Investigation of Polyester Coating for Ablative Thermal Protection

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Introduction

Effective *thermal protection* is usually a requirement in the design of rocket motors. In particular, protection of the *casing walls* from the high heat of combustion. Protection may take the form of a coating or a liner. It is usually necessary to minimize the operating temperature of the casing material, as significant loss of mechanical strength occurs at elevated temperature. This is particularly true for heat-treated aluminum alloys.

Another important form of thermal protection is in the role of *inhibitor* for a propellant grain. An inhibitor is a coating or liner that restricts burning surfaces of the grain to the non-inhibited surfaces. For example, a hollow cylindrical grain may have the outer diametrical surface inhibited.

In this investigation, polyester is considered as an *ablative* thermal protective coating. An ablative material undergoes an endothermic degradation (physical and chemical changes that absorb heat). Specifically, thermal protection is provided by initial low thermal conductivity, evaporation of the polymer (absorbing heat of vaporization), and endothermic decomposition into char and pyrolysis gases. These gases form a protective boundary layer over the charred material.

The polyester used in this series of experiments is consumer grade polyester resin of the type used for auto or boat repair (typically in conjunction with fibreglass reinforcement). Polyester has the advantages of being inexpensive, readily available, low mass density (measured as 1.26 g/cm^3), durable and easy to apply.

Apparatus

Aluminum (utility grade) sheet, 0.063 inch (1.6 mm) thickness, of dimensions shown below.

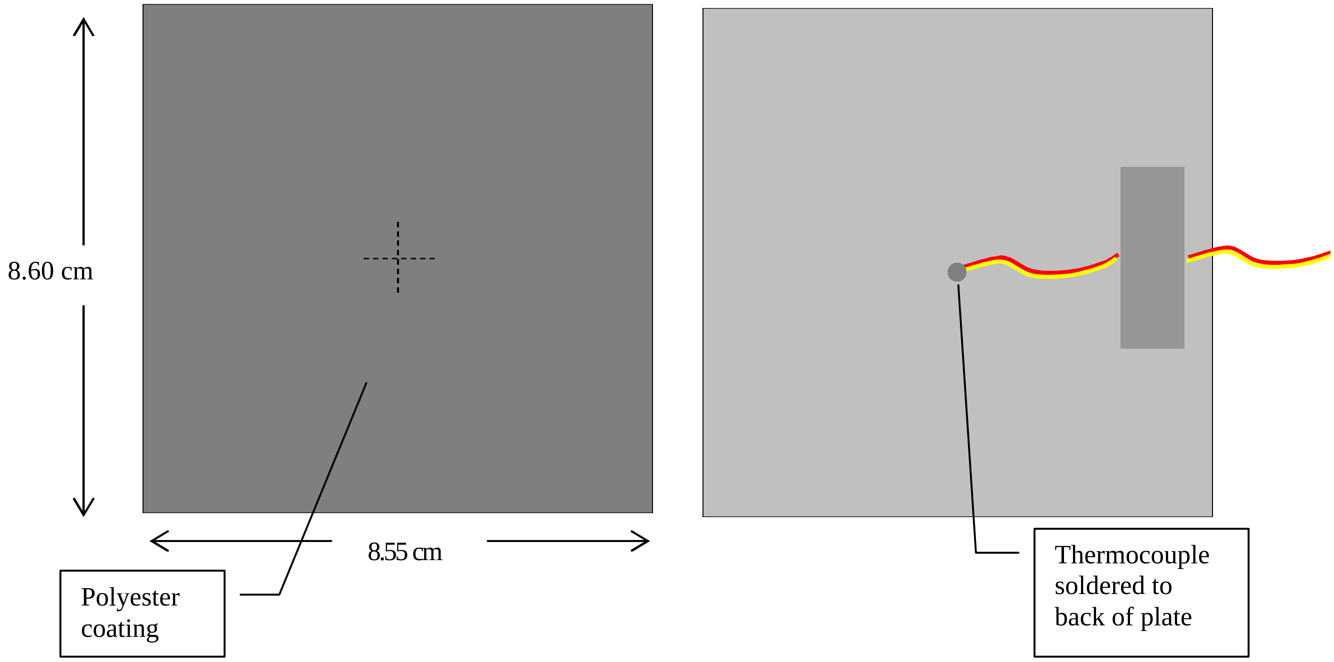

Figure 1

Four plate specimens were prepared, as follows

Plate # 1	Bare (uncoated) aluminum.
Plate #2	1 layer coating of polyester, measured thickness was 0.014 ±0.003 in. (0.36±0.1 mm).
Plate #3	2 layer coating of polyester, measured thickness was 0.023 ±0.003 in. (0.58±0.1 mm).
Plate #4	3 layer coating of polyester, measured thickness was 0.037 ±0.003 in. (0.94±0.1 mm).

