Research on Mechanical Performance of Titanium Alloy Laminated Structure

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Contents

Introduction & Background

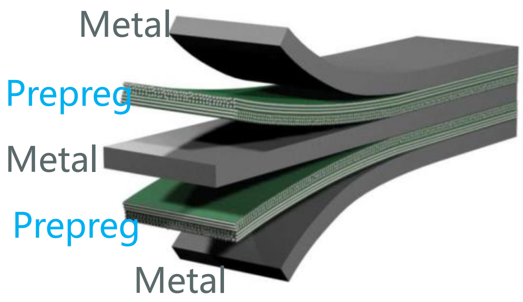
The Titanium alloy Laminated structure——TiGr (Titanium/Graphite Hybrid Laminates)

Composites

- Excellent fatigue resistance
- Good damage tolerance
- Low density

Metals

- High burn-through/ High temperature resistance
- Good impact resistance
- High specific strength
- Better strength & modulus when compared with GLARE laminates



- Tensile Performance
- Shear Performance
- Bending Performance
- Fatigue Performance

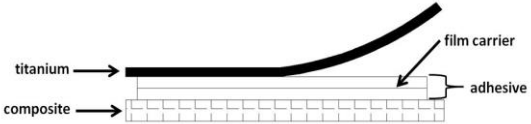
Static and Fatigue Test

Coding system

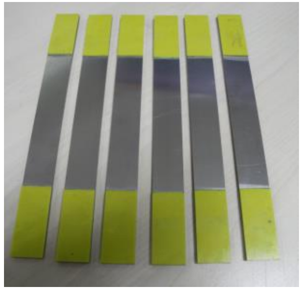
NO.	Lay-up	Grade
1	Ti/0/0/Ti	TiGr2A21
2	Ti/0/0/Ti/0/0/Ti	TiGr2A32
3	Ti/0/0/Ti/0/0/Ti/0/0/Ti	TiGr2A43
4	Ti+45/-45/Ti	TiGr6A21
5	Ti/+45/-45/Ti/-45/45/Ti	TiGr6A32

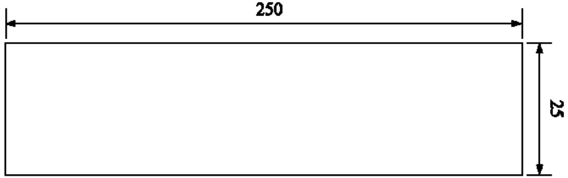
2A: 0 degree   6A: 45 degree

Layer	Material	Thickness
Titanium alloy	TC4(Ti-6Al-4V)	0.3mm
Prepreg	Epoxy reinforced carbon fiber(5228A/CCF300)	0.125mm
Adhesive film	Epoxy adhesive film	0.08mm

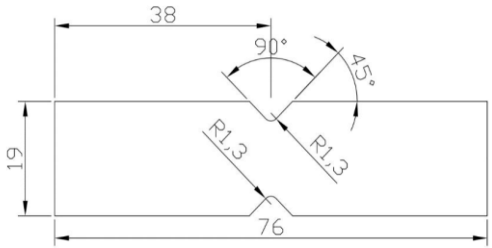


Test specimen configuration

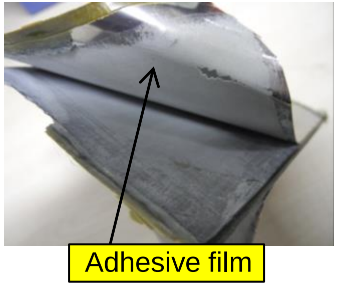


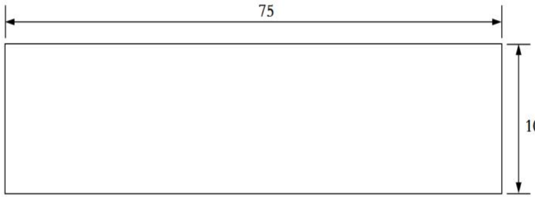


Tensile test specimen



In-plane Shear test specimen





Three-point Bending test specimen

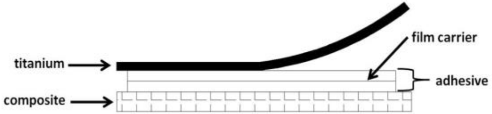
Static and **Fatigue** Test

Coding system

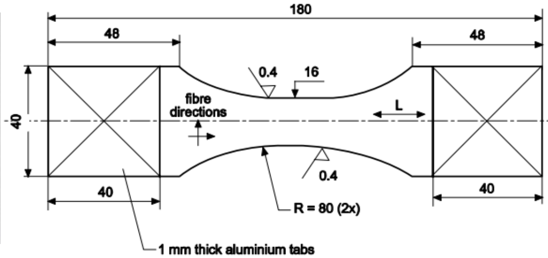
NO.	Lay-up	Grade
1	Ti/0/0/Ti	TiGr2A21
2	Ti/0/0/Ti/0/0/Ti	TiGr2A32
3	Ti/0/0/Ti/0/0/Ti/0/0/Ti	TiGr2A43
4	Ti+45/-45/Ti	TiGr6A21
5	Ti/+45/-45/Ti/-45/45/Ti	TiGr6A32

2A: 0 degree   6A: 45 degree

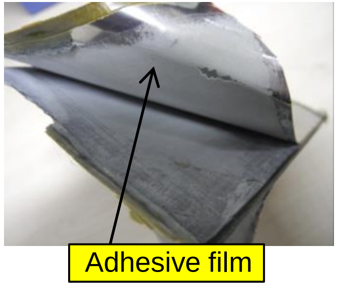
Layer	Material	Thickness
Titanium alloy	TC4(Ti-6Al-4V)	0.3mm
Prepreg	Epoxy reinforced carbon fiber(5228A/CCF300)	0.125mm
Adhesive film	Epoxy adhesive film	0.08mm

