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Experimental study on the breaking of A-IX-2 explosive by submerged cavitation water jet

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Abstract. It was investigated to break A-IX-2 explosive using the submerged cavitation water jet for emptying scrapped ammunitions charged A-IX-2 explosives. The Split Hopkinson pressure bar (SHPB) tests were firstly accomplished for A-IX-2 explosive to obtain its stress-strain mechanical properties. The breaking effect and its mechanism of the submerged cavitation water jet were investigated. The broken A-IX-2 explosives were tested by scanning electron microscope (SEM) to analyze the mesoscopic mode of cavitation water jet breaking A-IX-2 explosive. Finally, the internal temperatures of A-IX-2 explosive during the whole impact process were detected. The results showed that A-IX-2 explosive exhibits strain rate effect. The submerged cavitation water jet is available to use to empty ammunition charged A-IX-2 explosive by the submerged cavitation water jets is mainly caused by the combined action of micro-jets and shock waves generated by the collapse of cavitation bubbles. The mesoscopic mode is mainly the separation of crystals from binder and aluminum powder. The temperature change of A-IX-2 explosive in the whole process is about 20 °C.

1. Introduction

The de-military treatment of scrapped ammunition is a thorny issue for all countries in the peacetime. How to safely empty explosives from the ammunition shell is the primary problem faced by the ammunition green treatment technology, which directly affects the subsequent recovery and reuse of explosives [1]. As we all know, the ammunitions filled with TNT-based explosives can be melted and emptied from the shell by hot water or steam [2-4]. However, the ammunitions filled with the pressed and casted explosives, such as A-IX-2, PBX, etc. can not because of the high melting point [5]. In the past, this kind of ammunitions only can be destroyed through incineration in open air, so that it will cause environmental pollution and the waste of resources. This method is contrary to the environmental protection concept "reduce, recycle, and reuse" [6-7].

The application of water jet technology to empty ammunition has been a hot topic in recent years at home and abroad [8-11]. It is divided into two categories according to the application form. One is the high-pressure water jet method, commonly known as "waterjet". It uses a jet of hundreds of megapascals to cut or break the charge [12]. The disadvantage of this method is that the jet's pressure is too high, and the requirements for the manufacturing and installation of nozzles, pipes and seals are very high, which introduces a high cost. In addition, for some high-sensitivity explosives, this method is likely to cause an explosion accident. So this method is more suitable for emptying long-range missile and solid rocket engines. The other is the cavitation water jet method, which uses a jet of 20 to

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30 MPa to generate a large number of cavitation bubbles through the cavitation nozzle with a special structure [13]. The advantage of this method is the relatively low jet pressure and the formation of cavitation bubbles under submerged conditions, which has a significant effect on improving the jet's own cavitation intensity and operating efficiency. In addition, the explosive is submerged in water, which greatly reduces the risk of combustion and explosion during operation. Therefore, this method is an emptying ammunition technology with great application pote¹ntial.

A-IX-2 is one of the aluminum-containing pressed explosives, and it has gradually developed in China after the 1950s [14-15]. They are mostly used for aerial bombs, armor-piercing projectiles, and grenades. According to surveys, there are a large number of such ammunitions to gradually retire, and the number is increasing year by year in China. At present, there are very few theoretical and experimental studies on the emptying ammunition using the cavitation water jets. Therefore, this work choices the typical aluminum-containing pressed explosive as the object to investigate the breaking effect, mechanism and the temperature rise effect, etc. It can be provides a theoretical basis and practical guidance for the emptying other aluminum-containing explosives and non-TNT-based explosives.

