

Study on the Critic Ablation Property of 2D Carbon Reinforced Silicon Carbide (C/SiC) Laminated Composites via CVI Process

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Abstract

Two dimensions (2D) C/SiC laminated composites is the material with isotropic properties in laminated sheets, which is considered as a promising thermal skin for aircrafts. There are intense thermal flux and thermal impact at the local interference region during the flight of the aircrafts. Therefore, mastering ablation and mechanical properties of 2D C/SiC laminated composite under extreme environments become the guild lines for the designs of the flight corridor and the aircraft security. This paper presents the experimental results of the ablation and thermal impact of C/SiC composites under different thermal environments (thermal flux $\sim 5 \text{ MW/m}^2$), which were carried out with the equipments of free-jets and conduct pipes. The effects on the ablation and mechanical properties of the C/SiC composites are studied, including gas pressure, thermal temperature, and the rates of temperature increasing and decreasing. The results show that the active oxidation and ablation behaviors of 2D C/SiC laminated composites under the thermal flux 5 MW/m^2 consist with that of theoretical simulations. The critical failure conditions of 2D C/SiC laminated composite is also provided for the enveloping designs of the whole composites lightweight aircrafts.

Keywords

2D, C/SiC, Critic, Ablation Property, Experimental

1. Introduction

Continuous carbon fiber-reinforced silicon carbide (C/SiC) composites have been developed for high temperature structural applications such as engines and thermal protection system [1]. Two-dimensional C/SiC composite material is laminated isotropic materials, as the skin material of aircrafts' thermal structure

with good application prospect. But because of the interference between shock waves and boundary layers, an intense heat flux is induced at aircrafts' local area. So, for the flight security and designing of the flight corridor, researchers usually require thermal skin not to be ablated even in extreme environment. It is obvious that there is a large safe coefficient between designed performance and actual needed performance. In order to realize satisfied aircraft design, people need to know the ultimate ablation performance of C/SiC composites. This paper uses the data of arc wind tunnel experiments [2] and calculated results to predict T, ablation rate and ablation area, which supports the fine design of C/SiC composite aircraft.

2. Ablation Calculation Method of C/SiC Composite Material Selecting a Template

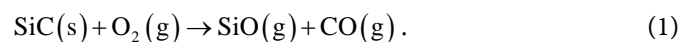
C/SiC composite material is mainly made of carbon fiber, carbon interface layer (PyC) and silicon carbide substrate. The ablation [3] behavior of C/SiC composite is dominated by SiC component. There are three chemical ablation modes: passive oxidation, active oxidation and melting/decomposition.

1) In the passive oxidation mode, the diffusion of oxygen is limited by the SiO₂ film generated at the surface and so the oxidation of SiC matrix is prevented. In this mode, the ablation needs not to be considered.

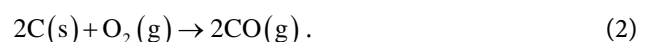
2) In the active oxidation mode, when the SiO₂ evaporation rate is greater than the rate of SiO₂ formation, SiO₂ film is difficult to maintain and SiC matrix is continuously oxidized. Due to the ablation of SiC surface, interfacial layer and the carbon fiber will also be exposed, directly react with oxygen, and be ablated. In this mode, the ablation must be considered.

3) In the melting/decomposition mode, it generally occurs above 2600°C, with numerous reactions and complicated processes. For engineering applications, C/SiC composite material is usually thin-walled structure, bearing both load and heat and usually cannot meet the requirements above 2600°C. That is beyond the requirements of anti-ablation design. On special occasions, because of the existence of carbon fibers, people use carbon sublimation ablation mode to value the ablation and finish the anti-ablation design of C/SiC composite materials.

For the active oxidative ablation of C/SiC composites, the reaction between silicon carbide and oxygen is shown as the Equation (1):



The reaction between carbon atoms and oxygen, known as "Combustion Glowing", is shown as the Equation (2):



For the C/SiC composite, according to the mass fraction of carbon and silicon carbide, a dimensionless mass ablation database is built with the results under different temperature and pressure.

The calculation procedure is as follows: first choose ablation mode, if it is confirmed neither thermochemical ablation nor passive oxidation model, C/SiC

composite materials will not be ablated; if it is confirmed the occurrence of thermochemical ablation or active oxidation model, the temperature field should be solved based on thermal environmental conditions, and then the ablation mode need to be confirmed based on the results of temperature; if thermochemical ablation or active oxidation mode occurs, the temperature history and thermal environmental conditions (including the pressure, heat, enthalpy) should be focused. The ablation rate will be obtained based on the dimensionless mass ablation database.

3. Experimental Study on Ultimate Ablation Performance of C/SiC Composites

The experiments [4] in arc wind tunnels were carried out to test the ablation performance of the SiC skin. Arc wind tunnel is composed of arc heater, mixing chamber, supersonic nozzle, test section, water cooling model support, diffuser, the pressure stabilizing chamber, cooler, vacuum system and so on. The nozzle used in the experiments is the Laval nozzle. The vacuum tank volume is 500 m³ and the highest vacuum is up to 200 Pa.

