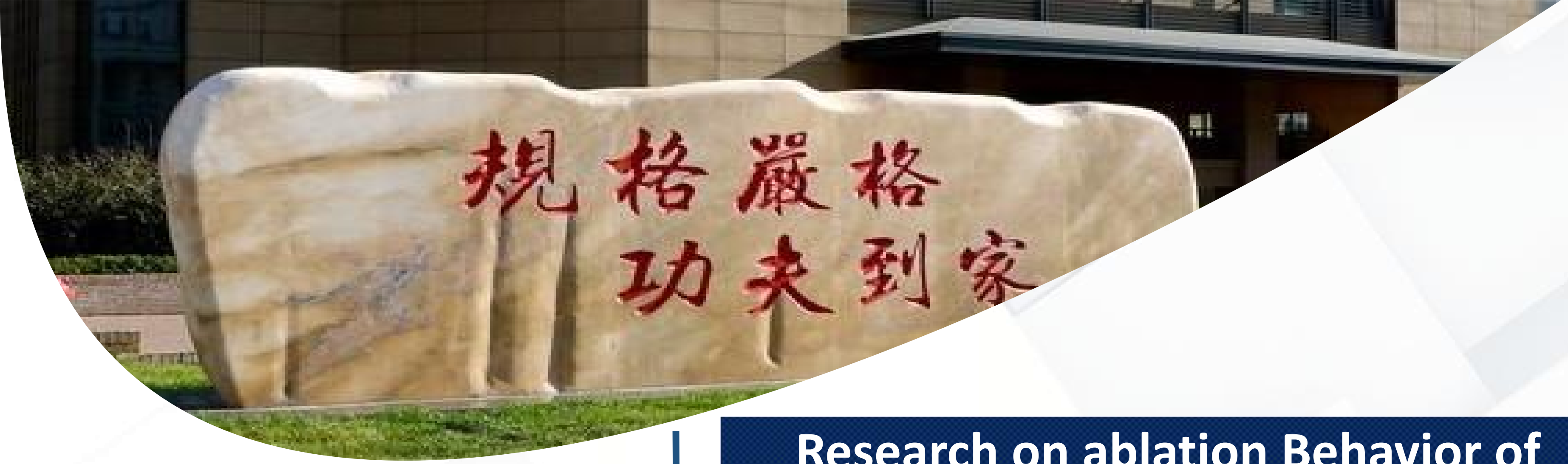

Research on ablation Behavior of C/SiC Composite Materials Under High-Energy Continuous Wave Laser Irradiation

Reported by: Junru Wang

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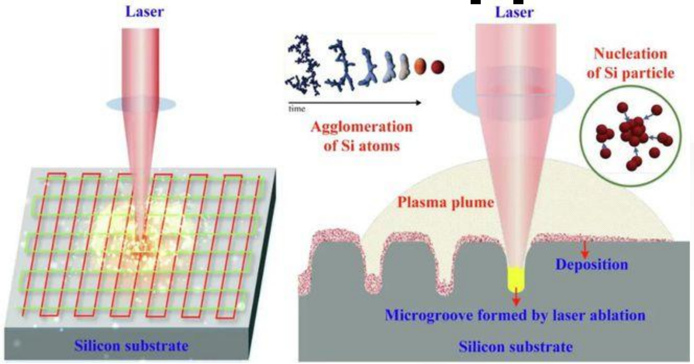
01 Background