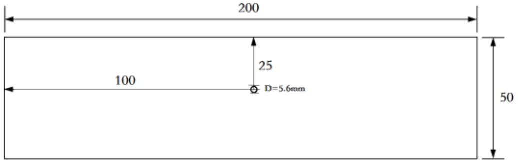


Test specimen configuration

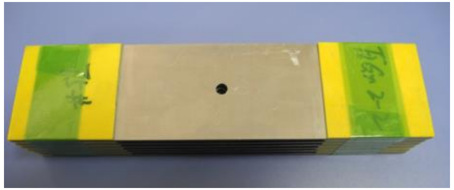


Dog-bone fatigue test specimen



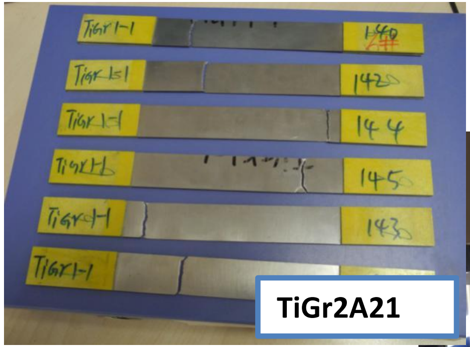


Center-hole fatigue test specimen



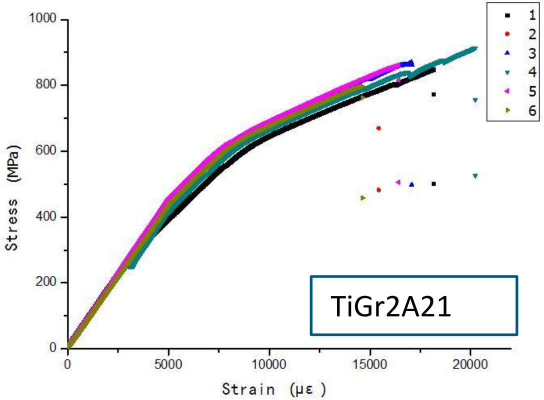
Static and Fatigue Test

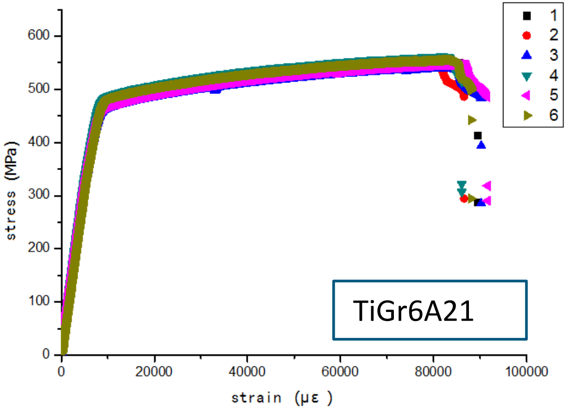
Tensile Test



Tensile failure mode

ASTM D3039

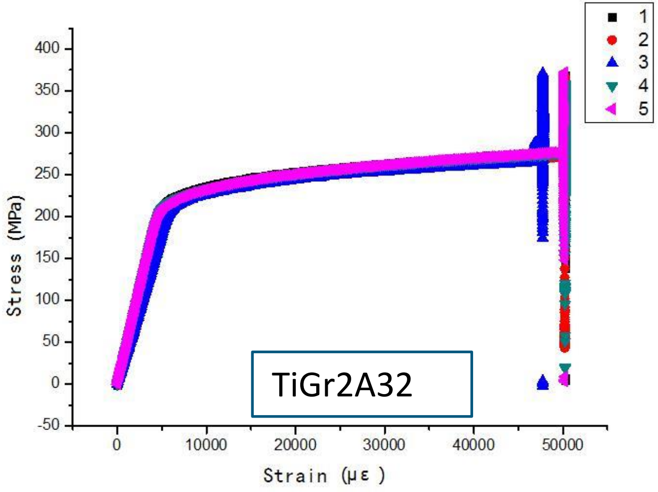


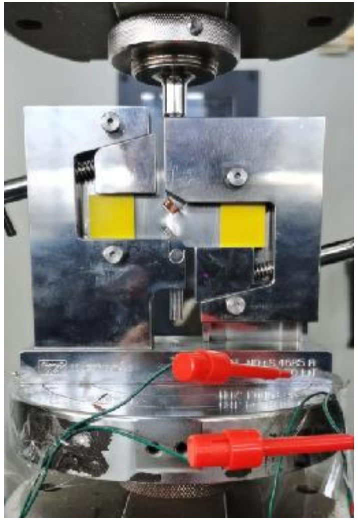


- Three stages during the tensile process: **elastic** stage, **yield** stage, **failure** stage;
- TiGr2A21 with **0° fiber** layers mainly relies on the composite constituent for load-bearing, and the yield process is more ;
- TiGr6A21 with **45° fiber** layers relies on the metal constituent, and the yield point is more obvious.

