Research on fabrication technology of PVV-5AVN explosive for explosive reactive armor

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ABSTRACT

PVV-5AVN explosive is a type of polymer-bonded explosive (PBX that typically comprises a mixture of RDX (hexogen), a high-explosive compound, and a polymer binder such as polyisobutylene. It finds extensive application in various generations of explosive reactive armor. This study investigates factors influencing the quality and specifications of PVV-5AVN explosives, including solvent choice, solvent ratio, mixing time, and ingredient proportions. Specifically, the RDX content is 85 ÷ 91%, and the binder system content is 9 ÷ 15% (with a DOS/PIB mass ratio of 2.75). These findings establish a fabricating process for laboratory-scale PVV-5AVN explosives that meets technical standards comparable to existing literature.

Keywords: PVV-5AVN explosive; Explosive reactive armor; Polyisobutylene; PBX; RDX.

1. INTRODUCTION

Explosive reactive armor is highly effective for protecting tanks and armored vehicles against anti-tank munitions. It offers a cost-effective solution with straightforward maintenance and replacement procedures. The functionality of explosive reactive armor is based on the explosive wave generated by the embedded explosives, which weaken, disrupt, and deflect the penetrating jet, thereby mitigating the destructive potential of anti-tank projectiles (figure 1) [1-3].

Depending on the intended application-whether to counteract shaped charges, kinetic energy penetrators, or both designers select the appropriate type of reactive armor, primarily by varying the explosive elements. Russian explosive elements have been researched and developed by the NII Stali Institute, resulting in key explosive elements such as 4C20, 4C22, and 4C23. The 4C20 element is used in Kontakt-1 reactive armor, 4C22 in Kontakt-5, and 4C23 in Relikt [4-7].

The explosives utilized in those above explosive reactive armor elements are typically PBX due to their enhanced stability, controlled detonation characteristics, and high energy output. The polymer matrix improves chemical stability, reducing sensitivity to mechanical stimuli such as shock, friction, and temperature fluctuations, thereby increasing safety in military applications. PBX enables precise energy release, disrupting incoming projectiles without compromising the vehicle's structural integrity. Its high energy density ensures efficient neutralization of threats like shaped charges. Additionally, PBX offers durability and customizability, maintaining performance under adverse conditions and allowing optimization for various armor configurations [8]. Specifically, 4C20 elements use the plastic explosive PVV-5A, 4C22 elements employ PVV-12M, and 4C23 elements utilize EG-85D, all of which are based on RDX combined with a polymer rubber matrix [9].

Additionally, the flexibility and elasticity of PBX explosives are essential to absorb mechanical stress without cracking, while tensile strength prevents tearing under stress. Finally, dimensional stability is important to minimize expansion or contraction under varying conditions. Currently, domestically produced PBX explosives, such as C4-VN, are equivalent to the C4-US product. Therefore, C4-VN plastic explosive is unsuitable for use in explosive reactive armor due to its excessive plasticity. On the other hand, plastic explosives such as PVV-5A and EG-85D have not yet been researched or fabricated locally. Additionally, the domestic defense industry is actively working on the research and production of tracked and wheeled infantry fighting vehicles. Equipping these combat vehicles with reactive armor is crucial, making the development of plastic explosive technology, particularly PVV-5A, a priority. According to DOSument [10], the explosive PVV-5A is composed of RDX and a polymer rubber mixture. It has a density of 1.4 g/cm³, a detonation velocity of 7400 m/s, an ignition temperature of 230 °C, and an impact sensitivity of 36%.