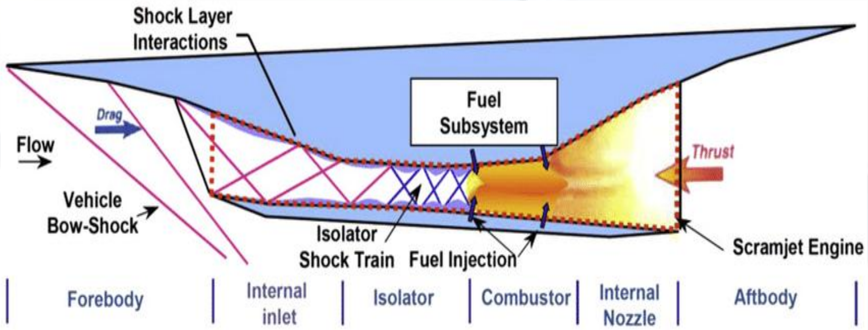
01 Backgroud

Laser ablation application



Laser cleaning

Laser processing



Scramjet engine

Breke pads

Thermal protective materals

02

Introduction of the experiment

02 Introduction of the experiment

Test conditions

Order Number	Theoretical Gaussian beam power density（W/cm²）	Action time（s）	Maximum surface temperature（℃）	Maximum ablation depth（mm）	Ablation pit diameter（mm）
1	127	25	2400	0	0
2	1018	25	2828	2	6.86
3	1273	25	2910	3.2	7.43
4	1591	25	3061	5	7.97
5	1591	8	3080	2.2	7.52
6	1910	8	3220	3.7	8.16
7	2228	8	3326	5	10.12
8	2546	7	Over range	5	10.90
9	3183	6	Over range	5	11.32
10	4456	4	Over range	5	12.44
11	7640	2.5	Over range	5	13.78

Table 1 Experimental conditions and results table

Test system

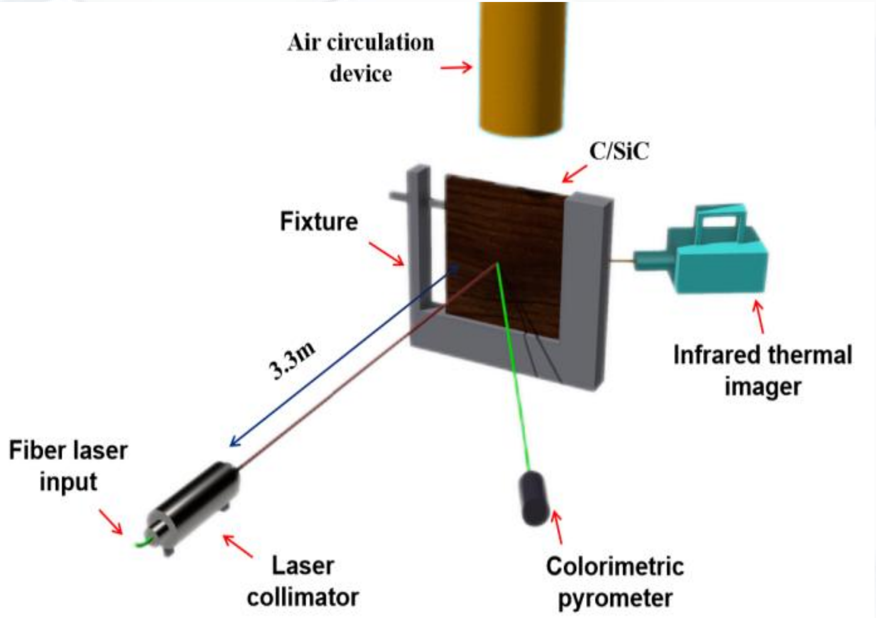
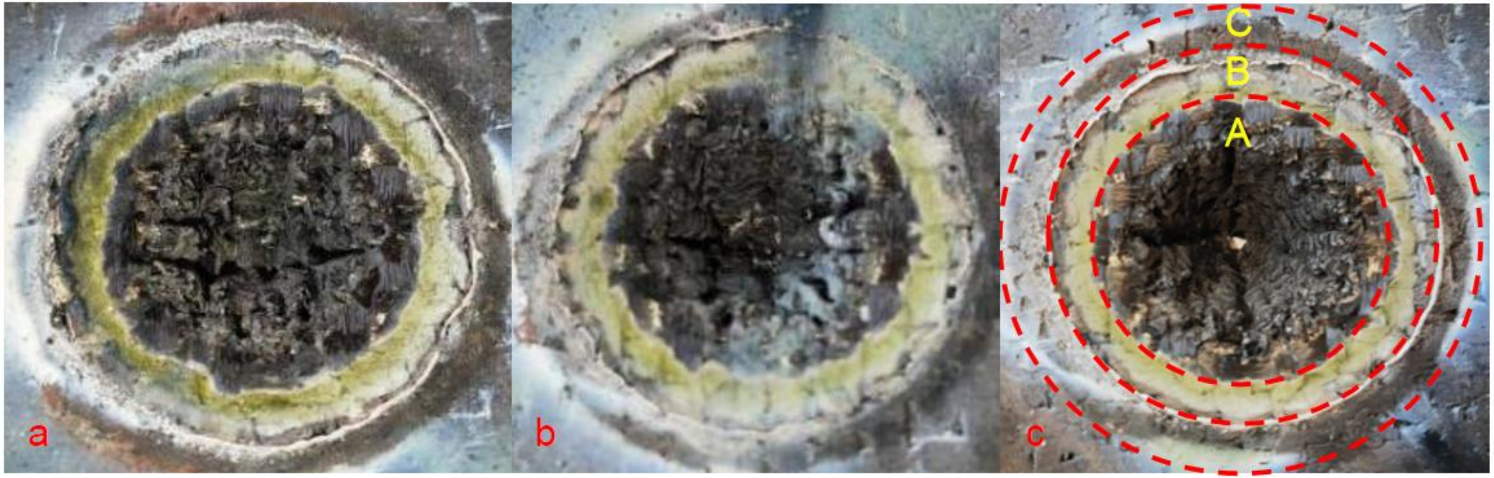