Static and Fatigue Test

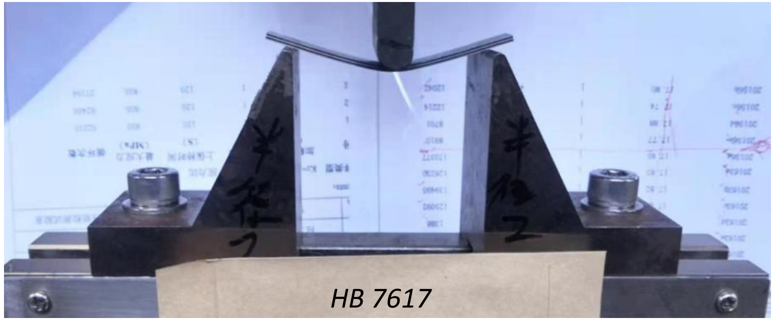
In-plane Shear Test





ASTM D5379

Bending Test

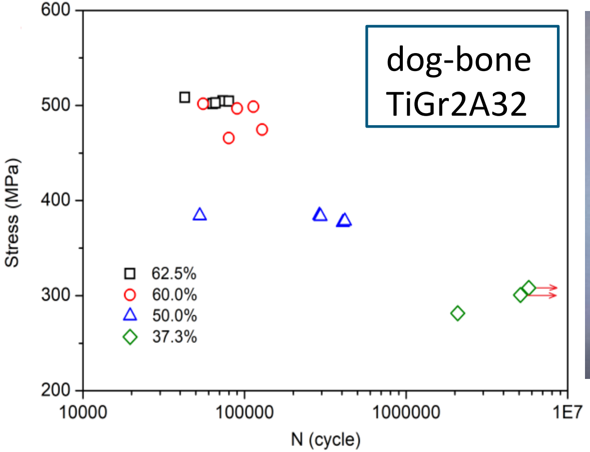


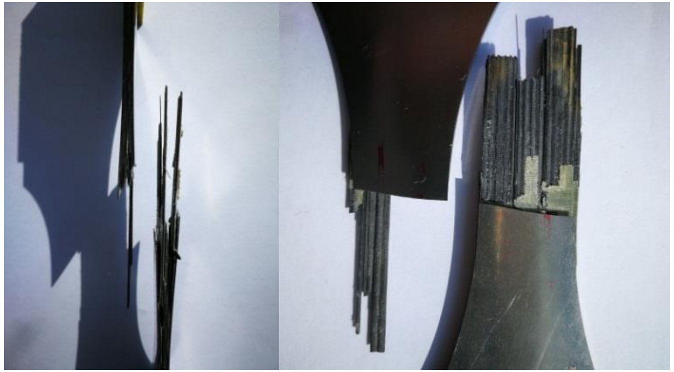
Type	Average shear strength	Average bending strength
TiGr2A32	367MPa	1325MPa
TiGr2A43	332MPa	1247MPa
TiGr6A32	/	915MPa

- The surface of TiGr (metal layer) has **large deformation** and local **convex**, the shear failure occurs in the carbon fiber composite layer.
- The stress increases **linearly** with the increase of strain, and after the yield point, the stress-strain curve becomes flat

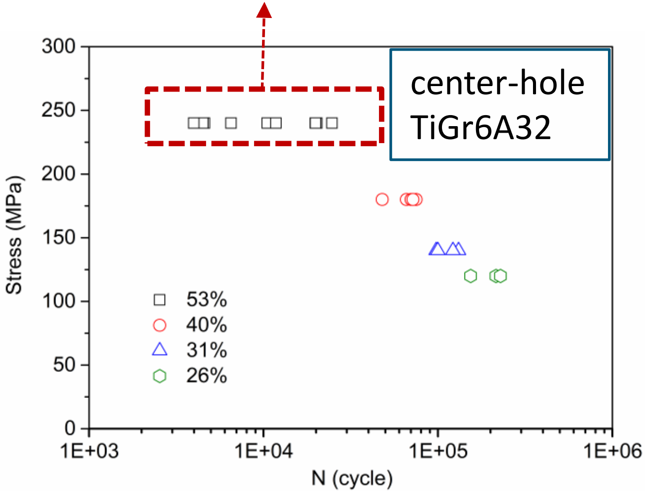
Static and **Fatigue** Test

Fatigue test





Scatter is related to the local plastic deformation near the hole edge .



Stress level	Average fatigue life	Dispersion coefficients
62.5%	65266 cycles	0.192
60%	93587 cycles	0.273
50%	292334 cycles	0.448
37.3%	1638498 cycles	0.063

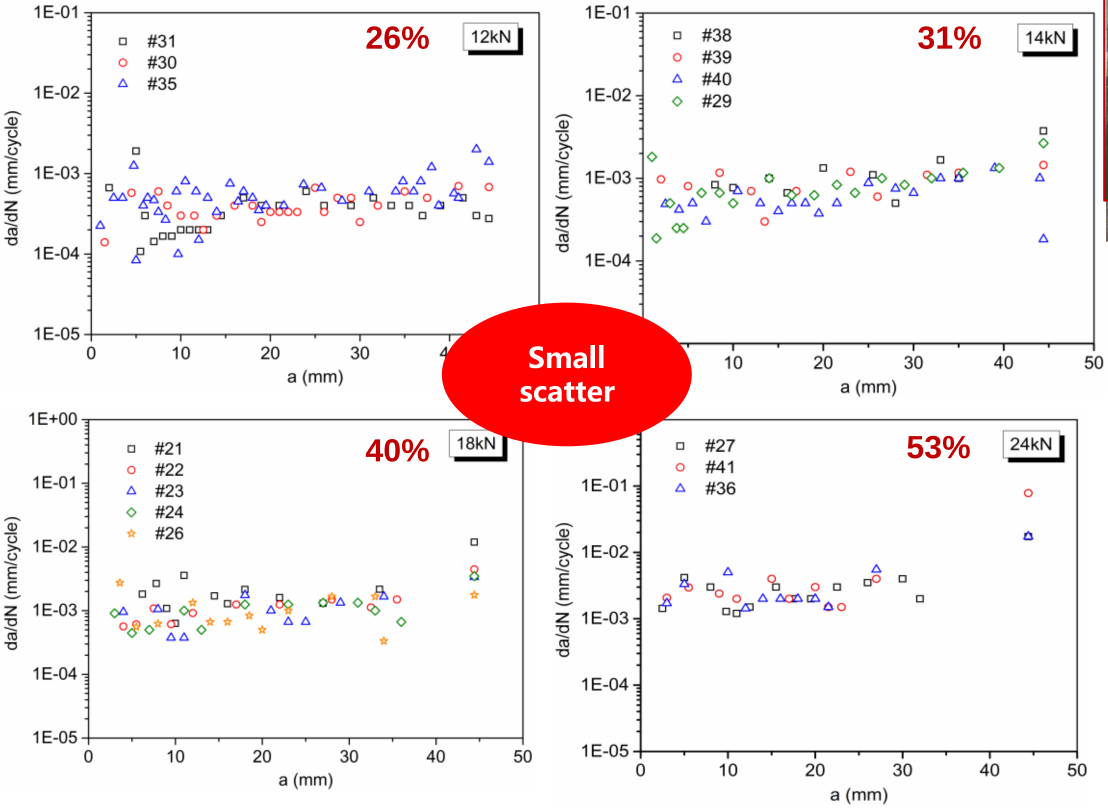
- Constant amplitude
- Stress ratio was 0.06

