Simulation of printer nozzle for 3D printing TNT/HMX based melt-cast explosive

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Received: 6 June 2021 / Accepted: 19 December 2021 / Published online: 5 January 2022
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Abstract
Fused deposition modeling (FDM) as one of the additive manufacturing (AM) technologies has been widely used in various manufacturing industries to fabricate products with complex structures; however, the application of FDM in energetic materials (EMs) was still less common. In this work, the effect of HMX solid content and particle size on the viscosity of molten TNT/HMX explosives were investigated. Then, the computational fluid dynamics (CFD) and discrete element method (DEM) were used to simulate the influence of viscosity, pressure, temperature, nozzle diameter, and particles on the fluid flow inside the 3D printer nozzle. In addition, an FDM 3D printer was used to prepare TNT/HMX-based explosives, and various characterization methods were applied to explore the structure and morphology of printed samples. This work provided guidelines for FDM technology to fabricate EMs and proved that FDM was more suitable than the conventional melt-casting method to prepare explosives with high viscosity and special-shaped structures.

Keywords 3D printing · FDM · TNT/HMX · FLUENT · Numerical simulation

1 Introduction

Recently, additive manufacturing (AM) or 3D printing (3DP) technology has attracted a lot of attention from the science and engineering communities due to its ability to print multiple materials and offer a much wider application prospect than the usual manufacturing methods, such as casting and machining [1]. Generally, 3DP fabrication process steps consist of (i) creating computer-aided design (CAD) model, (ii) generating stereolithography (STL) format file, (iii) slicing the design, (iv) creating tool path, (v) printing the design in the 3D printer, and (vi) finally post-processing [2]. Thus, the 3D printed products can reduce the waste of raw materials and maintain the geometric accuracy of products. Generally speaking, 3DP can be divided into many types according to the difference of manufacturing process and characteristics of the used raw materials [3], such as stereolithography (SL) [4], Polyjet [5], fused deposition modeling (FDM) [6], laminated object manufacturing (LOM) [7], selective laser sintering (SLS) [8], laminated engineering net shaping (LENS) [9], electron beam melting (EBM) [10], Prometal [11], and so on.

For the past few years, 3DP technology has been used to fabricate solid propellants, explosives, and pyrotechnics. Hu et al. used 3D vat photopolymerization technology to fabricate gun propellant which was mainly composed of hexogen (RDX) and photosensitive resin binder, and the tested mechanical strength at room temperature was comparable to conventional gun propellant [12]. He et al. prepared gradient structured HMX/Al composite via 3D printing technology by using well-dispersed HMX/Al-based ink. The tested results have shown that the burning rate and reaction heat can be controlled by adjusting the component ratio, which indicated that 3DP technology can be an effective approach
to control the combustion performance and energy output of explosives [13]. Huang et al. prepared three different CL-20/TATB composite charge structures by 3DP technology, which proved that 3D printing technology was suitable for complex pyrotechnics charge structure and explosive charge structure [14]. McClain et al. adopted a new AM technique (vibration-assisted printing, VAP) to fabricate propellant; surprisingly, the printed layered propellant was able to survive under higher pressure (1500 psi) than the cast layered propellant (200 psi) [15]. Chandru et al. adopted a direct extrusion-based 3D printing technique to manufacture composite propellant grains, and the 3D printed propellants possess higher density and elastic modulus (1.63 g·cm⁻³, 3.91 MPa) than conventionally casted propellants [16]. To overcome the limitation of traditional extrusion technologies, Yang et al. prepared gun propellant by using SLA technology, and the tested results have shown that no holes or defects in the gun propellant, and the compression strength and tensile strength were 21.6 MPa and 7.3 MPa, respectively [17]. It can be seen from the previous researches that the 3DP technology was a novel way to fabricate propellants with excellent performance. FDM as one of the 3DP technologies, as the process evolves, was being increasingly used in areas such as bioengineering and the aerospace and automotive industries [18]. Lower price, higher speed, and convenience of the process were the main advantages of FDM. In the FDM technology, a thermoplastic polymer was used to print layers of materials, the filament was heated at the nozzle to reach a molten or semi-liquid state and then extruded on the platform or top of previously printed layers. After finished a layer, the platform held the part moved vertically in the Z direction to begin deposited a new layer on the previous layer. The thermoplasticity of the polymer filament was the essential property for this method, which allowed the filaments to fuse and solidify at room temperature after printing [19]. In fact, FDM is not only suitable for conventional thermoplastic material, such as polycarbonate (PC) [20], polylactic acid (PLA) [21], polystyrene (PS) [22] and acrylonitrile butadiene styrene (ABS) [23], but also suitable for metal [24], ceramics [25] and biomaterials [26]. In addition, there is no doubt that FDM can be applied to fabricate explosives, and previous studies have been proved this view [27].