Fig. 1 Schematic diagram of experimental system

02 Introduction of the experiment

Test results

Action time : 8s



A Central area

B Transition area

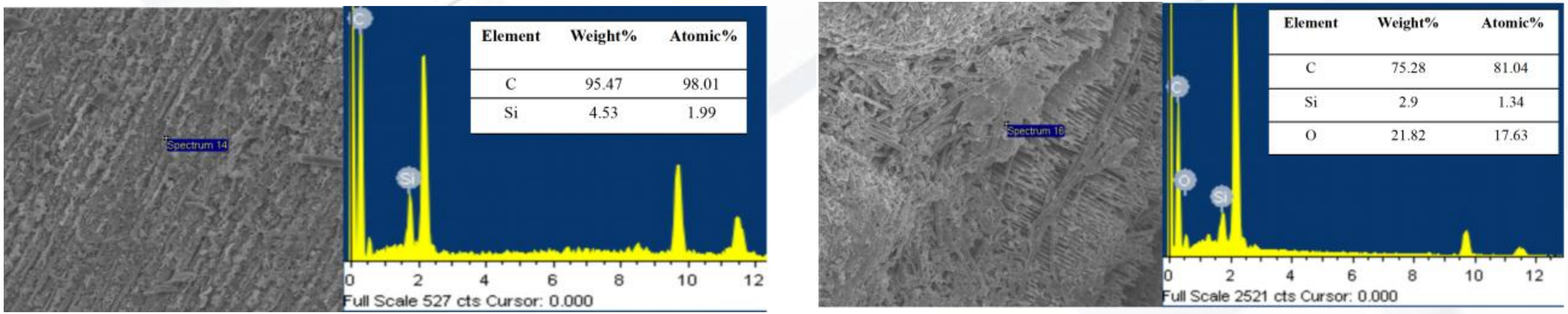
C Edge area

a.1591 W/cm²　　a.1910 W/cm²　　a.2228 W/cm²

Fig. 2 Schematic diagram of laser ablation morphology of C/SiC surface under different working conditions