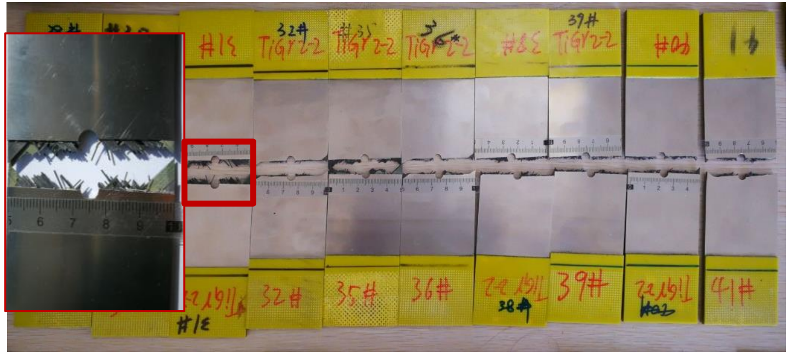
Stress level	Average fatigue life	Dispersion coefficients
53%	37342 cycles	0.65
40%	66160 cycles	0.14
31%	118397 cycles	0.191
26%	199201 cycles	0.162

Static and **Fatigue** Test

Crack growth test

center-hole/TiGr6A32





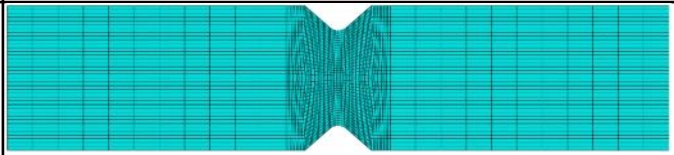
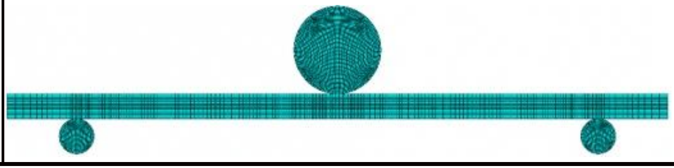
- The crack growth rate of TiGr is almost **constant**.
- The increase of load level leads to the **increase** of crack growth rate.
- Ti-layer shows **tensile failure**(crack is vertical to loading direction)
- CFRP-layer shows **tensile-shear coupling** failure (fiber fracture at hole edge + shear cleavage along fiber direction at free edge)

Calculation Results

Analytical method -----> **Finite element modeling**

Layer	Type	Criterion	Element
Titanium alloy	isotropic elastic-plastic material	Mises yield criterion	C3D8R
CFRP	anisotropic material	Hashin failure criterion	SC8R
Adhesive film	cohesive model	the secondary nominal stress criterion	COH3D8

- The cohesive element is connected to adjacent hexahedral and shell elements by **common node**.
- Mesh refinement on stress concentration areas.
- Consider the influence of **thermal residual** stress by a predefined field of cooling.

Type	Models
Stretch	
shear	
Bending	

Calculation Results

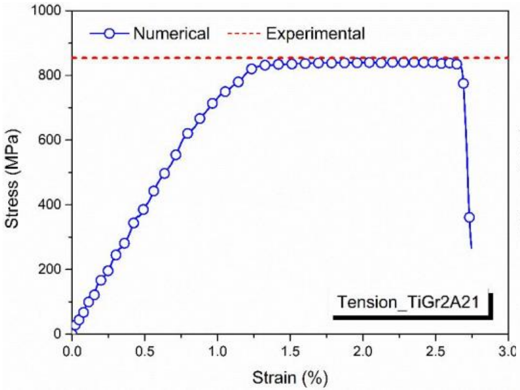
Tensile Strength Calculation Results

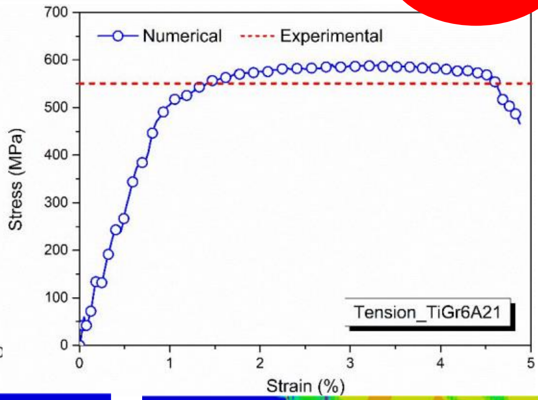
Validity of model

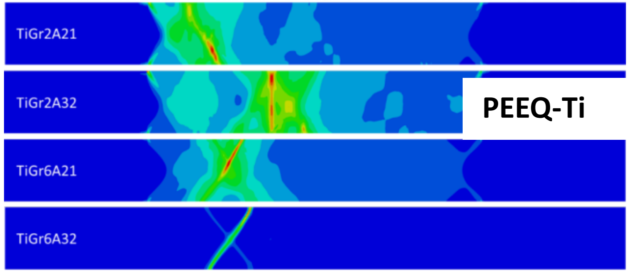
Higher volume fraction of the adhesive film

