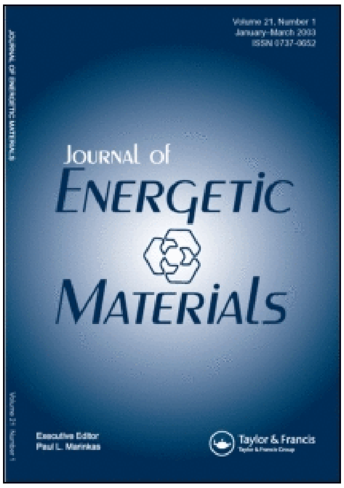

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A study on dynamic compressive properties of energetic materials at low temperature

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A STUDY ON DYNAMIC COMPRESSIVE PROPERTIES OF ENERGETIC MATERIALS AT LOW TEMPERATURE

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Abstract—The mechanical response of explosives at low temperature was investigated and an experiment apparatus is presented which is available to conduct dynamic compression for explosives at low temperature. Measurements of Comp. B and TNT explosives have been made. The data obtained experimentally depend greatly on the strain rate employed. It is found that the strain ε_m (ε_m is the strain at compressive strength σ_m) increased with increasing strain rate for both explosives at low temperature. The mechanical properties of Comp. B are higher than those of TNT for all measuring conditions in the present study. The effect of inertia on experiment curves was reduced by introducing a factor of flexibility.

I. INTRODUCTION

Trinitrotoluene (TNT) and a composite (Comp. B) of TNT and cyclotrimethylene trinitramine (RDX) were used in both military and civilian applications. For scientists, as well as materials manufacturers and design engineers, knowledge of the behaviour of these materials and, in particular, the conditions for failure over a wide range of strain rates and temperatures are of obvious importance.

The mechanical failure for explosives is thought to play a critical role in premature ignition during artillery launch [1~3]. Measurements of the mechanical properties of TNT and Comp. B have been made as a function of temperature and strain rate [4,5]. However, there is very little information in the technical literature on the dynamic response for explosives at low temperature. In an effort to understand these types of materials and determine failure conditions, the mechanical properties of TNT and Comp. B at low temperature have been investigated in the present study. And an experimental apparatus is presented which is available to measure the dynamic response of explosives at low temperature. The experimental results show that there exists a clear temperature and strain rate effect in TNT and Comp. B.

The dynamic effects, which mainly result from the high acceleration of the impacted specimen when it comes into contact with the load cell during the early stages of the experiment, often leads to meaningless results. The reduction of the transient initial acceleration and the dynamic nature of the experiment were made but the high loading rate was retained by introducing a factor of flexibility. The dynamic experiment curves are smoothed with the factor of flexibility.

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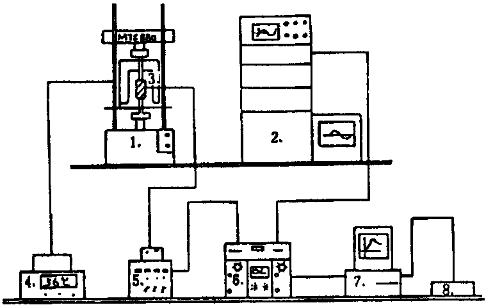
2. EXPERIMENTAL CONSIDERATION

A sample of Comp. B is made up of 39.5% TNT, 59.5% RDX, and 1% wax. The samples were all in the form of cylinders of lengths approximately 38.2 mm and diameters close to 19.1mm. The density of the cylinder samples is 1.686 g/cm^3 for Comp. B and 1.616 g/cm^3 for TNT respectively.

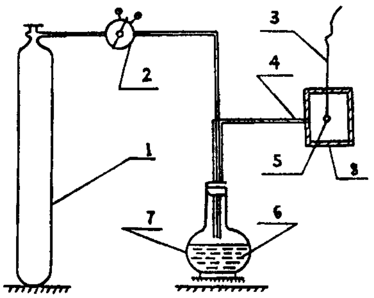
The experiment apparatus, as shown in figure 1, is mainly composed of the following parts: a material test machine system, a digital oscilloscope, a dynamic strain instrument, an environment room of low temperature and a measuring meter for low temperature.



1. MTS load platform
2. MTS console
3. Environment room
4. Temperature controller
5. Dynamic strain instrument
6. Digital oscilloscope
7. Computer
8. Display

Fig. 1 Schematic diagram of the experiment device

The cylindrically shaped specimens are coated on their end faces with a thin film of graphite powder in order to minimize binding and friction at the compressive faces before being placed on the top face of the load cell.