02 Introduction of the experiment

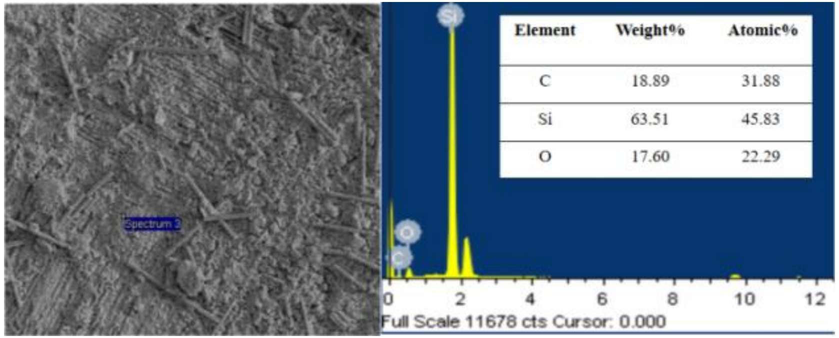
Microscopic observation analysis (1591 W/cm²)



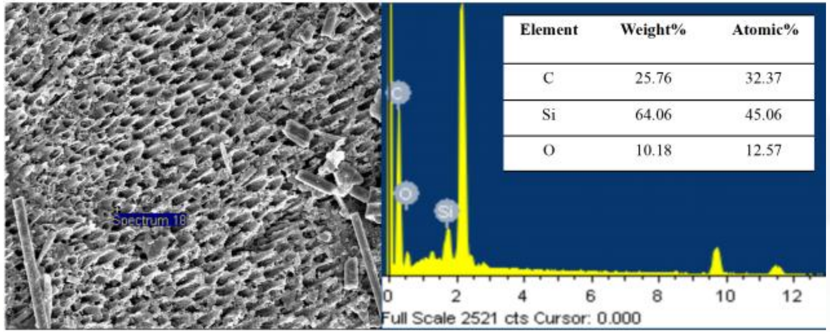
Element	Weight%	Atomic%
C	95.47	98.01
Si	4.53	1.99

Element	Weight%	Atomic%
C	75.28	81.04
Si	2.9	1.34
O	21.82	17.63

A Central area



Element	Weight%	Atomic%
C	18.89	31.88
Si	63.51	45.83
O	17.60	22.29



Element	Weight%	Atomic%
C	25.76	32.37
Si	64.06	45.06
O	10.18	12.57

B Transition area

C Edge area

Fig.3 Microscopic observation results

02 Introduction of the experiment

Calculation of ablation threshold

According to the formula of the zero damage method, obtain the relationship equation

$$y=b+ax$$

The relationship between slope ***a*** and waist radius w is

$$w=\sqrt{\frac{a}{2}}$$

According to the experimental results shown in Table 1, are shown in Figure 5.

y=0.61x-3.9

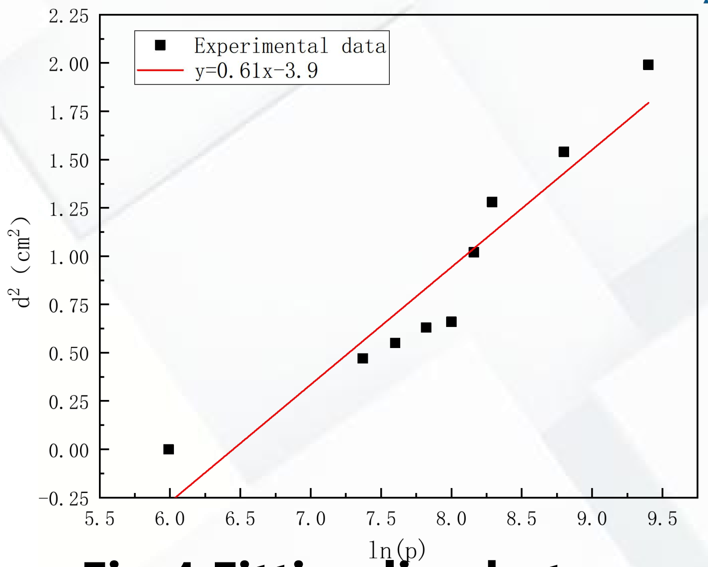


Fig.4 Fitting line between logarithm of power and square of ablation pit diameter

