

Biaxial Carbon fiber
LAMINATE
STATIC TEST REPORT

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Professional Laboratory for Composite Material Testing

The test results refer exclusively to the specimen under test. Opinions and interpretations are not part of the accreditation.



Title:

Status:

Client:

Test sample:

Test period:

Report no.:

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LIST OF ABBREVIATIONS

Symbol	Unit	Value
b	[mm]	Width
h	[mm]	Thickness
ρ_r	[g/cm ³]	Cured resin density
ρ_{fc}	[g/cm ³]	Assumed carbon fibre density
ρ_c	[g/cm ³]	Composite sample density
W_{fc}	[%]	Carbon fibre mass content
V_{fc}	[%]	Carbon fibre volume content
F_m	[kN]	Maximum load
σ_m	[MPa]	Stress at F_m
E	[GPa]	Young's modulus
ε_m	[%]	Strain at F_m
μ	[-]	Poisson's ratio
T_{12}	[MPa]	Shear strength at specimen failure
G_{12}	[GPa]	Shear modulus
γ_{12}	[%]	Shear strain
STDEV	-	Standard deviation
CV	[%]	Coefficient of variation
$R_k, GL2010$	-	Characterization value according to GL 2010 standard
$R_k, DNVGL-ST-0376$	-	Characterization value according to DNVGL-ST-0376 standard
VNS	-	V-notched rail shear test

1. INTRODUCTION

Material characteristic test of Biaxial Carbon fiber. All materials were provided by client and shipped to WMC China. Test panels were manufactured by vacuum assisted resin transfer moulding. Fibre content was measured, 6 specimens for mechanical testing at least for each series.

2. TEST PROGRAMME

Material characteristic test of Biaxial Carbon fiber. at standard conditions (23 ± 2 °C, 50 ± 10 % rel. humidity) according to ISO 291-2008 class 2.

Panel identification	Test items	Properties	Test standards	Number of specimens
T0	Tension at 0° (RT)	Tensile Strength, Modulus, Strain, Poisson's ratio	ISO 527-4-2023 ¹	6
T90	Tension at 90° (RT)	Tensile Strength, Modulus, Strain	ISO 527-4-2023 ¹	6
C0	Compression at 0° (RT)	Compressive Strength, Modulus, Strain	ISO 14126-2023 ¹	6
C90	Compression at 90° (RT)	Compressive Strength, Modulus, Strain	ISO 14126-2023 ¹	6
VNS	V-notched rail shear at 0° (RT)	Shear Strength, Modulus, Strain	ASTM D7078/D7078M-20 ¹	6

3. SAMPLE IDENTIFICATION

Each test panel was identified with unique code as follows:

Test no. —XX

XX: type of test and test direction

Each test specimen was identified with unique code as follows:

Panel no. —YY

YY: consecutive number

¹ The test standard is approved by DNV.

4. TEST RESULT SUMMARY

T0		T90		C0	
σ_m (Avg.) [MPa]	203.28	σ_m (Avg.) [MPa]	205.37	σ_m (Avg.) [MPa]	162.76
σ_m (R _k , GL 2010) [MPa]	197.77	σ_m (R _k , GL 2010) [MPa]	202.55	σ_m (R _k , GL 2010) [MPa]	156.72
σ_m (R _k , DNVGL-ST-0376) [MPa]	194.46	σ_m (R _k , DNVGL-ST-0376) [MPa]	200.86	σ_m (R _k , DNVGL-ST-0376) [MPa]	153.09
E (Avg.) [GPa]	14.92	E (Avg.) [GPa]	14.75	E (Avg.) [GPa]	12.67
ϵ_m (Avg.) [%]	18.21	ϵ_m (Avg.) [%]	15.27	ϵ_m (Avg.) [%]	12.80
ϵ_m (R _k , GL 2010) [%]	16.59	ϵ_m (R _k , GL 2010) [%]	14.41	ϵ_m (R _k , GL 2010) [%]	12.61
ϵ_m (R _k , DNVGL-ST-0376) [%]	15.61	ϵ_m (R _k , DNVGL-ST-0376) [%]	13.90	ϵ_m (R _k , DNVGL-ST-0376) [%]	12.49
μ [-]	0.78	W _{fc} [%]	65.87	W _{fc} [%]	66.46
W _{fc} [%]	66.52	V _{fc} [%]	54.65	V _{fc} [%]	55.32
V _{fc} [%]	55.43				

C90		VNS	
σ_m (Avg.) [MPa]	163.08	T ₁₂ (Avg.) [MPa]	294.10
σ_m (R _k , GL 2010) [MPa]	156.05	T ₁₂ (R _k , GL 2010) [MPa]	286.98
σ_m (R _k , DNVGL-ST-0376) [MPa]	151.83	T ₁₂ (R _k , DNVGL-ST-0376) [MPa]	282.70
E (Avg.) [GPa]	12.98	G ₁₂ (Avg.) [GPa]	28.51
ϵ_m (Avg.) [%]	12.76	γ_{12} (Avg.) [%]	1.11
ϵ_m (R _k , GL 2010) [%]	12.32	γ_{12} (R _k , GL 2010) [%]	0.61
ϵ_m (R _k , DNVGL-ST-0376) [%]	12.06	γ_{12} (R _k , DNVGL-ST-0376) [%]	0.31
W _{fc} [%]	66.14	W _{fc} [%]	66.16
V _{fc} [%]	55.02	V _{fc} [%]	55.03

5. DELIVERY

The carbon fibre fabric and the resin system were delivered. The materials were free of obvious defects. All materials were stored before testing at 23 ± 2 °C, 50 ± 10 % rel. humidity according to ISO 291-2008 class 2.

6. MATERIAL SPECIFICATION

Table 1. Fibre reinforcement

Material description	Supplier	Material	Batch No.	Fibre density ¹
Bi-axial carbon fibre fabric				1.80 g/cm ³

Table 2. Resin material

Material description	Supplier	Material	Mix ratio (by weight)	Cured resin density ¹
Resin	TECHSTORM ADVANCED MATERIAL CO., LTD.	TS180	100	1.15 g/cm ³
Hardener		TS185	32	

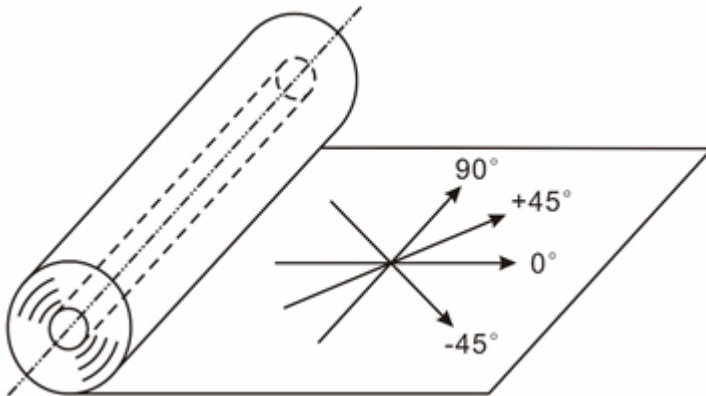


Figure 1. Laminate coordinates

¹ Fibre and cured resin density were provided by client.