1. Nitrogen gas vessel
2. Valve of pressure controling
3. Temperature probe
4. Gas pipe
5. specimen
6. Liquid Nitrogen
7. Dewar vessel
8. Environment room

Fig. 2 The scheme of the device for low environment temperature

The two loading rates were adopted, i.e. a lower strain rate of $1\times10^{-4}\ s^{-1}$, and a higher strain rate of $3s^{-1}$. The environment conditions for low temperature were selected as 0℃ and −30℃, and were controlled by a simple and convenient method as shown in figure 2. The important points of the method are: Nitrogen gas in a nitrogen gas vessel through a valve of pressure controlling was filled in a Dewar vessel in which liquid nitrogen exist and was continuously guided into the environment room of low temperature. The valve of low temperature in environment room is controlled by changing the pressure and velocity of flow with regulating value of pressure controlling.

3. RESULTS AND DISCUSSION

The typical curves of σ_x versus ε_x for TNT and Comp. B at rates of $3s^{-1}$and $1\times10^{-4}s^{-1}$ and at temperatures of 0℃ and −30℃ are given in figures 3 to 6 respectively. The curve of Young's modulus versus temperature is given in figure 7. The comparison of experiment curves between Comp. B and TNT was made in figure 8. The trend for the sensitivity of strain rate with changing temperature can be found in figures 9 and 10. The data at 20, 40 and 60℃ in figures 7 and 10 are quoted from the reference[4]. An appearence that the strain ε_m (ε_m is the strain at compressive strength σ_m) increased with increasing strain rate for Comp. B and TNT at low temperature was described in figures 11 and 12. R is the correlation coefficient of least−square fit in figures 7 to 12. The compressive strength σ_m, Young's modulus E and strain ε_m for Comp. B and TNT at the two temperatures and at the two strain rates are shown in tables 1 and 2 respectively.

Analysis of data are summarized as follows: (1). There exists a clear strain rate effect for Comp. B and TNT at low temperature. The compressive strength σ_m and Young's modulus E increased with

