

Tensile and Shear Response of Carbon Fiber Fabric Composites at Different Loading Rates

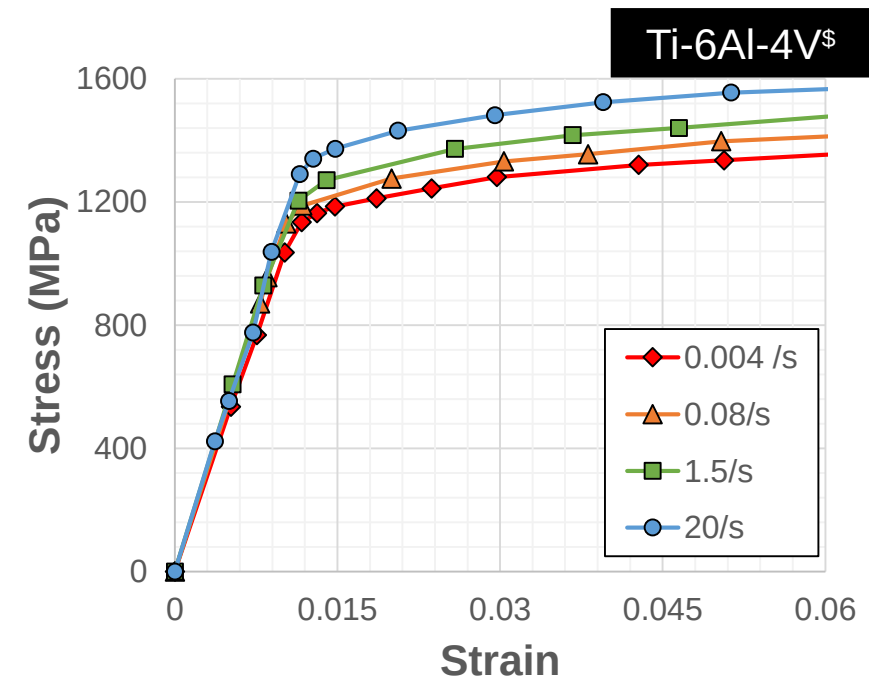
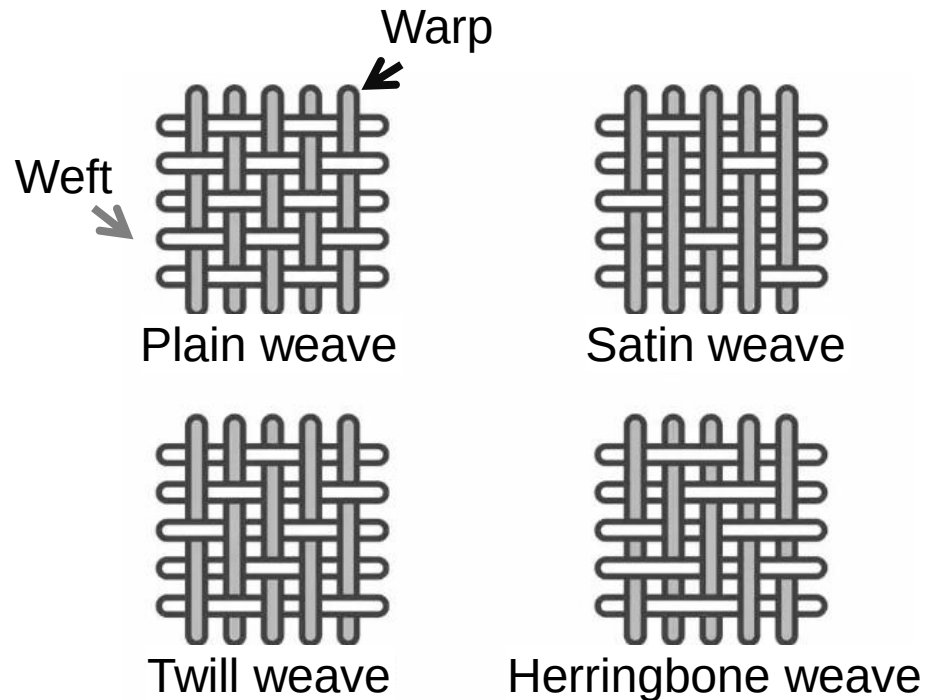
Tae-Seong Choi¹ and Wooseok Ji¹⁺

¹ Department of Mechanical Engineering
Ulsan National Institute of Science and Technology (UNIST)