7. MANUFACTURING DETAILS

- All test panels were manufactured from materials delivered by client
- The test panels were manufactured in a double-sided mould, using vacuum assistance to impregnate the fabrics, and automated self-heating table precisely controlled the cure cycle within $\pm 1^\circ\text{C}$. The mould did not have forced cooling
- A flat gasket with a certain thickness was put on the mould, both the mould and gasket were treated with release agent (Ease Release) to make double-flat surface
- The fabrics were precisely aligned on the mould
- Resin and hardener were stored at standard room temperature
- Prior to infusion, the mixed resin was degassed

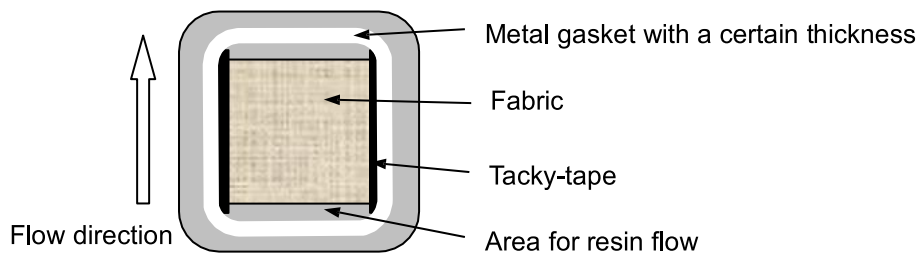


Figure 2. Test panel manufacturing

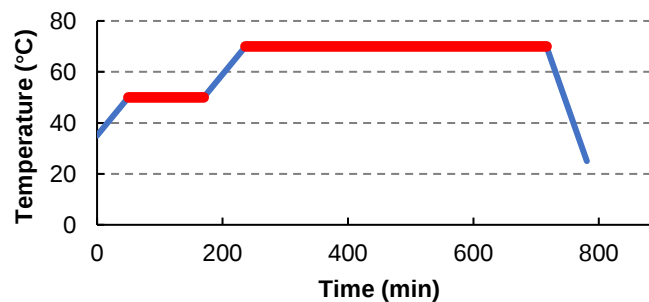


Figure 3. Curing cycle of laminate

Table 3. Infusion process parameters & curing cycle of infusion resin system

Parameter	Value	Unit
Resin temperature	35 ± 3	$^\circ\text{C}$
Vacuum	-950 ± 25	mbar
Mould temperature	40 ± 3	$^\circ\text{C}$
Heating rate	0.3 ± 0.1	$^\circ\text{C}/\text{min}$
Pre-curing temperature	50	$^\circ\text{C}$
Pre-curing time	2	hour
Post-curing temperature	70	$^\circ\text{C}$
Post-curing time	8	hour
Cooling rate	$\leq 1.0 \pm 0.1$	$^\circ\text{C}/\text{min}$

8. TEST SPECIMEN PREPARATION

- All specimens were manufactured from panels manufactured by WMC China
- All specimens were cut with a CNC milling machine
- Dimensions were measured using a digital calliper and a micrometer, with a read-out of 0.01 mm and 0.001 mm
- The specimen thickness might differ from the specifications in the standard due to client's requirements (number of layers, fibre content, etc.)
- Before and after testing, all specimens were photographed
- A cure cycle of 2 hrs. at 65 °C was required for the adhesive

Table 4. Test specimen specification

Specimen identification	Fabric lay-up	Test direction	Test standard	Geometry
T0-YY		0°	ISO 527-4-2023	250*25 mm
T90-YY		90°	ISO 527-4-2023	250*25 mm
C0-YY		0°	ISO 14126-2023	140*10 mm
C90-YY		90°	ISO 14126-2023	140*10 mm
VNS-YY		0°	ASTM D7078/D7078M-20	76*56 mm

9. FIBRE CONTENT

- Determination of carbon fibre content according to ASTM D3171-22, Standard test methods for constituent content of composite materials, A8. Matrix carbonization in a nitrogen-purging furnace
- 3 specimens per series with 2 g to 20 g mass were measured by electronic analytical and precision balances with an error limit of ± 0.1 mg after dried in an air-circulating drying-oven
- Determination of specimen density with buoyancy method according to ISO 1183-1-2019
- Determination of ignition loss with process temperature of 560 ± 40 °C using nitrogen-purging muffle furnace
- Fibre density and resin density for calculations were provided by client
- Fibre volume content calculation equation can be found in ANNEX A

Table 5. Fibre content

Panel identification	ρ_r	ρ_f	ρ_c	h	W_f	V_f
	[g/cm ³]	[g/cm ³]	[g/cm ³]	[mm]	[%]	[%]
T0	1.15	1.80	1.504	3.272	66.96	55.95
			1.499	3.268	66.46	55.36
			1.496	3.258	66.14	54.97
Mean			1.500	3.266	66.52	55.43
STDEV			0.004	0.007	0.42	0.49
CV			0.259	0.221	0.63	0.88

Panel identification	ρ_r	ρ_f	ρ_c	h	W_f	V_f
	[g/cm ³]	[g/cm ³]	[g/cm ³]	[mm]	[%]	[%]
T90	1.15	1.80	1.492	3.321	65.89	54.63
			1.493	3.314	65.82	54.60
			1.494	3.309	65.90	54.71
Mean			1.493	3.315	65.87	54.65
STDEV			0.001	0.006	0.04	0.06
CV			0.070	0.182	0.07	0.11

Panel identification	ρ_r	ρ_f	ρ_c	h	W_f	V_f
	[g/cm ³]	[g/cm ³]	[g/cm ³]	[mm]	[%]	[%]
C0	1.15	1.80	1.500	3.287	66.77	55.64
			1.497	3.305	66.41	55.24
			1.498	3.296	66.21	55.09
Mean			1.498	3.296	66.46	55.32
STDEV			0.002	0.009	0.29	0.29
CV			0.100	0.273	0.43	0.52



Panel identification	ρ_r	ρ_f	ρ_c	h	W_f	V_f
	[g/cm ³]	[g/cm ³]	[g/cm ³]	[mm]	[%]	[%]
C90	1.15	1.80	1.498	3.305	66.15	55.06
			1.497	3.317	66.02	54.91
			1.496	3.309	66.27	55.09
Mean			1.497	3.310	66.14	55.02
STDEV			0.001	0.006	0.12	0.10
CV			0.066	0.185	0.19	0.17

Panel identification	ρ_r	ρ_f	ρ_c	h	W_f	V_f
	[g/cm ³]	[g/cm ³]	[g/cm ³]	[mm]	[%]	[%]
VNS	1.15	1.80	1.494	3.325	65.61	54.47
			1.500	3.351	66.68	55.57
			1.497	3.332	66.20	55.06
Mean			1.497	3.336	66.16	55.03
STDEV			0.003	0.013	0.54	0.55
CV			0.190	0.403	0.81	1.00

10. DATASHEET-TENSION AT 0°

Static – Tension 0°	
Title:	Tensile testing Biaxial Carbon fiber
Datasheet number:	T0

Test specifications	
Test standard:	ISO 527-4-2023
Panel direction w.r.t. loading direction:	0°
Test machine:	INSTRON 5982
Grip pressure settings:	50 bar
Axial strain sensors:	YD50/10-N
Transverse strain sensors:	Epsilon E101691
Test speed:	2 ± 0.2 mm/min
Temperature:	23 ± 2 °C
Humidity:	50 ± 10 %
Test date:	2024-07-12
Location:	Mechanical test lab

Material specifications
Specimen ID: T0-YY
Fabric: Biaxial Carbon fiber
Resin system: TS180/185
Carbon fibre mass content: 66.52 %
Carbon fibre volume content: 55.43 %