2. Experiment

In this work, the submerged cavitation water jet device shown in figure 1 was set up. The device is mainly composed of a sprinkler head, a sample clamping and rotating device, a pressure gauge, a high-pressure pump, a water storage tank, and an explosive filtering device. The pressure of the high-pressure pump is adjustable and the distance between the sprinkler head and the explosive is adjustable. During the experiment, the explosive sample 1 is firstly fixed on the clamping and rotating device 3. The water in storage tank 8 is sent to the high-pressure pump 6 through a water pipeline 7, and pressurized to a specified pressure value. Then it is sprayed on the surface of the sample at high speed through a cavitation sprinkler head 2. After filtered by the explosive filtering device 5, the explosive particles with different sizes are obtained.



Figure 1. Experimental device of submerged cavitation water jet. 1-explosive sample, 2-sprinkler head, 3-clamping & rotating device, 4-pressure gauge, 5-explosive filtering device, 6-high-pressure pump, 7-water pipeline, 8-water storage tank.

The cavitation sprinkler used in the experiment is a combined three-nozzles device with a diameter of 16 mm. The angles between three nozzles' axes and the main axis of the sprinkler are not equal, so as to ensure that the coverage area of the cavitation jet is the largest. The outlet jet pressure is 25 MPa, and the distance from the sprinkler to the surface of the explosive sample is 30 mm. During the experiment, the explosive sample was fixed on the clamping and rotating device 3. With the device, the explosive was rotated uniformly and slowly around the central axis. Therefore, a relative rotation

occurred between the sprinkler and the explosive sample. The explosive sample was eroded by the cavitation bubbles, and the impact pits were formed on the sample surface. The impact traces diagram were shown in figure 2. The cavitation jets sprayed from three nozzles acted on the sample's surface at different angles, and the pits eventually developed an annular groove on the surface. With the slow feeding of the sprinkler, the sample were eroded layer by layer.



Figure 2. Impact traces diagram of cavitation water jet on explosive sample surface. 1-sprinkler head, 2-cavitation water jet, 3-explosive sample, 4-broken explosive, 5-pits,

6-annular grooves.

In order to confirm the safety of submerged cavitation water jet breaking explosives, we built a device as shown in figure 3 to detect the internal temperature changes of the explosives in the whole process. The diameter of the sample was 50 mm and its length was 120 mm. The temperature sensor was WRe5/26 thermocouple, the diameter of the wire was 0.2 mm, and the response time was less than 2 ms. The dynamic response error of the sensor was small, and it had sufficient anti-explosion strength. In the experiment, the temperature signal of the thermocouple was collected by the data collector, and after the analog-to-digital conversion, the digital signal was output to obtain the real-time temperature value at the detection point inside the explosive sample.



Figure 3. Temperature measuring device diagram.

1-protective tank, 2-sprinkler head, 3-explosive sample, 4-sample plate, 5-base plate, 6-thermocouple, 7-data collector.

3. Results and discussion

3.1. Stress-strain characteristics of A-IX-2 explosive

The impact of cavitation water jet to explosives can be regarded as a dynamic loading force. In order to deeply understand the breaking mechanism of the cavitation water jet to A-IX-2 explosive, it is necessary to study its stress-stain performance under dynamic loading. A-IX-2 explosives are a mixture of highly-filled particles. A certain amount of original damage such as micro-cracks and cavities is unavoidable between the particles of the explosive. Generally, the stress-strain performance

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of explosives containing the original damage will show stronger non-linear characteristic under dynamic loading [16].

Split Hopkinson pressure bar (SHPB) test is the most popular experimental technologies used for the dynamic characterization of various materials. On the SHPB device, the dynamic loading experiments were performed for the A-IX-2 explosive sample (diameter is 12 mm, thickness is 7 mm, sample density about 1.70 g/cm³), and the pulse signals in the incident rod and transmission rod were recorded to obtain the stress-strain curve of sample (see in figure 4)



Figure 4. Stress-strain curves of A-IX-2 explosive.

