RECENT ADVANCE ON LIGHTWEIGHT GRADED NON-ABLATION STRUCTURE FOR HYPERSONIC VEHICLES

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ABSTRACT

Thermal protection structures which are correlated to the safety of hypersonic vehicles, are one of the most critical techniques in design and manufacture of hypersonic vehicles. Light-weight, non-ablation and long-time insulation have been required for TPS due to long-time hypersonic flying in the atmosphere. Thermal environment of traditional hypersonic vehicles are of high enthalpy, non-high heat flux and long-time. Traditional thermal protection system does not meet the new environments. In addition, low cost is also an important factor for designer. The problem of present thermal protection system are prone to ablation or fragmentation.

In this paper, an integrated structure with graded-outer-layer, has been brought forward in order to avoid fragmentation and improve the strength. The preparation method and technology of lightweight graded article has been investigated. Fabrication and wind tunnel test have been performed. Graded lightweight article with dense low to 0.45g/cm^3 has been prepared successfully. High temperature test to evaluate the thermal performance of graded integrated structure has been performed in the wind tunnel, which surface temperature reached to 1973K high temperature for 550 seconds exposure.

1 INTRODUCTION

Thermal protection system (TPS) which are correlated to the safety of hypersonic vehicles, are one of the most critical techniques in design and manufacture of hypersonic vehicles [1]. Thermal environment of traditional hypersonic vehicles, such as hypersonic missels, capsule, and etc, is of high enthalpy, high heat flux and short time, which use ablation thermal protection system. For new-type hypersonic vehicles, due to its long-time flying in the atmosphere, thermal environment is of high enthalpy, non-high heat flux and long-time, traditional thermal protection system does not meet the new environments. Also, sharp-leading edge had been brought forth due to reduced drag, which different to traditional blunt edge configure. The advantage of a reentry vehicle with a sharp leading edge is its increased cross-range capability. However, the sharp leading edge results in much higher heat transfer rates during planetary entry than those experienced by a blunt body configuration, such as a capsule.

Therefore, light-weight, non-ablation and long-time insulation have been required for TPS due to long-time hypersonic flying in the atmosphere. Reusable ceramic tiles have been applied to many hypersonic vehicles, such as space shuttle and X-37B[2-6]. Current passive systems being proposed for sharp leading edge vehicles include hot structure,heat sink, and transpiration cooled technologies. Hot structures ,such as reinforced carbon-carbon (RCC) and silicon carbide ,are presently being used on the orbiter wing leading edge and nose cap. They has also been candidate TPS for advanced vehicle concepts, such as reusable launch. The RCC system with density 1.6g/cm^3 used on the Space Shuttle have large radii and operate at heat flux below 70w/cm^2 during reentry. A new lightweight fibrous TPS (TUFROC) used as wing leading edge and nose cap of X-37B, has a higher temperature capability (1970K) than AETB, which its density is only 0.4g/cm^3 .

In this paper, a kind of high-porosity ceramic fibrous composite material has been introduced. It is an excellent candidate for insulation which main components are Al_2O_3 and SiO_2, Another crucial advantage is that its density is only 0.350g/cm^3. It also can endure a temperature as high as 1900K.

While the fatal weakness of this kind of ceramic composite material is prone to fragmentation, as shown in Fig. 1.

Figure 1: Fragmentation of high-porosity ceramic fibrous article after test

In this paper, an integrated structure with graded-outer-thin-layer, has been brought forward in order to avoid fragmentation and improve the strength of ceramic composite materials as mentioned above. The preparation method and technology of lightweight graded article has been investigated. Fabrication and wind tunnel test have been performed,as shown in . Lightweight articles with dense low to 0.45g/cm^3 have been prepared successfully. High temperature test to evaluate the thermal performance of graded integrated structure has been performed in the wind tunnel, which surface temperature reached to 1973K high temperature for 550 seconds exposure.

2 TEST ARTICLES

In this paper, an integrated structure with graded-outer-thin-layer, has been brought forward in order to avoid fragmentation and improve the strength. Fig. 2 shows the schematic figure of graded integrity model. This graded integrated structure consists two parts: the graded-outer-layer which composed of mixture of Ta, Mo, Si and other elements, is very thin and density with high conductivity. The inner is thick, high-porosity ceramic fiber materials with low conductivity. During high-speed entries, the graded density surface treatment in combination provides dimensional stability, while the inner insulation material protects the vehicle structure.

