Feasibility Study on Cutting HTPB Propellants with Abrasive Water Jet

To cite this article: Dayong Jiang and Yun Bai 2018 IOP Conf. Ser.: Mater. Sci. Eng. 301 012053

Related content

- Study on the Compressive Mechanical Properties of HTPB Propellant at Low Temperature
  Xiangdong Chen, Xin-long Chang, Youhong Zhang et al.

- Experimental Study on Abrasive Water Jet Machining of PZT Ceramic
  Ajit Dhanawade, Ravi Upadhyai, Arunkumar Rouiniyar et al.

- Computational Fluid Dynamic Simulation of Flow in Abrasive Water Jet Machining
  S Venugopal, S Sathish, V M Jothi Prakash et al.
Feasibility Study on Cutting HTPB Propellants with Abrasive Water Jet

Dayong Jiang and Yun Bai

Equipment Engineering College, Engineering University of PAP, NO.1, Wujing road, Xi'an, Shaanxi province, P.R China
Email: wanghe717@163.com

Abstract. Abrasive water jet is used to carry out the experiment research on cutting HTPB propellants with three components, which will provide technical support for the engineering treatment of waste rocket motor. Based on the reliability theory and related scientific research results, the safety and efficiency of cutting sensitive HTPB propellants by abrasive water jet were experimentally studied. The results show that the safety reliability is not less than 99.52% at 90% confidence level, so the safety is adequately ensured. The cooling and anti-friction effect of high-speed water jet is the decisive factor to suppress the detonation of HTPB propellant. Compared with pure water jet, cutting efficiency was increased by 5% - 87%. The study shows that abrasive water jets meet the practical use for cutting HTPB propellants.

1. Introduction
The disposal of propellants in large rocket engines was a difficult military operation. One of the key and important aspects is the safe removal of propellants from rocket engines so as to realize the recycling of the housings. The traditional technical method mainly include using mechanical tools or high-pressure water jet to process the propellant, and their disadvantages were also obvious. HTPB propellant belongs to dangerous chemicals and its temperature will increase due to mechanical action, which will easily lead to combustion or explosion. High-pressure water jet is a developed Emerging technology in recent years, having the advantage of reducing the temperature during the cutting progress. It was once considered the first choice for solid waste disposal because of the less danger. After large-scale practice, people find that there is an unavoidable defect for high-pressure water jet cutting technology that is the cutting efficiency is so slow that probability of secondary hazards was greatly increased. Specifically, process of disposal by high-pressure water jet does not belong to cutting operations in the traditional sense, but generally belong to the scope of flushing operations. Therefore, the propellant can only be stripped layer by layer, that can not achieve the whole block removal. Because such operation often continued dozens of hours, besides of resulting in a lot of waste water, another disadvantage was more deadly that erosion dropping from the propellant mixed with water vapor was easy to leading to formation of explosive aerosols. This is considered to be the major cause of accidents at home and abroad in recent years. Therefore, the search for a safe and reliable new cutting method of propellant is imperative and urgent.

Pre-mixed abrasive water jet is a new type of technology, which will convert high-pressure and high-speed water into a liquid-solid two-phase high-energy beam through mixed with abrasive. It can produce extremely strong erosion for the material for cutting, but the export pressure was greatly reducing at the same time. So the modern cutting technology was especially suitable for cutting a variety of pressure-sensitive, thermal materials, flammable, explosive materials and composites [1]. Based on the reliability theory and related scientific research achievements, this study explored the
safety and efficiency of abrasive water jet cutting propellants in order to obtain the feasibility conclusion and provide guidance for its industrial application.