It can be seen from figure 4 that the stress-strain curve of the A-IX-2 explosive includes three phases, a brittle elastic phase, a nonlinear elasto-plastic phase and a strain softening phase. In the brittle elastic phase, the internal damage of the sample has developed, but it will not accumulate. When the loading force exceeds a certain stress value, it enters the nonlinear elasto-plastic phase. The evolution of the sample's damage will become an irreversible process, and the performance degradation caused by the damage will cause a decrease of the carrying capacity. In the areas where micro-cracks and even macro-cracks appear, the damage of micro-cracks and macro-cracks is still expanding. So the strain will continue to increase, and the full curve will show a decline, which is the strain softening effect of the sample. In the process of damage evolution, the critical stress-strain corresponding value from the elastic phase to the nonlinear elasto-plastic phase varies with the strain rate. It indicates that the damage of the sample has a strain rate effect. The stress-strain characteristics of A-IX-2 explosive under dynamic loading can provide a theoretical basis for studying the mechanism and breaking mode of cavitation water jet to explosives.

3.2. Breaking effect and mechanism of submerged cavitation water jet on A-IX-2 explosive

The breaking effect of submerged cavitation water jet to A-IX-2 explosive is shown in figure 5. The broken explosive particles are shown in figure 6. It can be seen from figure 5 that the surface of the explosive is flat before the experiment. During the experiment, due to the breaking effect of the cavitation water jet, an annular groove is formed on the surface, which is consistent with the guess in figure 3. After breaking for a period of time, the sample is completely broken. The size of the particles is different, and the maximum particle size does not exceed 3 cm. The experimental results show that the submerged cavitation water jet can be used to empty the ammunition charged A-IX-2 pressed explosive, and the broken explosive has a small particle size, which is conducive to the subsequent separation and recovery of the single explosive.

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(a) Before the experiment

(b) Surface of explosive

(c) Interior of shell

Figure 5. Breaking effect of submerged cavitation water jet to A-IX-2 explosive.



(a) Broken explosive particles

(b) Size of large particle

Figure 6. Broken particles and their size.

According to the theory of mechanical action, it can be considered that the breaking of the explosive surface by cavitation water jets is mainly the combined action of micro-jets and shock waves generated by the collapse of cavitation bubbles. The submerged cavitation water jet contains a large number of cavitation bubbles, which collapses on the explosive's surface due to a force imbalance. Along with the generation of micro-jets and impacts, a local high-pressure region is formed on or near the explosive's surface, resulting in extremely high stress concentrations. It may be the reason that the explosive's surface is broken. The diagram of breaking process is shown in figure 7.



Figure 7. Diagram of breaking explosive using the submerged cavitation water jet. 1-cavitation water jet, 2-explosive, 3-impact action, 4-broken explosive particles.

In order to further analyze the breaking mechanism of submerged cavitation water jets to the A-IX-2 explosive, according to the theory of breaking brittle materials combined with above-mentioned stress-strain characteristics of A-IX-2 explosive, the impact of submerged cavitation water jets and that introduced by the cavitation bubble collapse is assumed to be a rigid sphere with a certain speed. So, the assumed mechanical breaking process diagram is shown in figure 8.

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Figure 8. Assumed mechanical breaking process diagram of the submerged cavitation water jet to A-IX-2 explosive.

From figure 8, we can know the breaking mechanism of submerged cavitation water jet to A-IX-2 explosive. Figure 8(a) refers to the fact that an impact contact is formed in a certain area of the surface when a cavitation water jet impinges on explosive's surface. Under the action of the impact pressure, the explosive's surface undergoes a slight deformation. Figure 8(b) shows that the maximum shear stress is generated at point 1 and the maximum tensile stress is generated at point 2 in the impact contact area. Figure 8(c) shows that shear and tensile cracks will be generated in its interior when the maximum shear stress and the maximum tensile stress exceed the shear and tensile strength of the explosive itself. Figure 8(d) shows when the impact continues to increase, the shear and tensile cracks inside the explosive will continue to expand and gradually converge to the impact contact surface, and the internal cracks gradually connect to form a nucleus. That is, the crack is concentrated in a small range (see area 4), which is the basis of the breaking of the explosive. Figure 8(e) indicates that the micro-crack core area is gradually compressed with continuous impact and becomes an approximately ellipsoidal area. When this area is compressed to a certain extent, it will expand to cause tangential tensile stress surrounding explosive. When it is greater than the tensile strength of the explosive itself, radial cracks will appear on the side wall of the explosive (see area 5). Water jet fill these cracks quickly (see area 6), and break the explosive on the free surface with less resistance to form a pit with a certain volume. As shown in figure 8(f), the newly expanded cracks appear in area 7. Finally, the explosive will be completely broken into particles of different sizes with the iteration of above-mentioned process.

