Estimation of upper limit of AP content in AP/HTPB composite propellant
— A consideration based on flow characteristics of AP/HTPB suspension —

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Because of the requirements for the preparation of ammonium perchlorate (AP) / hydroxyl - terminated polybutadiene (HTPB) composite propellant, there is an upper limit content, ϕ_{max}(wt%), of AP contained propellant. It is necessary for the design of AP/HTPB composite propellant to estimate ϕ_{max}. In this study, an attempt was made to find out the universal powder property of AP which can determine ϕ_{max}, from the standpoint of the viscosity of AP/HTPB suspension. The results are as follows: 1) Concerning AP/HTPB suspensions prepared in this study, the relationship between the relative viscosity, η_r(-), and the volume fraction, ϕ_v(vol%), can be represented by the Mori-Ototake equation. k and ϕ_{vc} which are constant in the Mori-Ototake equation are dependent on specific surface area, S_{wp}(m²/kg), measured by the air-permeability method. It is found that η_r can be represented as the function of ϕ_v and S_{wp}. 2) η_r of AP/HTPB suspension containing ϕ_{max} was almost constant. 3) ϕ_{max} increases with decreasing S_{wp}. The relationship between ϕ_{max} and S_{wp} can be represented by the following equation.

$$\phi_{max} = 85 - 0.01S_{wp} \qquad (40\mathrm{m^2/kg} \leqq S_{wp} \leqq 1200\mathrm{m^2/kg})$$

It is found that ϕ_{max} can be estimated from S_{wp}.

1. Introduction

Ammonium perchlorate (AP) / hydroxyl - terminated polybutadiene (HTPB) composite propellant was adopted in this study because AP/HTPB composite propellant is the most widely used one at present time. In the preparation of AP/HTPB composite propellant, AP is mixed with HTPB sufficiently. The AP/HTPB suspension is added with a curing agent and mixed again. The AP/HTPB suspension, added with a curing agent, has fluidity for a while after its addition. The AP/HTPB suspension added with a curing agent during this period is called an uncured propellant in this study. The AP/HTPB suspension added with a curing agent was designated as an uncured propellant. The uncured propellant, mixed sufficiently, is cast into the rocket motor. Therefore it's required that at casting the uncured propellant has the suitable viscosity. On the other hand, when the proportion of bubble contamination in AP/HTPB composite propellant is more than 2.0 vol%, the burning rate of the propellant is influenced by the bubble contamination and consequently the reproducible burning rate can't be obtained[1]. That is to say, the reliability of the burning rate is poor. In order to prepare the propellant, of which the burning rate isn't influenced by the bubble contamination, it is necessary that the proportion of the bubble contamination in the propellant is less than 2.0 vol%. The uncured propellant is

Received on December 3, 1999

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mixed and cast under a vacuum in order that the air may not be introduced into the uncured propellant. However, when the volume of HTPB is smaller than that of void in AP powder, it is likely that the proportion of the bubble contamination in the propellant is more than 2.0 vol%. Because of the above two requirements for the preparation of AP/HTPB composite propellant, the upper limit content of AP contained propellant, ϕ_{max}(wt%), exists[2),3)].

The burning rate and the specific impulse are the very important properties of propellant. When a propellant is prepared from a certain AP sample, the burning rate and the specific impulse increase with increasing the AP content and these values of the propellant containing ϕ_{max} are maximum. If ϕ_{max} could be estimated, the maximum burning rate and specific impulse could be determined easily. It is an important subject for the design of AP/HTPB composite propellant to make the estimation of ϕ_{max}. It is reported that ϕ_{max} can be estimated by a void fraction, ε_{max}(-) at the loose packing of powder[2),3)]. The value of ε_{max} varies with the change of humidity, temperature, material of cylinder, drop height of powder, etc[4)]. That is to say, ε_{max} is dependent greatly on the measuring condition. It is difficult to measure ε_{max} under strict constant conditions. Therefore, it is not easy to estimate ϕ_{max} by use of ε_{max}. It is necessary to find out the universal powder property which can estimate ϕ_{max}.

Mori and Ototake[5)] reported that this relationship between the relative viscosity, η_r(-), and the volume fraction of solid, ϕ_v (vol%), of concentrated suspension can be expressed by the following equation.

$$\eta_r = 1 + \frac{k}{(100/\phi_v) - (1/\phi_{vc})} \tag{1}$$

where k and ϕ_{vc} are constant and are dependent on the particle property of the dispersoid. If the relationship of the concentrated AP/HTPB suspension could follow Eq.(1) and the dominating powder property for k and ϕ_{vc} could be found out, it is expected that ϕ_{max} could be obtained as a function of the particle property. In this study, an attempt was made to find out the universal powder property which can estimate ϕ_{max}, except ε_{max}. As a result of this study, it is found that ϕ_{max} can be estimated from specific surface area measured by the air-permeability method. This paper gives the experimental results for the determination.

