A study on the evaluation of linear burning rate of a gas generating agent in a closed vessel

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52ml deflagration test apparatus is a closed vessel to evaluate characteristics of gas generating agents with small amount of the sample. An evaluation method of the linear burning rate of gas generating agents by fitting a simulated time-pressure curve to results of 52ml deflagration test apparatus was established. The effect of heat loss was taken into consideration in this simulation. The time-pressure curves of experimental results with single base propellant were in agreement with simulated curves obtained by input of almost the same value as references into the coefficient *a* and the exponent *n*. The linear burning rate of a gas generating agent can be evaluated with small amount of the sample by using this method.

1. Introduction

Automobile is indispensable for transportation in modern society. But on the other hand, a lot of people are killed in traffic accidents. In order to protect drivers and passengers from traffic accidents, almost all of new cars are equipped with airbag systems. When a traffic accident happens, a sensor senses the shock and send the signal to the inflator to burn the gas generating agent in the inflator module. This generated gas inflates the airbag.

A gas generating agent is required various characteristics such as high linear burning rate, high gas generating efficiency, nontoxic generated gas, etc. In order to fulfill these characteristics, organic compounds that contain much nitrogen like 5-amino-1H-tetrazole are used as fuel and metal nitrates are used as oxidizer. However, new gas generating agents are being studied for further reduction in cost and control of toxic gas generation under the competitive circumstance.

Generally Vieille's law, $r=aP^n$, is applied to the linear burning rate of propellants. r denotes the linear burning rate [$mm\cdot s^{-1}$], P denotes pressure [MPa], and the value of the coefficient a and the exponent n are important for the design of a new inflator. The values of a and n are usually obtained from the result of the strand burner test. They can also be evaluated from a time-pressure curve obtained from the result of the closed chamber test with the assumption that the volume of burned sample is proportional to the pressure. A small closed vessel was used in this study to evaluate the characteristics of new gas generating agents. A time-pressure curve can be obtained from this apparatus with small amount of sample. But in a smaller closed vessel, the specific surface area of the vessel is too large to neglect the effect of heat loss, and this affects the pressure profile. In this study, establishment of the method, which evaluate the values of a and n by simulating the time-pressure curve obtained from the apparatus, was tried.

2. Calculation and experiment

2.1 Measurement

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The 52ml deflagration test apparatus was used in this study (figure 1). The vessel consists of a combustion room and an upper part, where the generated gas diffuses. And it has a strain gauge, electrodes, a nichrome wire heater, a gas outlet, thermocouples, a multi hole plate and heat insulators to measure burning characteristics of a sample. Ignition charge is ignited by the nichrome wire heater and ignite gas generating agents.

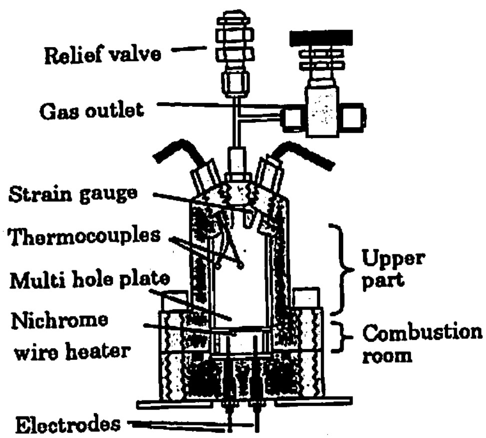

Fig.1 52ml deflagration test apparatus.

2.2 Sample

Because the linear burning rate has been studied in many references [1], single base propellant was used as standard sample in this study. The form of the sample is cylindrical and its length, diameter and weight are 17.4[mm], 7.77[mm] and 1.15[g]. It has 7 perforations and burns from both inside and outside, and the inside diameter is 0.73[mm].

The ignition charge was composition of Ti/KNO_3 (45/55[wt.%]), and it was used 100[mg] in the form of powder.

