Experimental Study on Shock Initiation of Composition B Explosive

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Abstract – **With the recent rise in wars, terrorist attacks, and accidental incidents, studies on explosives science and engineering have gained significant attention in academia. Research has focused on both the lethal effects and performance characteristics of explosives, with particular emphasis on safety parameters. In this study, twelve spherical charges of Composition B (comprising 60% RDX, 39% TNT, and 1% wax) were detonated by shock initiation using RDX booster pellets. For comparison, six charges of TNT with the same shape and booster were deflagrated to highlight the differences between successful detonation and deflagration processes. The study also presents a theoretical model of shock initiation, explaining the detonation test result.**

Keywords - Explosives, Composition B, Detonation.

I. Introduction

The investigation of explosives is fundamental for forecasting their impacts and mitigating associated risks. Worldwide, there is a substantial concern regarding terrorist incidents [1], unintended harm [2], as well as accidental [3] and deliberate [4] detonations. The chemical characterization and study of reliable initiation methods are also important for the safe handling of explosives [5].

Composition B (Comp B) is a cast-loaded explosive consisting of a mixture of TNT and RDX. TNT is melted at approximately 80ºC, and then RDX crystals are added and carefully blended into the mixture. Some formulations include a desensitizing agent, such as wax [5].

This study used Brazilian Comp B, which consists of 60% RDX, 39% TNT, and 1% natural wax, a common formulation used by the defense industry in grenades, ammunition, and petards [6]. This explosive offers several advantages, including relative safety [7, 8], ease of loading, and increased power compared to TNT, due to the presence of RDX [5].

Given its significance, understanding the characteristics of Comp B is essential. The primary sources of information on Comp B are traditional manuals and explosives reference books [5, 9, 10, 11]. Although these bibliographic resources are considered reliable, they are often over two decades old and lack contemporary experimental data specific to Brazilian Comp B.

This research is a follow-up to the works of Mendonça et al. [12 - 19] and Augusto et al. [20, 21].

There is a notable lack of comprehensive, modern studies on the shock initiation properties of Comp B, especially concerning the Brazilian formulation. This paper presents a Comp B shock initiation case.

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Twelve bare spherical charges of around 330 g of Brazilian Comp B were detonated by shock initiation using RDX booster pellets. Six spherical TNT charges with the same boosters, shape and dimensions were also detonated to observe the contrasts between detonation and deflagration processes. Additionally, this article presents a theoretical framework for shock initiation to elucidate the detonation test findings.

II. Material and Methods

A. Shock Initiation of Detonation

Detonation and deflagration are two distinct combustion processes in explosive materials, primarily differentiated by their reaction speed and intensity. In detonation, the chemical reaction occurs at a supersonic velocity, typically between 1,500 and 9,000 m/s, producing a high-pressure shock wave propagating through the material. This shock wave compresses the material ahead, triggering a rapid, self-sustaining reaction and releasing a powerful, destructive burst of energy. Detonation is commonly used in military applications for its high-energy output. In contrast, deflagration is a subsonic process, relying on thermal conduction and convection to spread the reaction. This results in a slower, less intense release of energy, without forming a shock wave. Deflagration is suited for controlled combustion, such as in fireworks or gunpowder, where a gradual burn is preferable [22].

There are several methods to initiate detonation in an explosive, including temperature, pressure, heating, impact, friction, electrical spark, or another shock wave [10]. The current study focuses on the initiation of Comp B through a shock wave induced by the detonation of RDX explosive. This method is commonly used in explosive devices, where a smaller, more sensitive explosive charge initiates a subsequent, larger, and less sensitive charge. This arrangement, known as an explosive train, may require multiple layers of charges until the final main load is detonated. Such a process demands extensive knowledge and engineering, as any design flaw can result in deflagration rather than detonation, undermining the intended function of the device [23].

The prediction of whether an explosive charge will initiate another explosive can be achieved through various methods, such as field tests, theoretical calculations, empirical data, or computational simulations [10]. This study relies on a combination of theoretical and empirical methods, validated by comparison with field detonation tests, in a case study.

B. Criteria for detonation

For the purpose of this study, two criteria will be considered to determine if the explosive can initiate and sustain detonation: critical diameter and critical energy fluence. These parameters are obtained experimentally for each explosive formulation.