According to $p_{th}=e^{-\frac{b}{2w^2}}$

The ablation threshold is 198W/cm²

03 Numerical Method

03 Numerical Method

Introduction to Technical Route

ABAQUS finite element software

Remesh
+
Map solution

Improve

Umeshmotion+ALE

Birth and Death element method

Laser perforation

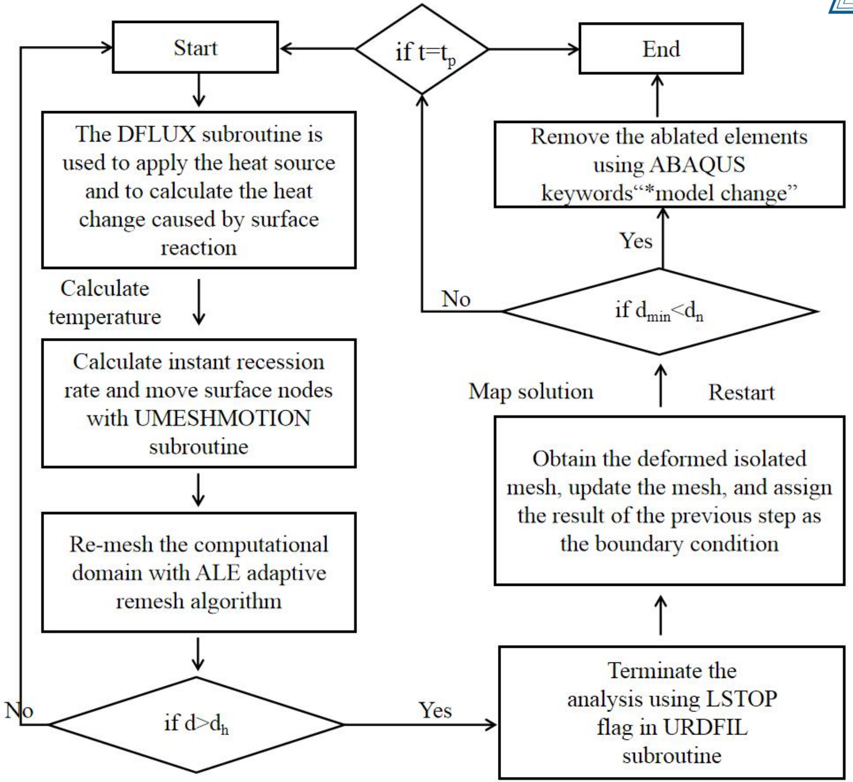


Fig.5 Road map of numerical simulation technology

03 Numerical Method

Oxidation Model of C/SiC (active oxidation)

Reaction control mechanism

$$v_{o-reac,i}=\frac{\dot{m}_i}{\rho_w}=\frac{1}{\rho_w}\frac{M_i}{Mo_2}A_{i,o}exp(-\frac{E_{i,o}}{RT_w})P_{Ow}$$

Diffusion control mechanism

$$v_{o-diff}=-\frac{\dot{m}_w}{\rho_m}=-\frac{\varphi q_c B_w}{\rho_m \mathrm{h_r}}$$

Assumption: All oxygen diffused to the wall is dissipated

$$B_w=\frac{C_{e,\ O_2}}{M_{O_2}(\frac{F_c}{2M_C}+\frac{F_{sic}}{M_{sic}})}$$

Oxidation rate

$$v_{ox}=\min(v_{a-reac},v_{o-diff})$$

Sublimation mechanism

According to the Clausius Clapeyron Equation of saturated vapor pressure:

$$\dot{m}_i=\sqrt{\frac{M_i}{2\pi RT}}P_{ref,i}exp[\frac{Q_{s,i}M_i}{R}(\frac{1}{T_{ref,i}}-\frac{1}{T})]$$

Project	Value	Project	Value
Density	2050kg/m^3	$T_{ref,\ sic}$	2673.2 K
C_p	1600J/kg.K	$T_{ref,\ c}$	3908K
k	5W/m.K	$P_{ref,\ c/sic}$	100kPa
Emissivity	0.85	Q_c	59.45（MJ/kg）
Absorption coefficient	0.8	Q_{SiC}	19.83（MJ/kg）