2.3 Calculation procedure

The flow chart used in the simulation is shown in figure 2. First, the values of a and n are assumed. The amount of combustion within a unit time (1ms) at time i is calculated by applying the equation $r_i = aP_i^n$, where assumed values of a and n are input. The calorific value ΔQ_{ei} from the amount of the sample is calculated, and the quantity of heat loss ΔQ_{li} is taken into consideration by the following equation,

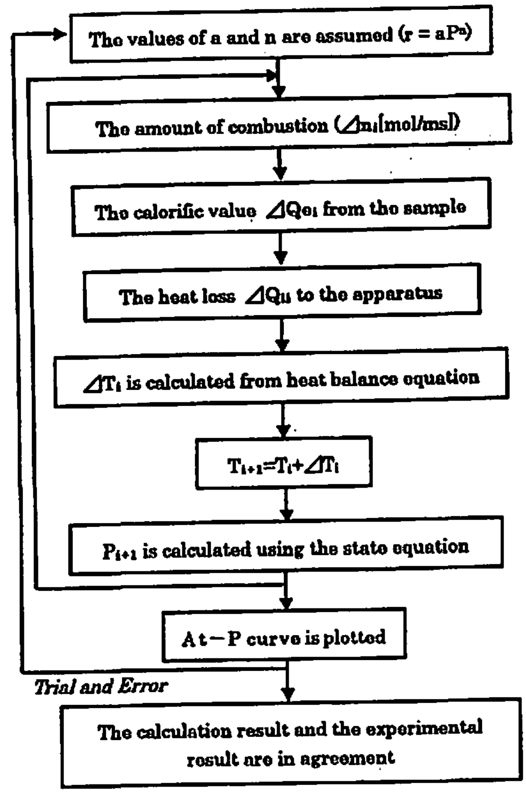

Fig.2 Flow chart of the simulation.

$$\Delta Q_{li} = hA(Tg_i - Tw_i)\Delta t$$

where h, A, Tg_i, Tw_i and Δt denote heat transfer coefficient, surface area, gas temperature, wall temperature and time respectively. Temperature change of the generated gas ΔT_i is determined by the heat balance equation,

$$\Delta Qe_i = n_i Cp_i \Delta T_i + \Delta Q_{li}$$

where Cp_i denotes the specific heat of the generated gas. P_{i+1} is calculated by the state equation. A time-pressure curve is drawn by repeating the series of calculation, and then fit the simulated curve to the experimental result by trial and error. Thus, the values of a and n of the sample is determined.

The heat transfer coefficient depends on the heat conductivity of each part (ceramics or stainless steel) of the apparatus. It is also considered to depend on the state of the flow in the apparatus. The following equation is empirically adapted to the turbulence in a cylinder (constant wall temperature),

$$Nu=0.023Re^{0.8}Pr^{0.3}$$

where Nu, Re, Pr denote Nusselt number, Reynolds number and Prandtl number respectively. In this study, the heat transfer coefficient was assumed to be proportional to the 0.8th power of the pressure. Composition of the generated gas was calculated by a chemical equilibrium calculation program.

3.Result and discussion

3.1 Effect of heat loss

To examine the effect of heat loss to a time-pressure curves, the 52ml deflagration tests were performed with two different types of pellets. The samples used in these tests were 1.5 [g] of HAT/ $KClO_4$ (15 pieces of 100 [mg] pellet and 6pieces of 250 [mg] pellet) [2]. The form of the pellet was cylinder and the diameter was 7.15 [mm]. The thickness of 100 [mg] pellet and 250 [mg] pellet were 1.99 [mm] and 3.44 [mm] respectively. The results are shown in figure 3. The maximum pressure of 15 pieces of 100 [mg] pellet was about 2 [MPa] higher than that of 6 pieces of 250 [mg] pellet. Because the 100 [mg] pellet was thinner than 250 [mg] pellet, it burned out faster and the total quantity of heat loss during the combustion was less. So heat loss was considered to affect a time-pressure curve, especially maximum pressure.

