Regression Rate Measurement of Hybrid Rocket Using Ultrasonic's

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ABSTRACT

A lab-scale hybrid motor burning test was conducted to investigate the solid-fuel regression rate. Real time ultrasonic sensors were used to determine the instantaneous and local burning rate. Polyethylene Glycol (PEG) was chosen as a hybrid rocket fuel. PEG is interest since PEG copolymerizes and mixes well with Glycidyl Azide Polymer (GAP) which is one of the top-rated candidates for next generation hybrid motor, and PEG works as a diluent material to depression the unusual high burning rate of GAP.

1. Introduction

Hybrid rocket systems have been studied for many years for the purpose of detailed knowledge of regression rate [1]. The complex relationship among pressure, overall size, mass fluxes, and geometric configuration is required for the design of hybrid rocket. By early year, regression rate is measured mainly based on the fuel mass or geometry before and after motor burning, and the data were correlating with some parameters, such as mass flow rate or pressure to get an empirical equation. The advantage is it fits well to a particular motor configuration or a particular burning condition. However, such correlation regression rate equation is difficult to scale up to other motor sizes. Additionally, it requires large number of tests under varying conditions. And also the transient phenomenon cannot be characterized. Hence instantaneous surface regression rate of solid fuel (rb) is needed for further research. The method of using ultrasonic wave with the help of sensors is rather cheap, more accurate and easy to design the combustion chamber used for experiment. Herein a mixture containing 100% PEG is prepared for the test of regression rate.

2. Method

Propulsion test was conducted using 775 mm long, and inside diameter 90mm motor. The motor was made using stainless steel, and has two special designed ports for ultrasonic sensors and the other two ports for thermocouples as shown in Fig. 1. The grains were loaded into the chamber having a single inner port for delivering oxidizer. The port size is 30 mm in diameter. Oxygen flow rate was controlled using orifice.

Ultrasonic sensors were manufactured by Honda Electronics Co., LTD. Each sensor was composed of two sets, pulsar and receiver which are shown in Fig. 2. The sonic wave frequency was set at 1MHz to have a good penetration in rubber material, and the surfaces of sensors were attached to the holder with the help of grease to have a better contact. From previous study, 10V of excitement voltage for the sensor was not sensitive enough to deduce the regression rate, so voltage was enhanced to 100V. The operation principle is by measuring the time of flight of plus, and the instantaneous fuel thickness can be calculated by simple algebra. As shown in Fig. 3, the signals were obtained from within the stainless steel holder, along the peripheral part of the combustor, and directly from the grain surface. The fuel thickness is equal to the time of flight of ultrasound (d2) multiply the sound speed.

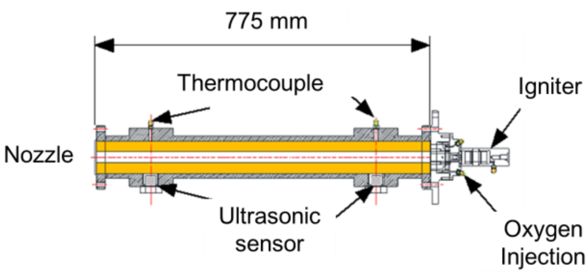


Fig. 1 Schematic diagram of hybrid motor with ultrasonic sensors and thermocouples.

Fig. 2 Ultrasonic sensor with two cables, one is for pulsar and the other one is for receiver.

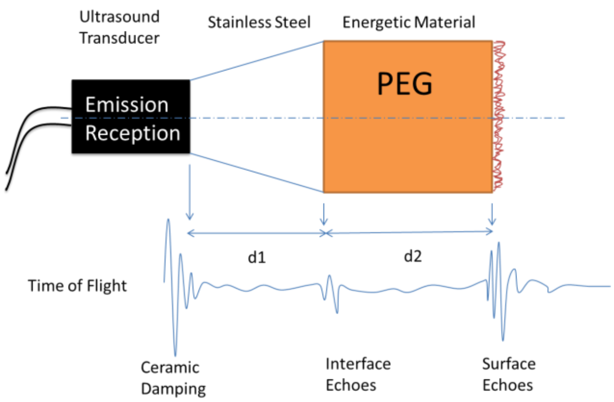


Fig.3 Principle of ultrasonic measurement

4. Ultrasonic Calibration

The calibration method for sonic speed is mainly based on Martin J. Chiaverini's publication at 1999 [2]. The sonic wave velocities are the function of pressure and temperature. The all calibration procedures were conducted under same room temperature as the burning test.

<u>pressure effect</u>

The corrected propagation time ($\tau_{p,\ corrected}$) is equal to measured propagation time (τ_p) plus artificial strain (ε_a) multiply the reference propagation time ($\tau_{p,\ ref}$) which is measured under atmosphere as the equation below.

$$\tau_{p,\ corrected} = \tau_p + \varepsilon_a \times \tau_{p,\ ref}$$

By definition, artificial strain is equal to the difference of propagation time under difference pressure divided by reference propagation time.

$$\varepsilon_a \equiv \frac{\Delta\tau_P}{\tau_{p,ref}}$$

The solid fuel was prepared in a hollow metal tube to make sure the compression was one direction as shown in the Fig. 4.