The thermocouple was type K (chromel-alumel) AWG 28 duplex diameter wire, covered with glassfibre sheathing. The "sensor" is formed by twisting the wires, then soldering the sensor to the backside of the aluminum plate. For plates #1 and #2, 40/60 Sn/Pb solder was used (m.p. 238 C.), however, for the remaining plates, 30/70 solder was used (m.p. 255 C.). A piece of aluminum tape secured the wire to the plate, for strain relief.

Heating was performed with a standard propane torch, of the type used for general purpose heating (e.g. soldering, paint removal). The torch tip was held 4 in. (10 cm.) away, such that the hottest part of the flame impacted the middle of the plate. (flame temperature for propane with 100% theoretical air is about 1900 C.)

The polyester resin used was "Motomaster" brand, with MEK catalyst, added at a ratio of 1:100 by volume. Cure time prior to conducting the heating experiment was 14 hours. Cure time between coatings for multiple layered specimens was typically 3 hours.

Data acquisition involved measuring and recording the thermocouple output voltage during the heating process. This was done by using a DVM interfaced to a personal computer (286AT), with software that sampled and recorded data points at a rate of 3.33 hertz. The thermocouple voltage was converted to degrees Celsius by the equation T (C.) = mV∗24.51, which is a linear fit of standard "k" thermocouple data in the temperature range of interest (see Figure 2).

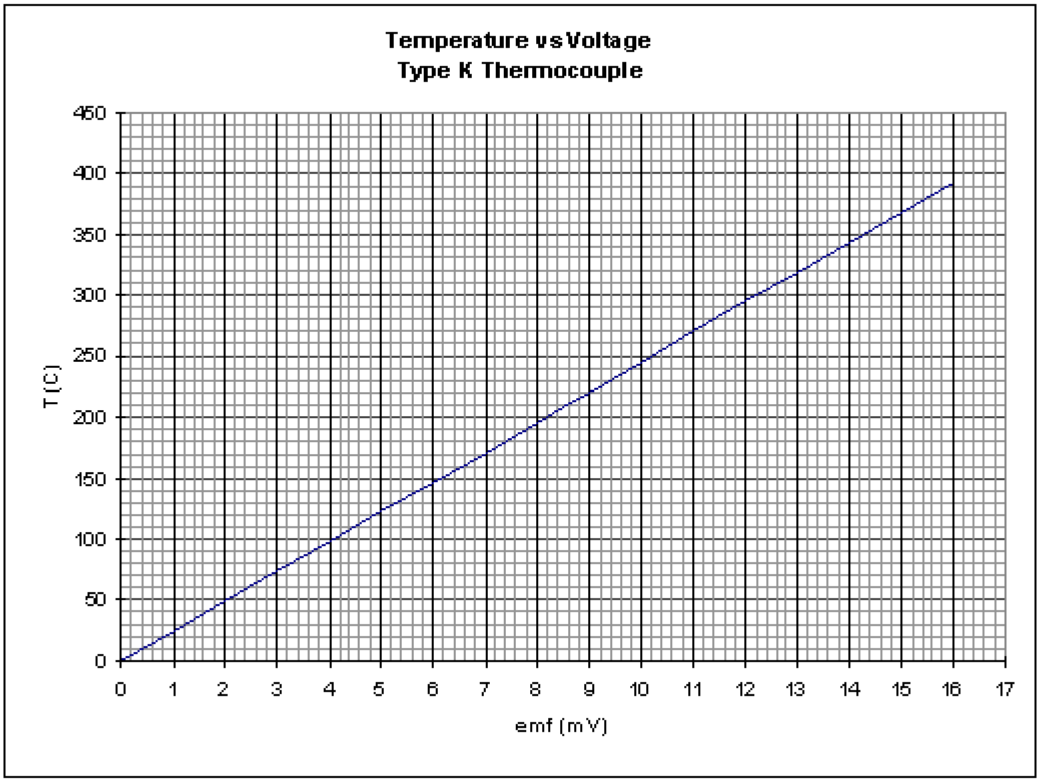

Figure 2

Method

The specimen plate was mounted vertically on a stand, with the propane torch mounted such that the torch tip was located 4 inches (10 cm.) from the plate front surface. The orientation was such that the flame impacted normal to the plate, at the plate centre. Prior to commencement of heating, the torch was fired up, with a steel plate held in front of the specimen to block the flame. At t=0, the steel plate was withdrawn, and data acquisition initiated. Heating continued until the solder that mounted the thermocouple melted, and the thermocouple fell away. This procedure was performed for all four specimen plates. All testing was conducted outdoors, with an ambient temperature ranging between 0C and +3C.

