Detonation Characteristics of Packed Beds of Metal Particle Saturated with Nitromethane

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1 INTRODUCTION

The addition of solid particles to liquid explosive changes the mechanism of detonation propagation of the explosive from homogeneous to heterogeneous. The effects of the addition of solid particles to liquid nitromethane (NM) has been the subject of many studies[1-6]. Many experiments with mixtures of NM and solid particles have been performed at small particle concentration. The results of these experiments show that the addition of small amount of solid particles drastically changes detonation properties; sensitivity increase and critical diameter decrease caused by particle induced hot-spots. Very limited data exist for heterogeneous mixtures consisting of densely packed beds of solid particles saturated with liquid explosive. Lee et al. [3,4] performed systematic studies of heterogeneous mixtures consisting of packed beds of spherical glass beads of different size saturated with chemically sensitized NM, and showed the effects of glass beads size on critical diameter of these mixtures. The authors suggested the existence of two different type of detonation propagation mode depending on particle size.

Recently, the interaction of detonation waves in NM with packed beds of spherical solid particles was investigated using two and three-dimensional mesoscale simulation by Milne[7] and Ripley et al.[8] Milne [7]suggested that complex wave interaction in the flow behind leading shock is characterized by two sonic points; the first is a standard CJ point and the second is a sonic point with respect to sound velocity of solid particles. He showed that detonation velocity of heterogeneous mixtures consisting of solid particles and NM is dependent on the sound velocity of solid particles. Milne[7] and Ripley et al.[8] showed that a steady state zone exists in the flow behind leading shock which is much longer than the reaction zone of NM, and that the width of this steady state zone scales linearly with particle size.

In this study, we measured detonation velocity and pressure of heterogeneous mixtures consisting of packed beds of metal particle saturated with NM. The effects of metal particle size on the detonation properties of these heterogeneous mixtures were presented. The experimental results were compared with the results of mesoscale simulation by Milne [7] and Ripley et al.[8]

2 EXPERIMENTAL

Five types of Al particles with mean diameter 3, 8, 35, 108 and 350μm, two types of Cu particles with mean diameter of 93 and 560μm and commercial grade NM were used in this series of experiments.

Properties of heterogeneous mixtures consisting of packed beds of Al or Cu particles saturated with NM (NM/Al, NM/Cu) were presented in Table 1.

Fig. 1 shows experimental arrangement for detonation velocity measurements. Detonation velocity measurements were performed for NM/Al and NM/Cu mixtures contained in PVC tubes of different inner diameter 13, 16, 20, 31 and 250mm in length. Detonation velocity was measured by four optical fiber probes placed at 50mm

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interval. First probe was set at 90mm from booster explosive to assure steady detonation propagation.

Fig. 2 presents experimental arrangements for detonation pressure measurements. Detonation pressure was measured using PVDF pressure gauge. NM/Al mixture was contained in PVC tube of 31mm in inner diameter and 150mm in length, and placed on PMMA plate of 1mm thick. PVDF pressure gauge was consisted of PVDF film of 10μm thick and 5mm square, which was sandwiched with polyimide films together with the electrodes made of copper foil. PVDF pressure gauge was placed on PMMA block of 50mm thick and then covered and glued with PMMA plate of 1mm thick.

TABLE 1. Properties of sample explosive mixtures

Sample Explosive Mixture	NM/Al					NM/Cu	
	Al-1	Al-2	Al-3	Al-4	Al-5	Cu-1	Cu-2
Mean Diameter of Solid Particle (μm)	3	8	35	108	350	93	560
Density of Mixture (g/cm^3)	1.71	1.86	1.84	1.97	1.83	5.75	5.75
Mass Fraction of Solid Particle (%)	57	68	66	72	66	92	92
Volume Fraction of Solid Particle (%)	35	46	44	51	44	59	59
Shape of Solid Particle	SP	SP	EL	SP	EL	SP	SP

SP: spherical , EL: ellipsoidal

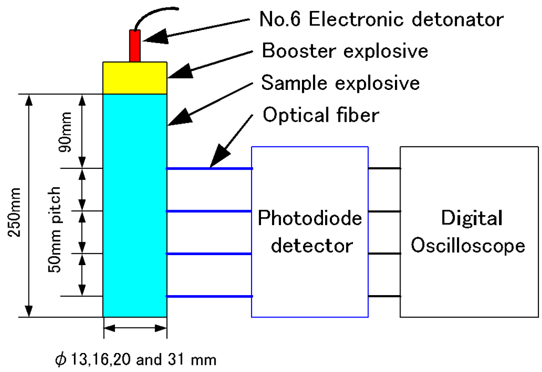

FIGURE 1 Experimental arrangement for detonation velocity measurements.