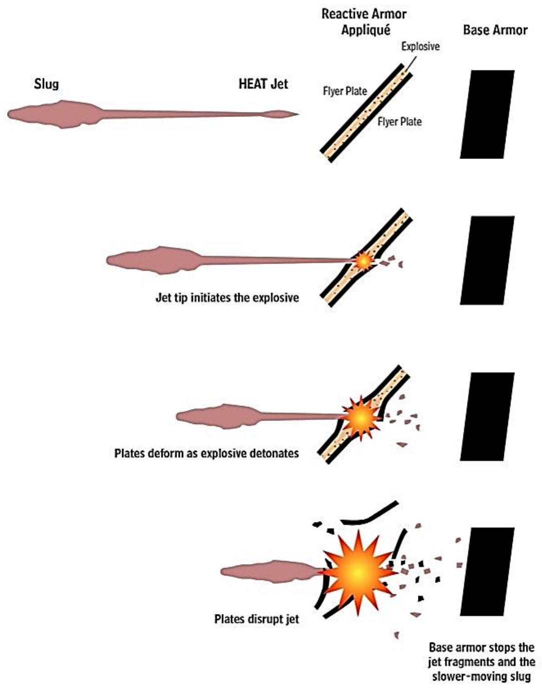

Figure 1. *Mechanism of explosive reactive armor (ERA).*

2. MATERIALS AND METHODS

2.1. Materials

Grade 1 hexogen (RDX, according to TCVN/QS 1274:2017) provided by Plant Z; Russian polyisobutylene (PIB) with molecular weight M = 100,000 - 170,000; n-heptane, acetone, n-hexane, cyclohexane, and dioctyl sebacate (DOS) sourced from China.

2.2. Samples preparation

Polyisobutylene (PIB) was dissolved in a suitable solvent, followed by the addition of dioctyl sebacate (DOS). The mixture was stirred for 30 minutes. Subsequently, dried RDX was gradually added to the polymer mixture at a stirring speed of 500 rpm continuously for 3 hours at a scale of 300 grams per batch. The solvent was evaporated by heating, resulting in a white, viscous explosive mixture. The mixture was then dried at 60 °C for 24 hours. The final explosive sample was evaluated for detonation velocity, energy output, impact sensitivity, and vacuum stability.

2.3. Experimental techniques

To determine the technical and energy characteristics and evaluate the quality of PVV-5AVN explosives, we employed standard measurement methods and specialized equipment at the Center for Explosive Materials Measurement and Testing/Institute of Propellants and Explosives, specifically:

- Impact sensitivity studies were carried out using the Cast Hammer Impact Test with a 10 kg drop hammer according to the TCVN/QS 1837:2017 (powder sample of about 0,05 g, the height of impact, 250 mm) [11].

- The detonation velocity of the explosive sample was measured by an EXPLOMET-FO-2QOO (Czech). The composition tested was prepared in the form of a cylinder with 24 mm diameter and 320 mm length. Two optical sensors were placed at a distance of 250 mm. Charges were detonated using detonator number 8 [12].

- The brisance by Hess was measured according to the TCVN/QS 6421:1998 (with a sample mass of 25 g and density of 1.45 g/cm^3) [13]. The strength of the explosive was measured by ballistic mortar according to the TCVN/QS 6424:1998 (sample mass of 10 g; density of 1.0 g/cm^3) [14].

- The thermal vacuum stability was conducted by the vacuum stability test (VST) using a STABIL apparatus (provided by OZM Research, Czech Republic) following the STAN/XG 4556-2A standard. The number of measured samples was 2 grams. Tests were performed at 100 °C for 40 hours [15].

3. RESULTS AND DISCUSSION

3.1. Study of the influence of solvents on the quality of PVV-5AVN explosives

PVV-5AVN explosive is fabricated by dissolving the binder PIB in a solvent, followed by mixing the binder solution with RDX explosive. Therefore, the choice of solvent and the solvent ratio affects the quality of the resulting explosive. The research group conducted the preparation of PVV-5AVN explosives using different solvents, with the mass ratio of RDX to the polymer mixture being 85% and 15%, respectively. The specific results are shown in table 1.