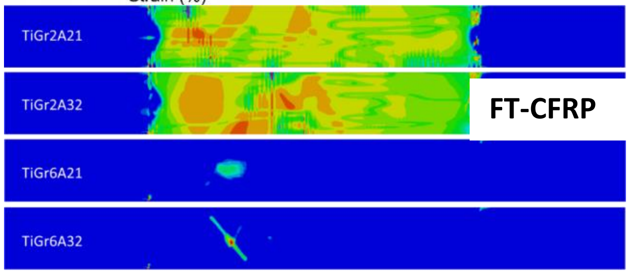
⇩

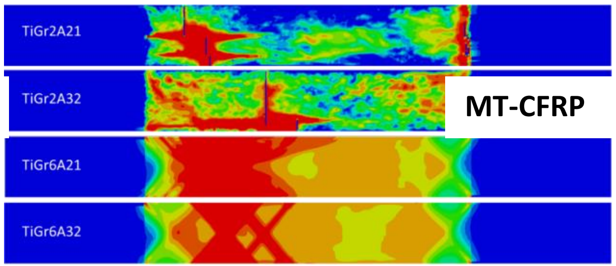
Grade	Experiment (MPa)	Simulation (MPa)	Relative Error (%)
TiGr2A21	853.7	841.48	1.43
TiGr 2A32	814.5	811.76	0.34
TiGr 6A21	550.5	590.73	7.31
TiGr 6A32	502.3	519.36	3.40







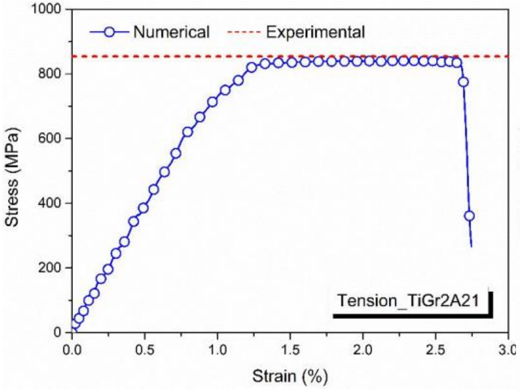


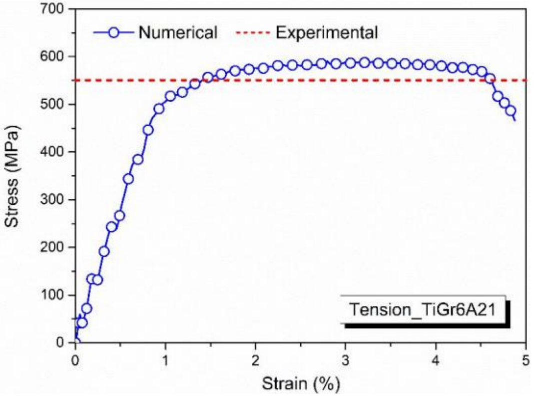


- Change of the FVF has little influence on the damage mode.**(32 vs 21)**
- 2A (0°) fiber tensile failure is dominant and 6A (45°) matrix shear failure is dominant. **(2A vs 6A)**

Calculation Results

Tensile Strength Calculation Results





Higher volume fraction of the adhesive film

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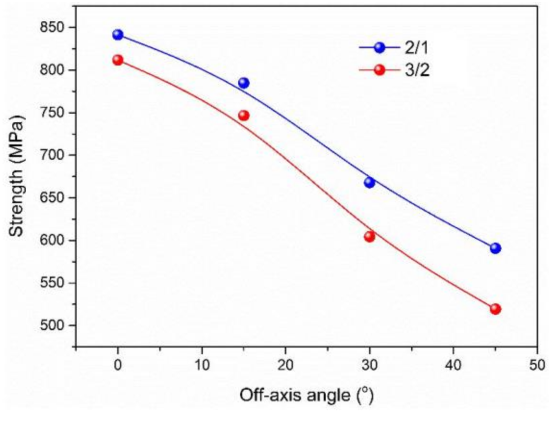
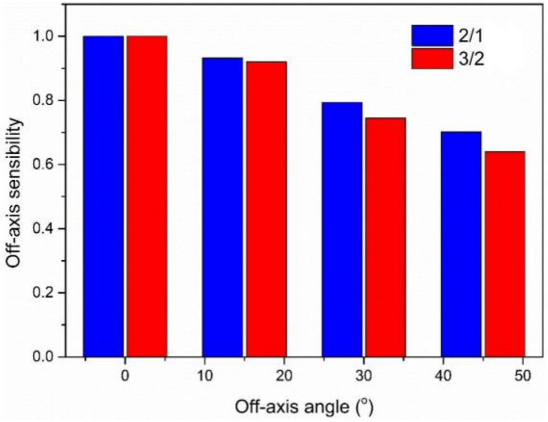