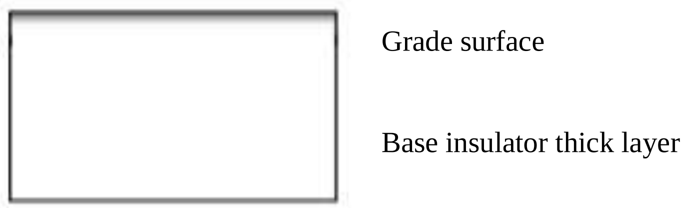


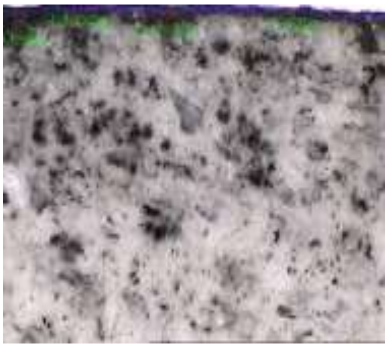
Figure 2 Schematic figure of lightweight thermal structure model

According to our design idea, the preparation method and technology of lightweight graded article has been investigated. Fabrication and wind tunnel test articles have been performed. Three blunt cone models are shown in Fig. 3. The blunt cone was 1-cm thick and had a 0.5cm corner radius.

Graded lightweight article with dense low to 0.45g/cm^3 has been prepared successfully. During its high-speed entries, the graded surface treatment on the cap provides dimensional stability, while the fibrous base insulation material provides a low thermal conductivity insulation to protect the vehicle structure.

The integrated article with graded surface, which micrographs of cross section of the article are shown in Fig. 4a-c, has graded surface treatments applied by impregnation to the whole articles.

Figure 3 Arc-Jet Test Models



(a) cross section of graded structure

(b) cross section of graded structure

(c) cross section of inner layer

Figure 4 Micrographs of graded structures

3 FACILITIES

Tests were conducted in FD04 wind channel at CAAA. Test facilities are shown in Fig.5, which included arc heater, nozzle, test chamber, model feeder, diffuser, vacuum and auxiliary system.

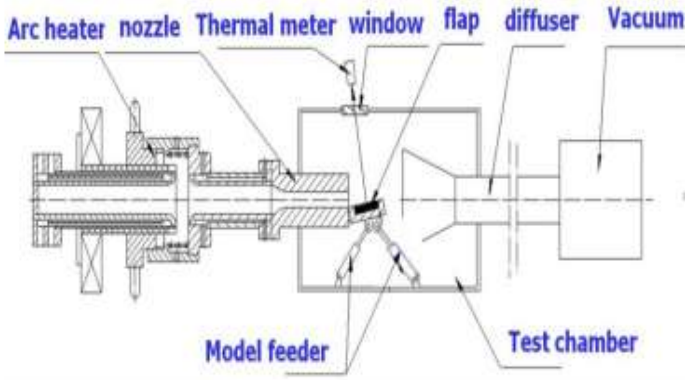


Figure 5 Test sketch of the Aerodynamic Heating Facility at CAAA

Huels arc heater is used for this test, as shown in Fig.6.The Huels-type arc heater is a relatively simple arc heater configuration consisting of two coaxial electrodes separated by a swirl chamber. Huels arc heater configuration is shown in Fig.4. The arc is vortex stabilized, meaning that the test gas is injected tangentially into the swirl chamber at the electrode interface. This generates a helical vortex as the fluid is heated by the arc discharge before being expanded through the nozzle. The arc is further stabilized by the use of two coaxial electromagnetic spin coils located at each electrode.