2. Experimental

2.1 Samples

AP samples used in this study are shown in Table 1. Samples A-E were prepared by grinding commercial AP for 5, 10, 20, 30 and 40 minutes with a vibration ball mill. The shape of samples A-E was spherical and the width of particle size distribution was wide (5-200 μm). Sample F was prepared by was shifting ground AP. A sonic sifter (SW-20, Tutui rikagaku) was used and the opening of the sieve was 38 μm. The shape of sample F was spherical and the width of particle size distribution was narrow. Samples G-Q were prepared by the spray-drying method[6)-8)]. Samples R and S were prepared by the freeze-drying method[9)]. The shapes of samples G-I, samples J-O and samples P-S were spherical, porous and hollow, respectively. The width of particle size distribution of samples G-S was narrow (0.5-17 μm). Mean volume-surface diameter, D_{vs} (μm), on the number basis of AP used in this study are shown in Table 1. D_{vs} is in the range of 1.6 to 110 μm.

HTPB R-45M(ARCO Co.) was used as a binder. HTPB was cured with isophorone diisocyanate (IPDI). IPDI was added to 8 wt% of HTPB[10)].

In order to determine ϕ_{max}, a propellant sample should be prepared with the optimum operating condition. The optimum operating condition was studied in Ref.10. In Refs.2 and 3, the preparation of the propellant sample was determined on the basis of Ref.10 and ϕ_{max} was measured. The propellant sample was prepared according to Refs.2 and 3 in this study.

2.2 Measurement of specific surface area

Specific surface area was measured by the BET absorption method or air-permeability method. Specific surface area, S_{wb}(m^2/kg), measured by the BET absorption method is determined by an amount of gas absorbed on the surface of a particle. Nitrogen was used as the absorption gas for S_{wb}. Specific surface area, S_{wb}(m^2/kg),

Table 1 Particle characteristics of AP used in this study and $\phi_{max.}$

Symbol	Sample	Shape	D_{vs} (μm)	S_{wb} (m²/kg)	S_{wp} (m²/kg)	ϕ_{max} (wt%)
A	AP ground in vibration mill for 5minutes	Spherical	110	60	40	85
B	AP ground in vibration mill for 10minutes	Spherical	70	80	50	85
C	AP ground in vibration mill for 20minutes	Spherical	50	150	100	84
D	AP ground in vibration mill for 30minutes	Spherical	40	190	150	83
E	AP ground in vibration mill for 40minutes	Spherical	40	210	180	83
F	38μm passd	Spherical	20	380	260	82
G	AP prepared by the spray-drying method	Spherical	1.6	2000	1060	75
H	AP prepared by the spray-drying method	Spherical	2.0	1800	450	76
I	AP prepared by the spray-drying method	Spherical	2.6	1700	780	77
J	AP prepared by the spray-drying method	Porous	6.3	2100	1010	73
K	AP prepared by the spray-drying method	Porous	7.5	900	840	80
L	AP prepared by the spray-drying method	Porous	7.1	1500	940	77
M	AP prepared by the spray-drying method	Porous	4.1	1900	990	77
N	AP prepared by the spray-drying method	Porous	3.1	2100	900	74
O	AP prepared by the spray-drying method	Porous	3.9	1600	860	76
P	AP prepared by the spray-drying method	Hollow	2.7	3100	1200	72
Q	AP prepared by the spray-drying method	Hollow	2.9	2600	1160	72
R	AP prepared by the freeze-drying method	Hollow	3.9	1400	610	80
S	AP prepared by the freeze-drying method	Hollow	11.2	700	370	81

measured by the air-permeability method is determined by the permeability of air when it passes through a packed bed of powder. S_{wp} is influenced by the void fraction of a packed bed[11]. According to a preliminary experiment, it was found that S_{wp} of AP used isn't influenced by the void fraction when it is in the range of 0.3 to 0.5. In this study, S_{wp} was measured by use of the AP packed bed, of which the void fraction was in the range of 0.3 to 0.5. The physical meaning of S_{wp} is different from that of S_{wb}.

2. 3 Measurement of viscosity

A viscosity of AP/HTPB suspension was measured by a flow tester in this study. The measuring temperature was 333±1 K, since this was the temperature used for mixing and casting of AP/HTPB suspension in this study[2),3),10)]. According to the result of a preliminary experiment, the flow curve of the AP/HTPB suspension prepared in this study rises in a concave curve. This indicates that the AP/HTPB suspension is a pseudo-plastic fluid. A viscosity of the pseudo-plastic fluid is dependent on a share rate. In this study, the end correction in the capillary flow[12] was conducted at the share rate which was $500s^{-1}$.

2. 4 Measurement of burning rate

The burning rate was measured in a chimney type strand burner which was pressurized with nitrogen at 288±1.5 K. The range of pressure was from 0.5 MPa to 8 MPa. The strand sample was ignited by an electrically heated nichrome wire attached on the top of each strand sample. Two fuse wires were threaded through the strand sample at 25mm distance. The fuse wire was cut as soon as the burning surface passed through the fuse wire. The burning rate was calculated with the cutoff period of two fuses.