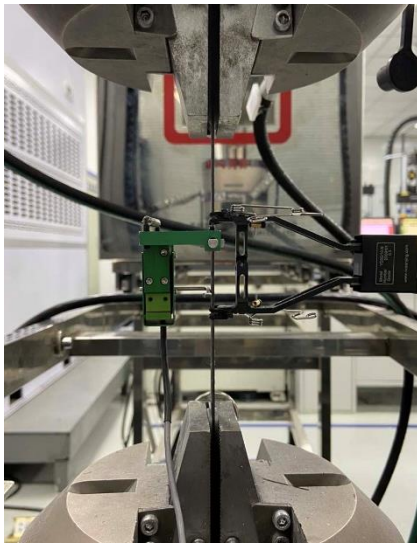


Figure 4. Test set-up

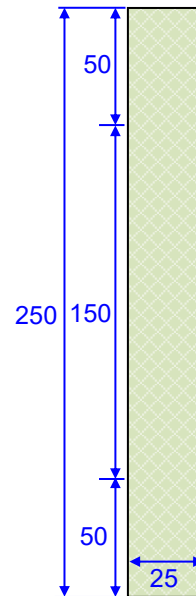
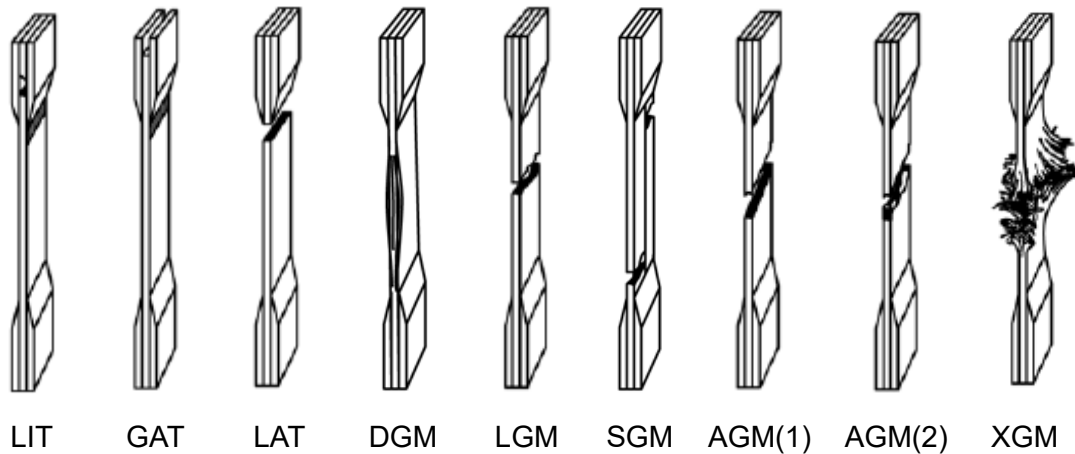


Figure 5. Nominal dimensions [mm]



First Character		Second Character		Third Character	
Failure Type	Code	Failure Area	Code	Failure Location	Code
Angled	A	Inside grip/tab	I	Bottom	B
edge	D	At grip/tab	A	Top	T
Grip/tab	G	<1W from	W	Left	L
Lateral	L	Gage	G	Right	R
Multi-mode	M(xyz)	Multiple areas	M	Middle	M
long Splitting	S	Various	V	Various	V
eXplosive	X	Unknown	U	Unknown	U
Other	O				

Figure 6. Tensile test failure codes/typical modes

Table 6. Test result summary

Identification	b_{avg} [mm]	h_{avg} [mm]	F_m [kN]	σ_m [MPa]	E [GPa]	ε_m [%]	μ [-]	Failure mode
T0-01	25.02	3.285	16.853	205.05	14.91	18.54	0.773	AGM
T0-02	25.03	3.265	16.840	206.07	14.63	18.47	0.742	AGM
T0-03	25.06	3.283	16.706	203.05	14.54	18.98	0.793	AGM
T0-04	25.03	3.285	16.636	202.32	15.30	17.94	0.836	AGM
T0-05	25.05	3.254	16.619	203.89	14.89	18.39	0.749	AGM
T0-06	25.02	3.266	16.285	199.28	15.26	16.95	0.808	AGM
Mean	25.04	3.273	16.657	203.28	14.92	18.21	0.784	
STDEV	0.02	0.013	0.207	2.38	0.31	0.70	0.036	
CV	0.07	0.401	1.244	1.17	2.10	3.85	4.591	
Max			16.853	206.07	15.30	18.98	0.836	
Min			16.285	199.28	14.54	16.95	0.742	
R_k, GL2010				197.77	14.20	16.59	0.700	
R_k, DNVGL-ST-0376				194.46	13.76	15.61	0.650	