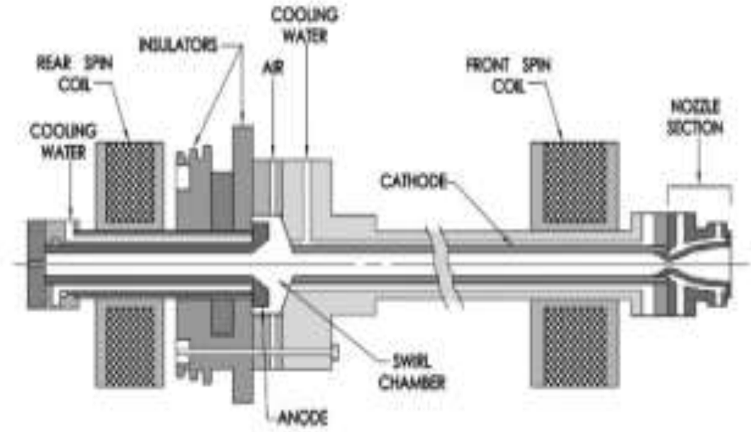


Figure.6 Huels arc heater configuration

4 EXPERIMENTS

High temperature test to evaluate the thermal performance of graded integrated structure has been performed in the wind tunnel, which surface temperature reached to 1973K high temperature for 550 seconds exposure. Wind tunnel test results are shown in Fig. 7. The results have been shown that the surface of articles still maintained original configure.

Figure.7 Arc-Jet Exposure of Test articles

Furthermore, Strength test of a cube model with 2mm×2mm×2mm have been performed, as shown in Figure 9. Strength has been improved apparently compared to original model, as you can see from Fig.9. The results that the surface of test articles maintained original configure also indicated that the strength of test article has been improved.

(a) Pro-photograph of test article *(b) Post-test photograph of test article after 600s* *(c) Temperature history of test article*

Figure 8 Wind tunnel test of articles with surface temperature reached to 1973K for 550 seconds

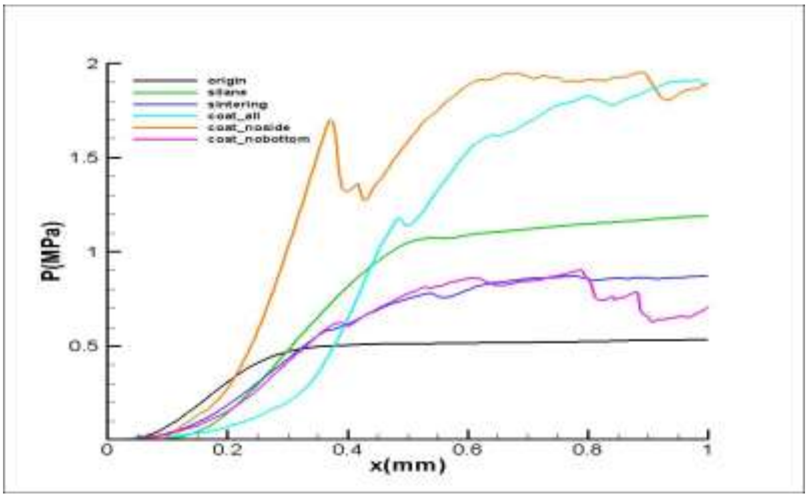


Figure 9 Strength measure of a cube model

9 CONCLUSIONS

Thermal protection system (TPS) which are correlated to the safety of hypersonic vehicles, are one of the most critical techniques in design and manufacture of hypersonic vehicles. For new-type hypersonic vehicles, due to its long-time flying in the atmosphere, thermal environment is of high enthalpy, non-high heat flux and long-time, traditional thermal protection system does not meet the new environments. Also, sharp-leading edge had been brought forth due to reduced drag. However, the sharp leading edge results in much higher heat transfer rates during planetary entry than those experienced by a blunt body configuration, such as a capsule. Therefore, light-weight, non-ablation, and long-time insulation have been required. The problems of present thermal protection system(TPS) are prone to ablation or fragmentation.

In this paper, an integrated structure with graded-outer-layer, has been brought forward in order to avoid fragmentation and improve the strength. The preparation method and technology of lightweight graded article has been investigated. Fabrication and wind tunnel test have been performed. Graded lightweight article with dense low to 0.45g/cm^3 has been prepared successfully. High temperature test to evaluate the thermal performance of graded integrated structure has been performed in the wind tunnel, which surface temperature reached to 1973K high temperature for 550 seconds exposure.

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