Introduction

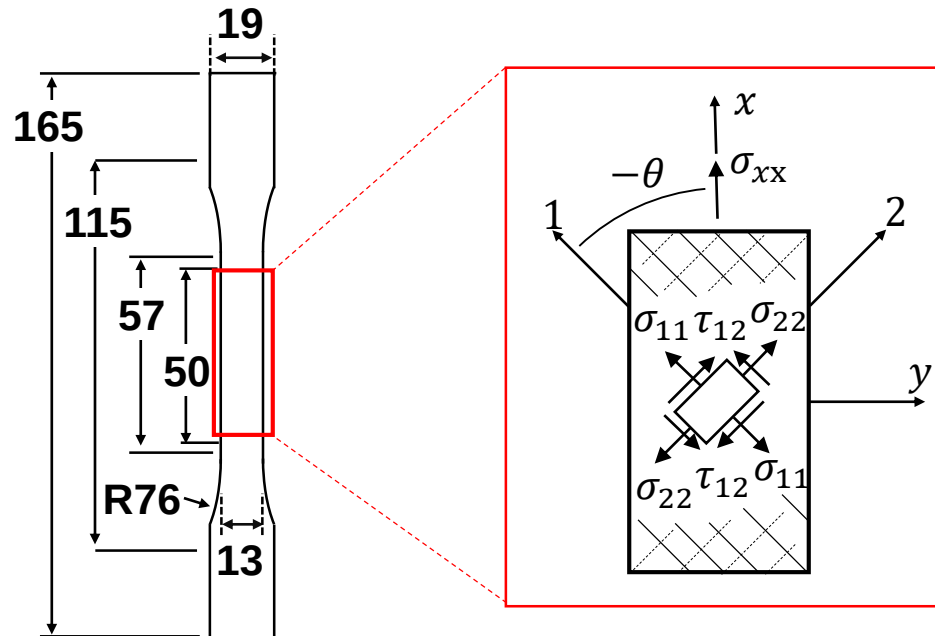
- **Numerous advantages of textile composites**
 - High dimensional stability, remarkable fatigue resistance, and so on compared to UD composite
- **Necessity of research for the rate-dependent behavior of textile composites**
- **Tension and shear tests at various loading rates**
 - Epoxy and carbon textile fabric-reinforced epoxy composite (CF/EP)



\$. Maiden, C. J et al. (1966)

Setup for tension and shear tests ^{1/2}

- **Strain rates:** 0.1/min, 1/min, 4/min and 16/min
 - Strain rate defined as loading rate/gauge length
 - Three repetitive tests at each strain rate
- **Materials**
 - Epoxy : INF-114/INF 211 (PRO-SET® Inc)
 - CF Fabric: 1321P plain weave textile (JMC Corp)
- **Same configuration for the specimen per ASTM D638**



*For shear tests ($\theta = 45^\circ$),

$$\tau_{12} = \frac{\sigma_{xx}}{2} = \frac{F_x/A}{2}$$

$$\gamma_{12} = \epsilon_{xx} - \epsilon_{yy}$$

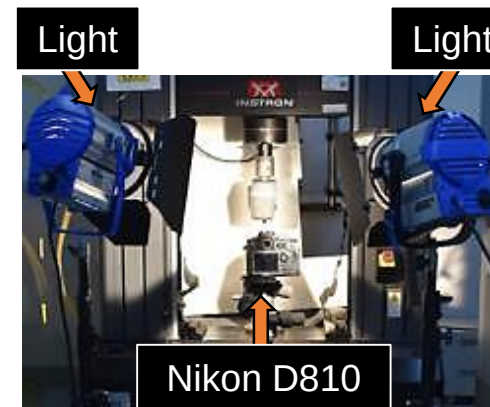
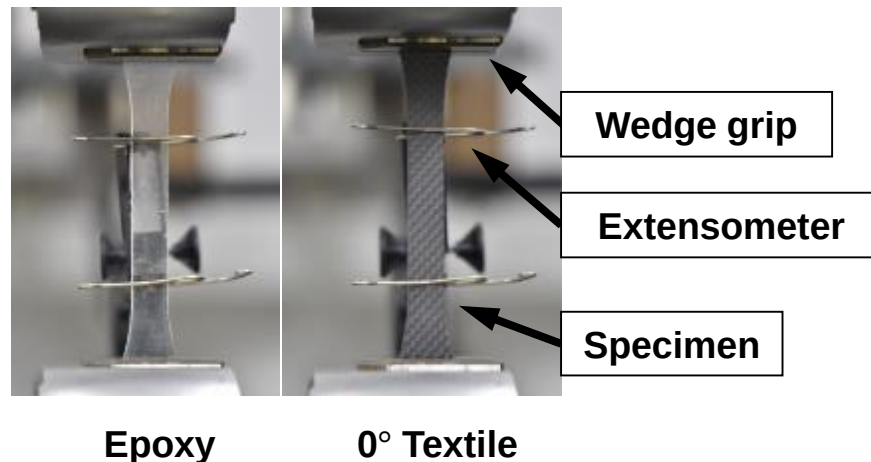
Setup for tension and shear tests 2/2

- **Load measurement:** Load cell of the loading frame
 - Loading frame: Instron 5982 (electromechanically-driven loading frame)
- **Strain measurement**

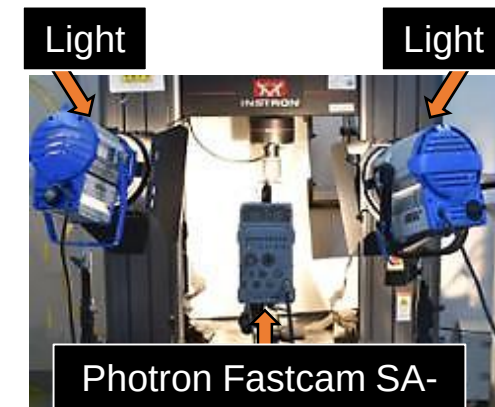
*Digital image correlation technic

**V-notched rail shear test

	Tension test		Shear test	
	Epoxy	CF/EP	Epoxy**	CF/EP
0.1/min	Extensometer	Extensometer	DIC	DIC
1/min	Extensometer	Extensometer	X	DIC
4/min	Extensometer	Extensometer	X	DIC
16/min	Extensometer	DIC*	DIC	DIC