Table 1. *Influence of different solvents on the quality of PVV-5AVN explosives.*

No.	Solvent	PIB dissolution time (hours)	Quality of PVV-5AVN explosive
1	n-hexane	2	Average adhesion, good plasticity
2	n-heptane	2	Good adhesion, good plasticity
3	acetone	2	Average adhesion, poor plasticity
4	cyclohexane	2	Average adhesion, poor plasticity

From the results in table 1, it is evident that with the same PIB dissolution time, using n-heptane results in the best quality PVV-5AVN explosive. This could be because n-heptane dissolves PIB more effectively within the same time frame compared to other solvents, leading to a more uniform mixture of the polymer and RDX. This means that the binder mixture more effectively coats the RDX particles, thereby increasing the plasticity and adhesion of the explosive.

Based on the selection of n-heptane as the solvent, we conducted further research on the effect of the solvent ratio on the quality of PVV-5AVN explosives. The specific results are presented in table 2.

Table 2. *Influence of solvent ratio on the quality of PVV-5AVN explosive.*

No.	Mass ratio n-heptane/PIB	PIB dissolution time (hours)	Quality of PVV-5AVN explosive
1	5	2	Average adhesion, good plasticity
2	7.5	2	Average adhesion, good plasticity
3	10	2	Good adhesion, good plasticity
4	12.5	2	Good adhesion, good plasticity
5	15	2	Good adhesion, good plasticity

From the data in table 2, we observe that increasing the mass ratio of n-heptane to PIB improves the quality of the PVV-5AVN explosive. However, beyond a certain point, further increases in the ratio do not result in significant changes in quality. Increasing the solvent amount enhances the dispersion of RDX particles in the polymer mixture, thus improving the explosive's quality. However, when the ratio exceeds 10, the quality of the explosive remains unchanged. Consequently, the optimal solvent/PIB ratio is determined to be 10. Beyond this ratio, the excessive solvent usage requires more time and energy for solvent evaporation without further improving the explosive's quality.

Figure 2. *Image of PVV-5AVN explosive.*

3.2. Study of the influence of mixing time on the quality of PVV-5AVN explosives

The fabricating process of PVV-5AVN explosive primarily involves the blending of the binder mixture and RDX explosive. Therefore, the quality and technical specifications of the fabricated explosive depend on the degree of dispersion of RDX within the binder matrix. To assess this influence, the research group produced PVV-5AVN explosives with an 85% RDX and 15% binder mixture ratio, varying the mixing times. The specific results are shown in the following table.

Table 3. *Influence of mixing time on the quality of PVV-5AVN explosives.*

No.	Mixing time (hours)	Quality of explosive
1	1	Average adhesion, good plasticity
2	2	Average adhesion, good plasticity
3	3	Good adhesion, good plasticity
4	4	Good adhesion, good plasticity
5	5	Good adhesion, good plasticity

From the results above, it is observed that increasing the mixing time from 1 to 3 hours enhances the quality of the explosive. The binding ability and plasticity of the explosive increase because, after 3 hours of mixing, the dispersion of the RDX particles and the polymer matrix reaches optimal levels, allowing the binder to effectively coat the RDX particles, thereby enhancing the quality of the explosive. At a mixing time of 5 hours, partial solvent evaporation occurs, reducing the dispersion capability of RDX in the binder matrix, thereby reducing the quality of explosives. Therefore, the optimal mixing time for fabricating PVV-5AVN explosives is determined to be 3 hours.

3.3. Study of the influence of component ratios on the properties of PVV-5AVN explosives

3.3.1. Study of the influence of RDX content on the detonation velocity, and explosive power of PVV-5AVN explosives

PVV-5AVN explosives are used as explosive elements in explosive reactive armor for tanks and infantry fighting vehicles. Thus, the explosive energy characteristics are crucial. To evaluate these characteristics, the authors optimized the RDX content in PVV-5AVN explosives, with the DOS/PIB ratio fixed at 2.75. The specific results are presented in table 4.