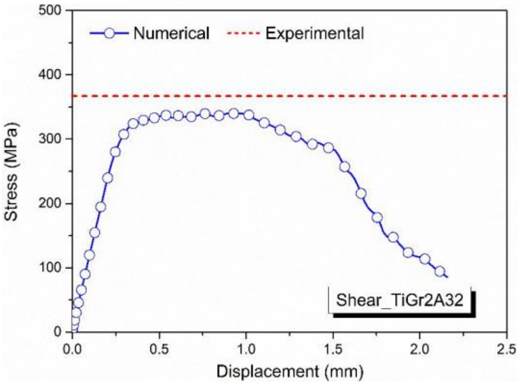


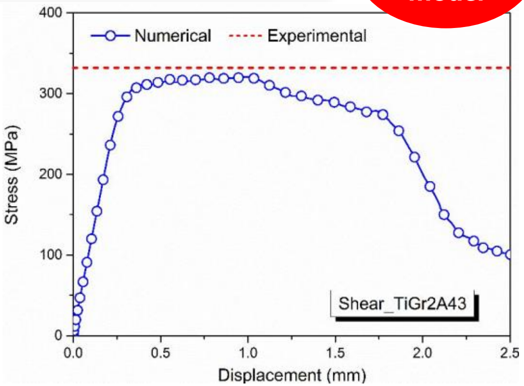
- The strength of TiGr21 is **higher** than that of TiGr32 under **any ply angle**.
- With the increase of the ply angle, the tensile strength **decreased** significantly.
- For TiGr21 or TiGr32, the decrease in strength due to change in ply angles is not **more than 40%**.

Calculation Results

Shear Strength Calculation Results

Validity of model

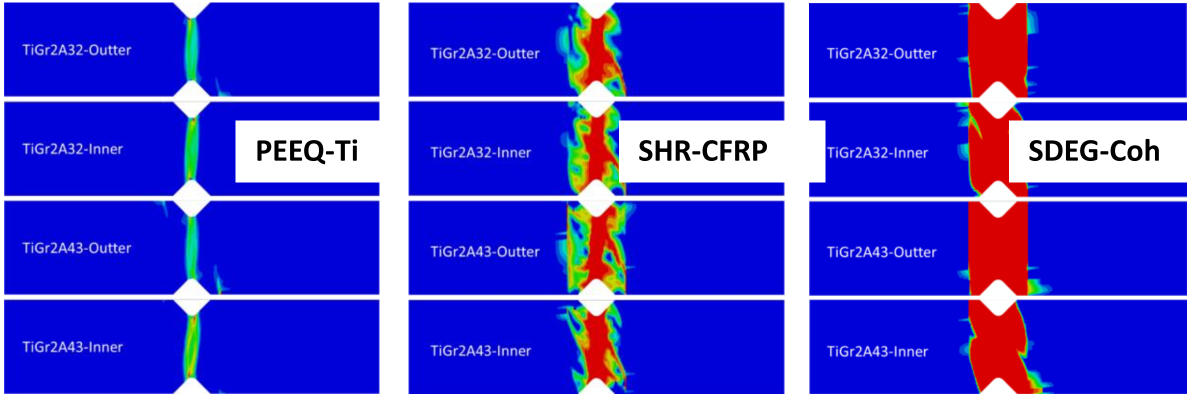




Higher volume fraction of the adhesive film

⇩

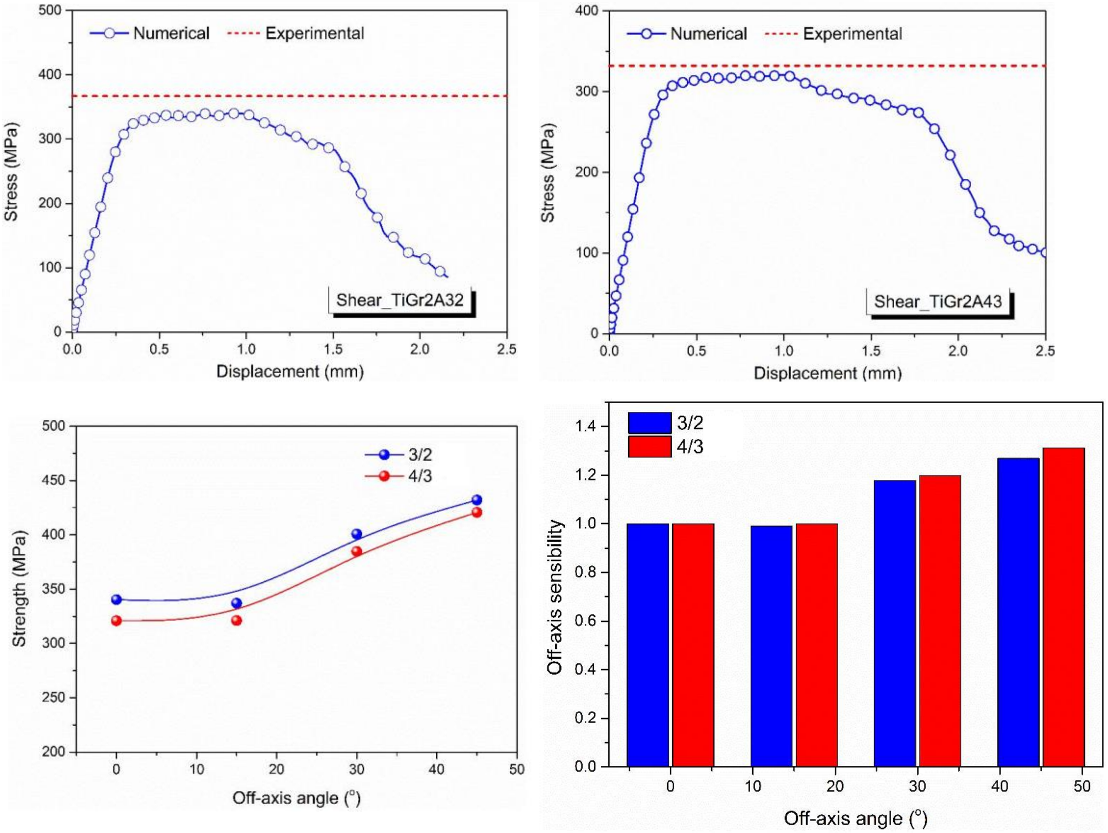
Grade	Experiment (MPa)	Simulation (MPa)	Relative Error (%)
TiGr2A32	367	340.36	7.26
TiGr2A43	332	320.88	3.35



- No significant difference in **damage modes** between the two TiGr variations.
- Interfacial delamination is obvious in the shear zone, indicating that **the interfacial delamination** is one of the main factors affecting the shear failure.

