

Experimental study of ablative materials by oxyacetylene flame flow system

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Abstract. A missile motor has precision design and complicated components, responsible to propel the missile forward to reach an expected range. The motor must be protected by the inhibitor, which limits the high temperature from the burning of propellant to the generator to ensure safety of shell. The solid rocket propellant grain burns in the parallel layer according to a certain rule. Recently, NBR (Nitrile Butadiene Rubber)、EPDM(Ethylene-Propylene-Diene Monomer), Silicon Rubber and Polyisoprene are usually applied to the inhibitor matrix in solid propellant. The inhibitor can protect the external steel shell, and remains at a temperature of 300-400K under severe conditions of high temperatures of 2300-3700 K inside, free from any damage arising from internal high temperature. The oxyacetylene ablation performance test system is simple, economic and useful to estimate the thermal process of ablative materials. Based on this method, the relative thermal insulation effectiveness during the early stage of material research is determined.

Keywords: oxyacetylene, NBR, EPDM.

1. Introduction

Inhibitors, that is to say thermal insulation materials, situated between the solid propellant and the motor case, are significant components of high performance solid propellant rocket motors in much aerospace and military utilization [1,2]. Aerojet Company has manufactured the inhibitor material by mixing asbestos fiber, silicon dioxide, and NBR in 1960s, and was applied in Pulse-motor [3]、 and solid propellant such as Titan Rocket and Minuteman Missiles.

EPDM (Ethylene-Propylene-Diene Monomer) has been widely used in rubber industry for a long time, and the modification of EPDM with silicon dioxide and Kevlar Fiber paved a way for the development of insulator materials [4], moreover, EPDM is applied in Trident-1, Small ICBM, and Pershing II Missile, because of the advantages of good bonding with HTPB (hydroxyl terminated polybutadiene binder) composite propellant.

One of the important factors that Dow Corning Company used Silicon Rubber as matrix, and filled with silicon dioxide, carbon silicon and carbon fiber to manufacture the inhibitor materials for Ram Burner [5,6] is the thermal and ablative properties of Silicon Rubber. But for the reason Silicon Rubber will expand the volume under high temperature, and extra procedures are required in case bonding [7,8], it is just applied in the solid propellant motor of diameter under 10 inches. An ethanol/oxygen combustion gas generator has been used to investigate the ablation behaviors of Carbon/Silicon composite nozzle [9]. In order to compare the rate of reaction of Carbon-Carbon materials at high temperature, a H₂-O₂ combustion chamber is used to generate the high-energy active gases [10].

This paper presented the ablation results of three different ablative materials under the finite element method and the oxyacetylene flame test procedure, discussed the changes of thermal characteristics under different temperature, and screened the ablative composites to determine the relative thermal insulation effectiveness during the early stage of material research.

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2. Experimental Process

2.1. Materials and Specimens Fabrication

There are three ablative materials in the present study, V44, EPDM/Kevlar and I-58 synthesized by Propellant Laboratories. The ablation performance test shall be carried out in light of different manufacturing conditions and EPDM/I-58 test pieces of different thickness, and V44 is used as a control group. The specimens under different manufacturing conditions were shown in Table 1 as well as the expression.

Table 1 The specimens under different manufacturing conditions

Specimen Number	Curing temperature (°C)	Curing time (Hr)	Thickness (mm)
EPDM/Kevlar	150	0.16	6.15
V44	150	6	6.00
I-58	150	72	6.07

2.2. Oxyacetylene flame flow system

The oxyacetylene flame flow system means that, according to the ASTM-E285-80 Test Standard, fix the material test piece to a jig, adjust the pressure of oxygen and acetylene, flow and mixing ratio, ignite to make the flame touch the test piece at a set position, provide a stable heat source, record the change in temperature when the test piece is ablated, and calculate relevant ablation performance parameters. This system combination includes the air fuel system, temperature recording system and nozzle mechanism as shown in Fig.1.