The critical diameter of an explosive is the minimum diameter at which a stable detonation wave can propagate through the material. Below this diameter, the explosive cannot sustain detonation and may instead undergo deflagration or fail to react completely. Critical diameter varies based on factors such as the type of explosive, confinement conditions, and environmental factors, and is essential in designing safe and effective explosive charges [23].

The critical energy fluence is the minimum energy per unit area needed to initiate a self-sustaining detonation in an explosive. If the energy fluence is below this threshold, the detonation will not propagate, resulting in failed initiation. Experiments to determine this parameter often use shock waves generated by flying disks to simulate the necessary conditions for reliable detonation. These shock waves can be compared to those produced by induced detonation waves [9].

Table I presents these parameters for the explosives used in the current study under equivalent conditions: casted (Comp B and TNT), bare, unconfined, and with similar densities.

TABLE I. CRITICAL DIAMETER AND ENERGY FLUENCE FOR THE UNCONFINED EXPLOSIVES USED IN THE STUDY [9]

Explosive	***Critical Diameter (mm)***	***Critical Energy Fluence (cal/cm²)***
Comp B	3.73 - 4.24	44
RDX	5.20	-
TNT	14.50	100

C. Detonation shockwave

The Rankine-Hugoniot Jump Equations describe the relationships between pressure (P), density (ρ), particles velocity (u), and energy (e) across shock waves, grounded in the conservation principles of mass, momentum, and energy in unidirectional wave propagation at velocity U. This theory assumes a continuous and isotropic medium, adiabatic compression, and equilibrium conditions before and after the shock [10]. A brief overview of this theory will be presented in this article.

Considering that the material was stationary prior to the shock wave impact ($u_0 = 0$), these equations can be summarized in (1) - (3) [23].

$$\begin{cases} mass: \dfrac{\rho_0}{\rho_1} = \dfrac{v_0}{v_1} = \dfrac{U}{U - u_1} & (1) \\ momentum: P_1 - P_0 = \rho_0 u_1 U & (2) \\ energy: e_1 - e_0 = 0.5\,(P_1 + P_0)(v_0 - v_1) & (3) \end{cases}$$

Where v is the specific volume, the subscript 0 indicates the conditions in the material before the shock wave impact, and the subscript 1 represents the conditions in the material after affected by the shock wave.

These equations have multiple solutions, with the resulting curves known as the Hugoniot planes. To solve the problem, certain assumptions must be made. The first relation establishes a correlation between U and u, as shown in (4) [23].

$$U = C_0 + s\,u_1 \tag{4}$$

Where C_0 and s are material-specific constants that must be determined experimentally. The combination of the (2) and (4), assuming $P_0 = 0$, results in Hugoniot P-u plane, as shown in (5) [10].

$$P_1 = \rho_0 u_1 C_0 + \rho_0 u_1^2\, s \tag{5}$$

This P-u plane describes the possible combinations of pressure and particles velocity that an intact material can experience when impacted by a shock wave. A target explosive will adhere to this equation before initiating detonation [10].

For an explosive undergoing a detonation process, additional concepts must be introduced, beginning with the Chapman-Jouguet (CJ) point. The CJ point is a condition on the Hugoniot planes where the detonation shock wave travels at a velocity that establishes stable pressure and density in the detonation products immediately behind the shock front. At this point, a specific pressure, known as the CJ pressure (P_{CJ}), is reached. In a detonating explosive, the shock wave propagates at a velocity known as the detonation velocity (D). Both P_{CJ} and D are determined through detonation tests and are unique to each type of explosive. In essence, the CJ point represents the equilibrium conditions at the shock front of a detonation wave [10].

Applying these concepts in (2), it is possible to demonstrate that the particles velocity at the CJ point (u_{CJ}) is determined by (6) [23].

$$u_{CJ} = \frac{P_{CJ}}{D\rho_0} \tag{6}$$

The empirical equation presented in (7), derived from numerous experiments with various explosives, represents the Hugoniot P-u plane for the detonation shock wave under conditions beyond the equilibrium CJ point [10].

$$P_1 = 2.414 P_{CJ} - \left(\frac{1.7315\, P_{CJ}}{u_{CJ}}\right) u_1 + \left(\frac{0.3195\, P_{CJ}}{u_{CJ}^2}\right) u_1^2 \tag{7}$$

When the detonation shock front of an explosive impacts a target material, it induces a mechanical shock wave in the target that follows (5). This collision shifts the detonation shock wave from its CJ equilibrium point, causing it to follow (7). In the collision region, the pressure (P_1) and particle velocity (u_1) must be equal at both the explosive shock front and the target material shock wave, adhering to the conservation of momentum and mass. Thus, (5) and (7) must share the same P_1 and u_1 values. With two equations and two unknowns, it is possible to solve for the Hugoniot P-u plane, defining the interaction between a detonation shock wave and a target material [10]. This process is illustrated in Fig. 1, considering that the target material is an explosive.