Table 2 Material parameters in the model

04

Result analysis

04 Result analysis

Laser scanning of ablation pits

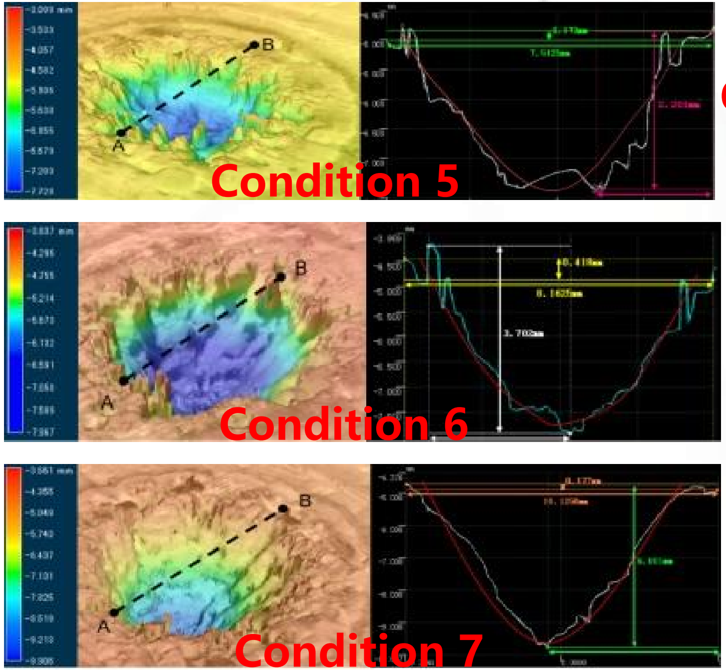


Fig. 5 3D scanning results

Comparison of simulation results

Simulation results

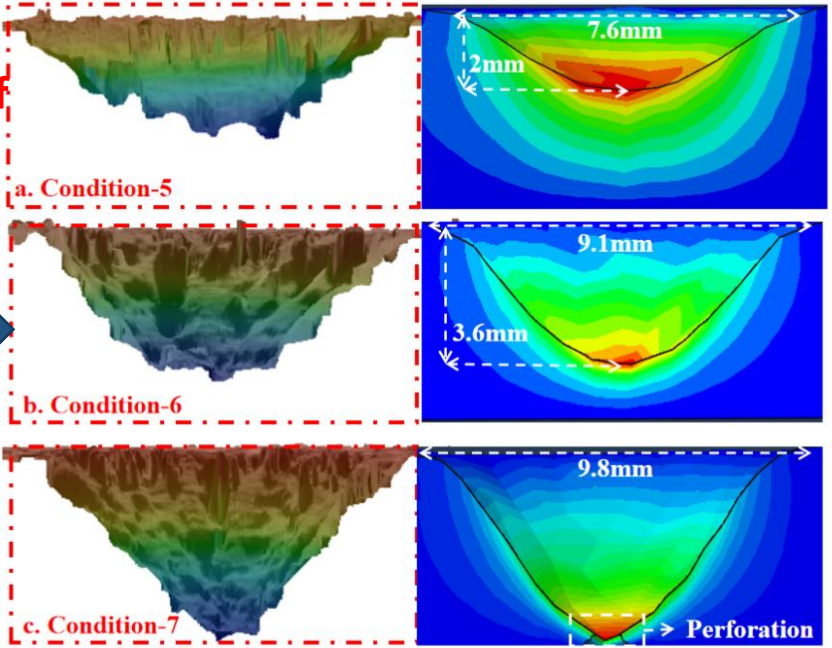


Fig. 6 Experimental and numerical simulation results ablation profile diagram

04 Result analysis