Results

The experimental data is presented in Figure 3,. in the form of the raw collected data for all four specimens.

Discussion

In Figure 4, the results are processed to indicate the temperature of the plates as a function of time, up to a temperature of 150C. This is the temperature range of particular interest with regard to thermal protection of heat-treated metals. For example, at 150C, aluminum alloy 6061-T6. experiences a reduction in strength such that the yield strength and ultimate strength are at 85% and 80% of the room temperature values, respectively. From this plot, it is seen that the effect of the polyester coating is to significantly decrease the rate of heating of the plates. As one would expect, the greater the thickness of the coating, the more pronounced the effect. The bare plate reached 150C. after 6.0 seconds. The coated plates reached this value after 10.8, 12.9, and 17.7 seconds for the single layer, double layer, and triple layer coatings, respectively.
Figure 5 shows the effectiveness of coating thickness as a thermal insulator, as a plot of rate of change of temperature (dT/dt) versus coating thickness. The values of dT/dt for the each of three results was determined by linear regression of the data. The effectiveness is seen to be approximately linearly proportional to coating thickness.

Although these experimental results cannot be readily correlated to indicate the effectiveness of a polyester coating under the actual conditions experienced in a rocket motor, it can be seen that this test provides certain conditions that are more severe. Since the heating is conducted in the open air, atmospheric oxygen sustains combustion of the polymer, adding heat in the process, and causing more rapid degradation of the coating than would occur in a rocket motor, where essentially no free oxygen normally is present. As well, the propane flame temperature (≈ 1900 C.) is greater than the combustion temperature for many propellants. For example, combustion temperature of the KN-"sugar" propellants is about 1400 C. Another condition that is more severe is that in a rocket motor, gas flow is parallel to the coating surface. In this experiment, the gas flow was normal to the plate. surface, thereby reducing the effectiveness of any "boundary layer" pyrolysis gases that would be generated during heating.

In a rocket motor, however, the combustion gases are at high pressure. This greatly increases the convective heat transfer from the gases moving over the surface, to the coating. To what extent this would change the effectiveness of the ablative coating is hard to say. It is known from experience, however, that even for short burn times of less than a second, the casing walls reach significant temperatures. For example, the temperature of the outside surface of the steel casing of the B-200 motor (which is fully exposed to the combustion gases during the burn) reaches upward of 350 C. in spots. This motor has a burn time of about 1/2 second.

It is emphasized that the goal of this experiment is not to duplicate the heating conditions that are present in a rocket motor, but rather to study the qualitative effect of a polyester coating with regard to thermal protection under the condition of severe heating.

As a side note, one may observe that a temperature plateau occurs at a temperature of about 160 C., where the temperature rise of the plate briefly subsides. This is the result of a phase change in the lead/tin solder which attached the thermocouples to the plate.

Conclusion

A polyester resin coating was effective in reducing the heating rate of specimen plates compared to a similar uncoated plate. The reduction in heating rate was found to be approximately proportional to the coating thickness. In this regard, polyester does provide some degree of ablative thermal protection under the conditions of this experiment. This material may therefore be useful for thermal protection in rocket motors, although further investigation should be conducted under heating conditions more closely resembling the actual operating environment, where convective heat transfer is much greater due to the elevated pressure in the combustion chamber.