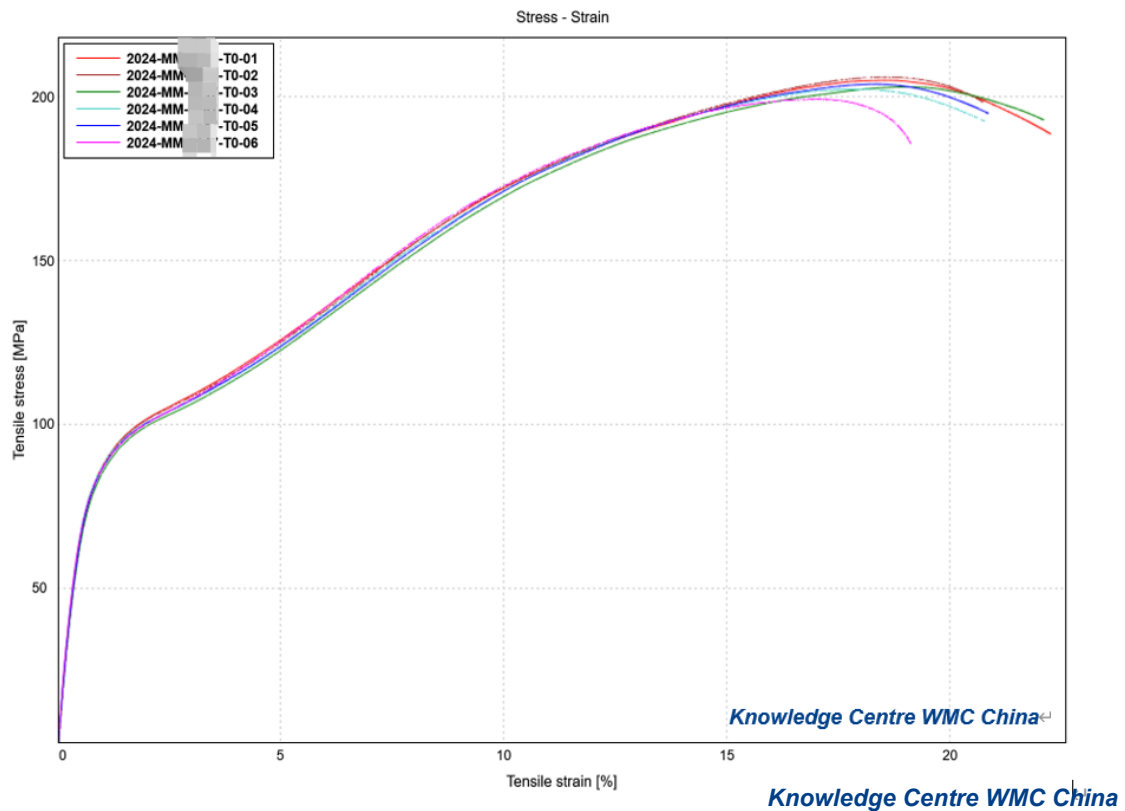


Figure 7. Test result plots

Figure 8. Picture of specimens before testing

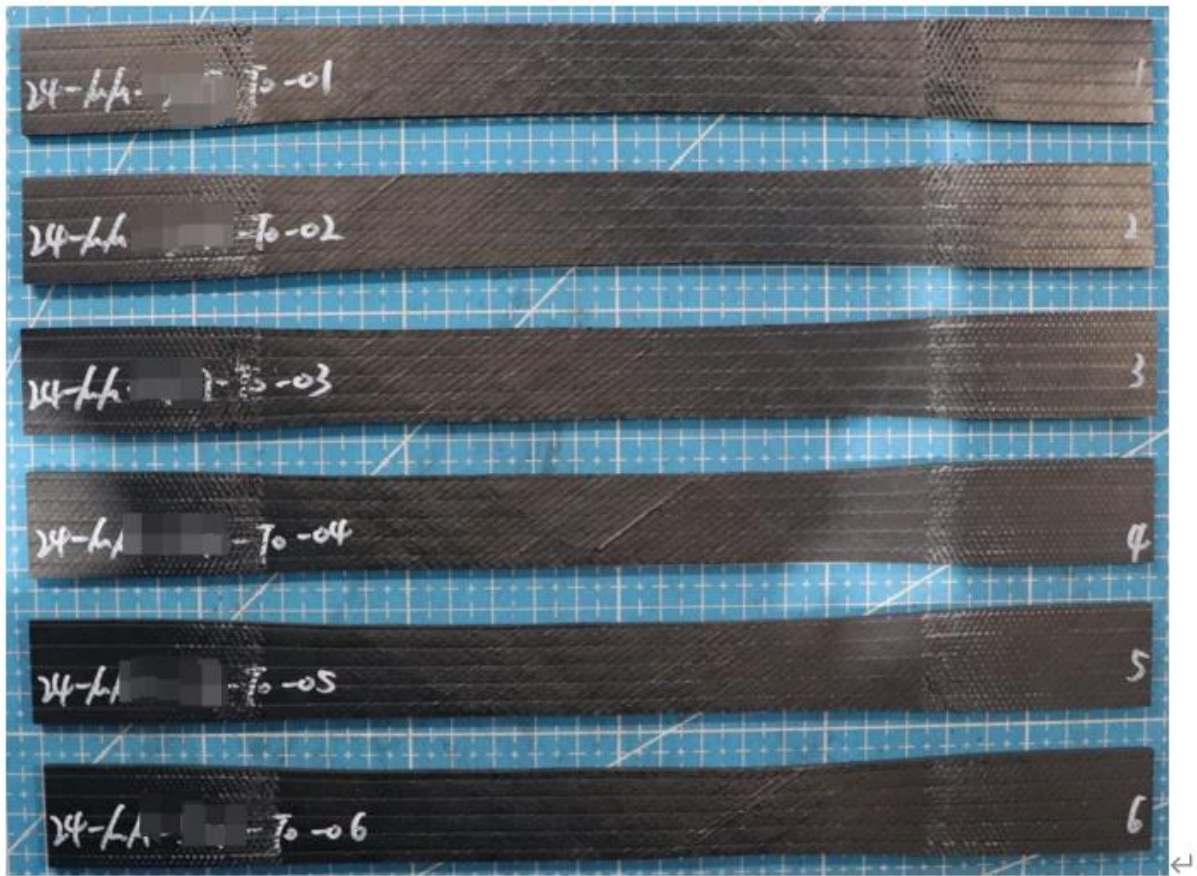


Figure 9. Picture of specimens after testing

11. DATASHEET-TENSION AT 90°

Static – Tension 90°	
Title:	Tensile testing BIAXIAL CARBON FIBER
Datasheet number:	T90

Test specifications	
Test standard:	ISO 527-4-2023
Panel direction w.r.t. loading direction:	90°
Test machine:	INSTRON 5982
Grip pressure settings:	50 bar
Axial strain sensors:	YD50/10-N
Test speed:	2 ± 0.2 mm/min
Temperature:	23 ± 2 °C
Humidity:	50 ± 10 %
Test date:	2024-07-16
Location:	Mechanical test lab

Material specifications
Specimen ID: T90-YY
Fabric: Biaxial Carbon fiber
Resin system: TS180/185
Carbon fibre mass content: 65.87 %
Carbon fibre volume content: 54.65 %

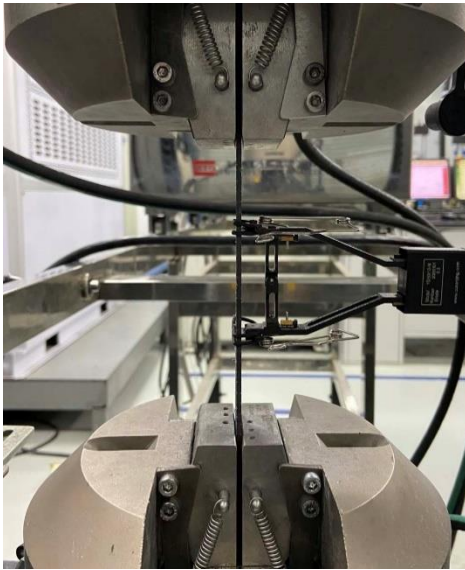


Figure 10. Test set-up

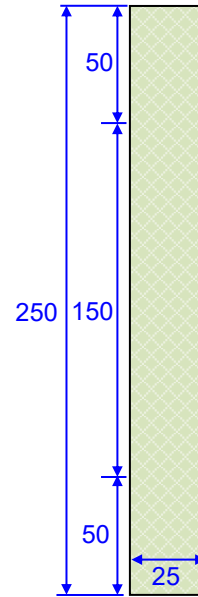
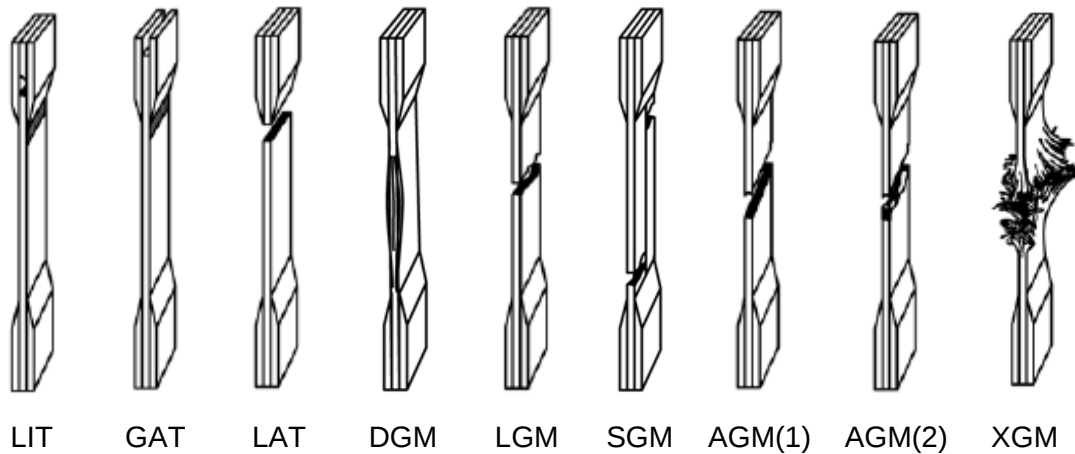


Figure 11. Nominal dimensions [mm]



First Character		Second Character		Third Character	
Failure Type	Code	Failure Area	Code	Failure Location	Code
Angled	A	Inside grip/tab	I	Bottom	B
edge Delamination	D	At grip/tab	A	Top	T
Grip/tab	G	<1W from grip/tab	W	Left	L
Lateral	L	Gage	G	Right	R
Multi-mode	M(xyz)	Multiple areas	M	Middle	M
long Splitting	S	Various	V	Various	V
eXplosive	X	Unkonwn	U	Unkonwn	U
Other	O				