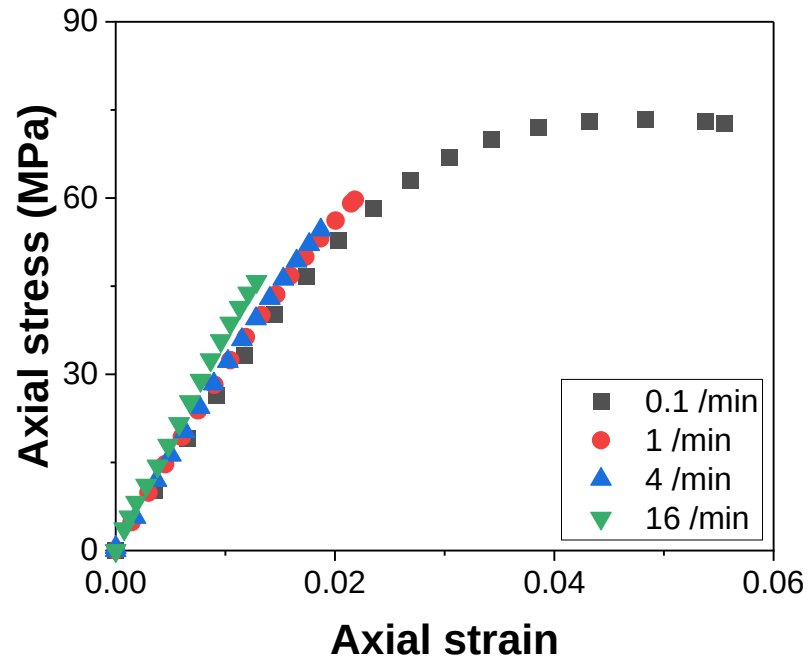
DIC setup
with DSLR camera



DIC setup
with high-speed camera

Results of tension tests on epoxy ^{1/2}

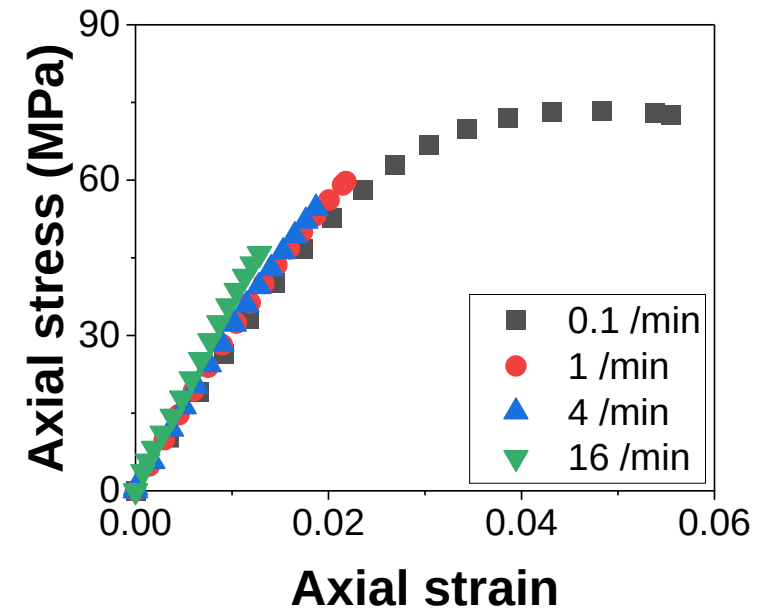
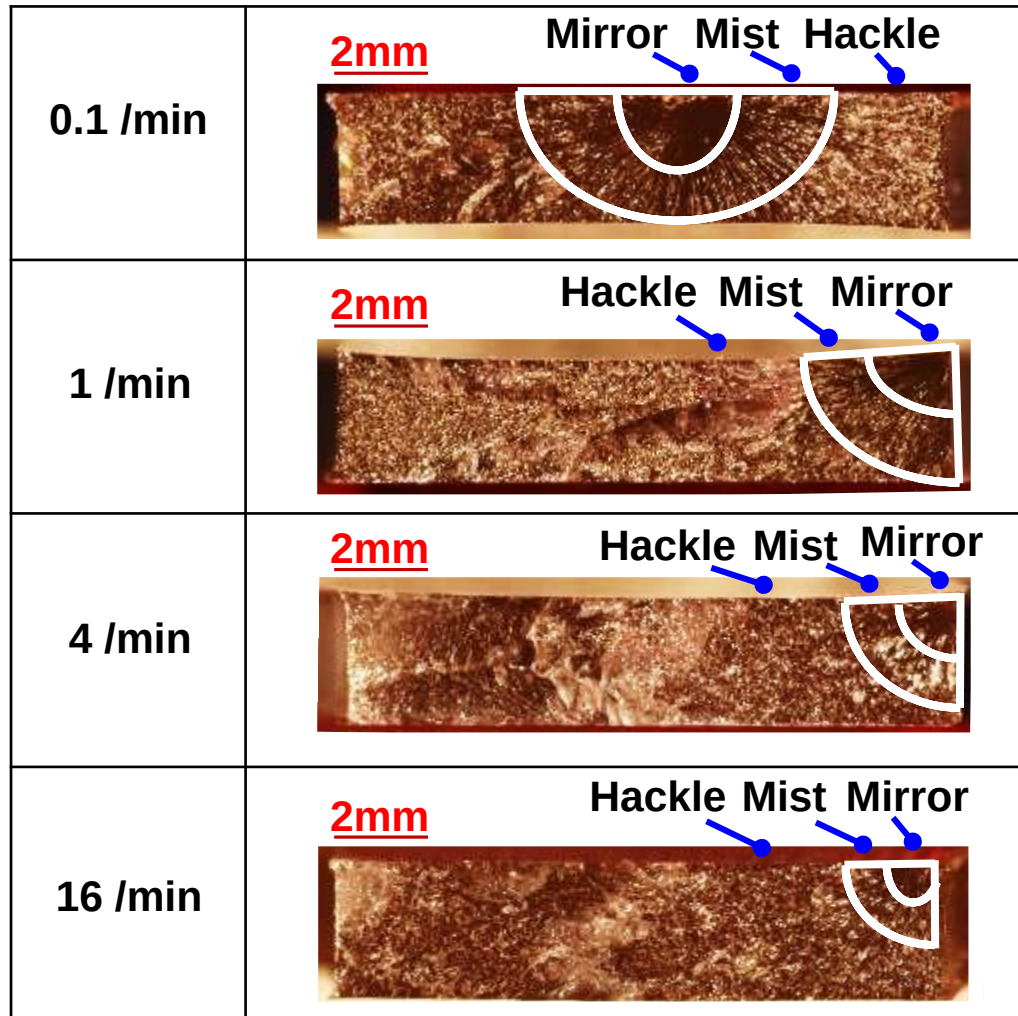
- As the strain rate ↑
 - Modulus: ↑
 - Strength and elongation at break: ↓



