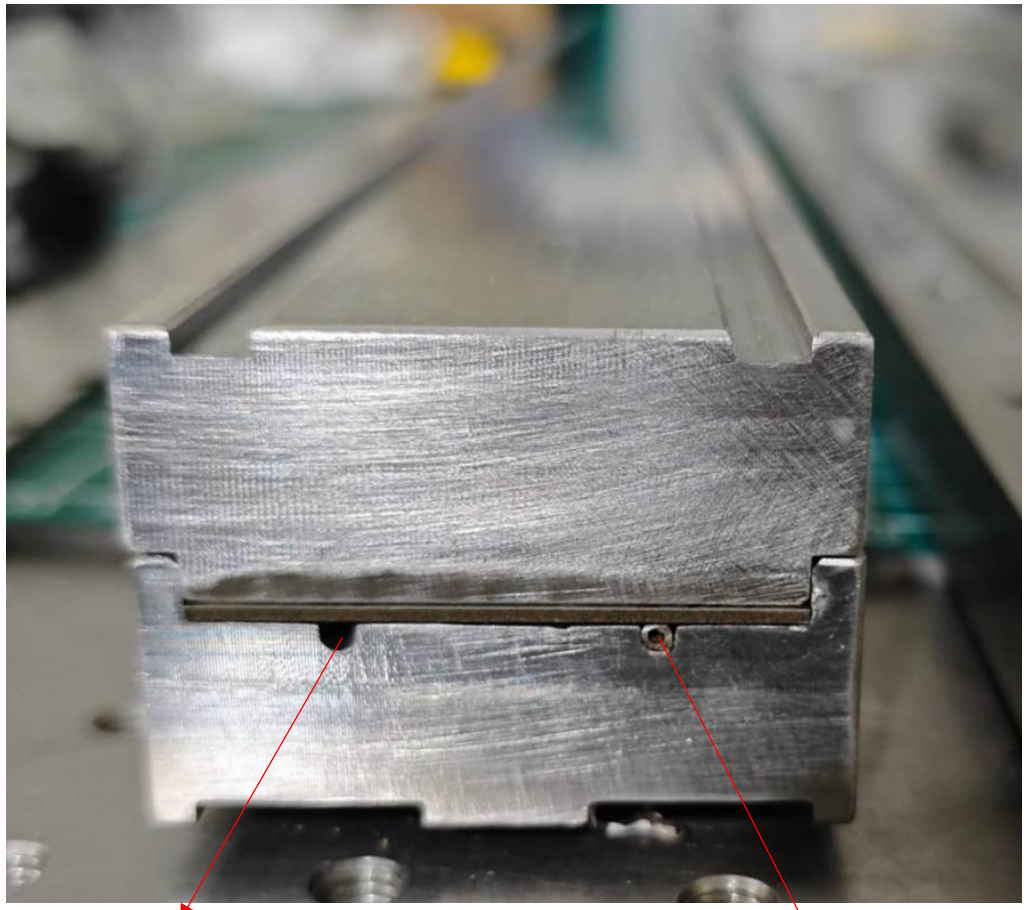
Manufacturing of 1000mm cold plate

Mold design of cold plate:

- The stainless steel mold features two elongated slots for inserting the cooling tubes
- Length of plate:1000 mm
- Put the different material film in the mold layer by layer