2. Feasibility Theory
According to the theoretical analysis of "hot-spot theory" of energetic material detonation, hot spots are only formed in HTPB propellants for a certain period of time (more than $10^{-7}$ s), reaching a certain size (radius of $10^{-3}$-$10^{-5}$ cm) and temperature (300-600°C), and then they can explode propellant. The process of cutting HTPB propellant with abrasive water jet is mainly the impact of abrasive dynamic pressure role, which was a type of erosion crushing rather than adiabatic compression. Although slight sparks caused by friction between abrasive and metal occur in the slits at any time, the heat is rapidly removed due to the spark being surrounded by the cold high-speed water jet in the cutting process. Water jet also acts as a lubricant to reduce the friction between abrasive and propellant, thereby inhibiting the growth of hot spots and reducing the impact sensitivity of HTPB propellant. According to the functional theorem of particle dynamics, the impact energy of abrasive water jet on the HTPB propellant was much higher than the experimental hammer in the test. This shows that the HTPB propellant does not detonate when the impact energy is greater than the detonation threshold and the hot spot temperature in the HTPB propellant has not yet reached the detonation threshold. For HTPB propellant, the cooling and antifriction effect of high velocity water jet is the decisive factor to suppress its initiation. The feasibility of using a pre-mixed abrasive water jet cutting propellant depends primarily on the safety and efficiency of the cutting process, which must be verified by testing.

3. Feasibility Test Verification

3.1. Test System Composition, Working Principle and Technical Parameters
Cutting test used "intelligent water-jet robot" system with self-developed. This system is mainly designed for extinction, can also be used for other energy-containing materials cutting test through minor improvements.

![Figure 1. Intelligent water-jet robot](image)

It includes pressure generating device, abrasive device, and control device and so on. The principle is as follows: water and abrasive from their tank were fully mixed and injected into the booster system. The booster system is driven by a high-pressure piston pump and driven by a power adapter to provide pressurized water throughout the work system. Abrasive system used pressurized water supplied by the pumping station to modulate into a certain concentration of abrasive slurry. The abrasive slurry is delivered to the nozzle through the high-pressure hose to eject and formed the abrasive water jet. The test material will be placed on movement mechanism under the cutting device so as to complete the cutting operation were in Table 1.
Table 1. The main technical parameters of system

| parameter       | scope          |
|-----------------|----------------|
| pressure/MPa    | 0~50           |
| flux/g·min⁻¹     | 0~110.39       |
| velocity/mm·min⁻¹| 100~500        |
| standoff distance/mm | 1~11         |
| inner diameter  | 0.1mm          |

3.2. Cutting Safety Test

The key to judging the cutting safety of abrasive water jet is whether the HTPB propellant will detonate during the cutting process. The higher the sensitivity of HTPB propellant, the stronger the impact kinetic energy of the abrasive water jet and the greater the probability of detonating of HTPB propellant during cutting. Therefore, the safety test should be conducted under the conditions with the highest probability of detonating of HTPB propellant.

3.2.1. Test sample. Specimens were selected with HTPB propellants containing cyclonite with relatively higher sensitivities. The diameter is 50m, the height is 40mm and the dosage is 100g. The mechanical properties are as follows: tensile strength $R_b \geq 570$MPa, yield strength $R_{0.2} \geq 335$MPa, elongation $D \geq 19\%$ and Mo type hardness HB187. In order to ensure the reliability of experimental data, the sample size of the experiment selected 474.

3.2.2. Test Method. The specimen is loaded among three strong magnet fixtures with the same shape, and the nozzle is at the top of it, so that the abrasive water jet can be the specimen breakdown. In order to increase the impact kinetic energy of the abrasive water jet, the water pressure is set to a maximum of 50MPa and the amount of abrasive supplied is adjusted to the peak range at a concentration of 60%.

3.3. Cutting Efficiency Test

3.3.1. Test Sample. The test samples were selected of HTPB propellant with three groups, and its mechanical properties were shown in Table 2.

Figure 2. Cutting safety test
Table 2. Mechanical properties of HTPB propellant with three groups

| Temperature / °C | Compressive Strength / kg·cm⁻² | Tensile Strength / kg·cm⁻² | Elongation / % | Damage Elongation / % | Impact Strength / kg·cm⁻² |
|------------------|--------------------------------|----------------------------|----------------|-----------------------|--------------------------|
| 50°C             | 75.9 (7.43 MPa)                | –                          | –              | –                     | 6.54                     |
| -20°C            | 111.1 (10.88)                  | 41.0                       | 6.0            | 6.3                   | 5.31                     |
| -40°C            | 250                            | –                          | –              | –                     | 3.32                     |

3.3.2. Test Method
Abrasive water jet is used to cut holes in the cut position of the test piece. After being penetrated by the abrasive water jet, the rotating mechanism rotates to drive the test piece and cut in the circumferential direction once, and abrasive water jets shall be perpendicular to the test piece. Cutting efficiency was related to some factors including material properties, cutting pressure and flow, cutting target distance, cutting speed and the amount of abrasive of abrasive water jet. Under the conditions of average traverse speed of 1 cm/s, the percentage of abrasive were 10-50%, cutting time was to measure to determine the cutting efficiency.

