Research paper

Characteristics of aluminum agglomeration in AP/AN composite propellants

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Abstract

Aluminum (Al) particles are used in composite propellant of solid rocket for improving performance and combustion stability. However, aluminum particles have a tendency to agglomerate at the burning surface of composite propellants. It is known that these agglomerated Al particles cause low combustion efficiency. Therefore, it is necessary to study the agglomerate characteristics of Al particles at the burning surface of composite propellants.

The relation between agglomerate diameter and burning rate of propellants is obtained. Agglomerate diameter decreases with increasing burning rate. And it is expected that agglomerate diameter decreases with decreasing stay time of Al particle at burning surface.

Keywords : composite propellants, aluminum, agglomerate, burning rate, stay time

1. Introduction

Aluminum (Al) particles are used in composite propellant of solid rocket for improving propulsion performance and combustion stability. However, aluminum particles have a tendency to agglomerate at the burning surface of composite propellants. It is known that these agglomerated Al particles cause low combustion efficiency. Therefore, it is necessary to study the agglomerate characteristics of Al particles of composite propellants.

Many researchers have investigated Al agglomerate formation in composite propellant. For example, agglomerate size distribution[1)], agglomeration of nano / micro -aluminized propellant[2)], pocket model[3)], effect of oxidizer size[4)], effect of pressure[5)], and effect of intermetallic compounds[6)] were investigated.

It is considered that understanding of agglomerate formation needed to investigate phenomenon of agglomerate at burning surface. It is expected that changing of burning rate influences agglomerate formation by gas velocity at burning surface and stay time of Al particles that is the particle remaining time in the burning surface. Furthermore, measurements of agglomerate size were reported by various experimental methods.[7)–8)] However agglomerate particle diameter is needed to be measured at burning surface.

In this study, we obtain the relation of burning rate and agglomerate diameter at burning surface. And we obtain the relation of stay time and agglomerate diameter at burning surface.

2. Experiment

2.1 Sample propellants

Composition of sample propellants is shown in Table 1. Sample propellant consists of AP (ammonium perchlorate) and ammonium nitrate (AN) as oxidizers, octadecyl alcohol (Oct) as a binder, and Al as metal fuel. AN and Oct reduce the burning rate with broadening the reaction zone. Therefore, AN and Oct make easily to observe the

Table 1 Composition of sample propellant.

Sample	Composition, parts			
	AP	AN	Oct	Al
AN 0	90	0	10	0, 5, 10, 15, 20
AN 5	85	5	10	0, 5, 10, 15, 20
AN 10	80	10	10	0, 5, 10, 15, 20

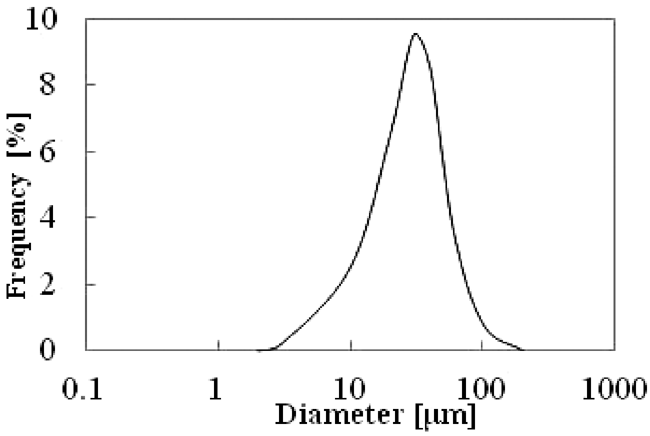

Figure 1 Particle size distribution of Al.