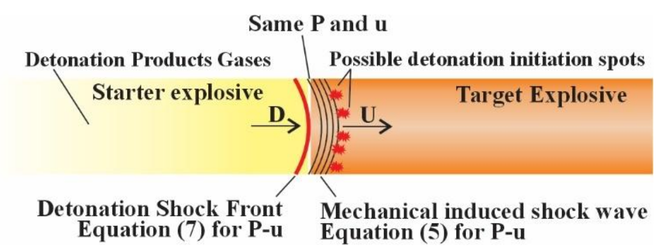

Fig. 1. Diagram of shock wave induced by a detonation shock front.

Once the shock wave parameters induced in the target material by the detonation shock front are determined, the energy generated by this wave can be calculated. The energy density (*e*) per area (*A*) is derived from the rate of work (*W*) equation, taking into account the shock wave duration (*t*), as shown in (8) [10].

$$W = P_1\, u_1\, A \rightarrow e = \frac{Wt}{A} = P_1\, u_1 t \tag{8}$$

Equation (9) is derived from (2) and (8), enabling the calculation of energy density using the induced shock wave parameters [9].

$$e = \frac{{P_1}^2 t}{\rho_0 U} \tag{9}$$

The duration of the detonation shock wave (*t*) can be calculated using (10).

$$t = \frac{r}{D} \tag{10}$$

Where *r* is the detonation reaction length and *D* is the detonation velocity of the explosive.

The energy per area calculated using (9) can be compared with the minimum required critical energy fluence (Table I) to determine whether the target explosive will initiate considering these criteria [9].

Table II presents the detonation parameters of RDX, used as the starter explosive, as well as the shock wave characteristics of TNT and Comp B, which served as the target explosives [10].

TABLE II. DETONATION PARAMETERS FOR STARTER EXPLOSIVE AND SHOCK WAVE PARAMETERS FOR TARGET EXPLOSIVES [10]

			RDX	***Comp B***	***TNT***
Density	ρ_0	kg/m³	1,600	1,671	1,595
Detonation Parameters	D	m/s	8,130	-	-
	P_{CJ}	GPa	26	-	-
	r	mm	0.83	-	-
Shock Wave Parameters	C_0	m/s	-	2,950	2,987
	s	-	-	1.58	1.36

D. Field detonation tests

Twelve charges of Comp B and six charges of TNT were initiated to verify successful detonation at IAE's field test site. All charges were spherical and bare, avoiding any debris. Each Comp B charge weighed 334 ± 1 g, with a diameter of 71.4 ± 0.1 mm. A central cavity measuring 8.0 ± 0.1 mm in diameter and 46.0 ± 0.1 mm in depth was included to allow for central initiation. The initiation system consisted of an electric No. 8 blasting cap, used to detonate booster pellets made of compressed RDX. Each RDX pellet measured 7.5 ± 0.3 mm in diameter, 18.0 ± 0.25 mm in length, and weighed 1.41 ± 0.01 g. The TNT charges had the same external dimensions but weighed 328 ± 2 g due to their lower density.

The electric No. 8 blasting caps were used to detonate the bare and the compressed RDX pellets. These pellets were placed in the central cavity of each charge, ensuring direct, gap-free contact between the RDX and the target explosive charges. The cavity depth was sufficient to hold one or two RDX pellets, allowing adjustments during testing.

All twelve Comp B charges detonated successfully, with no failures. Six of these charges were initiated with a single RDX pellet, and the other six with two pellets. On the other hand, all TNT charges failed to initiate, displaying a deflagration process, even using two RDX pellet boosters in all six tests. These results will be discussed in more detail later.

During the explosive tests, a pair of shock wave measuring systems (MSS), model B261 from High Pressure Instrument Company, were set up to record the atmospheric overpressure generated by the detonation over time. These systems use high-sensitivity, high-load capacity piezoelectric sensors with a linearity of 2% of the full scale. The MSS units were positioned 3.114 m from the detonation center and configurated to measure pressures between a maximum of 1.5 bar and a minimum of 0.05 bar.

