
# High Temperature Mechanical Properties of Carbon/Phenolic Composite at High Heating Rate

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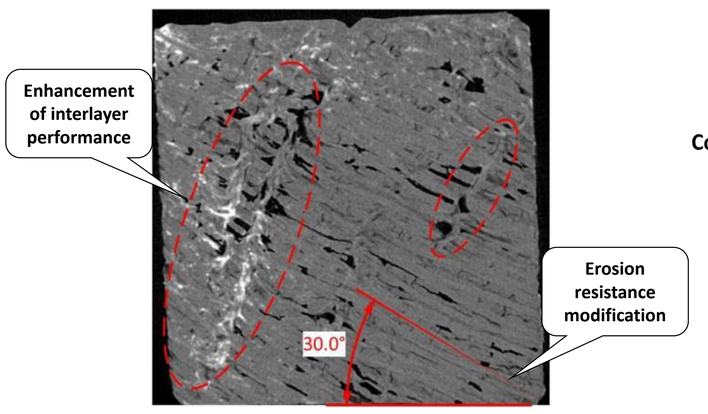
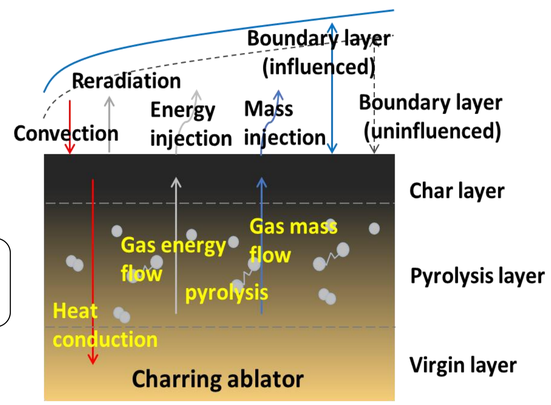
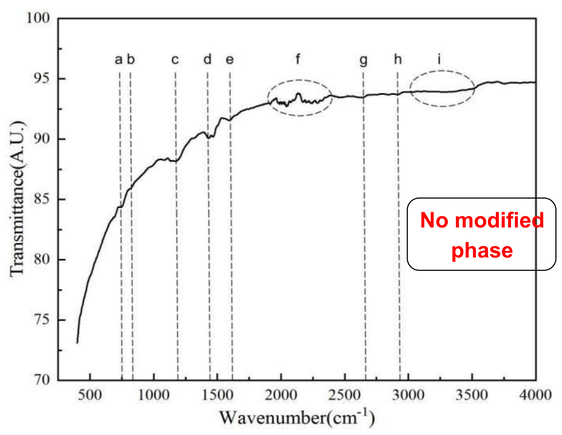
## Background




Cross Section of Carbon/Phenolic Specimen under CT Scanning



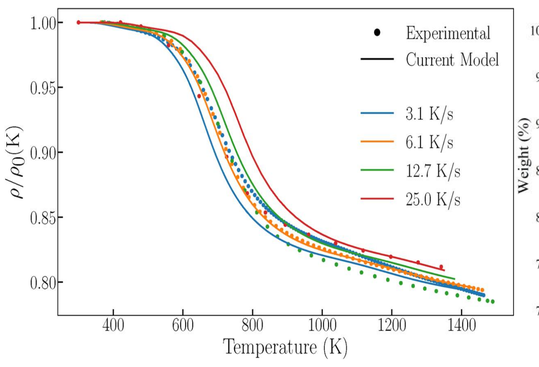

Virgin ablator → Charring ablator + Pyrolysis gases



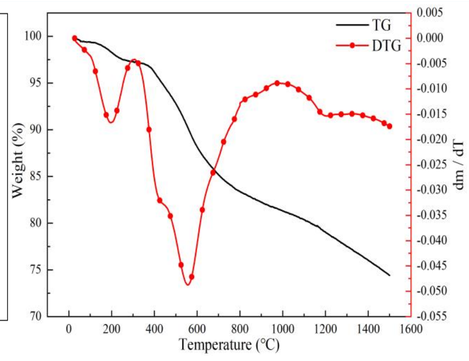

Fourier Transform Infrared Spectroscopy of the Specimen

- As a heat resistant material, **carbon/phenolic composite** has excellent high-temperature mechanical properties, making it **widely used in aerospace engineering**.
- At high temperatures, materials will undergo pyrolysis and ablation, forming a composite structure of the virgin layer, pyrolysis layer, and char layer, while also affecting their high-temperature mechanical properties.
- Adding modified phases to the composite matrix can improve its ablation resistance and mechanical properties.