3. Results and Discussion

3. 1 Specific surface area

S_{wb} and S_{wp} were measured and the results are shown in Table 1. The ranges of S_{wb} and S_{wp} are 60-3100m²/kg and 40-1200m²/kg, respectively. S_{wp} is 0.3-0.8 times value as S_{wb}. The relationship between S_{wb} and S_{wp} is shown in Fig.1. S_{wp} increases with increasing S_{wb}. Since the physical meaning of S_{wp} is different from that of S_{wb}, S_{wp} is not in agreement with S_{wb}. However, S_{wb} and S_{wp} are associated.

3. 2 Upper limit content of AP contained in propellant

It's required for the preparation of AP/HTPB composite propellant that uncured propellant has a viscosity required for casting and the proportion of bubble contamination in propellant is less than 2.0 vol%[2),3)]. ϕ_{max} was the largest AP content in the propellants, which satisfy the above two requirements for the preparation of AP/HTPB composite propellant. ϕ_{max} was determined in the following way experimentally according to Refs.2 and 3. First, the uncured propellants are prepared at various AP contents and the largest AP content in the uncured propellants which have the viscosity required for casting is determined. Second three lots of propellants were prepared with the same AP content. The AP content was decreased by 1wt% from the largest AP content in the uncured propellants which have the viscosity required for casting. When the proportion of bubble contamination in the propellant is less than 2.0vol%, the reproducible burning rate is obtained[1] and the relationship between burning rate and pressure follows Vieille's law according to the experience in this laboratory.

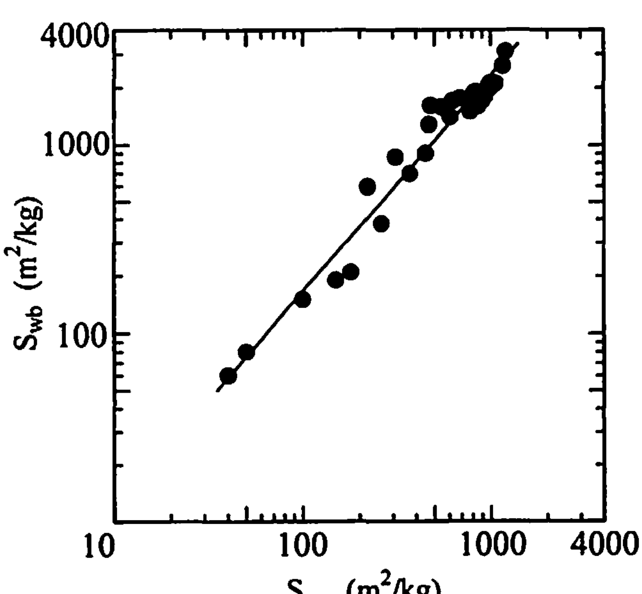

Fig. 1 Relationship between S_{wb} and S_{wp}

As mentioned above, three propellants were prepared at the same AP content. When the burning rate of three propellants is reproducible and the relationship between the burning rate of their propellants and pressure follows Vieille's law, it's judged that the burning rate of the propellant isn't influenced by the bubble contamination, that is, the proportion of bubble contamination in propellant is less than 2.0vol%. In this study, ϕ_{max} was determined as the largest AP content in the propellants, of which the reproducibility of the burning rate can be obtained and of which relationship between burning rate and pressure follows Vieille's law. The propellants were prepared from AP samples shown in Table 1 and burning rates of their propellants were measured. For example, concerning sample R, the relationships between the burning rate and pressure of propellants containing 79, 80 and 81wt%AP are plotted in Fig.2. When the AP content is less than 80 wt%, the reproducibility of the burning rate can be obtained and the burning rate increases lineally in a plot of ℓn(burning rate) versus ℓ n(pressure), that is, the relationships follow Vieille's law. When the AP content is 81wt%, the reproducibility of the burning rate can't be obtained and the burning rate does not increase lineally in a plot of ℓ n(burning rate) versus ℓ n(pressure), that is, the relationship does not follow Vieille's law. These results indicate that ϕ_{max} of the propellant prepared from sample R is 80wt%. With respect to the propellants prepared from AP samples shown in Table 1, ϕ_{max} was determined in the same way as above. The results of ϕ_{max} are shown in Table 1. ϕ_{max} is in the range of 72wt% to 85wt%. ϕ_{max} of samples A and B is maximum, and ϕ_{max} of samples P and Q is minimum.