The peak overpressures measured during the tests were compared with the established Kingery & Bulmash (K&B) equations [24], which are used by organizations such as the United Nations [2] and the U.S. Department of Defense [3] for predicting blast effects. These equations provide estimates of overpressure and other important blast parameters for spherical charges, using certain parameterizations, such as TNT equivalence. For Comp B, two values of TNT equivalence from different sources were considered: 1.28 [25] and 1.48 [26]. By comparing the expected overpressure values with the test results, it was possible to confirm whether a full detonation occurred.

The detonation events were recorded by two high-speed cameras (HSC) positioned over 30 meters away from the explosives to ensure protection from potential damage. The cameras used were Phantom VEO 640 models, with specifications provided in the manufacturer's datasheet [27]. Each camera was equipped with Nikkor 50mm f/1.2 lenses. One camera recorded at 20,000 frames per second (fps) with a resolution of 256 x 480 pixels, while the other captured at 8,000 fps with a resolution of 768 x 720 pixels. Both cameras recorded up to 140 ms of each event.

As shown in Fig. 2, the explosives were positioned 1.4 m above ground, suspended by a nylon rope attached to a bamboo pole—materials selected to prevent dangerous debris. Fuse wires connected the electric blasting cap to the test management bunker, where the technical team remained secure, more than 30 meters from the detonation site.

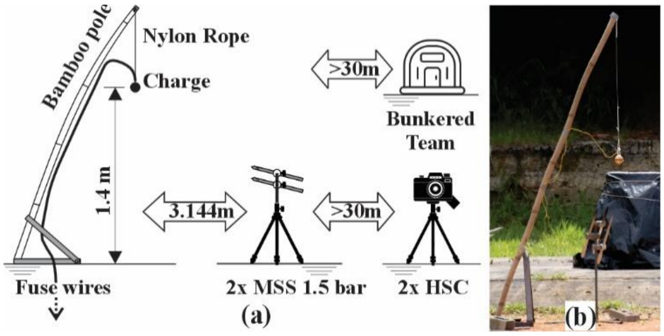

Fig. 2. Diagram of the detonation field test (a) and a photograph of the actual setup before detonation (b).

III. Results and Analysis

A. Theoretical and Test Results

The solution of (5) and (7), using data from Table II, is presented in Table III, with values compared to the threshold values in Table I. The calculated duration of the detonation shock wave (*t*) was 101.60 ns.

The eighteen detonation test fields were completed without incidents, and the results aligned with theoretical calculations. All twelve Comp B charges detonated successfully, using either one or two RDX pellets as boosters. As anticipated, however, the TNT charges did not detonate, even with two RDX pellets. These findings are supported by peak atmospheric overpressure measurements from the MSS during the tests. In the Comp B tests, the pressure aligned with theoretical calculations for a detonation. Conversely, during the TNT tests, no data was recorded, as the overpressure remained below the system threshold of 0.05 bar. This outcome demonstrates that TNT did not detonate, as the expected peak overpressure was 0.37 bar. Table IV presents the peak overpressure measured by the MSS in comparison to expected values

Fig. 3 presents the HSC results for one test of each explosive type. The footage from the Comp B detonation tests (Fig. 3.a) was similar across all twelve tests, regardless of whether one or two RDX boosters were used. Similarly, the footage from the six TNT deflagration tests (Fig. 3.b) was identical. Each test is displayed in eight frames, illustrating the evolution of both reactions over the same time period following initiation.

TABLE III. SHOCK INITIATION THEORETICAL CALCULATION RESULTS

Explosive	*Shock Diameter mm*	*Critical Diameter mm*	P_1 *GPa*	u_1 *m/s*	*U m/s*	*e generated Cal/cm²*	*e required Cal/cm²*
RDX	7.50	5.20	-	-	-	-	-
Comp B	7.50	3.73 - 4.24	23.40	2,186.67	6,404.94	124	44
TNT	7.50	14.50	22.17	2,280.15	6,094.84	123	100

TABLE IV. PEAK OVERPRESSURE EXPERIMENTAL DATA COMPARISON IO THEORETICAL EXPECTED RESULTS.