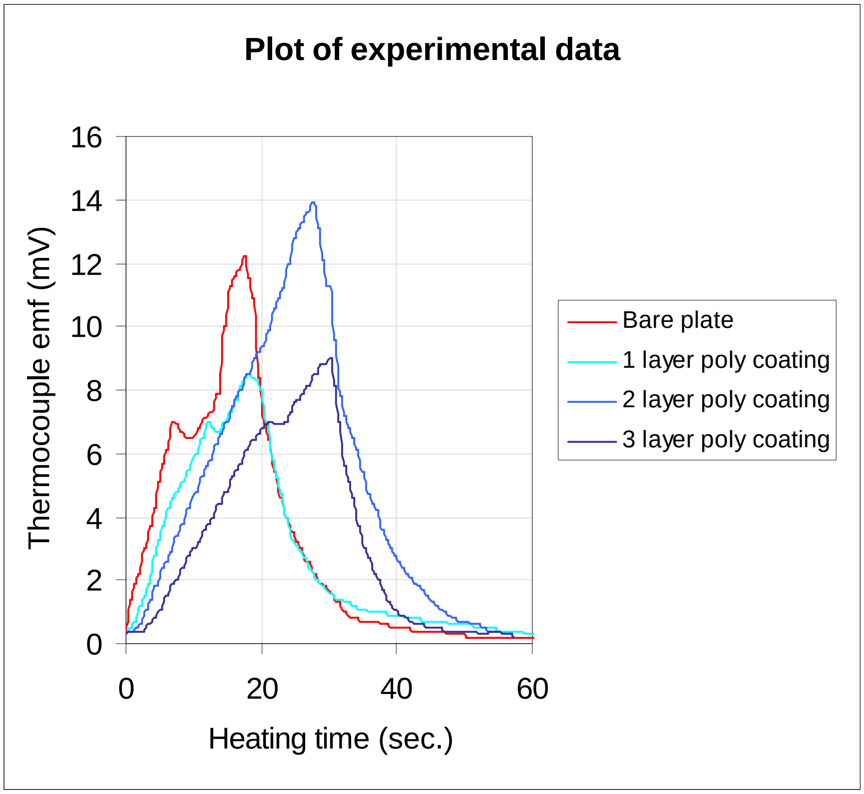

Figure 3

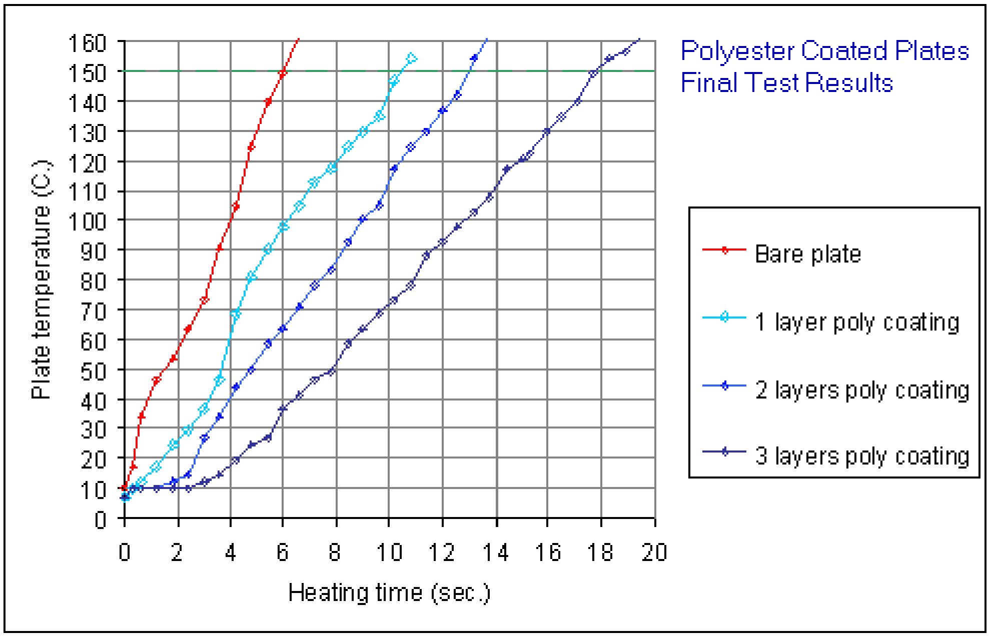

Figure 4

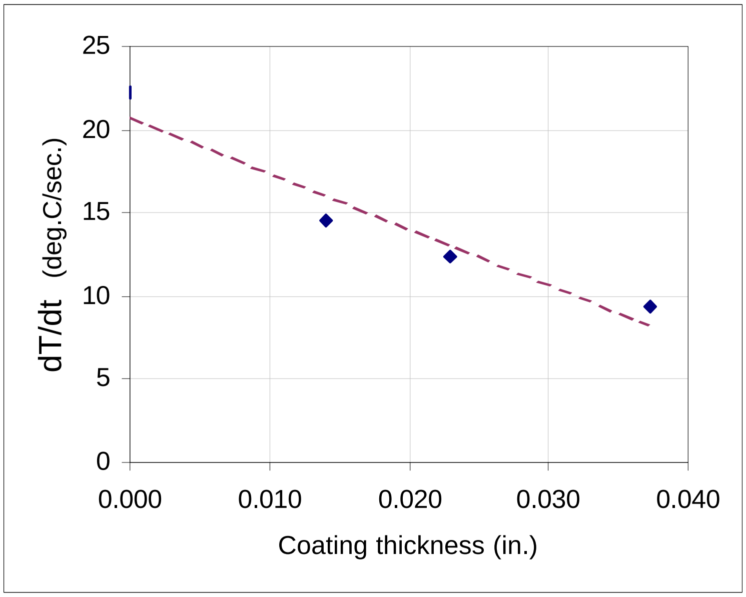
25
20
15
10
5
0
0.000
0.010
0.020
0.030
0.040
dT/dt (deg.C/sec.)
Coating thickness (in.)

Figure 5.