Strain rate [1/min]	Tensile modulus [GPa]	Tensile strength [MPa]	Tensile elongation [%]
0.1	2.89±0.09	74.6±1.4	5.03±0.70
1	2.94±0.10	68.2±9.6	3.13±1.37
4	3.07±0.15	53.0±1.7	1.96±0.29
16	3.35±0.35	49.8±3.5	1.50±0.21

Results of tension tests on epoxy 2/2

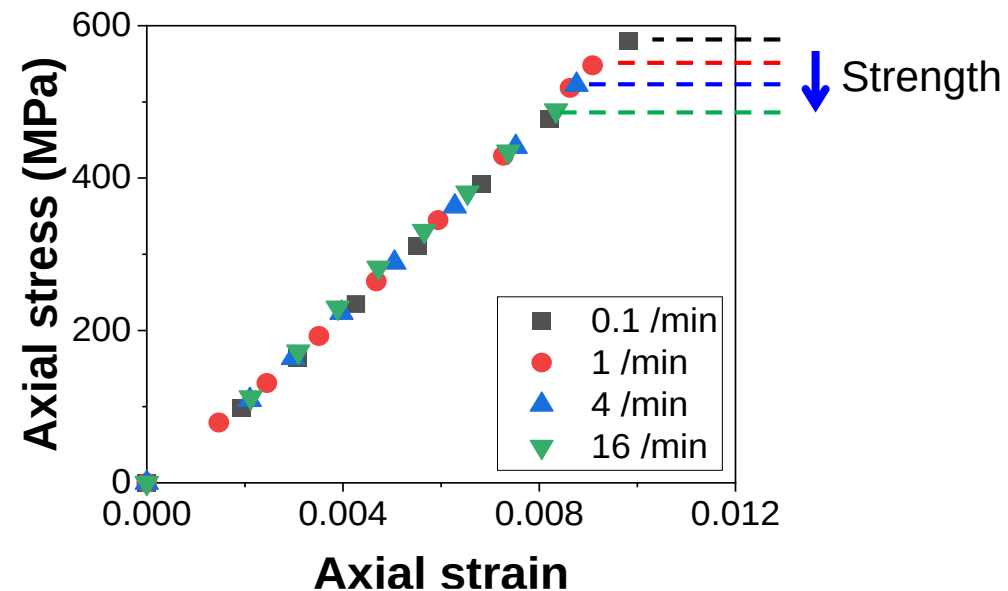
- Fractured surfaces at different strain rate
 - Reduction of mirror region implying a decrease in toughness[§]



§. Cantwell, W. J et al. (1988).

Results of tension tests on CF/EP ^{1/4}

- As the strain rate ↑
 - Modulus: no significant change
 - Strength and elongation at break: ↓