Temperature field analysis

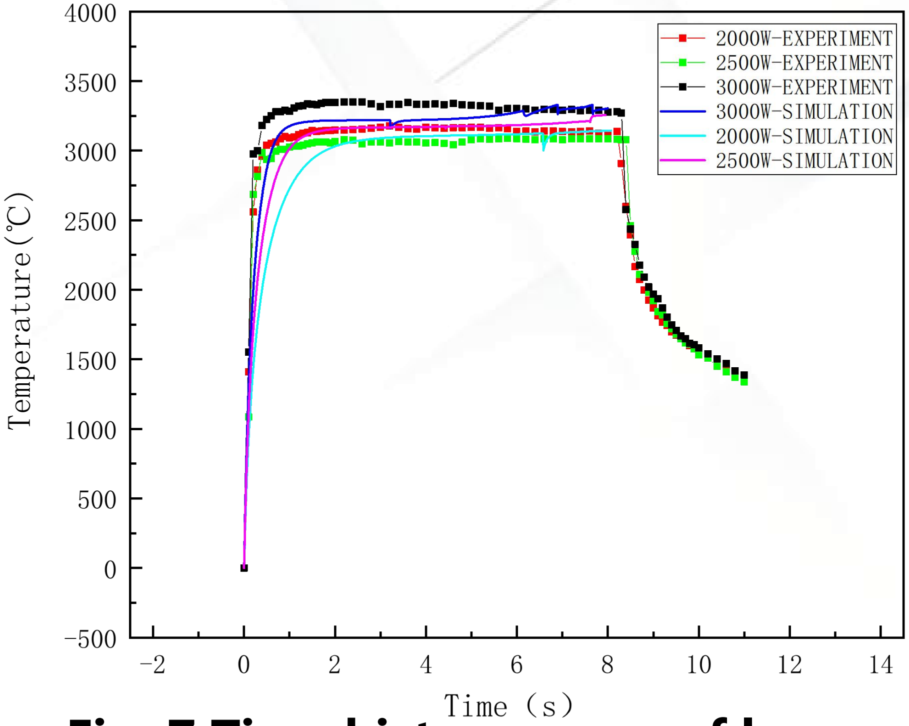


Fig. 7 Time history curve of laser irradiation center temperature

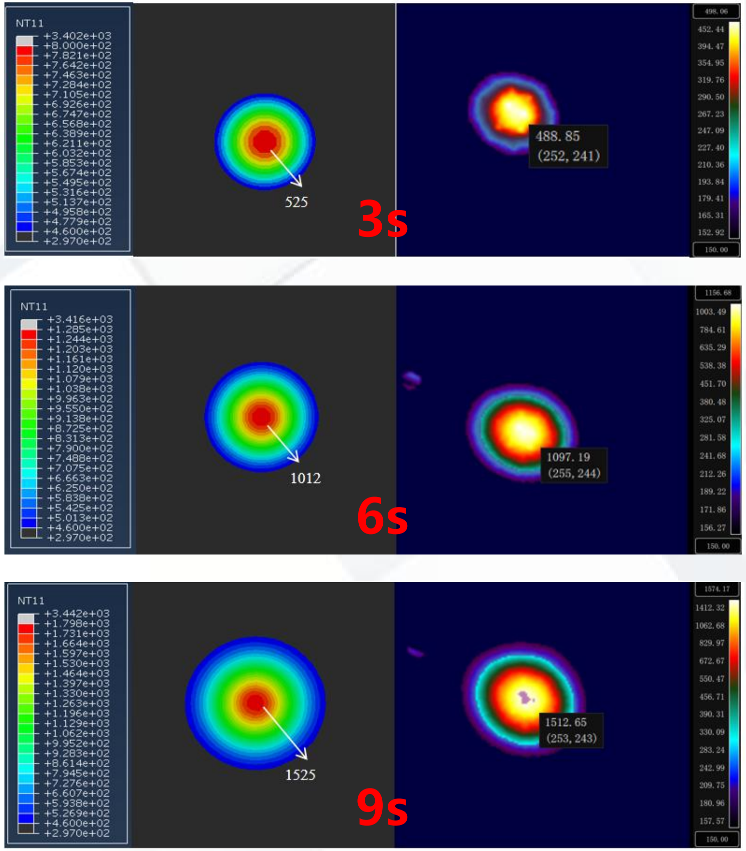


Fig. 8 Comparison of temperature fields at different times on the back of the target plate

04 Result analysis

Thermal stress analysis

The maximum contribution of shear thermal stress(0.7s) to material fracture damage.