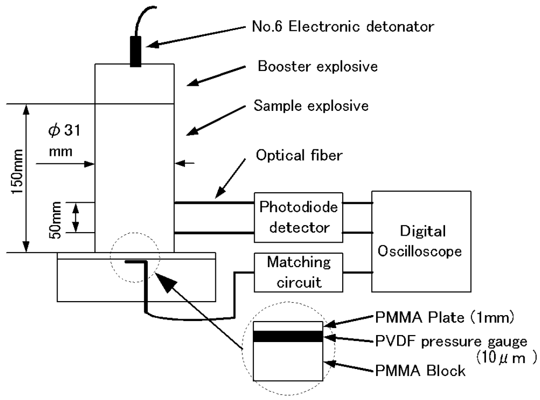

FIGURE 2 Experimental arrangement for detonation pressure measurements.

3 RESULTS AND DISCUSSION

Variation of measured detonation velocity with inverse charge diameter for NM/Al and NM/Cu mixtures is presented in Figure 3. Measured detonation velocity for NM/Al and NM/Cu mixtures is lower than that of NM. For mixture Al-3, Al-4 and Cu-1, detonation velocity decreases linearly with the increase of inverse charge diameter, and critical diameter is estimated to be much smaller than that of neat NM. Detonation velocity of mixture Al-3 and Al-4 agrees well with that measured by Haskins et al.[6] using Al particle of mean diameter 10.5μm. For mixture Al-2, detonation velocity was measured only at charge diameter 31mm. In the case of mixture Al-5, detonation failed to propagate at charge diameter 20mm, and detonation velocity at charge diameter 31mm is more than 700m/s lower than that of mixture Al-2, Al-3 and Al-4. In the case of mixture Cu-2, detonation failure was observed at charge diameter 16mm, and detonation velocity at charge diameter 31mm is about 150m/s lower than that of mixture Cu-1, but detonation velocity at charge diameter 20 mm is more than 500m/s lower than that of mixture Cu-1. Detonation velocity of mixture Al-5 and Cu-2 containing large particles presents strong charge diameter dependence. These experimental results indicate that critical diameter increases with the increase of particle size for NM/Al and NM/Cu mixtures.

Figure 4 summarizes the published data on the variation of detonation velocity with Al particle concentration with the results of present study. In the case of NM/Al mixtures containing Al particle smaller than 108μm, detonation velocity decrease linearly with the increase of Al concentration. However, in the case of NM/Al mixtures containing Al particle larger than 210μm, important velocity decrease is observed.

According to the results of detonation velocity measurements, detonation velocity of NM/Al mixtures is about 2000m/s higher than that of NM/Cu mixtures, and detonation velocities of NM/Al and NM/Cu mixtures are respectively lower than shock velocity in Al particle (~6400 m/s at ~14 GPa) and Cu particle (~4600 m/s at ~18 GPa). The results of detonation velocity measurements suggest that shock velocity in solid particles play a important role in determining detonation velocity, and support the results of mesoscale simulation by Milne[7] and Ripley et al.[8]

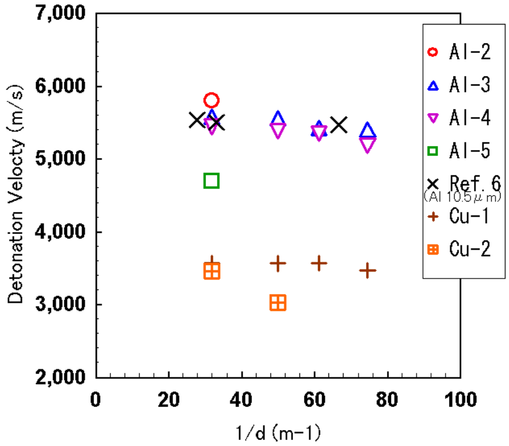

FIGURE 3 Relation between detonation velocity and reciprocal of charge diameter.

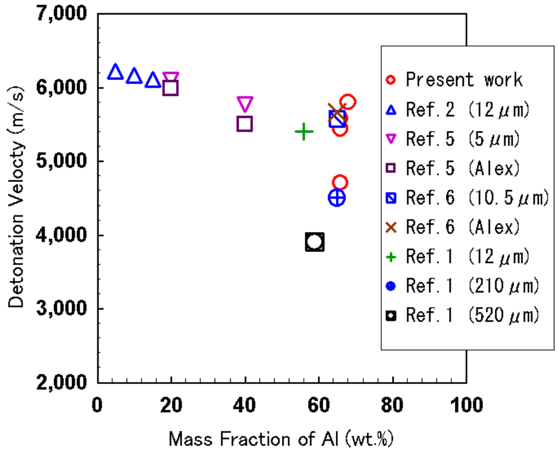

FIGURE 4 Relation between detonation velocity and mass fraction of Al (wt. %).