The research results show that increasing the RDX content from 83% to 91% increases the detonation velocity and explosive power (as indicated by lead compression strength). This is consistent since RDX is the main energy-producing component in PVV-5AVN explosives, while PIB binder and DOS plasticizer primarily ensure the mechanical properties of the product. To ensure high explosive power, impact sensitivity within permissible limits, and to meet the product's property requirements, the authors determine the optimal RDX content for fabricating PVV-5AVN explosives to be 85 ÷ 91%.

Table 4. *Influence of RDX content on the characteristics of PVV-5AVN explosives.*

No.	**RDX content (%)**	**Detonation velocity (m/s)**	**Bristance by Hess at 1.45 g/cm^3 (mm)**	**Impact sensitivity (%)**
1	83	7250	20.8	28
2	85	7320	21.5	32
3	87	7380	22.0	32
4	89	7450	22.4	32
5	91	7520	23.0	36

3.3.2. Study of the influence of DOS/PIB ratio on the impact sensitivity and quality of PVV-5AVN explosives

The DOS/PIB ratio significantly affects both the plasticity and adhesion of the explosive components. Increasing this ratio to a certain value improves both plasticity and adhesion, but further increases may reduce adhesion. The polymer binder system in PVV-5AVN explosives must fulfill two roles: binding the components into a cohesive mass and ensuring the necessary plasticity. To evaluate the influence of the DOS/PIB ratio on plasticity, adhesion, and impact sensitivity, the PVV-5AVN explosives were fabricated with different DOS/PIB ratios and an RDX content of 85%. The specific results are shown in table 5.

The results (table 5) show that increasing the DOS/PIB ratio from 1 to 2.75 improves the quality of the explosive and reduces its impact sensitivity. However, further increases beyond 2.75 do not significantly alter the sensitivity or quality of the explosive. This is because the degree and quality of the coating of RDX explosive crystals with a plasticized polymer binder membrane are crucial for the quality of PVV-5AVN explosive, and the coating quality depends on the DOS/PIB ratio. With a DOS/PIB ratio of 2.75, the plasticizing capability of DOS with PIB is optimal, yielding the best quality explosive. Therefore, the optimal DOS/PIB mass ratio for producing PVV-5AVN explosive is determined to be 2.75.

Table 5. *Influence of DOS/PIB ratio on the impact sensitivity, plasticity, and adhesion of PVV-5AVN explosives.*

No.	**Mass ratio DOS/PIB**	**Impact sensitivity (%)**	**Quality of explosive obtained**
1	2	40	Poor plasticity, average adhesion
2	2.5	36	Poor plasticity, good adhesion
3	2.75	32	Good plasticity, good adhesion
4	3	32	Good plasticity, good adhesion
5	3.5	28	Good plasticity, good adhesion

3.4. Development of the fabricating process for PVV-5AVN explosives

Based on the research results, the authors have developed a technological process for fabricating PVV-5AVN explosives at a scale of 300 grams per batch. The technological process flowchart for fabricating PVV-5AVN explosives is presented in figure 3.

Here are the specific results of the technical specifications for PVV-5AVN explosives fabricated according to the described technological process, as shown in table 6 and figure 4, and figure 5.