Cross section of cold plate mold



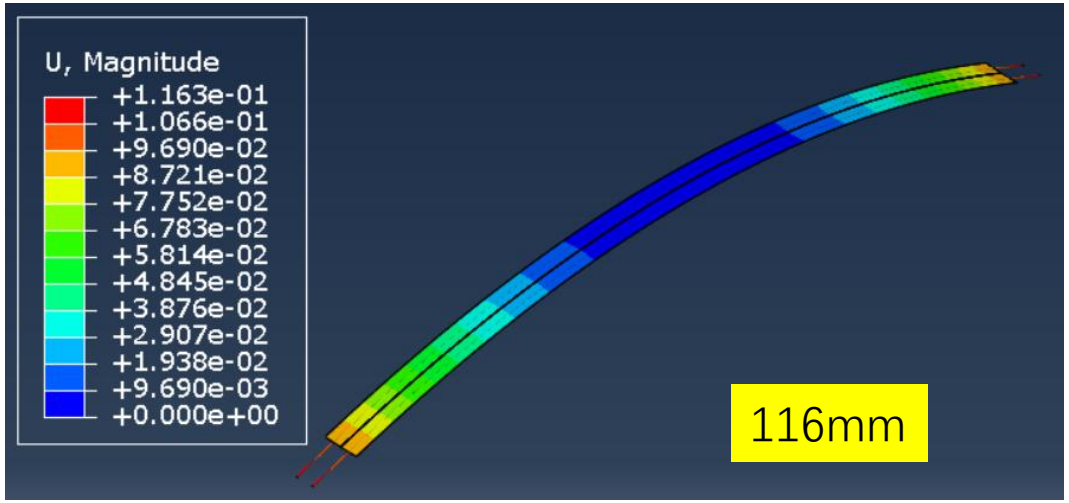
Slote for the cooling tube: OD1.6mm

cooling tube

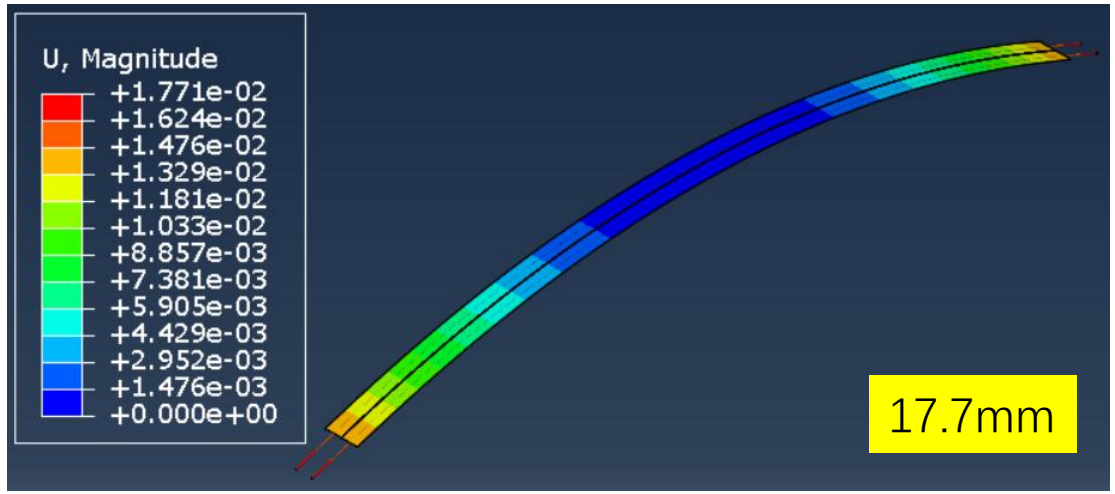
First cold plate
Bended for the thermal coefficient difference between materials



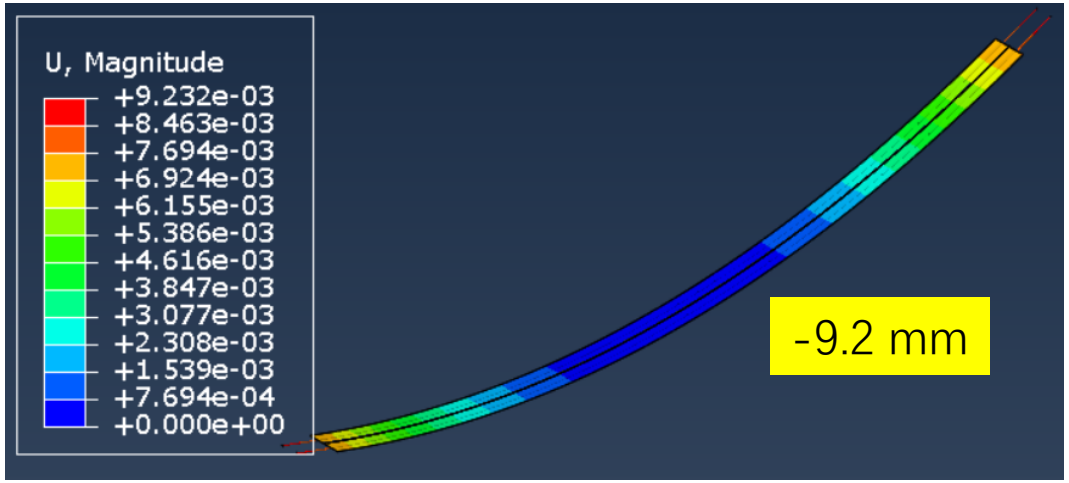
FEA of thermal deformation（load：120 to 20℃）



Carbon fiber direction: 0/0/90/0， stainless steel tube



Carbon fiber direction: 90/90/90/90， stainless steel tube



Carbon fiber direction: 90/90/90/90, Titanium tube

Cold plate manufacturing test of different direction

- Optimizing Layer to reduce the bending deformation of cold plate

1. Carbon fiber direction: 0/0/90/0,
2. Carbon fiber direction: 90/90/90/90, without Graphene film
3. Carbon fiber direction: 0/90/90/90, without Graphene film
4. Carbon fiber direction: 90/90/0/90, without Graphene film

- Good quality of the thickness consistency: 0.28±0.02mm