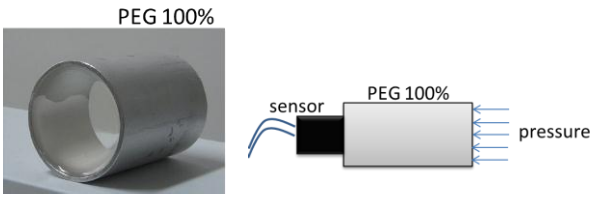


Fig. 4 PEG 100% sample for sonic calibration

Figure 5 shows the change in artificial strain under different pressure.

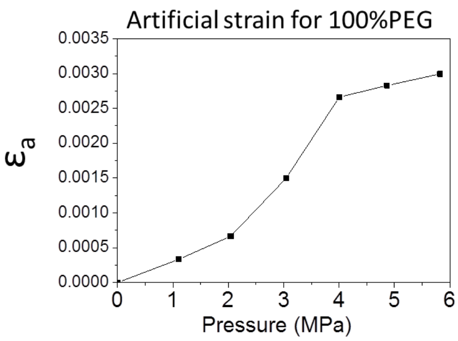


Fig. 5 Change in artificial strain under different pressure for 100% PEG

<u>dp/dt effect</u>

A Sudden pressurized causes an impact compression which makes a fake regression spike as show in Fig. 6. Although in Martin' publication provides some method to calibrate this phenomenon, the results were unsatisfying. A more easy way to eliminate the peak is to pre-pressurize before ignition.

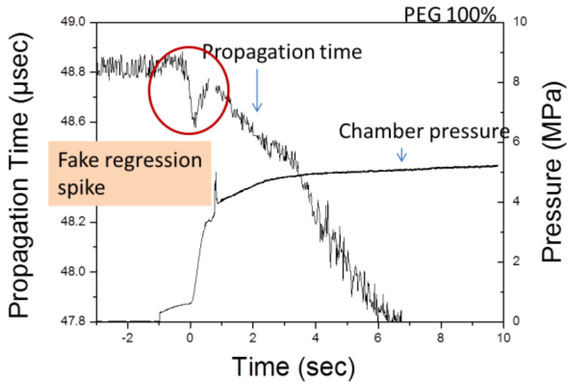


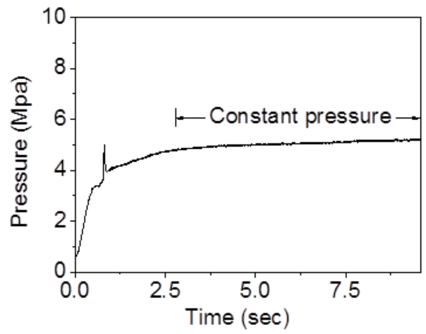
Fig. 6 A fake regression spike caused by sudden pressurizing

3. Results and Discussion

<u>Regression rate</u>

Fuel was 100% PEG. The burning test was conducted for 30 seconds and oxygen flow rate was constant and controlled by orifice. Figure 7 (a) shows the pressure at each second. The chamber pressure can be taken as constant after 2.5 sec of burning. We lost single after 10 sec, which may be caused by the strong vibration during motor burning makes the ultrasonic sensor disconnect from holder surface. The instantaneous regression rate was calculated during constant pressure period as shown in Fig. 7(b).

7(a)



7(b)

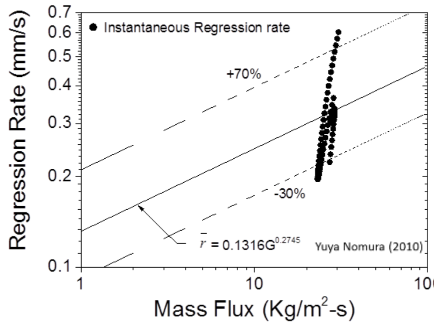


Fig. 7 (a) Pressure pattern (b) The instantaneously regression rate vs. mass flux

In Fig. 7, the sold line shows the average regression rate vs. the initial oxygen flux which was measured in previous study by Yuya Nomura at 2010. However, the recent study (solid circle) shows much different results. The regression rate highly depends on total mass flux. Many investigations have simply correlated the results with mass flux, such as the form $r = aG^b$ ($0.6 < b < 0.8$) and b may vary under different experiment condition. Comparing to the instantaneous regression rate, it shows at least ten times higher.

Thermocouple

Figure 8 shows the results of R-type thermocouple. Before the burning surface, the solid fuel temperature increased gradually by conduction. After burning surface, the temperature kept almost constant because of gas phase convection. When it reached to flame zone, the thermocouple broke. The distance between burning surface and broken point can be taken as the high of flam zone.

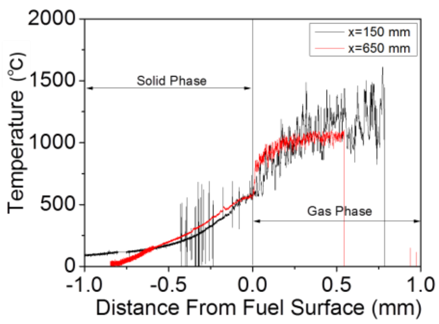


Fig. 8 Temperature trace for solid fuel

The results contradict to the boundary theory which indicates that the downstream should have higher flame zone. The reason may be caused by the deformation of thermocouple. In the future study, we will give the thermocouple a strain to make sure it won't flap with oxygen flow.

4. Concluding remarks

Ultrasonic technique successfully measured the instantaneous regression rate. The results suggest that the fuel regression rate depend on mass flow rate and it shows much different comparing to the average regression rate. The application of ultrasonic method is a strong help to establish the comprehensive combustion model of hybrid rocket motor.

References

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