Detonation pressure was measured using PVDF pressure gauge for NM/Al mixtures as well as NM. Figure 5 shows pressure-time profiles measured by PVDF pressure gauge. Detonation pressures presented in Figure 5 are those transmitted in PMMA plate. The results of detonation pressure measurements are summarized in Table 2.

In the case of NM detonation, pressure profile in the reaction zone behind leading shock wave was not observed because of very short reaction zone length of NM. However, Neumann spike pressure, abrupt change of pressure gradient at CJ point and following pressure decay in Taylor wave were measured. Measured Neumann spike pressure and CJ pressure are respectively 16.8GPa and 11.6GPa. In the case of NM/Al mixtures Al-1,Al-2,Al-3 and Al-4 pressure profile in the reaction zone behind leading shock wave and following pressure decay in Taylor wave were measured. Measured Neumann spike pressure and CJ pressure of detonation in NM/Al mixtures Al-1,Al-2,Al-3 and Al-4 are respectively 17.8~24.7GPa and 13.5~14.6GPa, and higher than those in NM. Pressure gradient in Taylor wave is very similar for NM/Al mixtures Al-2,Al-3,Al-4 and NM. In the case of NM/Al mixture Al-5, Neumann spike was not observed, but change of pressure gradient at CJ point was observed. Measured CJ pressure of NM/Al mixture Al-5 is 7.6GPa, which is 6~7GPa lower than CJ pressure of other NM/Al mixtures. According to measured pressure profile of NM/Al mixtures, the reaction zone length is largely extended.

The results of mesoscale simulation by Milne[7] and Ripley et al.[8] showed that a steady state zone exists in the flow behind leading shock wave which is much longer than the reaction zone of NM, and that a centered expansion wave exists behind this steady zone. The steady state zone is the results of significant interplay between detonation in NM in interstitial pores and shock waves in metal particles. The observed extended reaction zone corresponds to the steady state zone demonstrated by mesoscale simulation. In the case of NM/Al mixture Al-1 and Al-2, pressure increase due to Al particle reaction was observed respectively at about 1.5 and 2.5μs behind leading shock wave. However, pressure increase due to Al particle reaction was not observed for other NM/Al mixtures.

TABLE 2. Summary of the results of detonation pressure measurements.

Sample Explosive	NM	Al-1	Al-2	Al-3	Al-4	Al-5
Detonation Velocity (m/s)	6260	5750	5800	5580	5440	4700
CJ Pressure (GPa)	11.6	13.8	13.5	14.4	14.6	7.6
Neumann Spike Pressure (GPa)	16.8	24.7	22.2	17.8	19.4	---

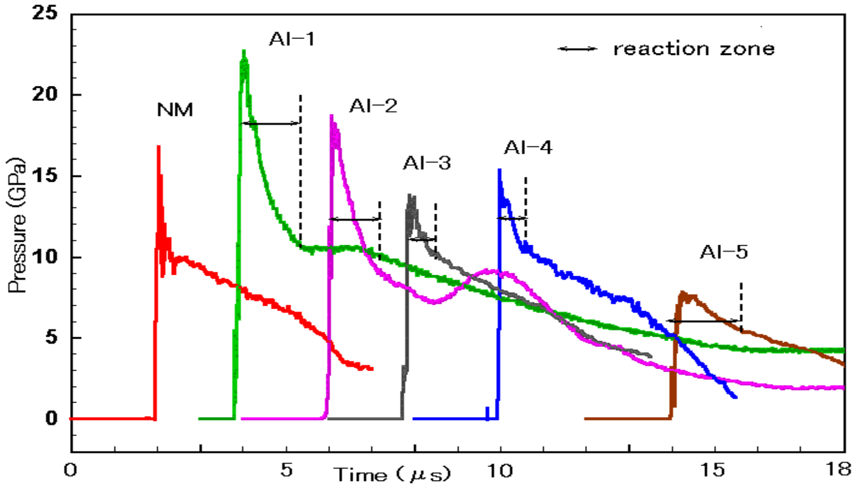

FIGURE 5 Pressure-time profiles measured by PVDF pressure gauge.

ACKNOWLEDGMENT

We appreciate very much kind cooperation of Dr. F. Zhang and Dr. A. Yoshinaka of DRES Canada, for suppling Al particles of smallest size.

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