Explosive type	*Sensor*	*Peak overpressure(bar)*								
		Test 1	*Test 2*	*Test 3*	*Test 4*	*Test 5*	*Test 6*	*Average*	*Ref. 1*	*Ref. 2*
Comp B with 2 RDX booster pellets	1	0.50	0.48	0.48	0.47	0.48	0.49	0.47± 0.01	0.49	0.45
	2	0.47	0.46	0.43	0.45	0.47	0.47			
Comp B with 1 RDX booster pellet	1	0.47	0.49	0.50	0.50	0.49	0.52	0.49± 0.01	0.49	0.45
	2	0.50	0.46	0.50	0.48	0.48	0.49			
TNT with 2 RDX booster pellets	Both	In all TNT tests, the pressure stayed below the minimum of 0.05 bar, with no recorded data.						≤ 0.05	0.37	0.37

TNT equivalence references: Ref. 1. [25]; and Ref. 2. [26].

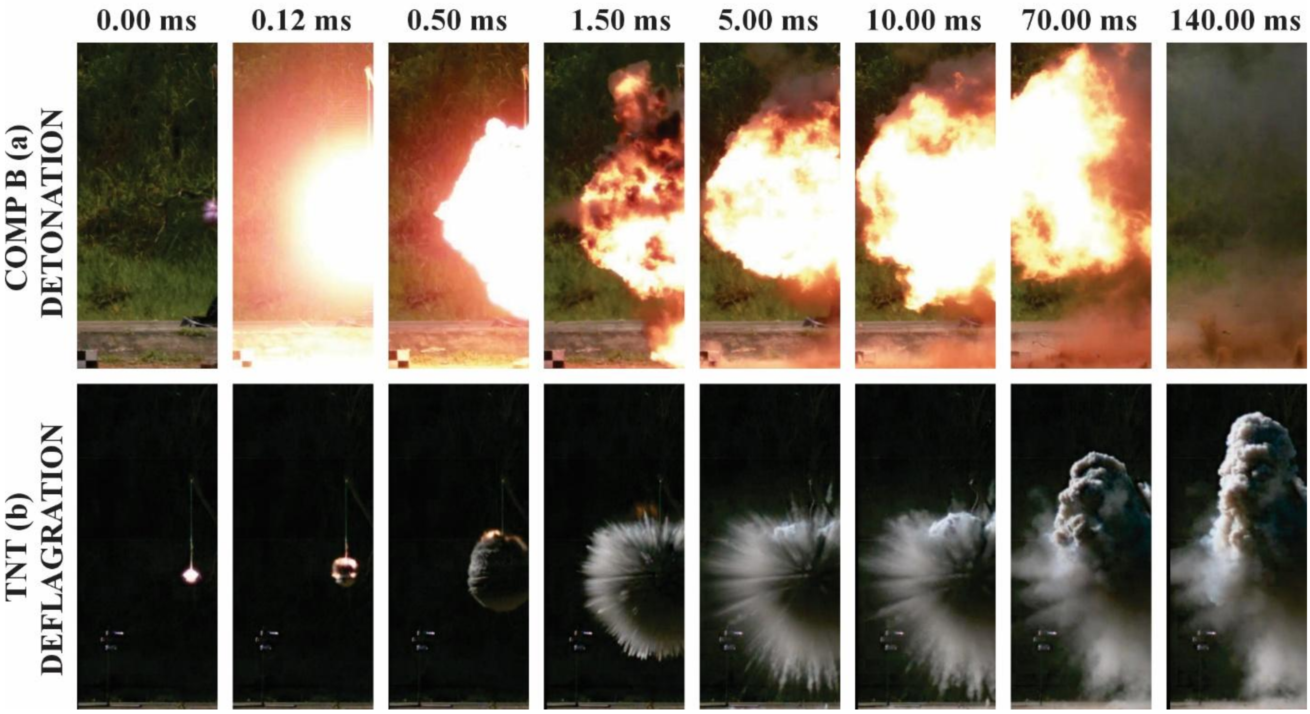

Fig. 3. High-speedy camera frames for a Comp B detonation (a) and a TNT deflagration (b). All tests presented similar results for the same explosive. The footage shows just half of the test, as the process were all symmetric. The timestamps indicate the elapsed time since initiation.

B. Analysis

Theoretical prediction results, using Rankine-Hugoniot and Chapman-Jouguet theories as presented in Table III, indicate that the Comp B charge should be capable of initiation by the RDX booster and able to sustain the detonation reaction during field tests while maintaining the same diameter. Although the TNT charges receive sufficient shock energy to initiate detonation, the booster shock front lacks the minimum critical diameter required for TNT to sustain the reaction, causing it to revert to a deflagration process. The field test results confirmed this prediction.