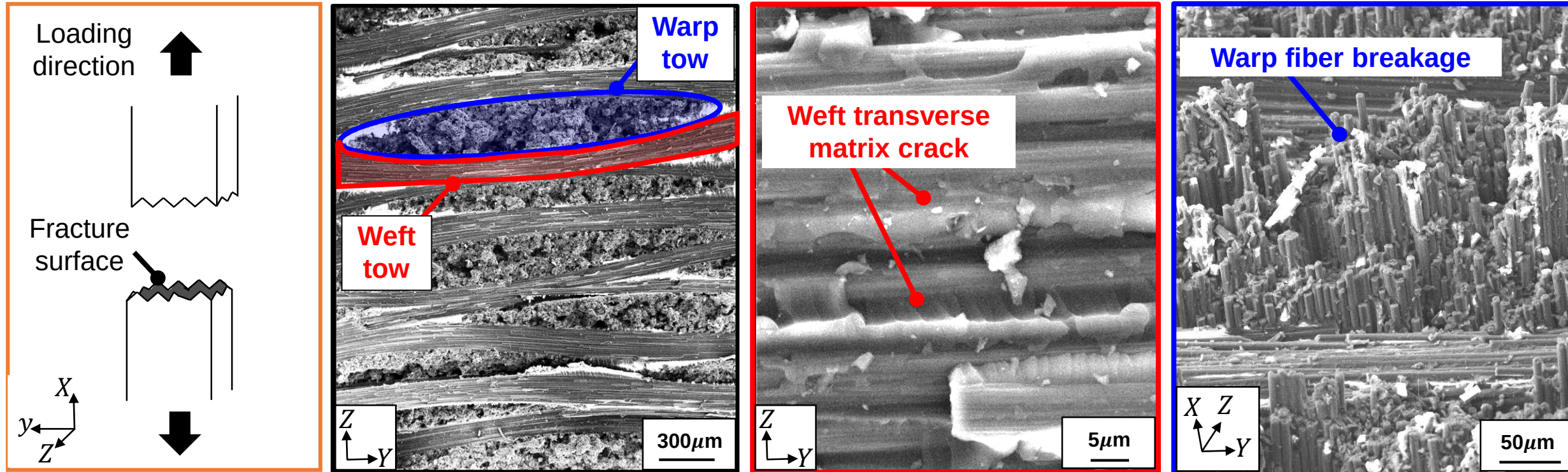


Strain rate [1/min]	Tensile modulus [GPa]	Tensile strength [MPa]	Tensile elongation [%]
0.1	61.23±1.77	576±17	0.98±0.06
1	62.16±0.90	540±21	0.90±0.02
4	61.14±2.64	525±26	0.88±0.03
16	57.88±1.99	522±58	0.89±0.08

Results of tension tests on CF/EP ^{2/4}

- Observation of damage patterns

Horizontal view of fracture surface (YZ plane)



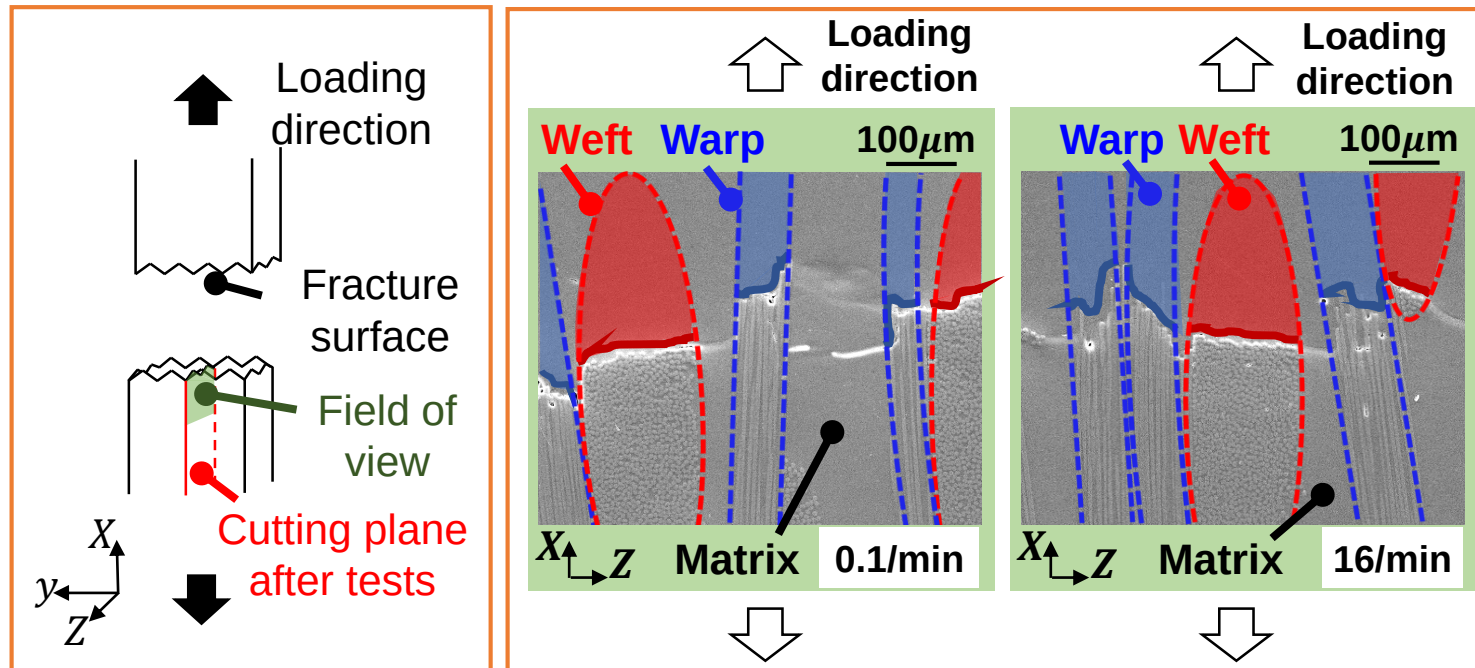
- X axis: warp direction and loading direction
- Y axis: weft direction
- Z axis: out of plane