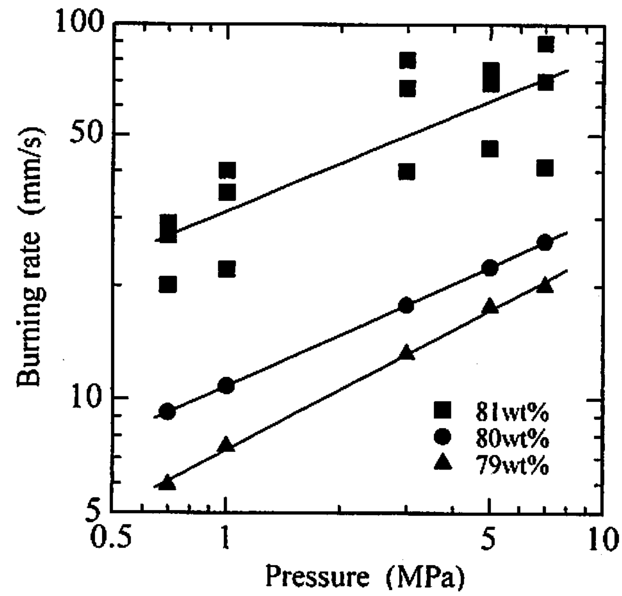

Fig. 2 Burning rate characteristics of experimentally prepared propellants from sample R

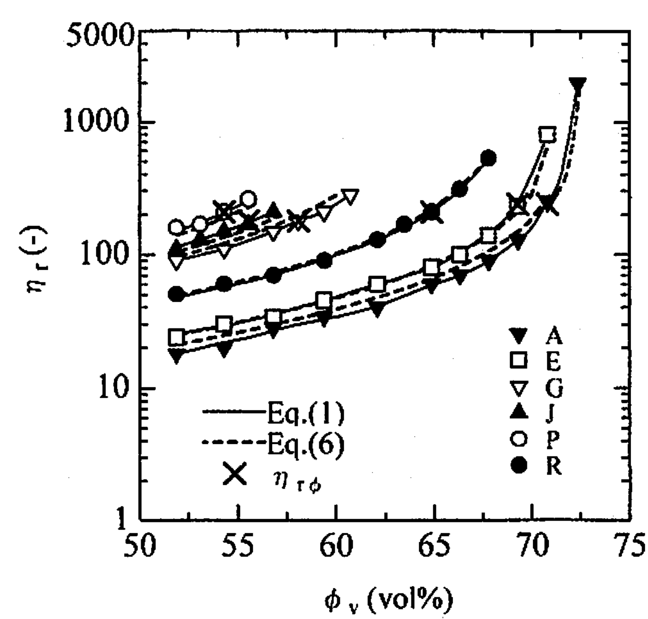

Fig. 3 Relationship between η_r and ϕ_v

3. 3 Viscosity of AP/HTPB suspension

The AP/HTPB suspension was contained above 50vol%AP in this study. The viscosity of the AP/HTPB suspension was measured and the relationship between η_r and ϕ_v was investigated. AP/HTPB suspension was not added IPDI. Some results are shown in Fig.3. η_r increases with increasing ϕ_v.

Mori and Ototake[5] reported that this relationship of concentrated suspension can be expressed by Eq.(1). k and ϕ_{vc} in Eq.(1) are constant and are dependent on the property of the suspended particles. This relationship of the AP/HTPB suspension prepared from spherical AP, of which particle size distribution is narrow, follows Eq.(1)[3),13),14)]. In this study, Some porous or hollow AP samples and some spherical AP samples, of which particle size distribution is wide, were used. It was investigated that the relationship of the AP/HTPB suspension prepared from AP shown in Table 1 could follow Eq.(1).

Eq.(1) can be converted to the following equation.

$$\frac{100}{\phi_v}=\frac{k}{\eta_r-1}+\frac{1}{\phi_{vc}} \qquad (2)$$

According to Eq.(2), the plot of $1/(\eta_r-1)$ against $100/\phi_v$ gives a straight line. k and ϕ_{vc} can be obtained from the slope and intercept of the straight line, respectively. On the basis of the data in Fig.3, the plot of $1/(\eta_r-1)$ against $100/\phi_v$ is shown in Fig.4. This relationship of the AP/HTPB suspension could be expressed by a straight line. k and ϕ_{vc} were calculated and the results are shown in Table 2. The relationship between η_r and ϕ_v, obtained by substituting k and ϕ_{vc} shown in Table 2 into Eq.(1), is represented by a solid line in Fig.3. The measured values can be approximated by the solid line. It is found that the relationship between η_r and ϕ_v of the AP/HTPB suspensions prepared in this study can be represented by Eq.(1).