Trinitrotoluene (TNT) has been widely used in mortars, grenades, artillery shells, warheads, and antipersonnel mines due to its low melting temperature (80.6 °C), good compatibility with other explosives, stability in a molten condition, and high decomposition temperature (240 °C) [28–30], and these characteristics also make TNT-based explosives more suitable for FDM. For example, the TNO has been successfully printed a TNT 3D product by using FDM technology [31]. In addition, TNT was less powerful and other high-energetic compounds were often incorporated with TNT to increase the efficiency of the composition, such as HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine). Xiao et al. prepared TNT/HMX based grains by using an independently developed explosive 3D printing principle prototype, the tested results have shown that the 3D printed grains have more compacting internal structures with the density of 1.65 g·cm⁻³, the compressive strength of 5.56 MPa, and the detonation velocity of 7143 m·s⁻¹ [32]. Thus, FDM technology provided an innovative and reliable manufacturing way for TNT-based explosives with special-shaped structures and excellent mechanical strength.

To explore the field of 3D printing TNT/HMX-based explosives, the viscosity of molten TNT/HMX explosives was investigated. And then, the CFD and DEM were used to analyze the influence of viscosity, pressure, nozzle diameter, and particle size on the fluid flow inside the nozzle. Finally, an FDM 3D printer was used to prepare the TNT/HMX-based explosive, the morphology and properties of the printed sample were investigated by various characterization methods. This work layed a technical foundation for the fabrication of special-shaped explosives.

2 Materials and methods

2.1 Raw materials and instruments

High-quality grade TNT and HMX with a purity of 99.9% were obtained from the Gansu Yinguang Chemical Industry Group Co., Ltd. Malvern Mastersizer 2000 particle analyzer was used to measure the particle distribution of HMX. HLG-50 ball mill was used to obtain HMX with four different particle sizes (1, 6, 13, and 20 μm), and the particle distribution was shown in Fig. 1. K6-MPC-NR Huber oil bath was used

![Fig. 1 Particle distribution of HMX with four different particle sizes](image-url)
to provide heat for melting and maintaining the temperature of molten TNT/HMX-based explosives. Brookfield Digital Viscometer was used to measure the viscosity of molten TNT/HMX-based explosives. EAM-D-1 3D printer (Nanjing University of Science and Technology) was used to print TNT/HMX-based explosives. The thermal decomposition studies of the 3D printed sample were carried out by using the technique of Differential Scanning Calorimeter (DSC, NETZSCH STA 449 C). X-ray diffraction (XRD) data of the printed samples were collected at room temperature on a Rigaku smartlab9 X-ray diffractometer. An Optical microscope (OM, OLYMPUS BX53) and scanning electron microscope (SEM, Phenom G2 Pro) were adopted to investigate the morphology of the 3D printed samples.

2.2 Simplified model of the 3D printer nozzle

To simulate the temperature distribution of the nozzle shell during printing, the 3D model of the nozzle was designed in SolidWorks software according to actual measured size, the initial geometry of the object was constructed and meshed, as shown in Fig. 2a, b. The total length of the nozzle was 14.4 mm, the diameter of the inlet was 4 mm. In addition, to simplify the process and improve accuracy, the external structure of the nozzle was omitted. The flow channel model of the nozzle was established by SolidWorks software to simulate changes in pressure and velocity of the internal flow field, as shown in Fig. 2c, d. The model would be imported into ICEM CFD software. The inlet, outlet, and wall were all defined in the ANSYS Mesh component system, and the finite element model would be imported into FLUENT software to carry out the fluid analysis.