Figure 12. Tensile test failure codes/typical modes

Table 7. Test result summary

Identification	b_{avg} [mm]	h_{avg} [mm]	F_m [kN]	σ_m [MPa]	E [GPa]	ε_m [%]	Failure mode
T90-01	25.04	3.311	16.943	204.35	14.74	15.55	AGM
T90-02	25.02	3.348	17.168	204.95	14.32	15.58	AGM
T90-03	25.03	3.286	17.062	207.44	15.17	14.56	AGM
T90-04	25.04	3.285	16.928	205.80	14.97	15.32	AGM
T90-05	25.02	3.293	16.814	204.08	14.82	15.30	AGM
T90-06	25.04	3.298	16.977	205.57	14.48	15.32	AGM
Mean	25.03	3.304	16.982	205.37	14.75	15.27	
STDEV	0.01	0.024	0.121	1.22	0.31	0.37	
CV	0.04	0.720	0.715	0.59	2.12	2.42	
Max			17.168	207.44	15.17	15.58	
Min			16.814	204.08	14.32	14.56	
R_k , GL2010				202.55	14.03	14.41	
R_k , DNVGL-ST-0376				200.86	13.59	13.90	

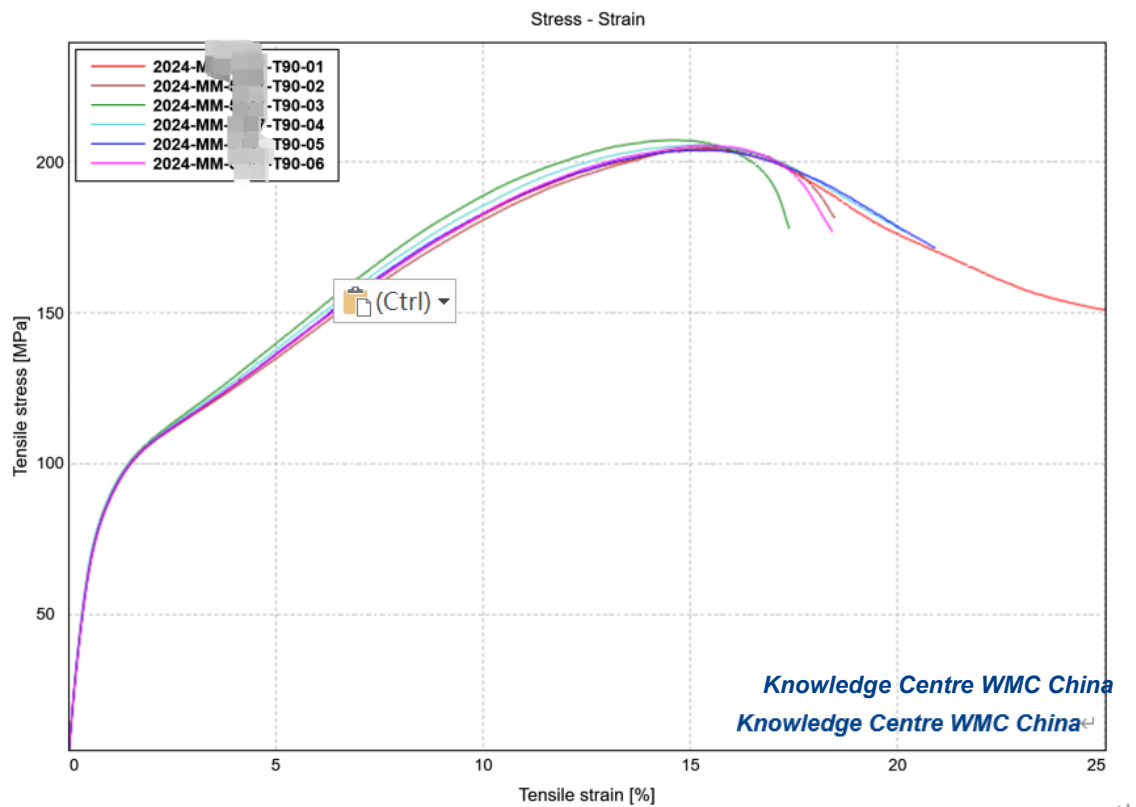


Figure 13. Test result plots

Figure 14. Picture of specimens before testing



Figure 15. Picture of specimens after testing

12. DATASHEET-COMPRESSION AT 0°

Static – Compression 0°	
Title:	Compressive testing BIAxIAL CARBON FIBER
Datasheet number:	C0

Test specifications	
Test standard:	ISO 14126-2023
Panel direction w.r.t. loading direction:	0°
Test machine:	INSTRON 3382
Test fixture:	HCLCF 100
Loading type:	Combined loading
Axial strain sensors:	Strain gauges, front & back
Test speed:	1 ± 0.2 mm/min
Temperature:	23 ± 2 °C
Humidity:	50 ± 10 %
Test date:	2024-07-15
Location:	Mechanical test lab

Material specifications
Specimen ID: C0-YY
Fabric: Biaxial Carbon fiber
Resin system: TS180/185
Carbon fibre mass content: 66.46 %
Carbon fibre volume content: 55.32 %



Figure 16. Test set-up

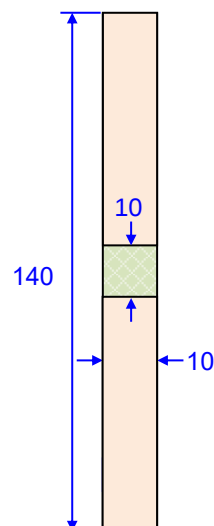


Figure 17. Nominal dimensions [mm]

Mode of failure	Figure	Code
In-plane shear		A
Complex		B
Through-thickness shear		C
Splitting		D
Delamination		E

Figure 18. Compressive test failure codes/Acceptable modes

Table 8. Test result summary

Identification	b_{avg} [mm]	h_{avg} [mm]	F_m [kN]	σ_m [MPa]	E [GPa]	ε_m [%]	Failure mode
C0-01	9.92	3.281	5.382	165.36	12.80	12.86	A
C0-02	9.94	3.303	5.308	161.66	13.27	12.70	A
C0-03	9.95	3.257	5.185	159.98	12.36	12.82	A
C0-04	9.94	3.320	5.487	166.26	12.89	12.69	A
C0-05	9.93	3.283	5.314	163.01	12.37	12.88	A
C0-06	9.94	3.282	5.230	160.31	12.35	12.85	A
Mean	9.94	3.288	5.318	162.76	12.67	12.80	
STDEV	0.01	0.022	0.108	2.61	0.38	0.08	
CV	0.10	0.655	2.029	1.60	2.98	0.65	
Max			5.487	166.26	13.27	12.88	
Min			5.185	159.98	12.35	12.69	
R_k, GL2010				156.72	11.80	12.61	
R_k, DNVGL-ST-0376				153.09	11.27	12.49	