According to the experimental parameters, the sample's surface temperature is above 2000°C and the average dimensionless mass ablation rates of 3 samples were about 0.245. The theoretical value of ablation rate is 0.227, only 7.9% difference to the tested results.

Take one model as an example. From the experimental video, there were some spots (**Figure 1**) at the high state, and the model surface started to melt. Based on the calculation model, the active oxidation started in the early stage and gaseous SiO was generated without melting. But in order stages, SiO₂ was generated via passive oxidation and the temperature was beyond 1700°C, so the surface started to melt. After the experiment, the surface of the model revealed exposed fibers and coating had been ablated.

Under the high enthalpy and low pressure conditions, Arc wind tunnel is suitable to simulate the hypersonic flight environment. Line ablation rate and Dimensionless quality ablation rate at thermal flux ~5 MW/m² are determined.

A higher state experiment was carried out and the install diagram was shown in **Figure 2**.

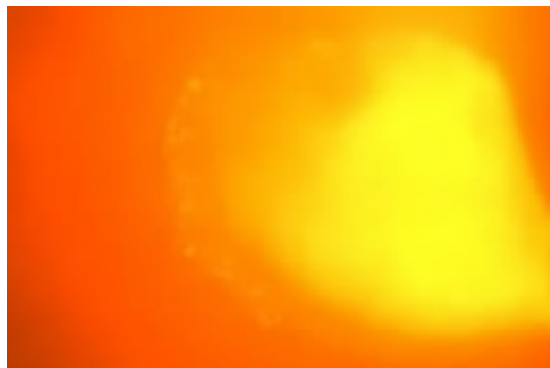


Figure 1. Surface ablation in the model 1# experiment.

According to the experimental condition parameters, the dimensionless mass ablation rates were 0.364, a small difference to theoretic value 0.31. The surface temperature was expected to be above 2600°C and the melting/decomposition occurred. **Figure 3** shows the surface morphology of 2# sample.

4. Summary

Ceramic matrix composites are ideal heat shield materials for reusable spacecrafts re-entering the Earth atmosphere. The interactions between the surface and the surrounding reactive gas determine the total heat flux to the wall and become design drivers for the thermal protection system [5]. In aircraft design, in order to obtain better cost-effectiveness, the limitations of the space and parts on the aircraft tend to be strict, and the request for fine design is demanded. The reach on the ultimate ablation performance of C/SiC composite can be used to improve the design and the reliability of the aircraft. This paper presents C/SiC composite ablation experimental method and calculation method, the results of test and calculation agree well, which is useful to design the flight corridor. The validity of the temperature/ablation calculation method is confirmed for C/SiC

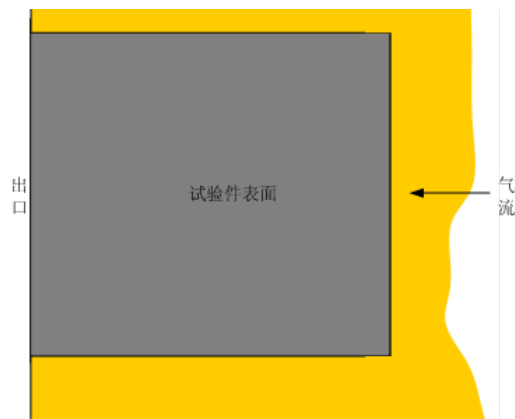


Figure 2. Schematic diagram of test parts installation.

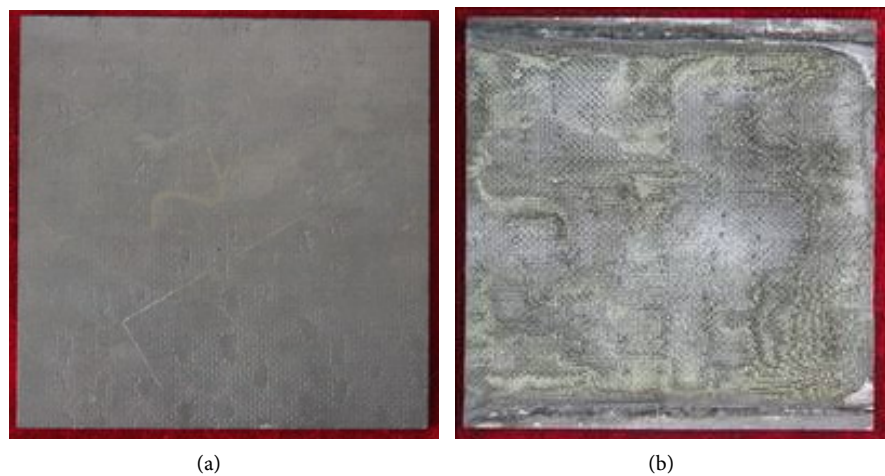


Figure 3. Morphology of the model before and after ablation. (a) Before the experimental. (b) After the experimental.

composites.

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