3 Results and discussion

3.1 Effect of HMX content and particle size on the viscosity of TNT/HMX based explosives

As is known to us, the HMX particle size and its solid content can change the viscosity of TNT/HMX-based molten explosives and affect the printing process in the end. For this purpose, the effect of HMX solid content and particle size on the viscosity of molten TNT/HMX explosives was investigated. Firstly, the TNT was placed in the Huber oil bath at 95 °C and prepared to melt. After the TNT completely liquefied, HMX was added to the TNT, meanwhile, continuous stirring and ultrasonic vibration were performed to ensure uniformly mixed and remove air bubbles suspended in the molten explosives. Brookfield Digital Viscometer (Model DV-I) was used to measure the viscosity of the molten explosives, the 3D model of the cone-plate rotor as shown in Fig. 3. And the effect of HMX content and particle size on the viscosity of molten TNT/HMX mixtures as shown in Fig. 4.

![Fig. 2](image-url) (a) 3D model of the nozzle; (b) nozzle model after meshed; (c) 3D model of the flow channel; (d) flow channel model after meshed.

![Fig. 3](image-url) 3D model of the cone-plate rotor
Figure 4 inferred that with the increased content of HMX in TNT, the viscosity increased accordingly. For a molten explosive with the same viscosity, the larger the particle size, the higher the maximum solid content, because at the same solid content, the smaller particle size led to the larger number of particles contained, which reduced the average distance between particles. A relatively strong network structure was formed between particles, and the force required to break this structure increased, so the shear stress increased and viscosity increased accordingly. Besides, as the number of particles increased, the total effective volume of the particles increased, which can be attributed to the surface adsorption effect. A film was formed on the surface, which makes the effective volume larger than the real volume, increasing the displacement resistance. Based on viscosity data, the viscosities of 7500, 10,000, 15,000, 20,000, and 25,000 mPa·s were used for the following simulations. Generally speaking, the HMX particles tended to sink to the bottom because of the density difference with molten TNT, and the settling velocity can be described by Stokes’ Law, as shown in Eq. (1):

\[ u = \frac{g d^2 (\rho_1 - \rho_2)}{18 \mu} \]

where \( u \) was the settling velocity of HMX particles in molten TNT, \( g \) was the acceleration due to gravity, \( d \) was the diameter of HMX particles, \( \rho_1 \) and \( \rho_2 \) represented the densities of HMX particles and molten TNT, respectively; and \( \mu \) was the dynamic viscosity of molten TNT/HMX mixtures. It can be seen that viscosity was one of the important influencing factors of settling velocity, and previous research has shown poor fluidity of molten TNT/HMX-based explosives when the viscosity was greater than 7500 mPa·s \[32\], which also indicated that the settling velocity of HMX was so slow that cannot influence the 3D printing process. Therefore, the molten TNT/HMX mixtures can be taken as a melt for further simulation.

### 3.2 Simulation results

#### 3.2.1 Effect of viscosity on velocity

The meshed flow channel model was imported into FLUENT software. The inlet pressure was set to 100 kPa and kept unchanged; meanwhile, the fluid viscosities of 7500, 10,000, 15,000, 20,000, and 25,000 mPa·s were selected to represent the changes of molten explosives in the flow channel. The velocity distribution in the flow channel was obtained, and the velocity contour at 25,000 mPa·s was shown in Fig. 5. The velocity of fluid was low on the top and changes sharply where the nozzle became thinner and the velocity decreased from the center to the periphery. The results of speed distribution have shown that all velocity distribution diagrams with different viscosity only differ in...
numerical values. Figure 5 presented the velocity contour of the flow channel with the viscosity of 25,000 mPa·s; it can be noticed from Fig. 5 that the red part had the highest speed, which also represented the printing speed, so this velocity was selected for further analyses.

The effect of viscosity on velocity was measured at 100 kPa pressure and the obtained data were presented in Fig. 6. The velocity of the fluid decreased in a nonlinear relation with the increased fluid viscosity, meanwhile, the slope of the curve also decreased, which can be attributed to the friction of the wall. The expression of the fitting curve as shown in Eq. (2):

\[
y = 69.5831x^{-0.9835} \quad R^2 = 0.999
\]  

(2)

3.2.2 Effect of pressure on velocity

The plunger 3D printer extrudes the energetic material from the nozzle by changing the pressure, so the change of the extrusion pressure has a significant impact on the printing effect. Adjusting the extrusion pressure to achieve the best printing effect is also the most convenient and commonly used method. Previous research has shown that the nozzle’s suitable pressure can be obtained by simulation. Yao et al. detailed the influence of direct writing pressure on the ink flow process [33]. Aiman et al. observed the pressure drop along the liquefier with different nozzle diameters by using the Finite Element Analysis (FEA) method [34]. In this paper, the relationship between extrusion pressure and the flow rate was simulated. The viscosity was set to 15,000 mPa·s, and the extrusion pressure was set to 80, 90, 100, 110, and 120 kPa, respectively. The expression of the fitting curve as followed:

\[
y = 0.04769x + 0.0762 \quad R^2 = 0.999
\]  