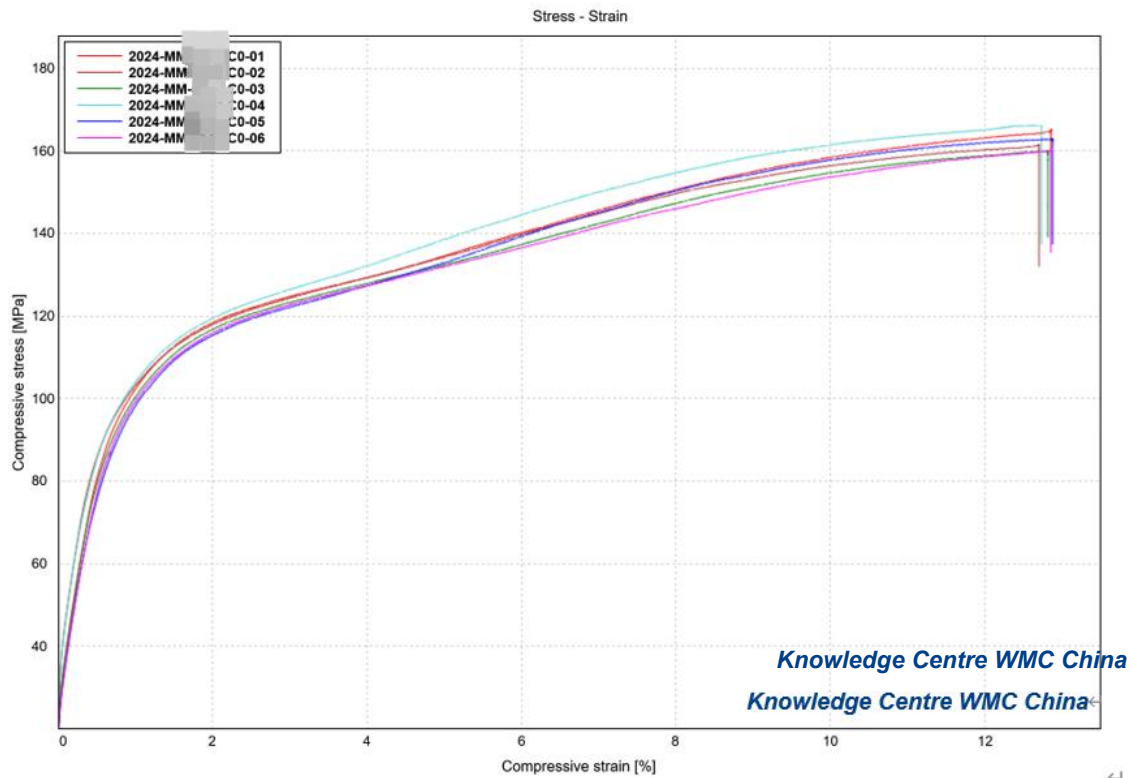


Figure 19. Test result plots

Figure 20. Picture of specimens before testing

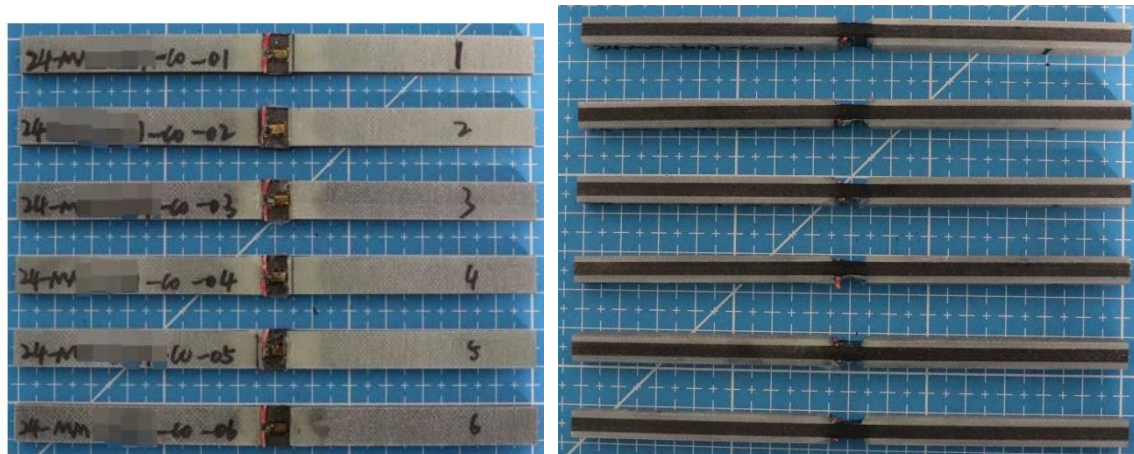


Figure 21. Pictures of specimens after testing

13. DATASHEET-COMPRESSION AT 90°

Static – Compression 90°	
Title:	Compressive testing BIAXIAL CARBON FIBER
Datasheet number:	C90

Test specifications	
Test standard:	ISO 14126-2023
Panel direction w.r.t. loading direction:	90°
Test machine:	INSTRON 3382
Test fixture:	HCLCF 100
Loading type:	Combined loading
Axial strain sensors:	Strain gauges, front & back
Test speed:	1 ± 0.2 mm/min
Temperature:	23 ± 2 °C
Humidity:	50 ± 10 %
Test date:	2024-07-13
Location:	Mechanical test lab

Material specifications
Specimen ID: C90-YY
Fabric: Biaxial Carbon fiber
Resin system: TS180/185
Carbon fibre mass content: 66.14 %
Carbon fibre volume content: 55.02 %

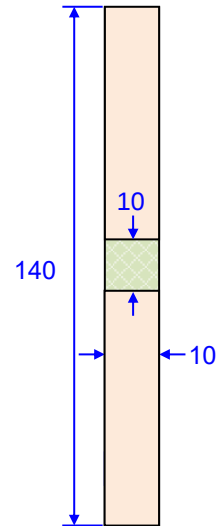


Figure 22. Test set-up

Figure 23. Nominal dimensions [mm]

Mode of failure	Figure	Code
In-plane shear		A
Complex		B
Through-thickness shear		C
Splitting		D
Delamination		E

Figure 24. Compressive test failure codes/Acceptable modes

Table 9. Test result summary

Identification	b_{avg} [mm]	h_{avg} [mm]	F_m [kN]	σ_m [MPa]	E [GPa]	ε_m [%]	Failure mode
C90-01	9.98	3.270	5.246	160.75	12.66	12.40	A
C90-02	9.98	3.296	5.244	159.42	12.27	12.78	A
C90-03	9.99	3.304	5.521	167.28	13.88	12.91	A
C90-04	9.98	3.274	5.405	165.41	13.51	12.73	A
C90-05	9.98	3.279	5.282	161.40	12.59	12.88	A
C90-06	9.98	3.286	5.386	164.24	12.97	12.87	A
Mean	9.98	3.285	5.347	163.08	12.98	12.76	
STDEV	0.00	0.013	0.110	3.04	0.61	0.19	
CV	0.04	0.400	2.052	1.86	4.69	1.49	
Max			5.521	167.28	13.88	12.91	
Min			5.244	159.42	12.27	12.40	
R _k , GL2010				156.05	11.57	12.32	
R _k , DNVGL-ST-0376				151.83	10.72	12.06	