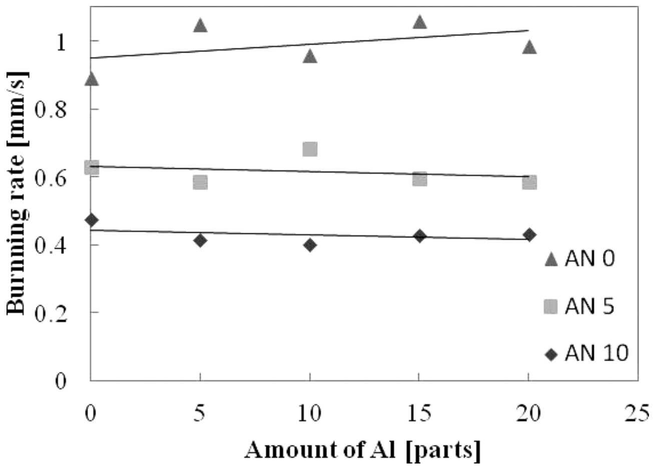

Figure 2 Burning rate for each composition.

behavior of Al particles at burning surface. And we changed burning rates by the ratio of AP/AN = 90/0 to 80/10. Average diameter of Al particle is 30 [μm] and diameter distribution is shown in Figure 1. And AP average diameter is 50 [μm]. In addition, we change amount of Al from 0 to 20 parts. Figure 2 shows the burning rate for each composition. This burning rate was obtained at 0.1 [MPa] in N_2. Burning rate is not changed by amount of Al.

It is considered that the difference of burning rate caused by changing of burning surface environment by addition of AN. In this study, we took up burning rate as a parameter to determine the relation between burning rate and agglomerate diameter.

2.2 Agglomerate size determination

The experimental apparatus is shown in Figure 3. The experimental condition is shown in Table 2. Sample propellant burned at atmospheric pressure in chamber. Burning surface images were taken by microscope attached to the high speed camera through the filter. This filter was stacked three layers of a negative film. This filter enables measuring agglomerated Al diameter, separating luminous flame and particle by weakening light at burning surface.

2.3 Stay time

Stay time was measured with high speed camera to

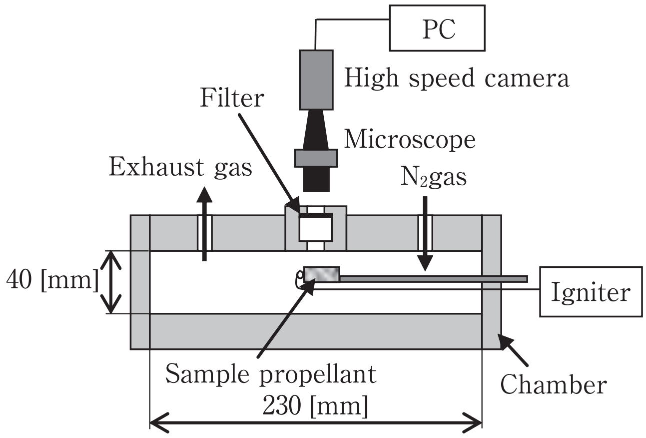

Figure 3 Experimental apparatus of burning surface observation.

Table 2 Experimental condition

Detail of Experiment	
Chamber pressure, [MPa]	0.1
Atmospheric gas	N_2
High speed camera setting	
Sampling rate, [fps]	8113
Exposure, [μs]	70

investigate the effect of burning rate to stay time. Stay time was defined from melting of aggregate as being visible at burning surface to moving away from burning surface after ignition. Ignition of agglomerates is defined from generation of luminous flame.

3. Results and discussion

3.1 Agglomerate size determination

Agglomerate formation at burning surface taken by high speed motion pictures is shown in Figure 4. Aggregate (accumulated Al particles on burning surface looks like flake) melts and transforms into sphere. Subsequently, agglomerated Al moved away from burning surface after ignition. In Figure 4, accumulated aggregates at burning surface[①] are gradually melted, and transformed sphere.[②③④] And agglomerates moved away from burning surface after ignition.[⑤⑥]

Agglomerate diameter before ignition at burning surface[④] was measured by three directions per one particle image. And averaged agglomerate diameter was obtained by average of fifty agglomerate particles.