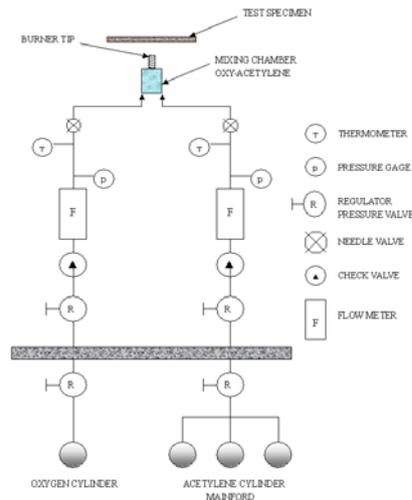


Fig. 1 ASTM-E285 testing system

3. Results and Discussion

3.1. The measurement of ablation rate

The oxyacetylene flame flow test system applies the heat flux to the surface of the materials, and provides vigorous convection effect, with the result that it causes mechanical destruction on the surface of the materials. In the present study, the thermal couple was used to measure the condition of the materials under ablation, and the reciprocal of ablation rate named as erosion resistance rate was adopted to compare with the results. The erosion resistance rate is higher; the ablation rate is lower, and the erosion resistance is better.

When the heat flux is under $250\text{W}/\text{cm}^2$, the erosion resistance rate of V-44 is distinctly larger than EDPM/Kevlar and I-58 in Fig.2. After heat flux is raising, the erosion resistance rate of three materials are getting smaller. It is because that as heat flux is raising, the thickness of char layer is insufficient for preserving the substratum material, as a result, the mechanical strength is destroyed.

3.2. The measurement of insulation index

The ablation behaviors of three specimens are shown in Table 2. As shown in this table, the EPDM composites have the best ablation behavior among the others. The results of ablation test of EPDM/Kevlar ranged between other researches for different formulations. Insulation Index is a method data of ablation experiment of ASTM, and the index is presented as follows: $I_T = \frac{t}{d}$, where I_T denotes the insulation index at $T^\circ\text{C}$, t is the time reaching to back temperature of the specimen at $T^\circ\text{C}$, and d is the thickness of the specimen.

Table 2 The results of ablation experiment (specimen dimension: $10 \times 10 \text{ cm}$)

Specimen number	Thickness (mm)	Ablation time (sec)	AR (mm/sec)
V44	6.00	39.94	0.150
EPDM/Kevlar	6.15	40.96	0.150
I-58	6.05	24.80	0.244

For the same specimen, the insulation index of three temperature- 80°C 、 180°C 、 380°C . The value of I_T is bigger, the time is longer to reach the temperature of $T^\circ\text{C}$ under the same thickness. In general, the organic compound-based material under high temperature, all the organic compound will decompose between 400°C to 500°C , so the I_T of 380°C has adequate representation to show the insulation characteristic of the material. As ARC Company made a research of non-asbestos insulation for the tomahawk booster motor, also measured the time of back temperature to calculate the value of I_T [12]. The I_T of V-44 under the ablation experiment is shown in Fig.3, the insulation index of 380°C is about 650000sec/m; the I_T of EPDM/Kevlar under the ablation experiment is shown in Fig.4, the insulation index of 380°C is about 118000sec/m; I_T of I-58 under the ablation experiment is shown in Fig.5, the insulation index of 380°C is about 90000sec/m. It is shown in Table 3 that I_T of I-58 is smaller than V-44 and EPDM.