Results of tension tests on CF/EP ^{3/4}

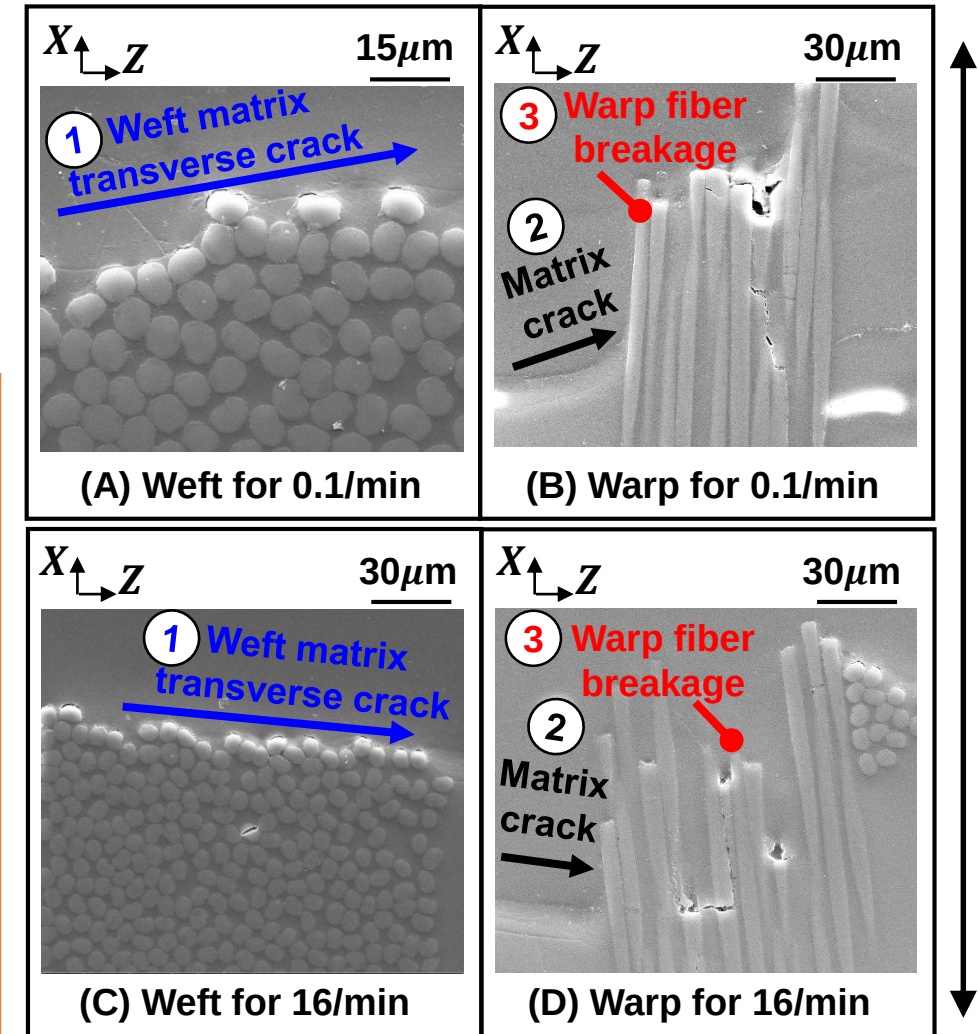
• Observation of damage patterns

Vertical view of fracture surface (XZ plane)

- Weft matrix transverse crack
- Matrix crack
- Warp fiber breakage
- No other cracks