ϕ_{max} is the percentage by weight and ϕ_v in Eq.(1) is the percentage by volume. ϕ_{max} which was converted into the percentage by volume was designated as $\phi_{v\,max}$. And η_r of AP/HTPB suspension containing $\phi_{v\,max}$ was designated as $\eta_{r\phi}$. As mentioned above, the relationship between η_r and ϕ_v of the AP/HTPB suspension can be represented by Eq.(1). This indicates that the relationship between $\eta_{r\phi}$ and $\phi_{v\,max}$ can exist on the curve presented by Eq.(1). Therefore, $\eta_{r\phi}$ can be represented by the following equation.

$$\eta_{r\phi}=1+\frac{k}{(100/\phi_{v\,max})-(1/\phi_{vc})} \qquad (3)$$

ϕ_{max} was determined in section 3.2 already. $\eta_{r\phi}$ was displayed with × in Fig.3. It is found that $\eta_{r\phi}$ is almost constant, approximately 200. Since $\eta_{r\phi}$ is almost constant, Eq.(3) indicates that $\phi_{v\,max}$ is dependent on k and ϕ_{vc}. k and ϕ_{vc} relate to the particle property of the dispersoid and especially k is dependent on D_{vs} and specific surface area[5]. It is expected that k and ϕ_{vc} could be obtained as a function of D_{vs} and/or specific surface area, if ϕ_{vc} would be also dependent on D_{vs} and/or specific surface area.

The relationship between k or ϕ_{vc} and D_{vs} is shown in Fig.5. As D_{vs} increases, k decreases and ϕ_{vc} increases. However, these relationships were

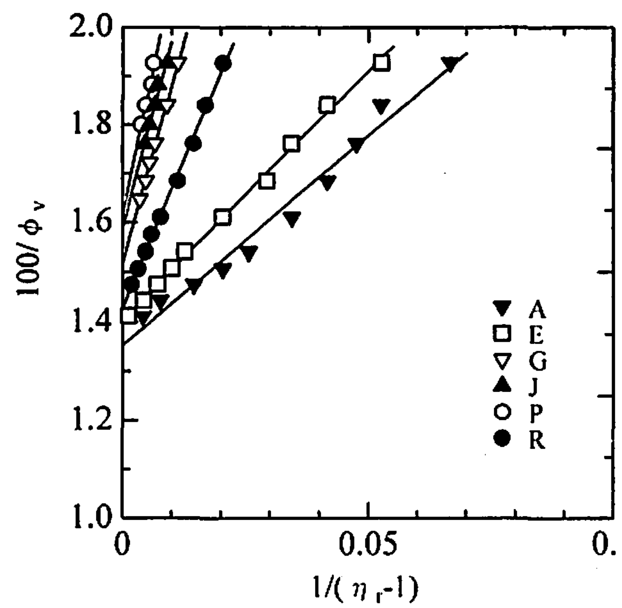

Fig. 4 Relationship between $100/\phi_v$ and $1/(\eta_r-1)$

Table 2 Results of k and ϕ_{vc}

Symbol	k (-)	ϕ_{vc} (-)
A	10	0.732
B	11	0.731
C	12	0.728
D	13	0.724
E	14	0.723
F	17	0.712
G	36	0.658
H	35	0.662
I	31	0.674
J	39	0.646
K	18	0.711
L	28	0.683
M	30	0.678
N	38	0.653
O	32	0.670
P	47	0.621
Q	44	0.627
R	23	0.699
S	20	0.704

scattered extensively. The shape of some AP samples used in this study were porous or hollow. It can be supposed that the void in porous or hollow AP particles would influence viscosity. D v s can't consider the void in porous or hollow AP particles, because D v s is measured on the basis of the projective figure of particle. Therefore, it can be considered that these relationships are scattered.

When the particle diameter is constant, specific surface area of porous or hollow particle is larger than that of spherical particle. It is supposed that that the better relationship between k or ϕ_{vc} and specific surface area could be obtained, compared with D_{vs}. S_{wb} and S_{wp} were adopted as specific surface area in this study.

The relationship between k or ϕ_{vc} and S_{wb} is shown in Fig.6. As S_{wb} increases, k increases and ϕ_{vc} decreases. These relationships showed some scattering. Porous or hollow AP had very small voids and cracks which could not be charged with HTPB. S_{wb} is determined on the basis of the area occupied by nitrogen molecule adsorbed on the surface of particle. This supported that S_{wb} would involve the surface area of the voids and cracks which could not be charged with HTPB. Therefore, it can be considered that these relationships are somewhat scattered.

The relationship between k or ϕ_{vc} and S_{wp} is shown in Fig.7. As S_{wp} increases, k increases and ϕ_{vc} decreases. These relationships show little scattering. S_{wp} is determined on the basis of the air permeability of packed bed. It is supposed that the surface area of very small voids and cracks which could not be charged with HTPB could be neglected, since air passes through in the packed bed of AP powder so as to slide on the surface of an AP particle. It can be considered that S_{wp} would relate to the surface area of an AP particle wetted with HTPB at the mixing of AP and HTPB. Therefore, it was supposed that S_{wp} was closely related to k and ϕ_{vc}. When S_{wp} ranges from 40m²/kg to 1200m²/kg, the relationship between k or ϕ_{vc} and S_{wp} can be represented by the following equation.

$$k = 10 + 0.015 S_{wp} + 1.2\times10^{-5} S_{wp}^{2} \quad (4)$$

$$\phi_{vc} = 0.728 - 1.17\times10^{-5} S_{wp} - 6.20\times10^{-8} S_{wp}^{2} \quad (5)$$

By substituting Eqs.(4) and (5) into Eq.(1), the following equation can be obtained.