3.2 Effect of burning rate

The relation of burning rate and averaged agglomerate diameter for each amount of Al is shown in Figure 5.

Averaged agglomerate diameter decreased with increasing burning rate at every amount of Al. It is shown that the effect of burning rate to averaged agglomerate diameter appears strongly at 20 [parts], but the effects at 5 [parts] and 10 [parts] are small. It appears that agglomerate diameter decreases with increasing burning rate. At the same time, increasing of amount of Al (decreasing of interparticle distance) brings about

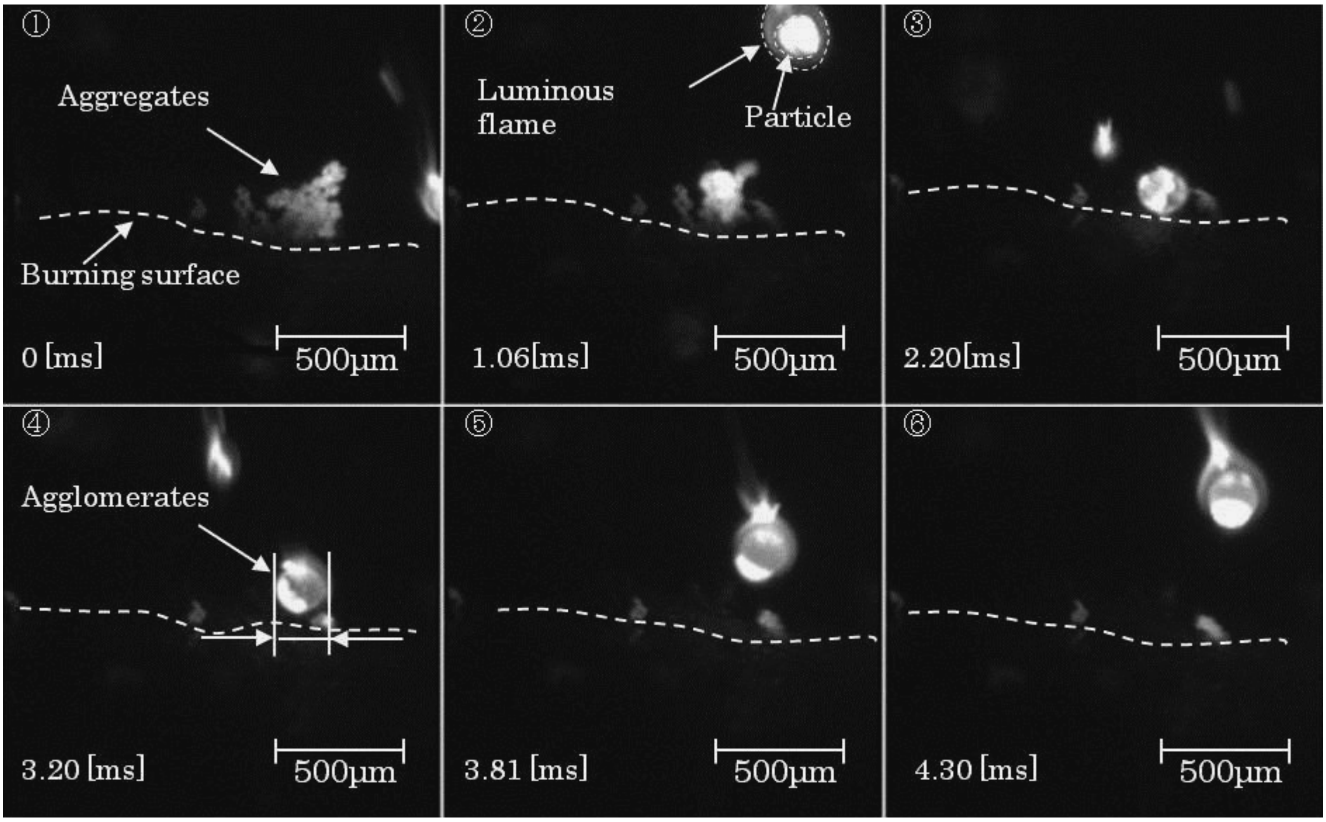

Figure 4 Agglomerate formation at burning surface (AN10−Al20 parts).