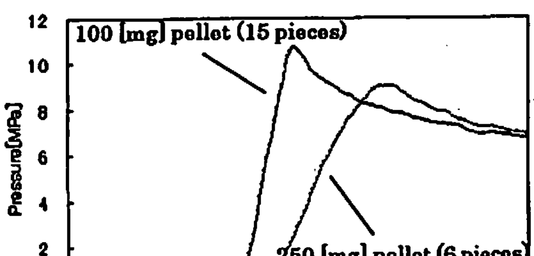

Fig.3 The effect of heat loss to the pressure curve

3.2 Ignition charge

The combustion of the ignition charge in the 52ml deflagration test apparatus was simulated on the assumption that the high temperature products produced from the combustion of ignition charge gradually radiated its heat. The comparison of the simulated time-pressure curve and the result of the experiment are shown in figure 4. The two pressure curves were in good agreement, especially in the part of pressure increasing. So this result was adapted to the simulation of samples.

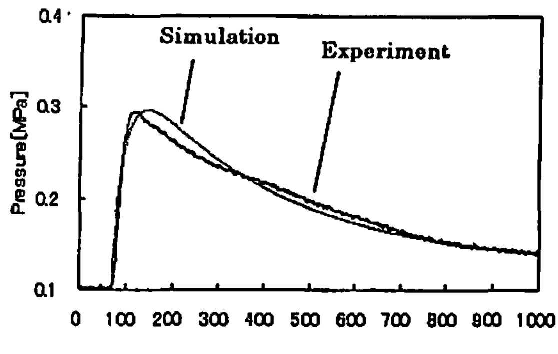

Fig.4 Comparison of the experimental data of ignition charge and the simulation result

3.3 Single base propellant

A time-pressure profile of a piece of single base propellant in the 52ml deflagration test apparatus was obtained and a simulated time-pressure curve was fitted with the experimental result by varying the values of a and n by trial and error. The generated gas composition, calculated by a chemical equilibrium calculation program, used in the simulation is shown in table 2. When input 1.43 into a and 0.77 into n, the experimental result and simulated curve were in agreement (figure 5). These values are almost the same with references. To examine the reproducibility, the 52ml deflagration test was performed three times (figure 6). The same heat transfer coefficients were applied for each simulation. The values of a and n determined by fitting the simulated curve to the

Table 1 Heat transfer coefficient of each part of the apparatus during the combustion of ignition charge

		$h[J \cdot m^{-2}s^{-1} \cdot K^{-1}]$
Combustion room	Multi hole plate	6.5×10^2
	Stainless ring	6.5×10^2
	Ceremic ring	1.3×10^2
	Casted ceramic	1.3×10^2
Upper part	Multi hole plate	1.0×10^2
	Ceramic tube	2.0×10^2
	Stainless pipe	2.0×10^2

Table 2 The result of chemical equilibrium calculation for the composition of the generating gases from single base propellant

	CO	CO_2	H_2	H_2O(g)	N_2	O_2
Conc.[%]	40. 4	14. 3	10. 8	22. 3	11. 7	0. 0
Vol[mmol]	18. 3	6. 5	4. 5	10. 1	5. 3	0. 0

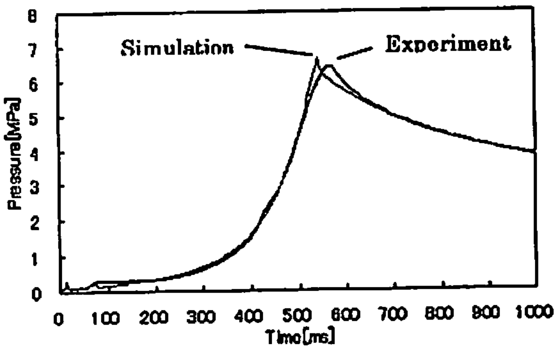

Fig.5 Comparison of the experimental result of single base propellant and the simulation result (1 piece)