(3)

It can be seen from Fig. 7 that as pressure increased, the maximum velocity of the fluid in the nozzle increased accordingly. In addition, there was a clear linear relationship...
between the pressure (80–120 kPa) and velocity, which indicated that pressure was a very important parameter for the adjustment of print quality.

### 3.2.3 Effect of nozzle diameter on velocity

Another critical element that had a high impact on the 3D printing process is the nozzle diameter, and the nozzle diameter had a direct relationship with the outlet velocity, especially its flowability [35]. The nozzle with a large diameter will lead to difficulty in forming, while a small diameter may cause nozzle clogging. In our approach, we used different nozzle diameters ranging from 0.1 mm to 0.7 mm, this work was done to determine which diameter of the nozzle is optimal for printing. To investigate the effect of nozzle diameter on velocity, set the pressure to 100 kPa and the viscosity to 15,000 mPa·s. Velocity of fluid was measured at seven different nozzle diameters (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7 mm). The relationship between nozzle diameter and velocity as shown in Fig. 8. It can be seen clearly that as the nozzle diameter increased, the velocity increased accordingly. The expression of the fitting curve as followed:

\[
y = 8.3516x^{1.9635} \quad R^2 = 0.999
\]

### 3.2.4 The move motion of HMX particle inside the nozzle

In recent years, the Discrete Element Method (DEM) has been widely applied to various powder systems to evaluate contact force acting on a computational particle, and the adequacy of DEM has been proven in countless studies, but, the fluid flow was also important in many engineering applications; therefore, the DEM coupled with CFD was regarded to be a standard approach in a numerical calculation of fluid–solid flow [36–38]. In this section, a coupled CFD-DEM method was used to explore the move motion of HMX particles inside the nozzle. The pressure-inlet and viscosity were set to 100 kPa and 15,000 mPa·s, respectively. As shown in Fig. 9a, a particle factory was built in the nozzle, and the density and the diameter were 1.98×10³ kg·m⁻³ and 20 μm, respectively. A large number of particles will make the calculation results unreasonable, thus, just 5×10⁴ particles were considered and the whole simulation was carried out for 0.05 s. Figure 9b–f shown the front view and vertical view of the nozzle at different times. It can be seen that when t = 0.01 s, the 20 μm particles filled the nozzle and started to move to the outlet under the force of extrusion and gravity. When t = 0.02–0.05 s, most of the particles left the nozzle and the velocity of particles increased gradually from the top part to the outlet. Moreover, it can be noticed from the vertical view that the velocity of particles close to the wall was lower than other positions, which was caused by the friction between fluid/particles and the wall.

### 3.2.5 Simulation analysis of temperature

A great deal of fundamental research relevant to FDM processes has been performed since FDM was recognized as the most commercialized 3D printing process. The study of printing parameters on characteristics of the final products is a crucial topic to improve quality [39]. In this section, the FDM used TNT/HMX based explosives as raw material and then dispensed them on the plate layer-by-layer to produce the desired 3D structure. Thus, the temperature is also important in the printing process. According to the
characteristics of TNT-based explosives, set the inlet temperature to 373.3 K and observe the temperature decreasing along the flow channel. The fluid viscosity was set to 15,000 mPa·s, the inlet velocity of fluid was set to 40 mm/s, and the material property of the nozzle was structural steel.

As shown in Fig. 10, the inlet and outlet temperatures changed slightly, but at the end of the flow channel, due to the narrowing of the flow channel suddenly, which resulted in the reduction of the temperature. The difference between the highest temperature and the lowest temperature was 2.3 °C. The simulation can be applied to check the actual working conditions. In addition, the temperature distribution of the nozzle was analyzed, and the nozzle was heated by a constant heating tube and regarded the top surface of the nozzle as the heating face. Once the heat transfer reached a dynamic equilibrium, there is no heat exchange that occurs with the outside, and the internal temperature remains constant. The steady-state thermal module was selected to simulate the temperature distribution of the nozzle. The material of the nozzle was structural steel.