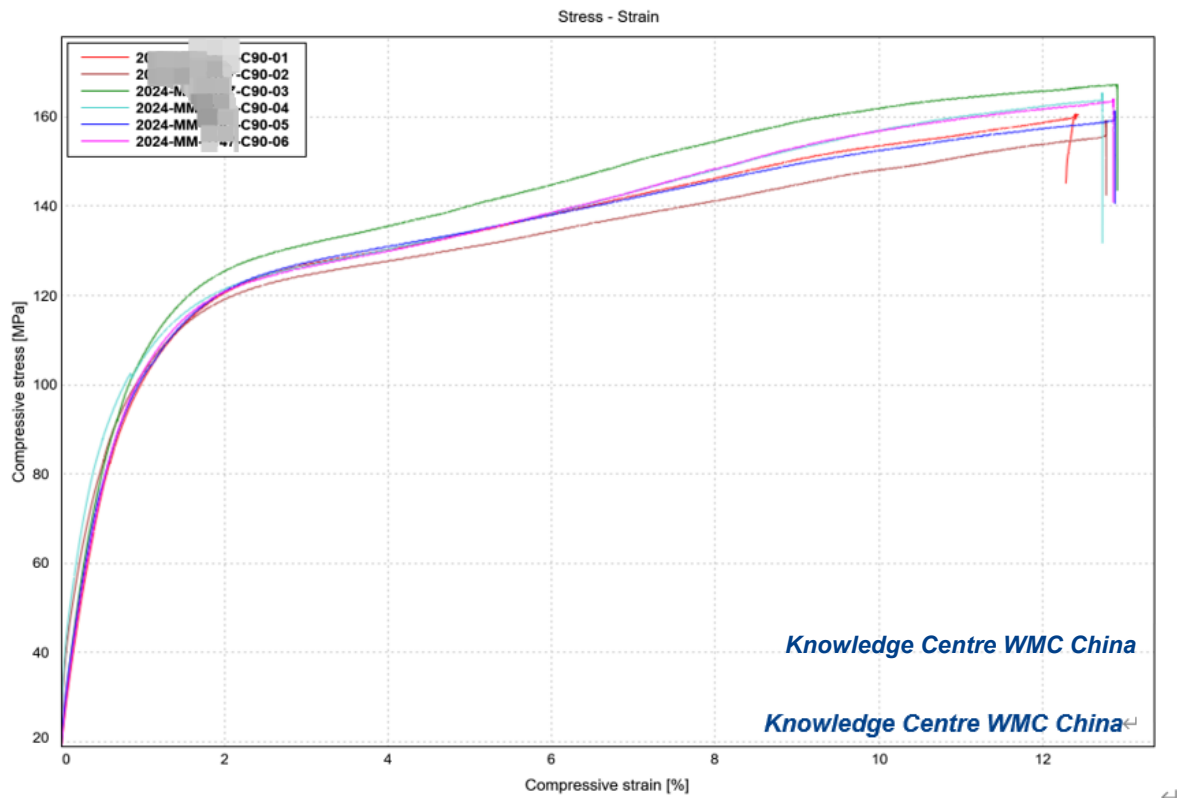


Figure 25. Test result plots

Figure 26. Picture of specimens before testing

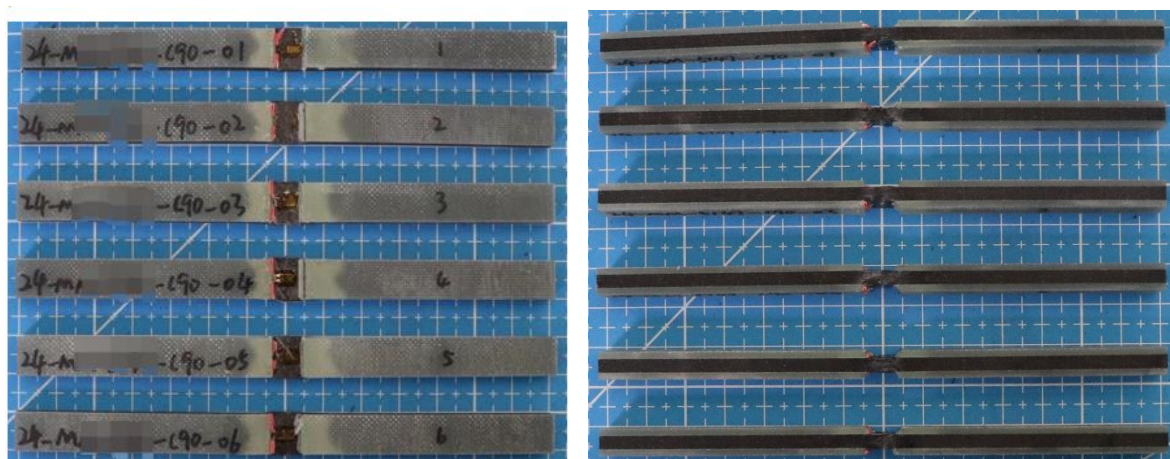


Figure 27. Pictures of specimens after testing

14. DATASHEET-V-NOTCHED RAIL SHEAR AT 0°

Static – VNS 0°	
Title:	V-notched rail shear testing BIAXIAL CARBON FIBER
Datasheet number:	VNS

Test specifications	
Test standard:	ASTM D7078/D7078M-20
Panel direction w.r.t. loading direction:	0°
Test machine:	INSTRON 3382
Grip pressure settings:	30 Nm
Strain sensors:	Cross gauge
Test speed:	2 ± 0.2 mm/min
Temperature:	23 ± 2 °C
Humidity:	50 ± 10 %
Test date:	2024-07-13
Location:	Mechanical test lab

Material specifications
Specimen ID: VNS-YY
Fabric: Biaxial Carbon fiber
Resin system: TS180/185
Carbon fibre mass content: 66.16 %
Carbon fibre volume content: 55.03 %

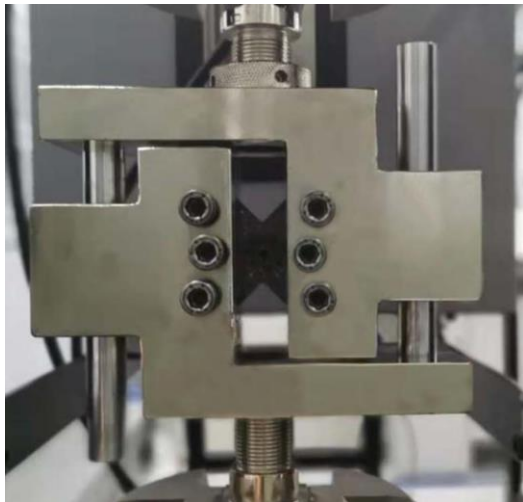


Figure 28. Test set-up

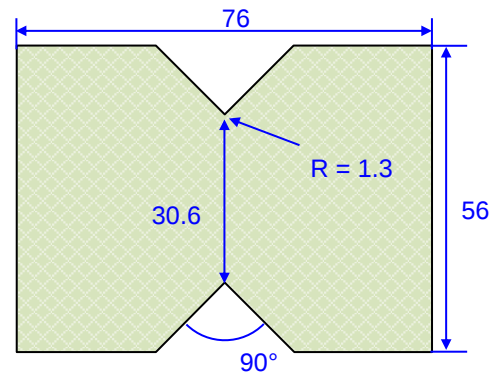


Figure 29. Nominal dimensions [mm]

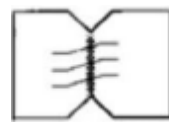
Typical
acceptable
failure
modes



VGN



HGN



M(hv)GN



AGN

Common
non-
acceptable
failure
modes



AMV



VSE



HNA

First Character		Second Character		Third Character	
Failure Type	Code	Failure Area	Code	Failure Location	Code
Horizontal	H	Gage section	G	Bottom	B
Vertical cracking	V	Notch region	N	Top	T
Angled cracking	A	Side region	S	Left	L
Edge crushing	E	Multiple areas	M	Right	R
Multi-mode	M(xyz)	Various	V	between Notches	N
Other	O	Unknown	U	Adjacent to notch	A
				top and/or bottom Edge	E
				Various	V
				Unknown	U