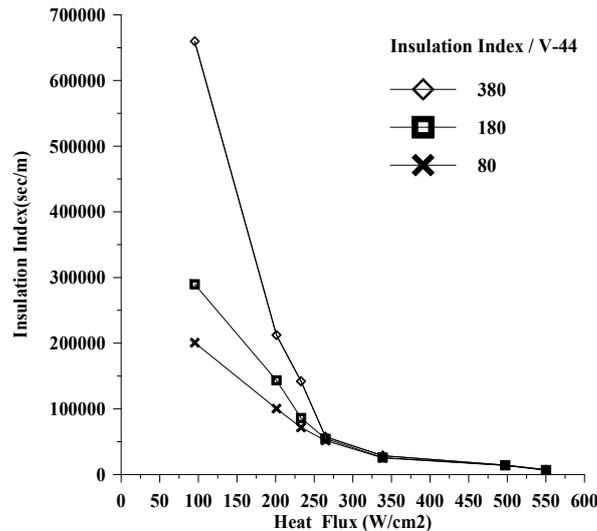


Fig.3 The insulation index of V-44

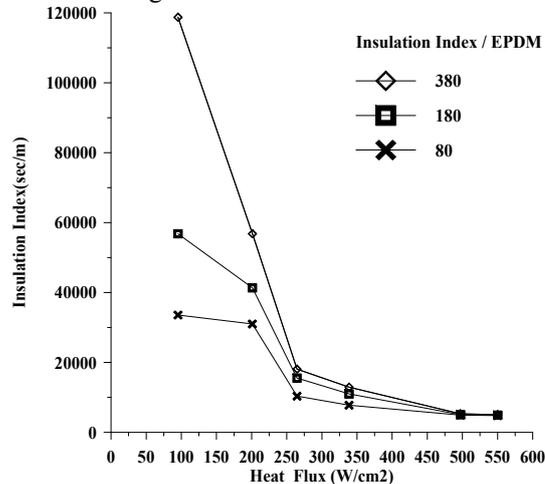


Fig.4 The insulation index of EPDM/Kevlar

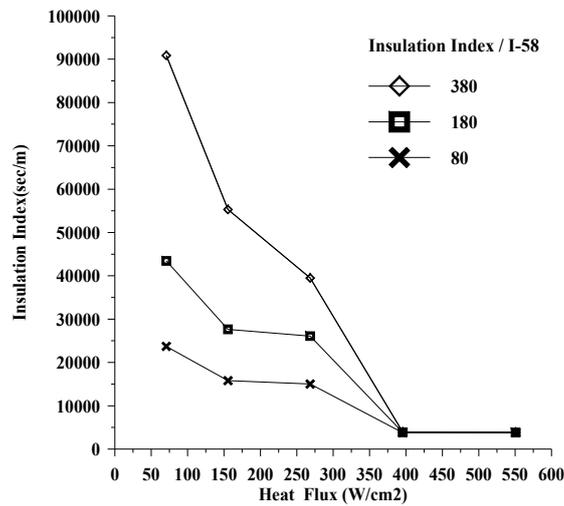


Fig.5 The insulation index of I-58

Table 3 The time of arrival back temperature

The time of arrival back temperature	Materials		
	V-44	EPDM/Kevlar	I-58
80°C	13.65	8.75	9.64
180°C	20.42	14.85	14.46
380°C	43.61	31.06	23.42

*Heat flux=550W/cm²

4. Conclusions

By oxyacetylene flame flow system, it was found that white powder layer appeared gradually on the heated surface layer of V-44 in the ablation experiments, and more to the inside, dark and hard carbon layer was found. After cooling, there was deformation phenomena in the middle of the specimen.

In this study, the ablation experiment was found that when the heat flux was under 280W/cm², the erosion rate of V-44 was better than EPDM/Kevlar and I-58, however, the erosion rates of three materials were less obvious when the heat flux was over 350W/cm². This was because that V-44 is composed of butadiene-acrylonitrile rubber, silicon dioxide and asbestos fibers, V-44 would not only result in pyrolysis, but also created molecular structures as ladder with butadiene-acrylonitrile and acrylonitrile molecular under high temperature, because of this, the final formed char layer including the structure of high temperature resistance has strong mechanical strength. Asbestos fibers are originally ablative materials, they are able to make char layer attached to the fiber surface, and catch hold of unheated parts like an anchor by reinforcement effect. The combined char layers of asbestos and silicon dioxide were difficult to remove so that heat transfer effects were blocked, according the above reasons, V-44 was made anti-ablation material; however, asbestos has been discarded for its environment pollution and potential cancer threat to human health [2], as a result, V-44 was rejected from the application of thermal insulation.

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