According to these theories, the energy generated by the shock wave induced by the RDX booster detonation was about 120 Cal/cm² for both explosives. For Comp B, this energy is sufficient to initiate a detonation with a comfortable margin, as the experimental minimum fluence energy value is 44 Cal/cm². For TNT, however, the margin is much smaller, as the experimental threshold value is 100 Cal/cm².

It is important to note that the RDX pellets had a diameter of 7.5 mm, producing a detonation with similar dimensions in the target explosive. As previously described, for an explosive to sustain a detonation reaction, it must meet a minimum diameter, known as the critical diameter. Both Comp B and RDX have critical diameters smaller than 7.5 mm, enabling them to sustain a detonation at this dimension. However, the critical diameter of cast and unconfined TNT is 14.5 mm, nearly double what the booster could generate. For this reason, it was anticipated that TNT would not be able to detonate.

The test configuration and choice of explosives took these factors into consideration. The main objective was to study the detonation behavior of Comp B when initiated by RDX pellets and to verify the accuracy of the theoretical predictions. TNT charges were used for comparison, as it was anticipated they would not detonate, allowing observation of the differences between detonation and deflagration processes.

As previously described, during the detonation field tests, the primary method for verifying the occurrence of detonation was the measurement of blast overpressure, as this parameter could be compared with theoretical calculations. As shown in Table IV, all atmospheric peak overpressures for Comp B were consistent with detonation events. Notably, the use of one or two booster pellets did not significantly affect the results, with the average overpressure for one pellet being approximately 4% higher than for two pellets. Considering that the pressure sensor's linearity is within 2% of the full scale, this difference is likely attributable to the equipment's natural imprecision.

This provides further indication that the theory employed, which did not account for the booster's length or mass, can be considered valuable for predicting shock initiation. The type of explosive and its diameter appeared to have more significant influence than the booster's size. However, additional studies are necessary to confirm with greater precision whether these conditions hold true across all scenarios.

As expected, the TNT charges did not detonate. The first indication was the low air pressure generated, measured below 0.05 bar, which is the minimum detectable value for the MSS. For reference, a pressure of 0.37 bar would have been expected if TNT had detonated. Additional observations during the field test provided further indications, such as low noise levels, a smell of burnt gunpowder at the test site, the production of fumes, and the absence of ground vibrations. In contrast, during the detonation of Comp B, the observations were entirely opposite: strong noise and vibrations, with no residual smell or fumes.

The HSC footage provides crucial observations highlighting the differences between both scenarios, as shown in Fig. 3. The first notable difference is in reaction velocity. At 0.12 ms after initiation, Comp B had completely reacted, releasing a massive amount of energy, evidenced by the intense light. In contrast, during the same time frame, TNT was still in the early stages of its deflagration process. At 140 ms, no residual material or ongoing reaction was observed in the detonation of Comp B, whereas for TNT, significant material and fumes were still being dispersed.

Another important observation is the difference in light emission. While the detonation produced a bright luminescent fireball, caused by the afterburning of hot reaction products in contact with the atmosphere, the TNT reaction was obscured by residual material released during deflagration. Since the deflagration reaction is significantly slower than the mechanical shock wave produced, and the explosive is unconfined, particles are ejected faster than the reaction can consume them. This accounts for the strong residual smell in the area. After a much longer time compared to the detonation reaction, a portion of the particulate explosive begins to react, producing fumes indicative of an incomplete reaction.

In other words, an unconfined explosive undergoing deflagration will crack and disperse before the reaction can reach all the material, resulting in significant energy loss. The slower reaction inherently reduces the ability to generate concentrated power compared to a detonation. This is demonstrated by the very low overpressure generated.

IV. Conclusion

A Comp B batch was loaded into twelve spherical, bare charges of approximately 330 g each and detonated using RDX booster pellets in field tests. Each pellet weighed 1.4 g and had a diameter of 7.5 mm. All charges detonated successfully, as confirmed by air pressure measurements and high-speed camera footage. These findings highlight the safety and good performance of this Comp B formulation.

A reliable theory for the shock initiation of Comp B was also presented. For comparison, TNT charges of the same shape and size were initiated using the same RDX booster. However, for TNT, the theory predicted that detonation would not occur due to the lack of a sufficient critical diameter for this explosive, which was confirmed in the tests. This research provided valuable insights into the differences between detonation and deflagration processes. Further studies are required to validate the theory under different scenarios and with other explosives.

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