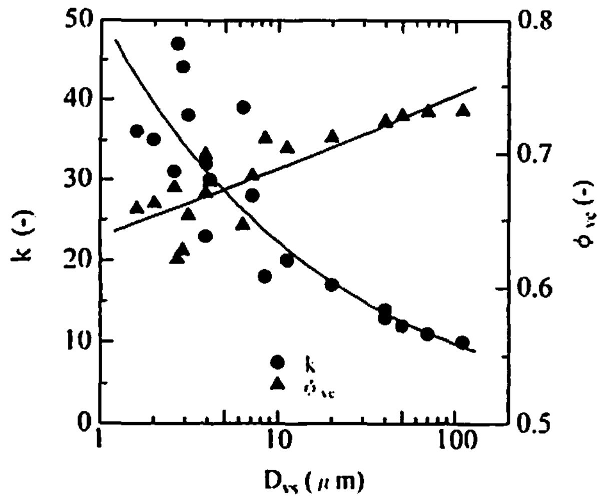

Fig. 5 Relationship between k or ϕ_{vc} and D_{vs}

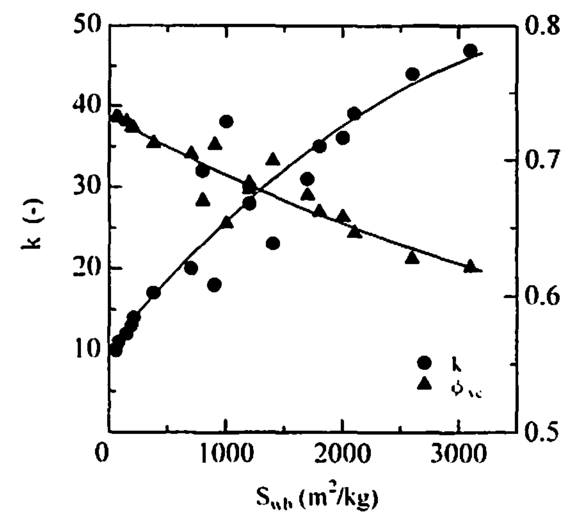

Fig. 6 Relationship between k or ϕ_{vc} and S_{wb}

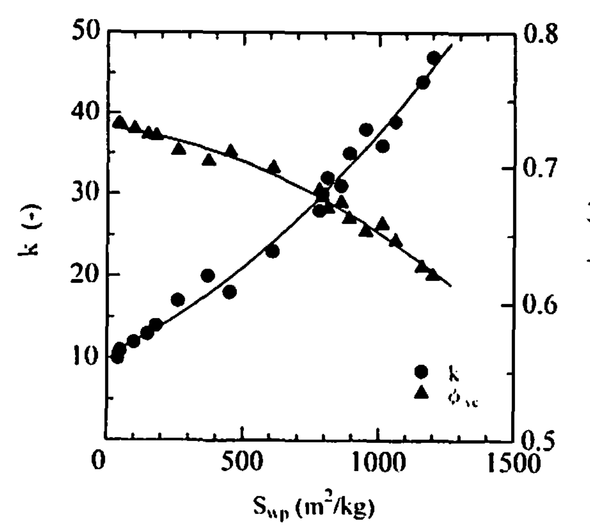

Fig. 7 Relationship between k or ϕ_{vc} and S_{wp}

$$\eta_r = 1 + \frac{10 + 0.015S_{wp} + 1.2\times10^{-5}S_{wp}^{2}}{(100/\phi_v) - (1/(0.728 - 1.17\times10^{-5}S_{wp} - 6.20\times10^{-8}S_{wp})} \quad (6)$$

The relationship between η_r and ϕ_v obtained by Eq. (6) is represented by a broken line in Fig.3. The broken line is in almost agreement with the measured values and the solid line. It is found that η_r can be represent as the function of ϕ_v and S_{wp} in this study.

It is expected that ϕ_{max} could be represent as the function of S_{wp}. Because this relationship between η_r and ϕ_v of the AP/HTPB suspension can follow Eq. (1), and k and ϕ_{vc} can be obtained as a function of S_{wp}.