It can be seen from Fig. 11 that temperature decreased from top to bottom, about 3.4 °C difference between maximum temperature and minimum temperature. According to the simulation results, it illustrated that the nozzle with this structure can effectively avoid the blockage of the material due to the decreased temperature before extrusion, these simulated results can provide theoretical support for the selection of nozzle configuration and heating temperature.

As shown in Fig. 12, the temperature of the nozzle gradually decreased from top to bottom and changed rapidly between points 1 and 2. Because in this position the nozzle diameter was larger than other positions and the area contact with air was bigger, which caused the temperature dropped faster than in other positions. However, it can be noticed that all the temperatures were higher than the melting point of TNT, which indicated the molten explosives will not solidify again in the nozzle.

3.3 3D printing TNT/HMX-based explosives

3.3.1 Particle distribution and morphology

The HMX particles ($d_{50} = 6.3 \mu$m) used for 3D printing were fabricated by a bi-directional bead mill, the SEM patterns of raw HMX and milled HMX as shown in Fig. 13. It can be seen that the raw HMX was prismatic and the milled HMX was plate-shaped, the detailed particle distribution as shown in Fig. 14.
3.3.2 TNT/HMX based explosives prepared by FDM 3D printer

A self-developed EAM-D-1 FDM 3D printer was adopted to fabricate TNT/HMX-based explosives, according to the tested data between printer and formulations, the formulations with the loading of TNT and HMX ($d_{50} = 6.3 \, \mu m$) were both restricted to 50% by weight was regarded as the most printable formulation for this printer. Moreover, the ring-structures model used for 3D printing as shown in Fig. 15, the nozzle diameter was 6 mm, and layer height was 0.2 mm.

Figure 16a showed the flow chart of 3D printing TNT/HMX-based explosives and Fig. 16b presented the prepared sample. From the optical micrograph of Fig. 16c, the grooves can be found clearly between layer and layer, and the surface was smooth without scratches and defects. Figure 16d was the SEM image of products (sectional
Figure 16e was the SEM images of products (front view), it can be seen that almost every layer was divided into two parts, and the bottom of every layer was tightly filled but at the top part existed many small holes. During the printing process, the molten explosives will gradually solidify after being extruded from the nozzle, and the top parts were solidified faster than the bottom due to contact with the air. Moreover, the bottom parts can be influenced by the extrusion pressure from the nozzle and the gravity from the slurry itself, which makes the bottom parts more tightly and compact than the top parts, and the new layer contacted the previous one when the slurry layer extruded from the nozzle. The new layer will sink and flatten due to the gravity and extrusion force. Moreover, the new layer will transfer heat to around when it begins to solidify, which can cause the precious layers to melt and solidify again. The SEM and OM pictures of printed ring-structured explosive grain proved that 3D printing is more satisfactory than conventional melt-casting ways to prepare high viscosity and unconventional structure explosives.

### 3.3.3 XRD analysis

XRD was conducted to investigate the crystal type and composition of TNT/HMX-based explosives fabricated by 3D printing.

Figure 17 showed the XRD patterns of raw HMX, raw TNT, and TNT/HMX-based explosives prepared by 3D printing. In raw HMX, the sharp characteristic peak of HMX at 14.7°, 16.1°, 20.4°, 23.0°, and 31.9°, all the peaks confirm to the standard PDF card (PDF#28–1945). For TNT, the sharp characteristic peak appeared at 12.6°, 20.9°, 23.1°, 30.0°, and 33.5°, and all the peaks confirm to the standard PDF card (PDF#42–1768). All the diffraction peaks of TNT/HMX-based explosives were consistent with raw HMX.
and raw TNT, which indicated that the raw materials exist in these two different preparation methods and the crystal structure of the HMX and TNT were not influenced by the melting process.

### 3.3.4 Thermal performance

As is known to us, thermal decomposition and thermal stability of energetic material play a crucial role in safety characteristics. The DSC curves of the samples were obtained at the heating rates of 5, 10, 15, and 20 °C·min⁻¹, respectively. Detailed information as shown in Fig. 18.