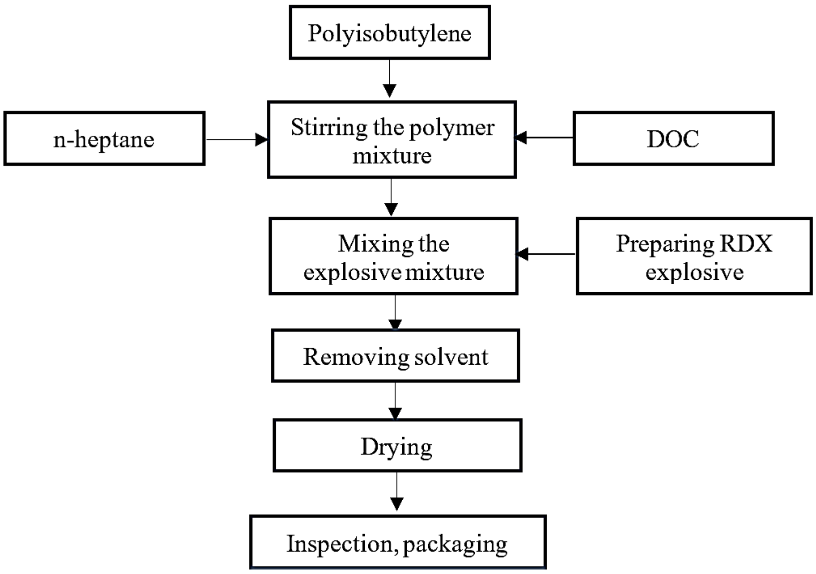

Figure 3. *Flowchart of the laboratory-scale fabrication process for PVV-5AVN explosive.*

Figure 4. *Lead cylinder before compression testing.*

Figure 5*. Lead cylinder after compression testing.*

Table 6. *Results of technical specifications of PBX explosives.*

No.	Technical specification	PVV-5AVN	PVV-5A [10]	C4-VN [15]
1	Detonation velocity (m/s)	7320 (1.40 g/cm^3)	7440 (1.40 g/cm^3)	7400 ÷ 7700 (1.45 g/cm^3)
2	Strength of explosive (% TNT)	112	-	116 ÷ 136
3	Brisance by Hess at 1.45 g/cm^3 (mm)	21.5	-	≥ 22
4	Impact sensitivity by cast hammer test (%)	32	36	8 ÷ 32
5	Vacuum stability (Stabil, cm^3/g)	0.25	-	≤ 0.26

These results demonstrate that PVV-5AVN explosive meets the specified technical requirements, exhibiting good performance characteristics such as high detonation velocity, explosive power, impact sensitivity and stability, comparable to published data.

4. CONCLUSIONS

This paper has presented a study on the effects of solvent, stirring time, and the ratios of RDX, PIB, and plasticizer on the quality and technical specifications of PVV-5AVN explosives. Based on this study, optimal conditions for fabricating PVV-5AVN explosives have been determined:

specifically, 85 ÷ 91% RDX content, 9 ÷ 15% binder system (with a DOS/PIB mass ratio of 2.75), using n-heptane solvent with a solvent/binder mass ratio of 10, and a stirring time of 3 hours for the RDX-binder mixture. From the research findings, the authors have developed a laboratory-scale fabricating process for PVV-5AVN explosives. PVV-5AVN explosive was fabricated according to the developed technological process, meeting technical requirements equivalent to PVV-5A explosive used in explosive reactive armor.

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TÓM TẮT

Nghiên cứu công nghệ chế tạo thuốc nổ PVV-5AVN dùng trong giáp phản ứng nổ

PVV-5AVN là một dạng thuốc nổ liên kết polyme (PBX), thường bao gồm hỗn hợp RDX (hexogen), một hợp chất nổ mạnh và chất kết dính polyme như polyisobutylene. Nó được ứng dụng rộng rãi trong nhiều thế hệ giáp phản ứng nổ khác nhau. Bài báo này đã nghiên cứu các yếu tố ảnh hưởng đến chất lượng và thông số kỹ thuật của thuốc nổ PVV-5AVN, bao gồm lựa chọn dung môi, tỷ lệ dung môi, thời gian trộn và tỷ lệ thành phần. Cụ thể, tỷ lệ thuốc nổ RDX từ 85÷ 91% và hệ chất kết dính từ 9 ÷ 15% (với tỷ lệ DOS/PIB là 2.75). Từ những kết quả nghiên cứu trên đã xây dựng được quy trình chế tạo thuốc nổ PVV-5AVN ở quy mô phòng thí nghiệm đáp ứng các tiêu chuẩn kỹ thuật có thể so sánh với tài liệu đã công bố.

Từ khóa: Thuốc nổ PVV-5AVN; Giáp phản ứng nổ; Polyisobutylene; PBX; RDX.