3.4 Estimation of upper limit content of AP contained propellant

As described in section 3.3, it is expected that ϕ_{max} could be expressed by S_{wp}. On the basis of Table 1, the relationship between ϕ_{max} and S_{wp} is plotted in Fig.8. ϕ_{max} increases with decreasing S_{wp}. The plot ϕ_{max} against S_{wp} is found to be linear. AP samples shown in Table 1 were unimodal. In general AP which is mixed the samples with different sizes is used as an oxidizer of AP/HTPB composite propellant. With regard to bimodal AP, the relationship between ϕ_{max} and S_{wp} was investigated. Bimodal AP samples were prepared by mixing samples A, G, J, P and R. The composition and S_{wp} of bimodal AP samples are shown in Table 3. ϕ_{max} of the propellant prepared from bimodal AP were examined and the result is shown in Table 3. The relationship between ϕ_{max} and S_{wp} of bimodal AP samples is also plotted with ▲ in Fig.8. The relationship of bimodal AP agrees with that of unimodal AP. When S_{wp} ranges from 40m^2/kg to 1200m^2/kg, the relationship between ϕ_{max} and S_{wp} can be represented by the following equation.

$$\phi_{max} = 85 - 0.01S_{wp} \quad (7)$$

The error between ϕ_{max} calculated from Eq. (7) and the experimental value was within ±2%. It is found that ϕ_{max} can be estimated from S_{wp} by use of Eq. (7).

As mentioned at section 2.1, the shape of AP samples used in this study is spherical, porous or hollow. The width of particle size distribution is unimodal or bimodal. D_{vs} is in the range of 1.6 to 110 μm. The ranges of S_{wb} and S_{wp} are 60-3100m^2/kg and 40-1200m^2/kg, respectively. Therefore, the AP samples used in this study had multiple powder characteristics. In spite of multiple powder characteristics of the AP used, ϕ_{max} can be represented as a function of S_{wp} as a whole. This indicates that the influences of the multiple powder characteristics of AP on ϕ_{max} could be expressed by S_{wp} inclusively.

It is reported that ϕ_{max} can be estimated by ε_{max}[2),3)]. ε_{max} is dependent greatly on measuring conditions such as humidity, temperature, cylinder material, drop height of powder, etc[4)]. It is difficult to measure ε_{max} under strict constant conditions. Therefore, it is not easy to estimate ϕ_{max} by the use of ε_{max}. On the other hand, S_{wp} is influenced by the void fraction of a packed

Table 3 S_{wp} and ϕ_{max} of bimodel AP

AP	S_{wp} (m^2/kg)	ϕ_{max} (wt%)
G:A=80wt%:20wt%	480	80
J:A=60wt%:40wt%	470	80
P:A=50wt%:50wt%	550	80
R:A=40wt%:60wt%	220	83
R:A=60wt%:40wt%	310	82
G:R=80wt%:20wt%	820	78
G:R=60wt%:40wt%	690	79
G:R=50wt%:50wt%	630	79

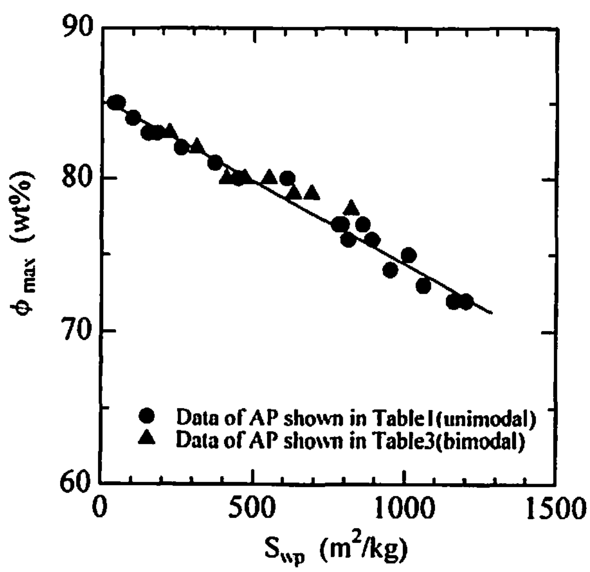

Fig. 8 Relationship between ϕ_{max} and S_{wp}

bed[11]. S_{wp} of AP is reproducible when the void fraction is in the range of 0.3 to 0.5, as mentioned in section 2.2. It is found that ϕ_{max} can be estimated easy and accurately by the use of S_{wp}, compared with ε_{max}.

In this study HTPB widely used was adopted as a binder. It was predicted for composite propellant prepared from another binder that ϕ_{max} could be represented as a function of S_{wp}.

4. Conclusions

For the preparation of ammonium perchlorate (AP)/ hydroxyl-terminated polybutadiene (HTPB) composite propellant, it is required that the uncured propellant has the viscosity required for casting and the proportion of the bubble contamination in the propellant is less than 2.0 vol%. Because of these requirements, an upper limit content of AP contained propellant, ϕ_{max} (wt%), exists. It is necessary for the design of AP/HTPB composite propellant to estimate ϕ_{max}. From the standpoint of flow characteristics of AP/HTPB suspension, an attempt was made to find out the dominating powder property of AP for ϕ_{max}.

Concerning AP/HTPB suspensions prepared in this study, the relationship between the relative viscosity, η_r (-), and the volume fraction, ϕ_v (vol%), of AP can be represented by the Mori-Ototake equation. k and ϕ_{vc} which are constant in the Mori-Ototake equation are dependent on specific surface area, S_{wp}(m^2/kg), measured by the air-permeability method. It is found that η_r of AP/HTPB suspension can be represented as the function of ϕ_v and S_{wp} and η_r of suspension containing ϕ_{max} was almost constant.