As can be seen from Fig. 18, with the increase of the heating rate, the decomposition temperature increased accordingly. There are two endothermic peaks and two exothermic peaks in every DSC curve, the first endothermic peak is corresponding to the melting point of the TNT peak, the next small endothermic peak corresponding to the melting point of HMX, and the two exothermic peaks are corresponding to the decomposition temperature of raw HMX and raw TNT, respectively. In a word, DSC results indicated that TNT and HMX only mixed in the TNT/HMX-based explosives without chemical reaction [40]. Based on the peak decomposition temperature at a different heating rate, the apparent activation energy (Ea, kJ·mol⁻¹) can be calculated by Kissinger’s method [41], which can be expressed as Eq. (1). Where \( \beta \) is the heating rate (K·min⁻¹); \( T_p \) is the temperature of the exothermic peak in DSC curves (K); A
is the pre-exponential factor (min⁻¹); R is the gas constant (8.314 J·mol⁻¹·K⁻¹).

\[
ln \left( \frac{\beta}{T_p^2} \right) = ln \left( \frac{\Delta R}{E_a} \right) - \frac{E_a}{RT_p}
\]  

(5)

Moreover, according to the \(E_a\), other thermodynamic parameters, such as the activation enthalpy (\(\Delta H^\ne\)), the activation entropy (\(\Delta S^\ne\)), and the activation Gibbs free energy (\(\Delta G^\ne\)) can be obtained from Eqs. (6), (7), (8) and (9) [42]. Where \(T_{p0}\) was the peak temperature when \(\beta\) was closed to 0; \(k_B\) represented the Boltzmann constant (1.381 × 10⁻²³ J·K⁻¹); \(h\) represents the Planck constant (6.626 × 10⁻³⁴ J·s⁻¹). The calculated thermodynamic parameters as presented in Table 1.

\[
T_{p0} = T_p - a\beta_i - b\beta_i^2 - c\beta_i^3
\]  

(6)

\[
\Delta H^\ne = E_a - RT_{p0}
\]  

(7)

\[
\Delta S^\ne = R \left( \ln A - \ln \frac{k_B T_{p0}}{h} \right)
\]  

(8)

\[
\Delta G^\ne = \Delta H^\ne - T_{p0} \Delta S^\ne
\]  

(9)

It can be found from Table 1 that the value of \(\Delta H^\ne\) was positive (+339.3 kJ·mol⁻¹), which indicated that the TNT/HMX-based explosives need to absorb energy from outside to the activated state. The value of \(\Delta S^\ne\) was also positive, which indicated that the confusion degree of activated TNT/HMX-based explosives was higher than that of the reactant molecules. The nonnegative values of \(\Delta G^\ne\) illustrated that the pyrolysis of TNT/HMX-based explosives did not occur spontaneously, in a stable state in the common condition, namely, its molecules would not be activated unless sufficient energy (>\(\Delta H^\ne\)) was introduced.

4 Conclusion

In this paper, the viscosity of molten TNT/HMX-based explosives were investigated. The CFD and CFD-DEM coupled simulations were applied to explore the influence of pressure, nozzle diameter, viscosity and particles on the printing process. According to the simulation results, larger nozzle diameter and inlet pressure can improve the printing velocity, but higher viscosity resulted in lower printing velocity. Furthermore, a ring-structured TNT/HMX-based explosive grain has been successfully designed and fabricated by an FDM 3D printer. The SEM shown that many small holes existed in the top part of every printed layer due to the solidification of TNT, the XRD results indicated that the crystal structure of HMX and TNT was not influenced by the melting process, and the DSC results indicated that the \(E_a\) and \(\Delta H^\ne\) of the formulation were 343.9 kJ·mol⁻¹ and 339.3 kJ·mol⁻¹, respectively. More importantly, the printed ring-structured grain proved that FDM has certain technical advantages in terms of special-shaped structure for the preparation of TNT-based explosives, and this work could provide some theoretical and practical support for 3D printing explosives.

Acknowledgements The machines, devices, and tools used in this work are the properties of the National Special Superfine Powder Engineering Research Center of China.
Funding  This work was financially supported by the National Natural Science Foundation of China (No. 21805139 and 51706105), the Natural Science Foundation of Jiangsu Province (BK20170846), the Qing Lan Project, a project funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD), and Basic Product Innovation Technology Research Project of Explosives.

Availability of data and material All authors affirm that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Code availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The submitted work is original and it not has been published elsewhere in any form or language. This research did not involve using of living beings (humans or animals) or organisms or anything vegetable species nor voluntary or involuntary participation in activities that cause detrimental or defamatory on humans in all experimental activities.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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