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The Ablation of Slip-Cast Fused Silica

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Introduction

CONSIDERABLE attention has been devoted to investigating the use of various ceramic and glassy materials in ablative thermal protection systems. Quartz and pyrex glass have been investigated extensively. In this Note, the results of an analysis of the ablation of slip-cast fused silica (SCFS) in a hydrogen–oxygen environment are compared with data obtained on ablation of SCFS specimens in the exhaust of a hydrogen-oxygen rocket motor.

Slip-cast fused silica is formed by sintering a casting formed in a plaster mold from an aqueous suspension of vitreous silica which is nearly pure silicon dioxide (SiO_2). The casting process results in the entrapment of vast numbers of minute air pockets which cause the density to be approximately 15% lower and the thermal conductivity to be considerably lower than corresponding properties of quartz. For the most part, the ablation behavior of SCFS can be expected to be similar to quartz. Like other forms of fused silica, SCFS has excellent resistance to thermal shock.

Analysis

The details of the analysis are reported in Ref. 1. It is sufficient here to remark that the analysis considers melting, vaporization, and chemical reaction of the vaporizing species with the external flow when SCFS is exposed to the exhaust of a hydrogen–oxygen rocket motor. Although only equilibrium chemistry is treated, the effects of nonequilibrium vaporization are investigated. The analysis is restricted to laminar, axially symmetric stagnation point flow.

Exerimental Investigation

The geometry, operating conditions, and other related characteristics of the rocket motor used in the experimental portion of the investigation are summarized in Table 1.

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Table 1 Summary of operating conditions of rocket motor

Fuel	Gaseous Hydrogen
Oxidizer	Gaseous Oxygen
Equivalence Ratio	2.0
Measured Chamber Pressure	275 psia
Theoretical Chamber Temperature	5925°R
Theoretical Exit Velocity	12,500 ft/sec
Theoretical Exit Temperature	3360°R
Theoretical Exit Mach Number	2.74
Area Ratio Exit/Throat	3.14
Exit Diameter	0.276 in.
Cold Wall Heat Flux at 6 in.	1500 Btu/ft²-sec
Cold Wall Heat Flux at 8 in.	700 Btu/ft²-sec
Cold Wall Heat Flux at 10 in.	290 Btu/ft²-sec

The rocket exhausted into the atmosphere. Cold wall heat flux data as determined with a steady-state calorimeter are also given in the table. In order to make the theoretical calculations and to compute the experimental heat of ablation, it was necessary to extrapolate the heat flux data. At 6 in. from the exit of the rocket motor, the conditions correspond approximately, except for chemistry, to flight of an axisymmetric body having a nose radius of the order of 1/4 in. at a velocity of 12,000 ft/sec and an altitude of 95,000 ft.

Measurements on the ablation of flat plates of SCFS placed normal to the flow were obtained at 4-, 5-, 6-, and 7-in. from the exit of the rocket motor. The plates were ½-in. thick, 2-in. wide, and 6-in. long. By considering the width of the plates relative to the jet diameter, these specimens behaved as infinite flat plates. Duration of the tests varied from 15–30 sec. The experimentally determined average ablation rate was computed by dividing the depth of ablation at the stagnation point by the duration of the run. It was not possible to distinguish between the ablation by melt flow and vaporization.

Comparison of Experimental and Theoretical Results

Figure 1 shows the theoretical and experimental average ablation rates along the centerline of the rocket exhaust. The difference in trends of the theory and experimental data is thought to be primarily due to errors in extrapolating the heat flux. It is noted that agreement is very good at the 6-in. location where the measured value of heat flux could be used in the calculation. Figure 2 shows the experimental and theoretical heat of ablation of SCFS in the rocket exhaust. The heat of ablation here is defined as the cold wall stagnation point heat flux divided by the average rate of mass ablation. It is interesting to note that the theoretical heat of ablation is virtually independent of location along the centerline of the rocket exhaust, whereas the experimental heat of ablation shows considerable dependence on location. Based on other ablation studies (Refs. 2 and 3), the experimental heat of ablation would not be expected to exhibit very much dependence on location, which lends further substantiation to the

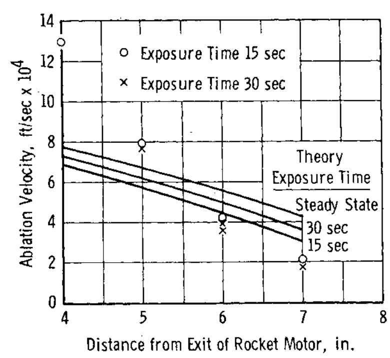

Fig. 1 Ablation Velocity vs plate position in rocket exhaust.

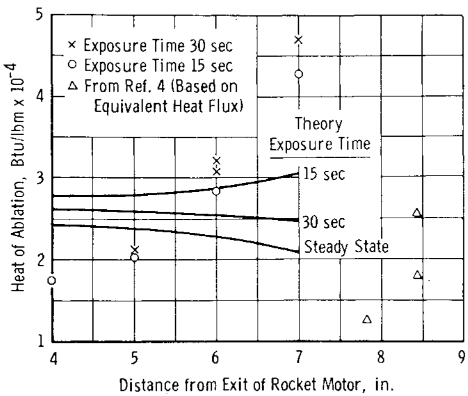

Fig. 2 Heat of ablation of slip-cast fused silica in rocket exhaust.

idea that the extrapolated values of heat flux are in error. A large error in extrapolated heat flux is possible in view of the limited experimental data available and the uncertainty in the shape of the heat flux curve. A 40% increase in the extrapolated heat flux at the 5-in. location would have little influence on the theoretical heat of ablation but would increase the experimental heat of ablation by 40% and bring it into close agreement with the theory.

Also shown in Fig. 2 are data of Pierson (Ref. 4). Only a qualitative comparison with the data of his investigation should be made because the test environments and methods of data reduction were so different. The data are plotted on the graph corresponding to the location in the rocket exhaust where the cold wall heat flux is equal to that of the actual test.

Conclusions

Both experiment and theory indicate a nominal ablation rate of 0.006-in./sec for the SCFS in the rocket motor exhaust. This yields a heat of ablation of about 24,000 Btu/lbm based on the cold wall heat flux or about 4500 Btu/lbm based on the heat flux at the ablating surface temperatures. This value is in reasonable agreement with published data on the ablation of quartz. It should be mentioned that the results of the analysis indicate that the heat of ablation in air would be somewhat lower than the heat of ablation in the rocket exhaust at the same fluid density, velocity, and pressure because of chemical effects.

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