The plot of ϕ_{max} against S_{wp} is found to be linear. ϕ_{max} increases with decreasing S_{wp}. When S_{wp} ranges from 40m^2/kg to 1200m^2/kg, The relationship between ϕ_{max} and S_{wp} can be represented by the following equation.

$$\phi_{max} = 85 - 0.01 S_{wp}$$

It is found that ϕ_{max} can be estimated by S_{wp}.

References

1) T. Yamaya, A. Iwama and H. Tokui," Combustion and Detonation of Porous Composite Propellants (1) Microspheres included Propellant", J. Ind. Expl. Soc., 43, 381-386 (1982)

2) M. Kohga and Y. Hagihara, "Experimental Study on Estimation of Upper Limit of Ammonium Perchlorate Content in Ammonium Perchlorate /Hydroxyl-Terminated Polybutadiene Composite Propellant", Trans. Japan Soc. Aero. Space Sci., 41, 74-78 (1998)

3) M. Kohga and Y. Hagihara,"Estimation of Maximum Volume Fraction Based on Flow Characteristics of Ammonium Perchlorate/ Hydroxyl-Terminated Polybutadiene Concentrated Suspension", J.Soc. Powder Technol., 35, 482-490 (1998)

4) S. Miwa,"Funryuutai Kougaku", pp.121 (1972), Asakura Shoten.

5) Y. Mori and N. Ototake,"On the Viscosity of Suspensions", Chem. Eng., Japan ,20, 488-494 (1956)

6) M. Kohga and Y. Hagihara,"The Preparation of Fine Porous Ammonium Perchlorate by the Spray-drying Method", J.Soc. Powder Technol., 33, 273-278 (1996)

7) idem,"The Preparation of Fine Ammonium Perchlorate by the Spray-drying Method-The Effect of Organic Solvents on the Particle Shape and Size-", ibid., 34, 437-442 (1997)

8) idem,"The Spray-drying of Ammonium Perchlorate by Ultrasonic Comminution", ibid.,34, 522-527 (1997)

9) idem,"Preparation of Fine Ammonium Perchlorate by Freeze-Drying", Kagaku Kogaku Ronbunshu, 23, 163-169 (1997)

10) idem,"Experimental Study on Processability of Ammonium Perchlorate/Hydroxyl Terminated Polybutadiene Composite Propellant (I)-Influences of Operating Temperature on Viscosity of Uncured Propellant-", J. Japan Expl. Soc., 59, 1- 5 (1998)

11) Funtaikougaku Kenkyuukai,"Ryuudo Sokutei Gijutu", pp.295 (1975), Nikkan Kougyo Shinbunsha.

12) E. B. Baglay,"End Corrections in the Capillary Flow of Polyethylene, J. Appl. Phys., 28, 624-627 (1957)

13) Ito, T., Y. Hagihara, and K.Ikenomoto: "Effects of Particle-Size on the Flow Behavior of Ammonium Perchlorate/Polybutadiene Mixture," J. Ind. Expl. Soc., Japan, 28, 391-397 (1967)

14) Hagihara, Y.:"Correlation of Flow Behavior between Ammonium Perchlorate Particles and the Perchorate-Polybutadiene Paste", J. Soc. Powder Technol., Japan, 6, 141-142 (1969)

AP/HTPB系コンポジット推進薬に混入できるAP含有率の上限界の推算
― AP/HTPB分散系の流動性に基づく一考察 ―

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過塩素酸アンモニウム(AP)/末端水酸基ポリブタジエン(HTPB)系推進薬は製造上の条件があるために，推進薬中に混入可能なAP含有率の上限界，ϕ_{max}(wt%)が存在する。AP/HTPB分散系の流動性の観点から，ϕ_{max}を推算できるようなAPの粒子特性値を見出すことを試みた。なお，本実験では球状，多孔質と中空のAPを用いた。その結果は次のようにまとめられる。

1．本実験で調製されたAP/HTPB分散系において，相対粘度，η_r(−)と固体容積濃度，ϕ_v(vol%)の関係は，森・乙竹の式で表すことができた。森・乙竹の式の定数である k とϕ_{vc}は，APの空気透過法で測定された比表面積，S_{wp}(m²/kg)で表すことができ，η_rはϕ_vとS_{wp}の関数で表せることがわかった。
2．ϕ_{max}で調製されたAP/HTPB分散系のη_rはほぼ一定であった。
3．ϕ_{max}はS_{wp}が小さいほど大きかった。ϕ_{max}とS_{wp}の関係は，次式によって表すことができた。

$$\phi_{max} = 85 - 0.01 S_{wp} \quad (40\,\mathrm{m^2/kg} \leq S_{wp} \leq 1200\,\mathrm{m^2/kg})$$

ϕ_{max}は用いたAPのS_{wp}を測定すれば上式でほぼ正確に推算できることがわかった。

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