3.3. Breaking mesoscopic mode for A-IX-2 explosive

Usually there are three breaking mesoscopic modes for an explosive, they are crystal particles separated from the binder, crystal particle fragmentation, and binder fracture, respectively. Under a certain compression, the internal stress of the explosive will increase, and a certain amount of energy will be accumulated in the interior. If the energy is not released in time in the form of macro damage, it will cause the formation and expansion of macro cracks. When the energy is greater than a certain value, the crystal will be broken with the propagation of the internal micro-cracks. If the bonding strength of the adhesive to the crystal's surface is greater than the strength of the adhesive itself, the breaking of the adhesive is exhibited. On the contrary, it shows that the separation of the binder from

the crystals. Among them, the breaking of explosive crystals is most likely to increase the potential hot-spot, which in turn increases the probability of accidental explosion.



Figure 9. SEM for broken A-IX-2 explosive.

In order to conform the breaking mesoscopic mode of A-IX-2 explosive under the action of cavitation water jets, we performed morphological characterization of the broken A-IX-2 explosive particles using SEM. As shown in figure 9, the light-colored part in the figure is adhesive, and the large dark part is mainly RDX, and the small dark part is aluminum powder. It can be seen that a pit is left after the RDX crystal is debonded from the adhesive (see figure 9(a)), and the RDX crystal has

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cracks (see figure 9(b)) and a small amount of penetrating crystals (see figure 9(c)), but no crystal breakage is found. It shows that the breaking mesoscopic mode of A-IX-2 explosive is mainly the separation between the crystal and binder and aluminum powder. This may be because the explosive contains the desensitizing agent, which has a low strength and a weak adhesion to the crystal particles. Acted by external forces, it is easy to form macroscopic damages firstly, thereby preventing the crystal particles from breaking.

3.4. Temperature effect of breaking A-IX-2 explosives using the submerged cavitation water jet

The cavitation water jet impact test was performed on the A-IX-2 explosive sample. The water temperature at the inlet of the cavitation sprinkler was 30 °C. After 8 minutes of continuous impact, the data collector connected to the thermocouple showed that the internal temperature of the sample became stable. At this time, the water temperature at the outlet was about 50 °C, and the test was stopped. The temperature change curve of sample during the test is shown in figure 10.



Figure 10. Temperature curve of A-IX-2 explosive in the impact process of cavitation water jet.

It can be seen from the figure that the temperature of the explosive sample has a rising trend during the impact of the cavitation water jet. The process can be divided into two different stages. The rise rate of internal temperature in the first 140 s of the whole process is higher than that in the later stage, and the temperature changes about 20 °C in the whole process. The reason for this trend may be the accumulation of heat generated by the continuous impact and friction of the cavitation water jet on the sample. There also may be an exothermic reaction between water and aluminum powder in the sample. These heats are released too slow and causes the sample's temperature rising. The slow temperature rise and even stabilization in the later stage may be caused by the formation of grooves in the sample, which is not easy to accumulate heat. Therefore, the heat is continuously released by a large number of water jets.