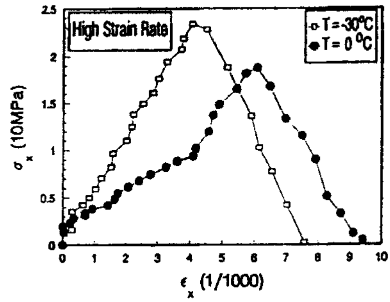


Fig. 3 Axial stress versus axial strain at high strain rate for Comp. B

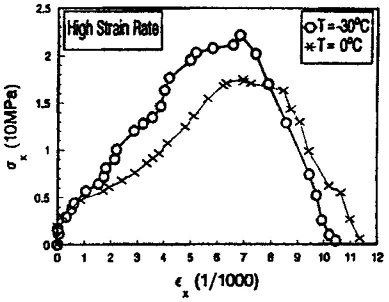


Fig. 4 Axial stress versus axial strain at high strain rate for TNT

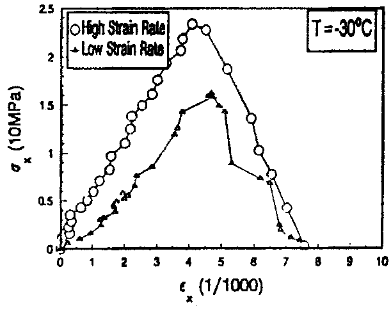


Fig. 5 Axial stress versus axial strain at −30℃ for Comp. B

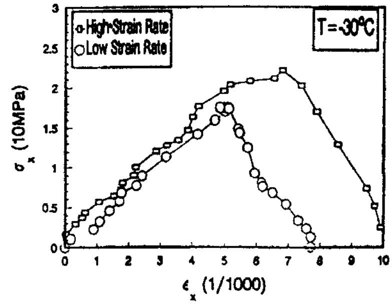


Fig. 6 Axial stress versus axial strain at −30℃ for TNT

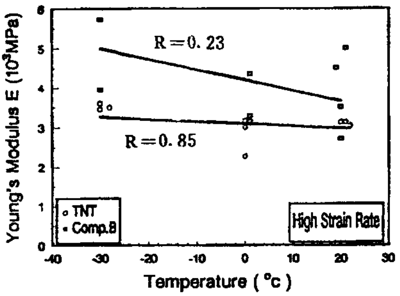


Fig. 7 Comparison of the experiment data for Comp. B and TNT

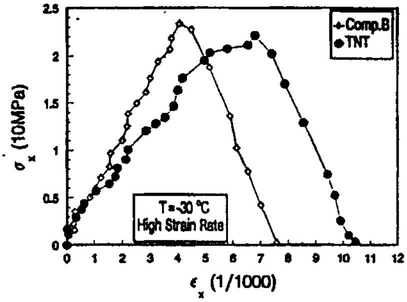


Fig. 8 Comparison of the experiment data for Comp. B and TNT

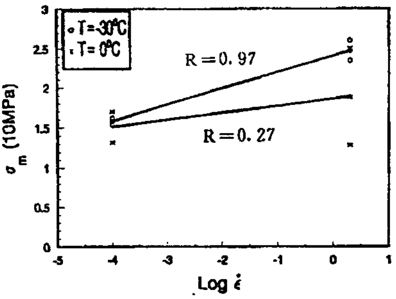


Fig. 9 Experiment curve of low temperature for Comp. B

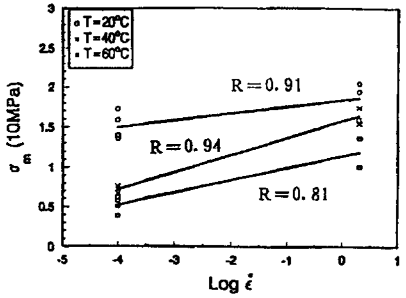


Fig. 10 Experiment curve of high temperature for Comp. B

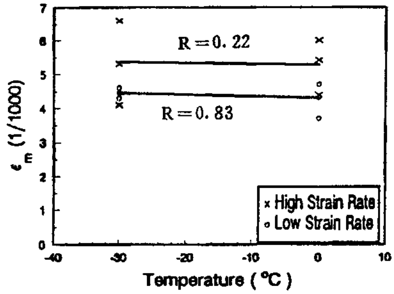


Fig. 11 strain ε_m versus temperature for Comp. B

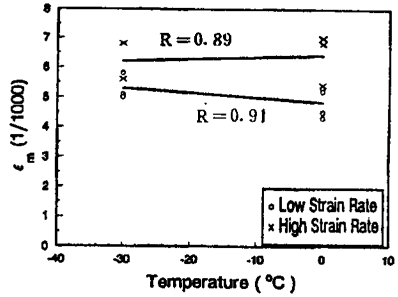


Fig. 12 strain ε_m versus temperature for TNT

increasing strain rate. (2). Both the materials are also sensitive to temperature at low temperature, and the values of σ_m and E increased with decreasing temperature. (3). It is found that the strain ε_m increased with increasing strain rate at low temperature for Comp. B and TNT. It is different from the cases at high temperature. (4). The Young's modulus for Comp. B is higher than that for TNT. The result indicates that RDX is stiffer than TNT and so it makes Comp. B to deform less under elastic loading. (5). From figure 7 it can be found that Comp. B is more sensitive to temperature than TNT is. (6). Figure 9 showed that the sensitivity of strain rate for Comp. B increases with decreasing temperature at low temperatures (i. e. 0℃ and −30℃). But in figure 10 it can be found that the slope of σ_m—Log$\dot{\varepsilon}$ curves increase with increasing temperature at higher temperatures (i. e. 20 to 60℃).

Table 1 Summary of the experiment data for Comp. B

Strain rate	3/s		10^{-4}/s	
Temperature(℃)	−30	0	−30	0
Compressive strength σ_m(10MPa)	2.47±0.13	1.88±0.62	1.58±0.04	1.51±0.19
Young's modulus(GPa)	4.84±0.89	3.59±0.76	4.23±0.18	3.75±0.64
Strain ε_m(10^{-3})	5.35±1.25	5.27±0.87	4.45±0.15	4.20±0.50

Table 2 Summary of the experiment data for TNT

Strain rate	3/s		10^{-4}/s	
Temperature(℃)	−30	0	−30	0
Compressive strength σ_m(10MPa)	2.08±0.02	2.05±0.30	1.58±0.24	1.36±0.30
Young's modulus(GPa)	3.52±0.08	3.09±0.82	2.97±0.63	2.82±0.28
Strain ε_m(10^{-3})	5.70±1.10	6.40±1.00	5.30±0.50	4.83±0.53

The test curves under dynamic loading are different from those under static loading. There are marked saw tooth waves at the initial part of curves for dynamic measuring. It is difficult to interprete the data and the results obtained using static and imapct tests cannot be compared. In order to overcome this question and reduce the effect of inertia on experiment, a factor of flexibility was introduced. The flexibility for the complete set of equipment was firstly calibrated and the curves of load versus displacement were obtained for entire test system at different loading capacity. The factor was determined by the length and the types of material of loading cell, test machine system, and so on. Using the flexibility factor to process the data, the reduction of inertia effect in samples and the smoothing on the initial part of test curves have been made.

4. CONCLUSIONS

The main conclusions are as follows:

(1). An experimental equipment is presented which is available to measure the mechanical response of explosives at low temperature. Measurements of TNT and Comp. B explosives have been made at low temperature (i. e. 0 and −30℃). The compressive strength σ_m, Young's modulus E and strain ε_m have been determined.

(2). The experiment results show that there are clear temperature and strain rate effects in TNT and Comp. B. The values of σ_m and E are increasing with decreasing temperature and increasing strain rate.

(3). At low temperature (i. e. 0 and −30℃), it is found that the strain ε_m(ε_m is the strain at compressive strength σ_m) increased with increasing strain rate for both the explosives. It is different from the cases at high temperature (i. e. 20 to 60℃).

(4). The results indicate that Comp. B is stronger and stiffer than TNT for all measuring conditions employed. It might reasonably be attributed to the presence of RDX particles in Comp. B.

(5). The effect of inertia on experiment curves was reduced by introducing a factor of flexibility.

5. ACKNOWLEDGEMENTS

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