## Pyrolysis and ablation at high temperatures



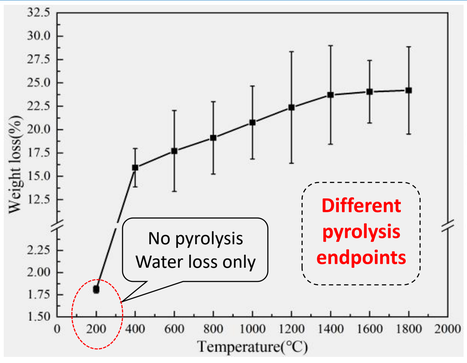

Thermogravimetric (TG) Curves of Phenolic Matrix Composites at Different Heating Rates[1]



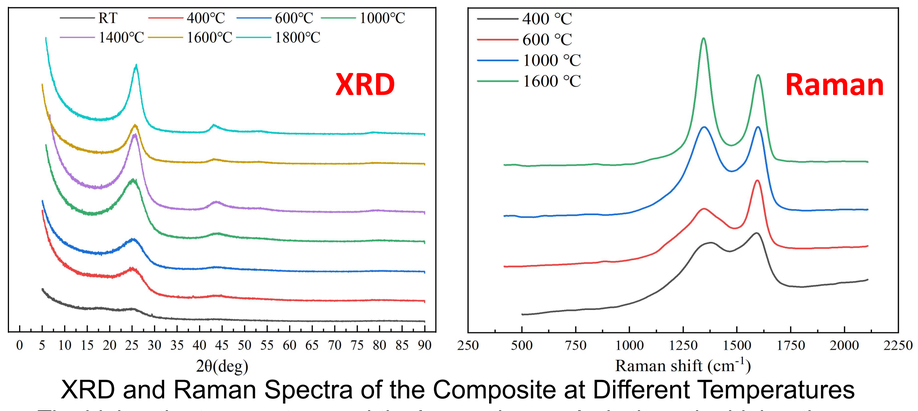

TG and DTG Curves of Carbon/Phenolic Composite

➢ The basis for controlling the degree of material pyrolysis through high-temperature mechanical testing.

*DTG: Abbreviation of derivative thermogravimetric analysis




The Weight Loss Rate of Materials at High Heating Rates and Different Temperatures[2]

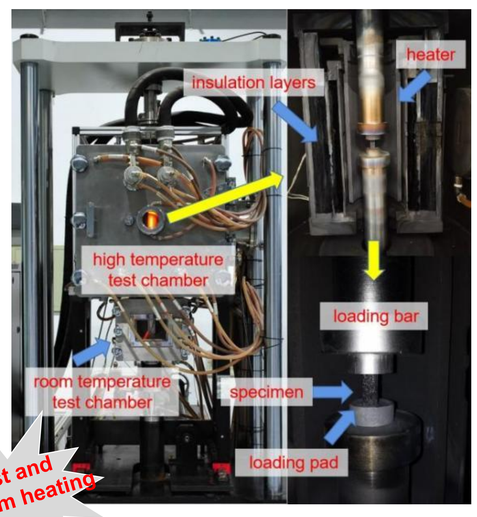



XRD and Raman Spectra of the Composite at Different Temperatures

- The higher the temperature and the longer the pyrolysis time, the higher the graphitization degree of phenolic matrix, and the lower the disorder degree and fewer defects.

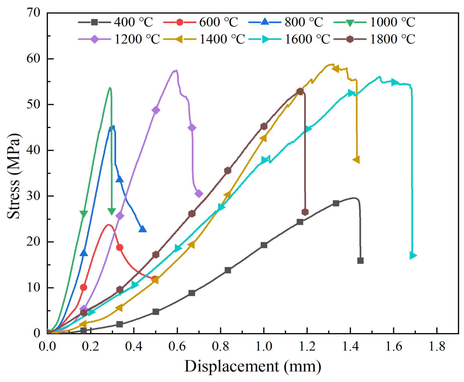
*XRD: Abbreviation of X-Ray diffraction

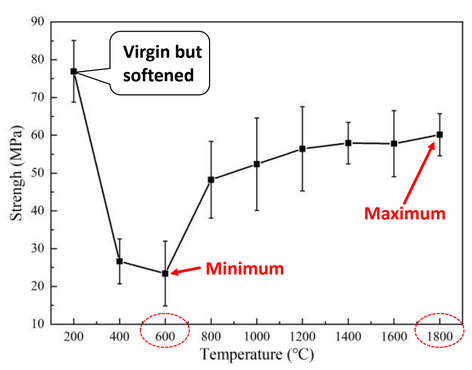
## Mechanical properties



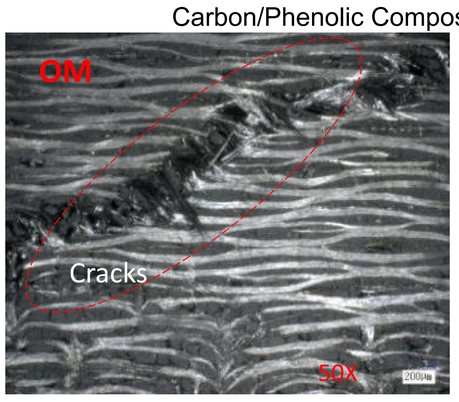

Split-Type Radiation Heating High Temperature Mechanical Testing Machine and its Compression Device