4. Conclusions

In the present work, an experimental research on the breaking A-IX-2 explosive using the submerged cavitation water jet was performed. Firstly, the mechanical properties of A-IX-2 explosive were tested by the SHPB. Secondly, the breaking effect and mechanism of the submerged cavitation water jet were investigated. Thirdly, the breaking mesoscopic mode was analyzed. Finally, the temperature effect in whole impact process was studied. The results showed that A-IX-2 explosive includes three phases, a

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brittle elastic phase, a nonlinear elasto-plastic phase and a strain softening phase. The breaking of the A-IX-2 explosive has a strain rate effect. The submerged cavitation water jet can be used to empty the ammunition charged A-IX-2 pressed explosive, and the broken explosives have small particle size (not exceed 3 cm). The breaking of the explosive by submerged cavitation water jets is mainly caused by the combined action of micro-jets and shock waves generated by the collapse of cavitation bubbles. During the process, the explosive is subjected to shear stress and tensile stress. When the stress exceeds the yield strength limit of the explosive itself, cracks are formed in the interior. With the continuous impact, the cracks expand and the explosive is eventually completely broken. The breaking mesoscopic mode of A-IX-2 explosive is mainly the separation between the crystal and binder and aluminum powder. The temperature of the explosive has a rising trend during the impact process. The whole process can be divided into two different stages. The temperature rises rapidly in the first stage, followed by a small temperature increase rate and gradually stabilized. The temperature change of the whole process is about 20 °C.

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References

- Liou M and Lu M C 2008 J HAZARD MATER Catalytic degradation of explosives with goethite and hydrogen peroxide 151(2) 46-54
- [2] Xiang H J, Lei B and Xing Y C 2015 J. Pro. RMG Analysis and design on technology of emptying explosive from pellet by EM-induction heating 35(4) 47-50
- [3] Yan G B and Yu Y L 2011 *J. Eng Blasting* Engineering blasting technical exploration of destruction of discarded ammunition **17(3)** 92-4
- [4] Guo T, Qi S F and Wong S M 2011 J. Eng Blasting Applications of blasting technology of large quantities of discarded ammunitions 17(2) 89-91
- [5] Kong M, Lei L, Yue X and Shi H F 2018 J. Ord Auto Safe automatic separation technology for energetic propellant shell 37(1) 89-92
- [6] Wang X 2006 *J. Exp & Pro* Development and application of green propellants and explosives and related technologies **29(5)** 67-71
- [7] Yi J H, Zhao F Q, Li S W, Gao H X and XU S Y 2006 J. Pro &Pol Mat Research progress of green destruction and reclamation technology of obsolete rocket motor charge in America and Russia 4(6) 25-8
- [8] STEVE D R 2013 USA: IEEE Ultra-high pressure water jets in demilitarization 162-71
- [9] Zhu Z M, Wang X J and Han Q L 2013 J. Exp & Pro Feasibility analysis of high-pressure waterjet clearing NEPE propellant charge 36(6) 55-9
- [10] Jiang D Y 2013 J. Sci. Tec. of PLA Chipping performance of HTPB propellant by high-pressure water jet 14(4) 430-5
- [11] He Y H, Yu H T and Zhang Q M 2008 J. Ins. tran. Tec. of Beijing Ignition mode of solid propellant processed with high-pressure water jet 28(2) 97 -9
- [12] Zhang G W and Chen X F 2001 J. Eng. Mat. Reaearch on water jet cutti'ng parametrization test

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for simulated material of explosive 9(1) 24-7

- [13] Man H T, Luo X B, Ding Y K, Liu G Q and Zhen J W 2015 J. exp. Mat. Experimental study on erosion of muminant candle based on the hydrodynamic cavitation technology 44(4) 60-4
- [14] Zhang D M, Chang H and Zhang C M 2014 J. Ini & Pyr Failure modes analysis of pressed charge A-IX-2 (1) 29-32
- [15] Liu R P and Wang S Y 2013 J. Sicuan Ord & Env Compatibility of aluminum explosives with different contents of plasticizer 34(2) 35-7
- [16] Lu F Y, Lin Y L, Wang X Y and Wu H M 2006 J. Exp & Pro Experimental investigation on dynamic response of energetic materials at high strain rate 29(1) 1-4