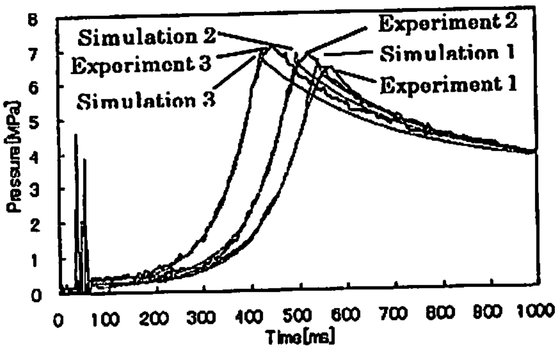

Fig.6 Reproducibility of the pressure curve of single base propellant.

Table 4 The value of a and n of the simulation

	a	n
simulation1	1. 43	0. 77
simulation2	1. 55	0. 76
simulation3	1. 80	0. 70

Table 3 Heat transfer coefficient of each part of the apparatus during the combustion of single base propellant (1 piece)

		$h[J \cdot m^{-2}s^{-1} \cdot K^{-1}]$
Combustion room	Multi hole plate	8.0×10^3
	Stainless ring	8.0×10^3
	Ceremic ring	1.6×10^3
	Casted ceramic	1.6×10^3
Upper part	Multi hole plate	1.5×10^3
	Ceramic tube	3.0×10^3
	Stainless pipe	3.0×10^3

experimental result are shown in table 4. These values, especially values of n that are important for the design of an inflator are also agreement with references.

The 52ml deflagration test with two pieces of single base propellant was also performed. The generated gas flow in the apparatus with two pieces of single base propellant is thought to be more intense than the flow with one piece. Because the intensity of the gas flow affect the heat loss, the heat transfers coefficients get larger (table 5). The comparison of the experimental result and the simulated time-pressure curve is shown in figure 7. The values of a and n determined by fitting the simulated curve to the experimental result were 1.50 and 0.80. These values are also in good agreement with references.

Table 5 Heat transfer coefficient of each part of the apparatus during the combustion of single base propellant (2 pieces)

		$h[J \cdot m^{-2}s^{-1} \cdot K^{-1}]$
Combustion room	Multi hole plate	1.1×10^4
	Stainless ring	1.1×10^4
	Ceremic ring	2.2×10^3
	Casted ceramic	2.2×10^3
Upper part	Multi hole plate	2.0×10^3
	Ceramic tube	4.0×10^2
	Stainless pipe	4.0×10^2

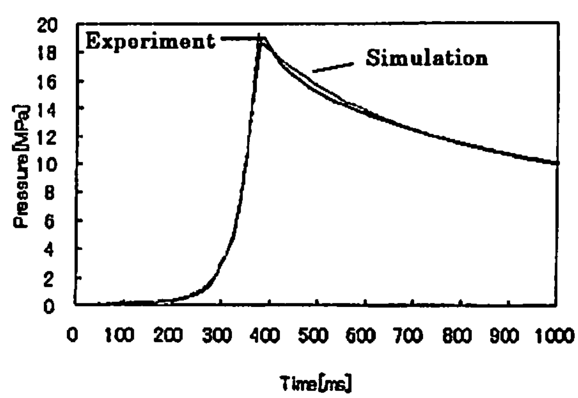

Fig.7 Comparison of the experimental data of single base propellant and the simulation result (2 pieces)

4. Conclusions

An evaluation method of the linear burning rate of gas generating agents in the closed vessel by fitting a simulated time-pressure curve was established. The effect of heat loss was taken into consideration in this simulation. The time-pressure curves of experimental results with single base propellant and simulated curves obtained by input of almost the same value as references into the coefficient *a* and the exponent *n* were in agreement. The linear burning rate of a gas generating agent can be evaluated with small amount of the sample by using this method.

References

1) H. Higuchi, H. Tachiya, N. Suzuki and T. Hukuda Journal of the industrial explosives society, Japan, 45, 365 (1984)
2) K. Hasue, T. Akanuma, H. Hodai, and S. Date Journal of Japan Explosives Society, 60, 31 (1999)