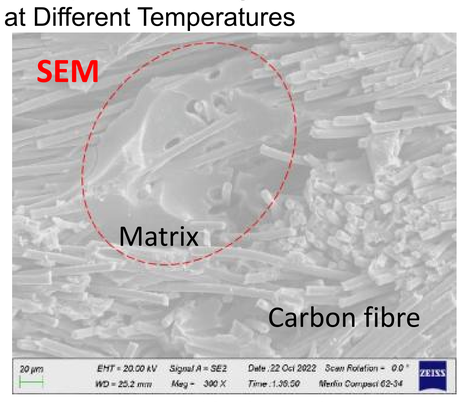
- The specimen is first placed at room temperature chamber, and when the high-temperature chamber reaches the testing temperature, it is lifted into the testing area and the holding time is accurately controlled to obtain the high-temperature mechanical properties of carbon/phenolic composite at different pyrolysis degrees.




Stress-Displacement Curves and In-plane Compressive Strength of Carbonized Carbon/Phenolic Composite at Different Temperatures




Typical Morphology of Specimen under Optical Microscope (OM) and Scanning Electron Microscope (SEM) after High Temperature Mechanical Test

High Temperature Mechanical Test Parameters and In-plane Compressive Strength of Carbon/Phenolic Composite

| Test temperature(℃) | 200 | 400 | 600 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 |
|---|---|---|---|---|---|---|---|---|---|
| Holding time(minutes) | 10 | 37 | 25 | 81 | 115 | 83 | 82 | 71 | 66 |
| Weight loss rate(%) | **1.81** | 15.92 | 17.71 | 19.12 | 20.75 | 22.37 | 23.71 | 24.05 | 24.20 |
| In-plain compressive strength(MPa) | **76.91** | 26.64 | **23.42** | 48.24 | 52.38 | 56.42 | 57.79 | 59.04 | **60.16** |

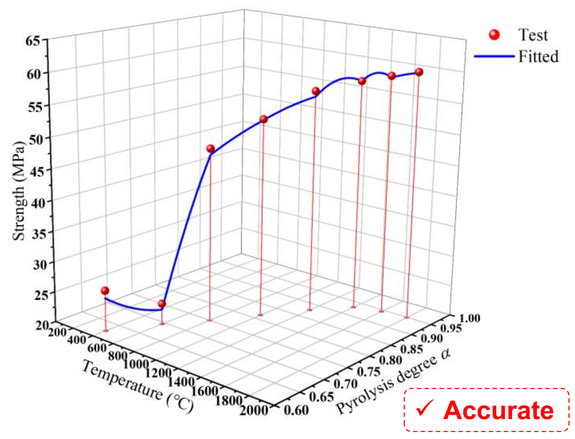
**Degree of pyrolysis:**

$$\alpha = \frac{w_l}{w_0}$$

$w_l$ — the weight-loss rate of the specimen during the test (%)
$w_0$ — end point of the pyrolytic reaction at different temperatures (25.5%)
$S$ — high-temperature in-plane compression strength
$\alpha$ — degree of pyrolysis ($0<\alpha\leq1$)
$T$ — 1 % of the test temperature (℃, $4\leq T\leq18$)

**High temperature compressive strength fitting based on material pyrolysis degrees and testing temperatures:**

$$S = 0.8055T^2 + 9514\alpha^2 - 336.6\alpha T + 294.4T - 13200\alpha + 4208.16$$




✓ Accurate

A Comparison of the Test Value and the Fitting Curve

## References

[1] F. Torres-Herrador, J. B. E. Meurisse , F. Panerai, et al. A high heating rate pyrolysis model for the phenolic impregnated carbon ablator (PICA) based on mass spectroscopy experiments[J]. Journal of Analytical and Applied Pyrolysis, Vol. 141, No. 104625, pp 1-10, 2019.

[2] X. Lin, F. Yi, W. Xie, et al. Experimental research on the high-temperature compression mechanical properties of carbon/phenolic composites in rapid carbonization conditions[J]. Polymer Composites, Vol. 44, No. 5, pp 3007-3019, 2023.