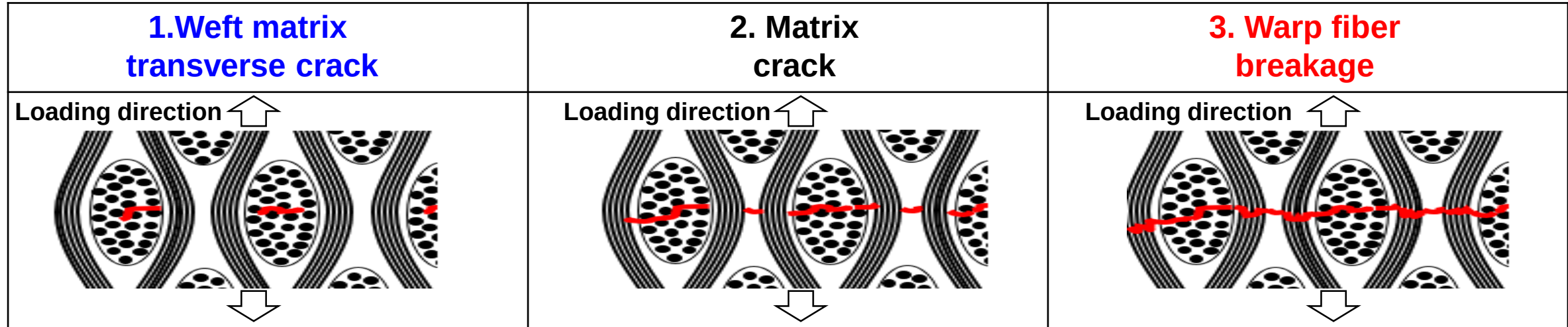


- ① Due to weft matrix transverse crack not the fiber breakage



Results of tension tests on CF/EP ^{4/4}

- Effect of rate dependency of the epoxy on the CF/EP

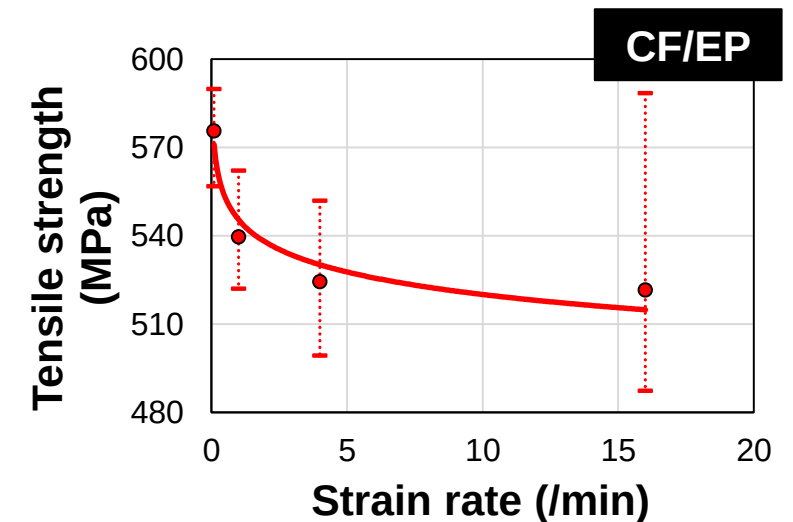
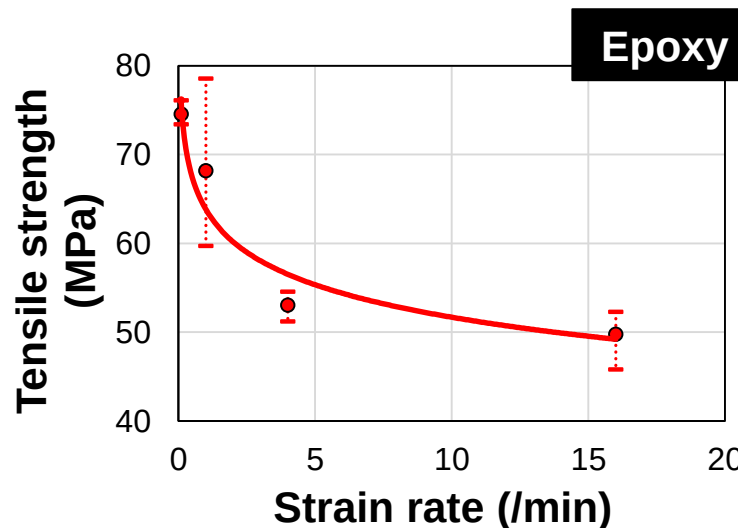


Epoxy (rate dependent)

- matrix crack
- Weft matrix transverse crack

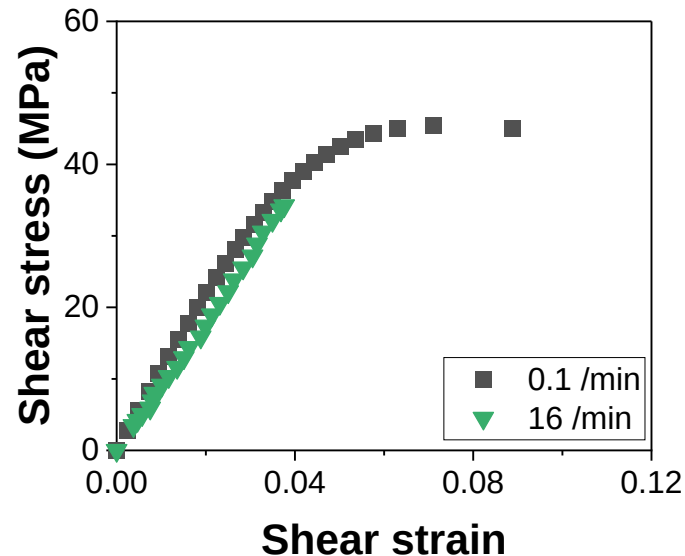


CF/EP (rate dependent)