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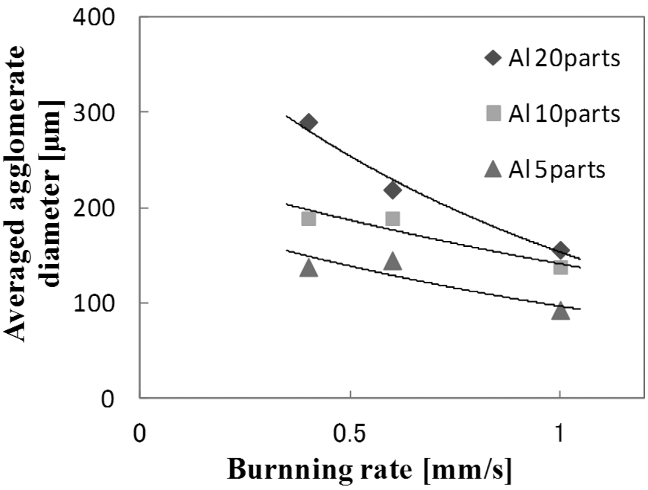

Figure 5 The relation of burning rate and averaged agglomerate diameter.

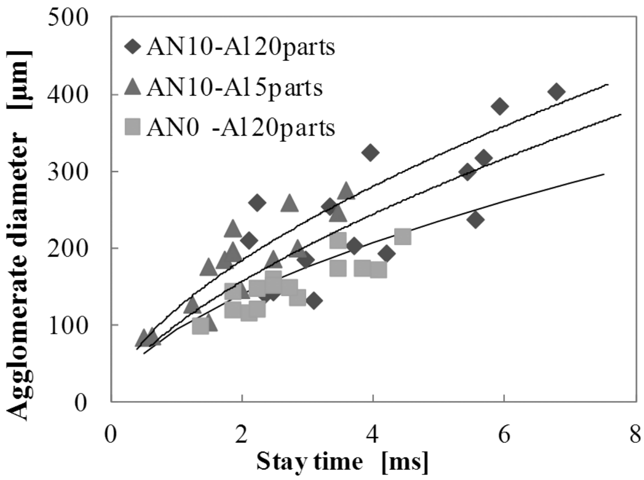

Figure 6 The relation of stay time and agglomerate diameter.

increasing of agglomerate Al diameter. Thus, agglomerate Al diameter is function of burning rate and interparticle distance.

3.3 Stay time

The relation of stay time and agglomerate diameter is shown in Figure 6. Stay time were measured for fifteen particles for each composition.

Agglomerate diameter increases with increasing stay time. And agglomerate diameters show the trend of ever-increasing, even if composition of propellant is different. Therefore, agglomerate diameter only determined by stay time of agglomerate particle at burning surface.

4. Conclusion

1) Agglomerate diameter decreases with increasing burning rate.

2) Agglomerate diameter decreases with decreasing stay time.

Acknowledgment

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AP/AN系コンポジット推進薬におけるAl粒子の集塊特性

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コンポジット推進薬に金属燃料として添加されているアルミニウム（Al）粒子は，固体ロケットの性能や燃焼安定性を向上させる一方，集塊を形成し燃焼効率の低下を招くことが知られている。したがって燃焼表面におけるAl粒子の集塊特性を知ることは推進性能の向上を考える上で重要であると考えられる．本研究では，燃焼速度の増加により集塊粒子径は縮小することを認め，それが燃焼表面における集塊粒子の滞留時間の減少によるものであることを明らかにした．

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