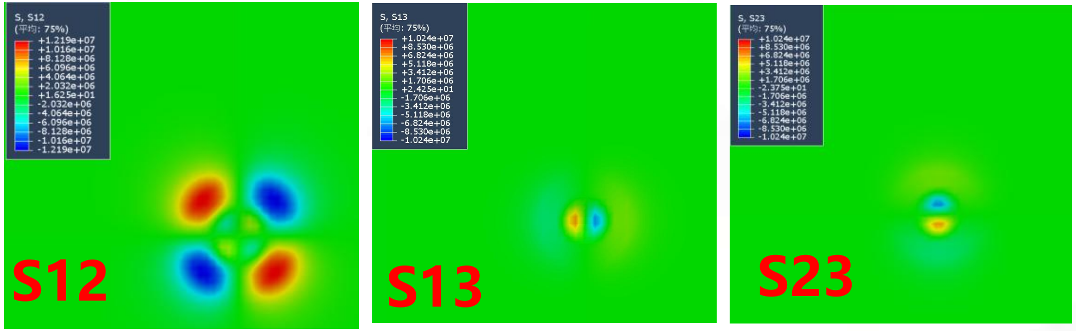


Fig. 9 Shear stress cloud map of the ablation center area under condition 6

S13 and S23 are about 10.2Mpa, and the shear stress S12 in the in-plane direction is about 12Mpa

Shear strength is greater than 100Mpa

The material will not undergo fracture or failure

04 Result analysis

Contribution rate of oxidation and sublimation

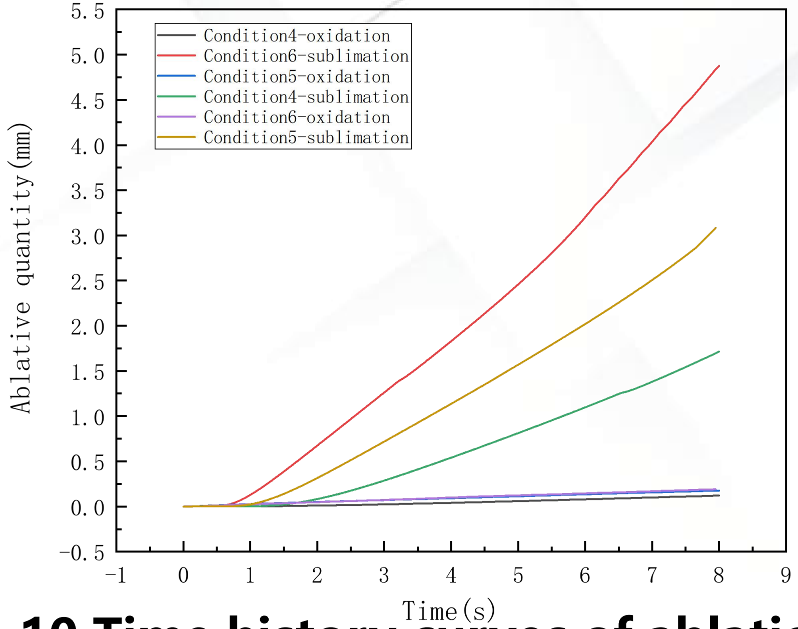


Fig. 10 Time history curves of ablation rate for oxidation and sublimation at the ablation center under different operating conditions

The contribution of sublimation reaction in the central region to ablation is much higher than that of oxidation reaction

05 Conclusion

(1)The experiment found that the morphology of ablation pits under different laser power densities was significantly different.

(2)The material ablation threshold and perforation time are obtained.

(3)The process of ablation in the area irradiated by the high-energy laser until the materail perforation is realized by using the improved Umeshmotion+ALE method and the birth and death element method.

(4) According to the numerical simulation results, the thermal stress analysis of the material under laser irradiation and the contribution rates of oxidation and sublimation to the ablation rate are mainly carried out.

Thank you for listening!