Results of shear tests on epoxy

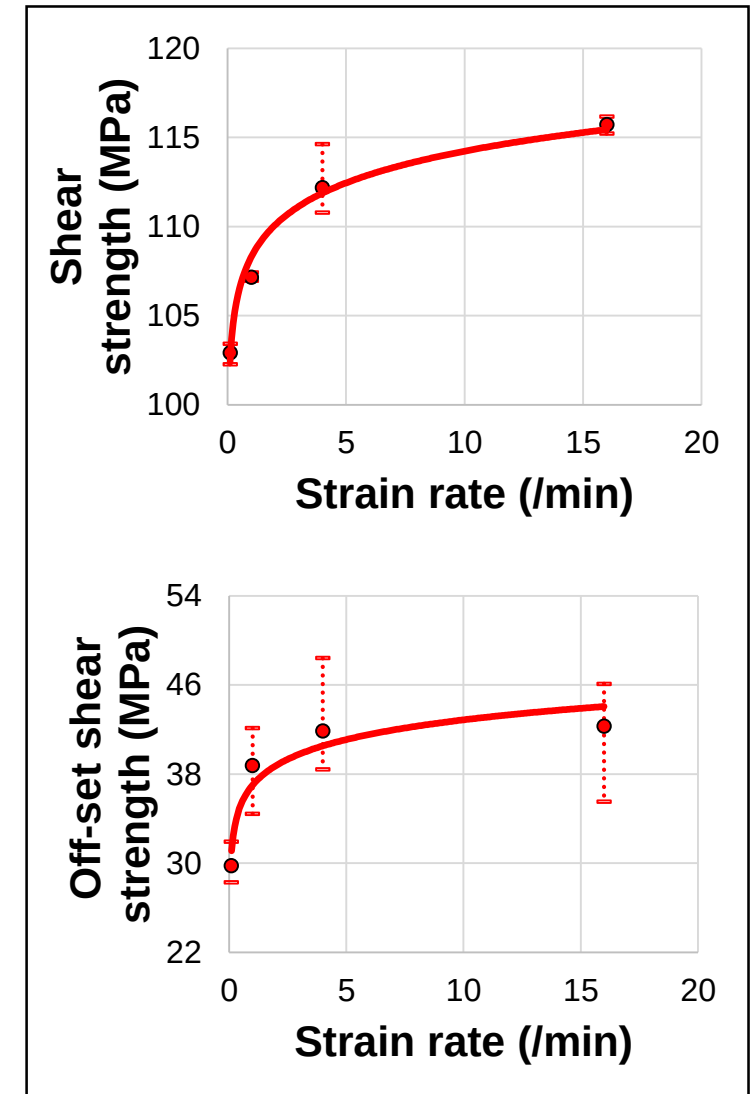
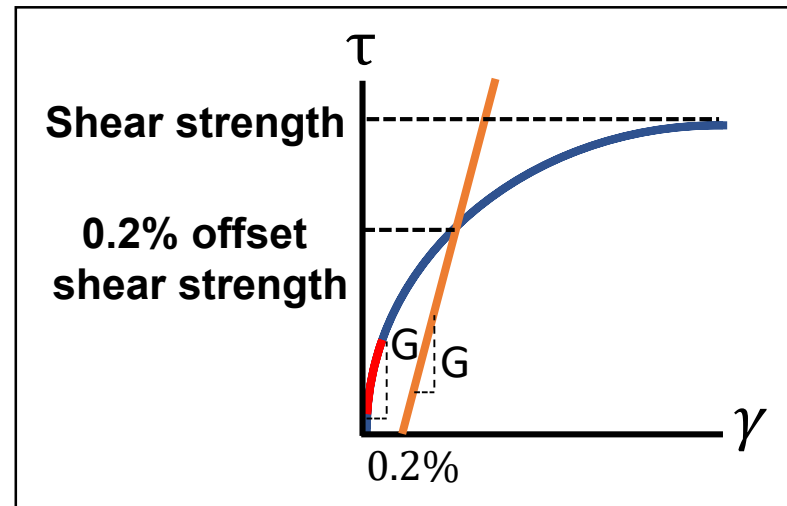
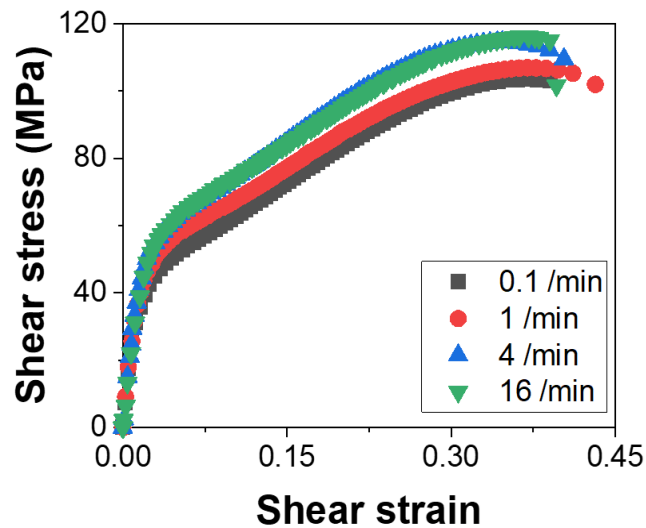
- **Strain rate** ↑
 - Shear modulus: ↓
 - Shear strength: ↓
 - Shear elongation at break: ↓



Strain rate [1/min]	Shear modulus [GPa]	Shear strength [MPa]	Shear elongation [%]
0.1	1.09±0.02	45.5±0.1	7.84±0.90
16	0.91±0.03	33.2±11.7	4.10±1.31

Results of shear tests on CF/EP

- **Strain rate** ↑
 - Shear modulus: no obvious trend
 - Ultimate shear strength: ↑
 - 0.2% offset shear strength: ↑



Concluding remarks

- **Tensile tests of the epoxy**

- Strain rate ↑ $\Rightarrow$ tensile modulus ↑
- Strain rate ↑ $\Rightarrow$ tensile strength and tensile elongation ↓

- **Tensile tests of the CF/EP**

- Strain rate ↑ $\Rightarrow$ no significant change in the tensile modulus
- Strain rate ↑ $\Rightarrow$ tensile strength and tensile elongation ↓

- **CF/EP tensile strength and tensile elongation ↓**

- $\because$ Epoxy tensile strength and tensile elongation ↓

- **Ongoing work**

- Effects of the rate-dependent shear behavior of the epoxy material on that of the CF/EP

Thank you!