Figure 30. V-notch shear test failure codes/typical modes

Table 10. Test result summary

Identification	b_{avg} [mm]	h_{avg} [mm]	F_m [kN]	τ_{12} [MPa]	G_{12} [GPa]	γ_{12} [%]	Failure mode
VNS-01	30.61	3.278	29.140	290.41	29.22	0.99	AGN
VNS-02	30.59	3.307	30.226	298.79	27.10	1.22	AGN
VNS-03	30.55	3.287	29.266	291.44	29.84	0.96	AGN
VNS-04	30.63	3.303	29.652	293.09	28.59	1.09	AGN
VNS-05	30.62	3.314	29.987	295.51	27.20	1.49	AGN
VNS-06	30.65	3.323	30.081	295.35	29.11	0.91	AGN
Mean	30.61	3.302	29.725	294.10	28.51	1.11	
STDEV	0.03	0.017	0.448	3.07	1.13	0.22	
CV	0.11	0.509	1.508	1.05	3.95	19.48	
Max			30.226	298.79	29.84	1.49	
Min			29.140	290.41	27.10	0.91	
R _k , GL2010				286.98	25.90	0.61	
R _k , DNVGL-ST-0376				282.70	24.33	0.31	

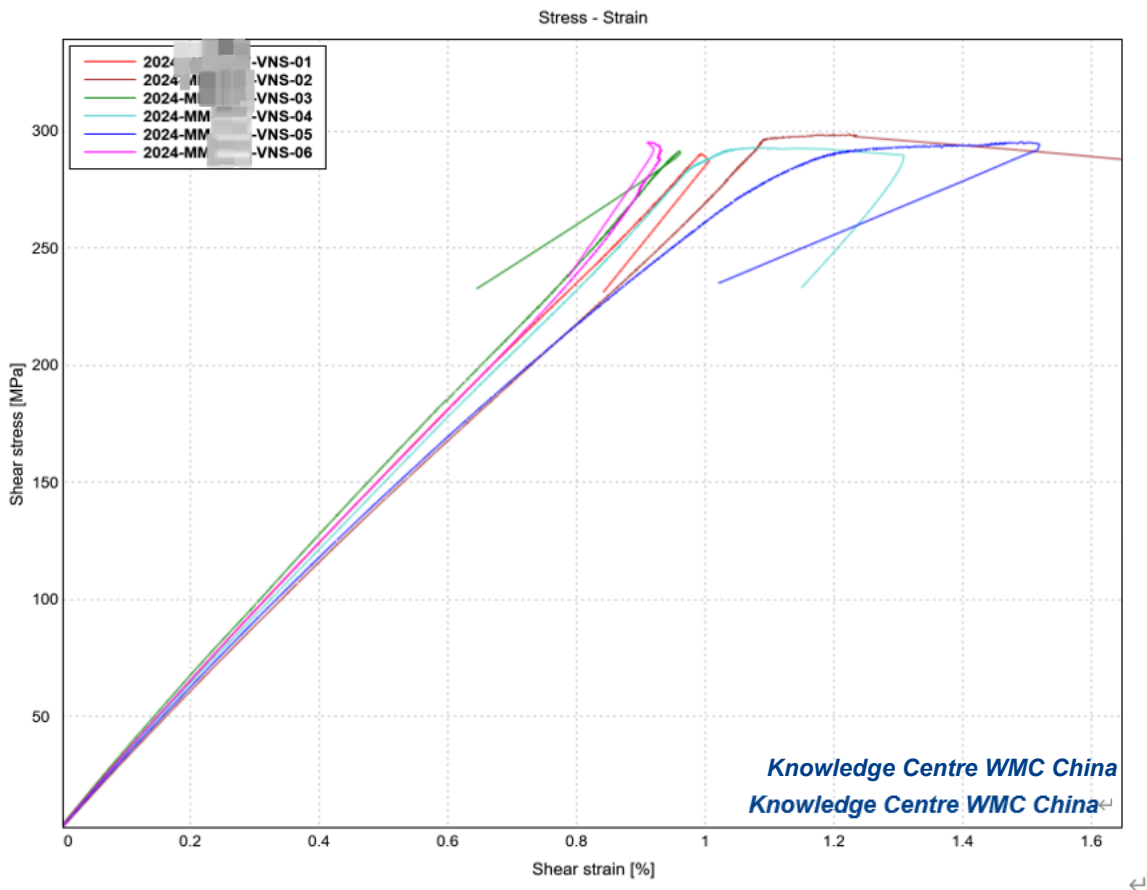


Figure 31. Test result plots

Figure 32. Picture of specimens before testing

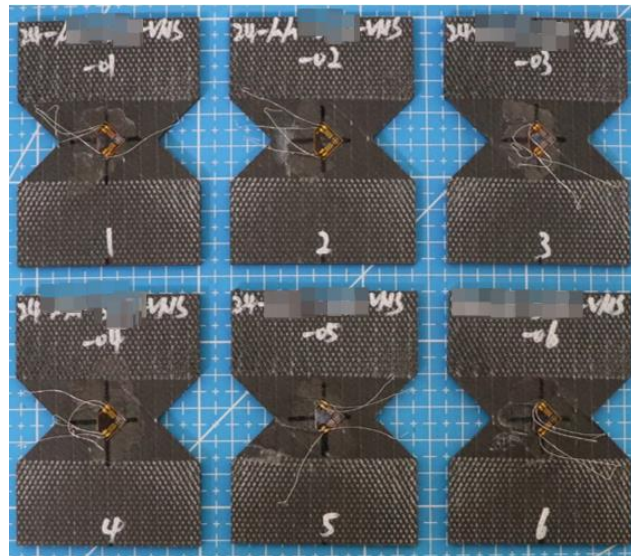


Figure 33. Picture of specimens after testing

Annex A: CALCULATIONS

- Calculation of the modulus of elasticity is determined via linear regression in the strain range of 0.05 % to 0.25 % strain
- Calculation of the shear modulus of elasticity is determined via linear regression in the strain range of 0.15 % to 0.55 % shear strain for ASTM D7078/D7078M-20
- Calculation of standard deviation (s) is carried out by (STDEV in Excel):

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{(n-1)}}$$

Where n indicates the number of tests, $\{x_1, x_2, \dots, x_n\}$ are the values of the sample items and $\bar{x}$ indicates the mean of the test values.

- Calculation of coefficient of variation (CV) is carried out by:

$$CV = \frac{S}{\bar{x}} \times 100\%$$

Where s indicates the standard deviation and $\bar{x}$ indicates the mean of test values

- Calculation of characteristic value ($R_{k, GL 2010}$) is carried out by:

$$R(5\%, 95\%, v, n) = \bar{x} \left[1 - v \left(1.645 + \frac{1.645}{\sqrt{n}} \right) \right]$$

Where $\bar{x}$ indicates the mean of the test values, v indicates the CV and n indicates the number of tests. A normal distribution is assumed. Formula is taken from “GL guideline for the certification of wind turbines”, Edition July 2010, section 5.5.2.3

- Calculation of characteristic value ($R_{k, DNVGL-ST-0376}$) is carried out by:

$$R_{k, DNVGL-ST-0376} = \bar{x} - k \times s$$

Where $\bar{x}$ indicates the mean of the test values, s indicates the Standard deviation estimated from values. A normal distribution is assumed. Formula is taken from “DNVGL-ST-0376, Rotor blades for wind turbines standard”, Edition December 2015

- Calculation of fibre volume content is carried out by:

$$V_{fc} = \frac{\rho_c \times W_{fc}}{\rho_{fc}}$$

Where W_{fc} indicates carbon fibre weight fraction (not in %, ie $0 \leq W_{fc} \leq 1$), V_{fc} indicates carbon fibre volume fraction (not in %, ie $0 \leq V_{fc} \leq 1$), ρ_{fc} = density of carbon fibre, ρ_c = density of composite

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