Calculation Results

Shear Strength Calculation Results



Higher volume fraction of the adhesive film

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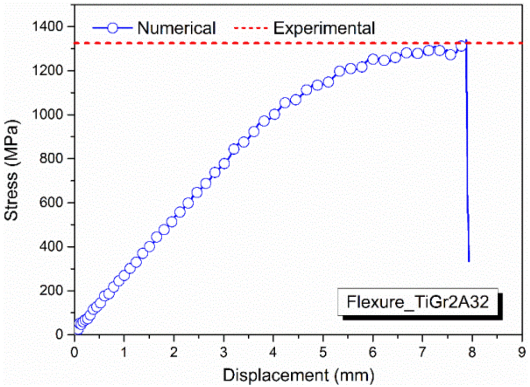
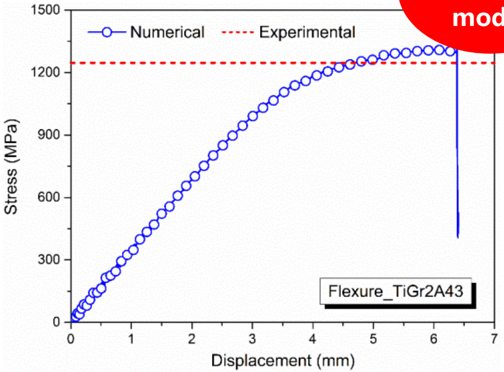
Grade	Experiment (MPa)	Simulation (MPa)	Relative Error (%)
TiGr2A32	367	340.36	7.26
TiGr2A43	332	320.88	3.35

- Shear strength of TiGr32 is higher than that of TiGr43(**high** FVF & **low** MVF)under **any ply angle**.
- When ply angle increases to 45^0, the shear strength increases significantly due to the increase of **bearing capability** along the fiber direction.

Calculation Results

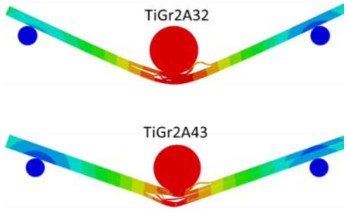
Bending Strength Calculation Results



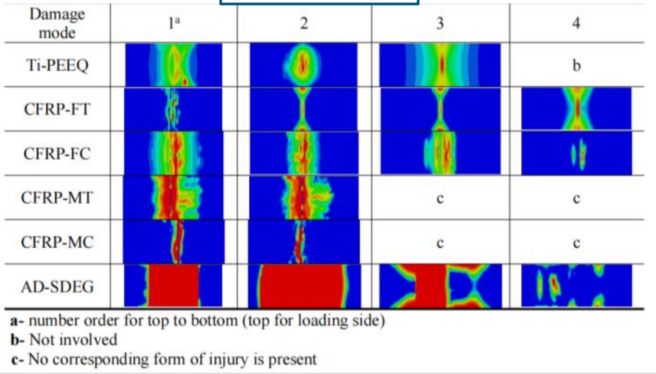


Validity of model

Grade	Experiment (MPa)	Simulation (MPa)	Relative Error (%)
TiGr2A32	1325	1339.99	1.13
TiGr2A43	1247	1320.30	5.88
TiGr6A32	915	1013.20	10.73



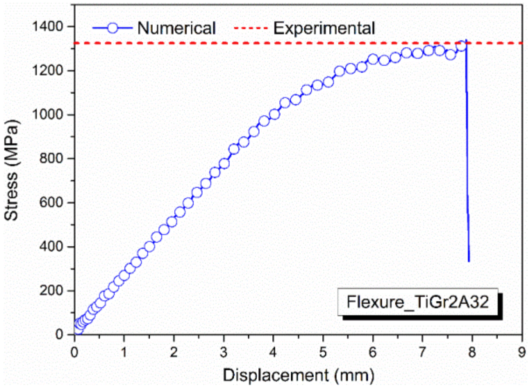
TiGr2A32

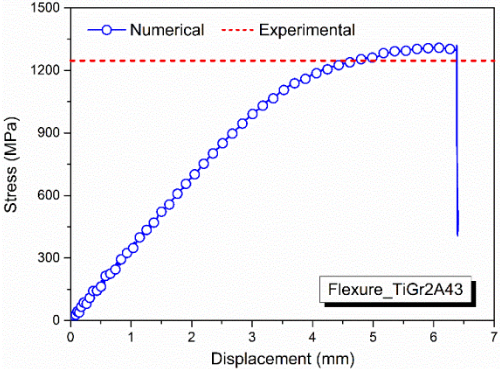


- Upper fiber layer—mainly **compression** damage Lower fiber layer—mainly **tensile** damage.
- **Interfacial delamination** leads to failure.
- FVF has **little influence** on the damage mode.