Figure 3. Cutting efficiency test

4. Results and Discussion
4.1. Cutting Safety Test
Under the condition of water pressure $p = 50$ MPa, target distance $S = 7$ mm, cutting speed $v = 2.83 \times 10^3$ m/s, abrasive supply amount $m = 10.83 \times 10^{-3}$ kg/s and high pressure water flow rate $q = 5 \times 10^{-5}$ m³/s of the process parameters, a total of 474 specimens with sensitive HTPB propellant were cut, all of these were without exploding or resolving.

According to the unilateral confidence lower bound method of binomial distribution in reliability theory, the probability of failure in the case of failure is not true, that is, the confidence of corresponding lower limit of reliability is that [3]:

$$c = 1 - R_n$$

The lower limit of reliability is that:

$$R = (1-c)n$$

Where: $n$——the number of successful trials without failure, if $c = 0.9$, it is known that $n = 474$, then $R = 0.9952$.

Based on the data, it can be seen that the high-speed water jet generated by 320MPa high-pressure water, the high-energy abrasive water jet formed by absorbing $10.83 \times 10^{-3}$ kg / s mixed abrasive, The safety of non-explosive reliability by impacting HTPB propellant was that at 90% confidence level,
the safety and reliability is not less than 99.52%. For the low sensitivity HTPB with actual cutting pressure of about 30MPa, the safety is sufficient assurance.

4.2. Cutting Efficiency Test
The test results are shown in Table 3.

| Abrasive percentage/% | Time/s |
|-----------------------|--------|
| 10                    | 630    |
| 20                    | 480    |
| 30                    | 392    |
| 40                    | 28     |
| 50                    | 20     |

According to the projected cutting efficiency and practical cutting efficiency required for the basic equivalent. It should be pointed out that, the rotary mechanism from manual feed to motorized feed, cutting time can be shortened by about 5-87%.

5. Conclusions
The process of Abrasive water jet cutting propellant is safe under normal working pressure, and cutting efficiency can reach practical needs. Therefore, it is a safe and feasible new method for propellant disposal. The cooling and anti-friction effect of high-speed water jet is the decisive factor to suppress the initiation of HTPB propellant. This pilot project on the reliability engineering of propellants is also instructive and practical for applying abrasive water jet technology to the defence industry.

6. Acknowledgments
The Project Supported by Nation Natural Science Basic Research of China (Program No. 51503224).

7. References
[1] GUO Tao, QI Shi-fu, WANG Shu-min and etc. Applications of Destruction Technology of Large Quantities of Discarded Ammunitions. Engineering Blasting. 2011, 17(2): 89-91.
[2] YU Hong-chun, ZHANG Yong-li. Mechanism of abrasive jet slottung and establishment of its mathematical model. Journal of Liaoning Technical University, 2017, 26(6): 850-853.
[3] Zhang Sha, Gong Liehang, Wang Wenhua. Research on Cutting Metal Flash Detonator by Premixed Abrasive Water Jet. Lubrication engineering, 2011, 36(2): 72-75.
[4] XU Fancheng. Research on system of ammo destruction and layout of cutting model by Premixed Abrasive Water Jet. Chang Sha mining industry academy, M.Sc. thesis.
[5] LOU Jianwu, LU Yun. Research on performance of explosion of potassium chlorate. Blasting material, 2015, 37(1): 15-17.
[6] ZHONG Shuliang, LI Zhenquan, BO Ping. Research on safety Test of Cutting Explosive with Waterjet. Theory and exploration, 2016, 3: 44-46.
[7] ZHANG Guo-wen, CHEN Xin-fa. Research on Waterjet Cutting Parametrization Test for Simulated Material of Explosive. Energetic materials, 2011, 9(1): 72-75