Calculation Results

Bending Strength Calculation Results





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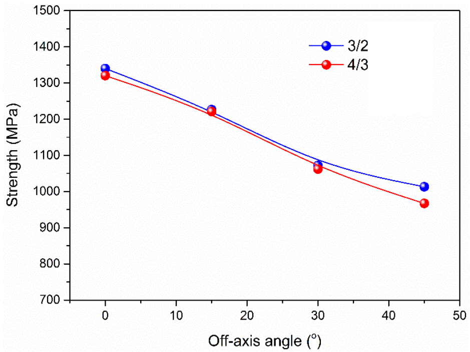
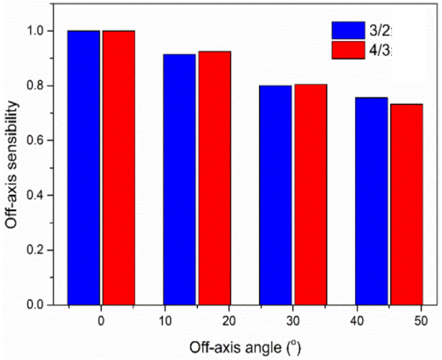


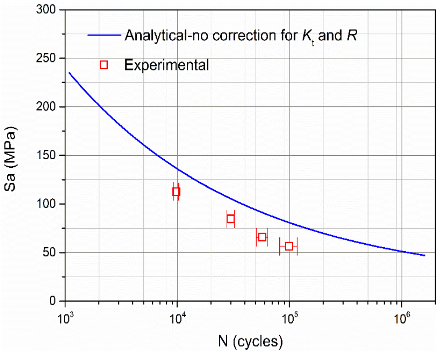


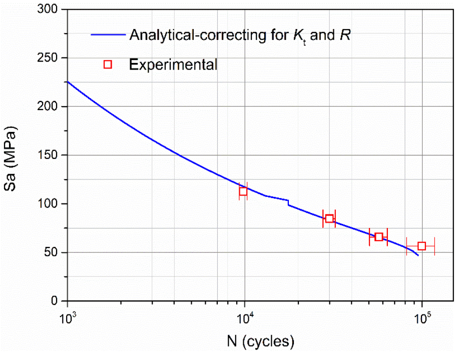
- The variation in bending strength with ply angle is **similar** to that of tensile strength.
- There is little difference between the bending strength when changing the **FVF** (The failure mode is the same).

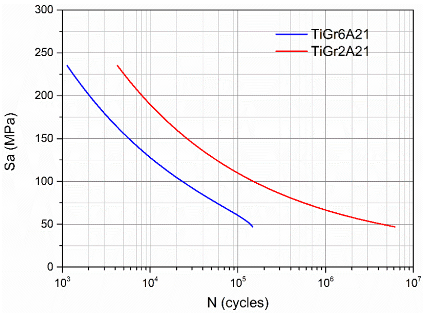
Calculation Results

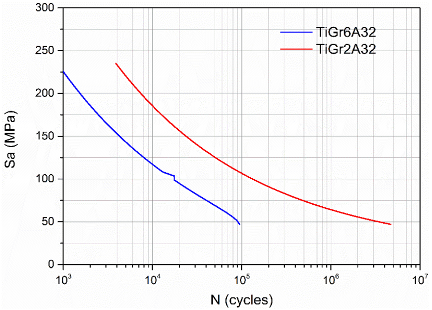
Analysis results of fatigue crack initiation life of TiGr6A32 of center-hole specimen.

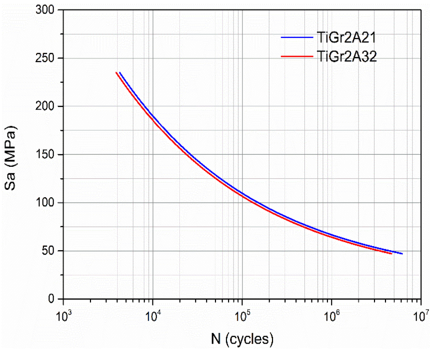
$$\sigma_{a,R_{ref}}^{Ti,eq}=\frac{f\,\sigma_{xx,nom,max}^{Ti}\,\sigma_{u}^{Ti}\left(1\text{-}R_{xx,peak,eff}^{Ti}\right)\left(1\text{-}R_{ref}\right)}{2\left[\sigma_{xx,nom,max}^{Ti}\left(R_{ref}\text{-}R_{xx,peak,eff}^{Ti}\right)+\sigma_{u}^{Ti}\left(1\text{-}R_{ref}\right)\right]}$$

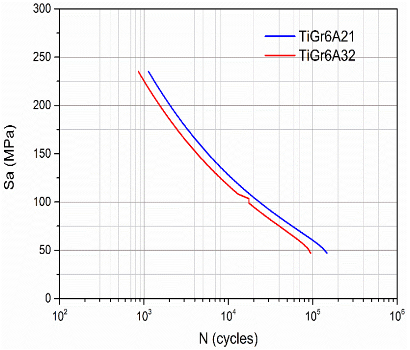












- The fatigue crack initiation life prediction method was validated using experimental data.
- The model was used to predict fatigue crack initiation life for different TIGR variations.
- The ply angle affects the fatigue initiation cycles more than the metal volume fraction of TiGr.

Summary

The strength performance of TiGr are studied experimentally and theoretically. The conclusions are as follows:

- Static test results shows that TiGr exhibits composites behavior.
- The failure strength showed a strong correlation with the metal behavior due to a low FVF.
- Besides, higher adhesive volume fraction affects the mechanical properties.
- TiGr shows an excellent fatigue crack growth resistance.
- FE Model was validated using experimental results.
- The damage mechanism, the effects of FVF, ply angle and other factors on the mechanical properties were analyzed.

Question & Comments