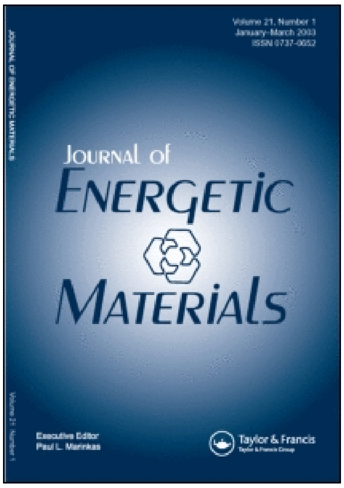

Journal of Energetic Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713770432

Experimental investigation of adiabatic shear bands formation in TNT explosives under impact

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To cite this Article Han, X. P. , Zhang, T. H. and Zhao, Z. H.(1997) 'Experimental investigation of adiabatic shear bands formation in TNT explosives under impact', Journal of Energetic Materials, 15: 2, 185 — 191

To link to this Article: DOI: 10.1080/07370659708216082

URL: http://dx.doi.org/10.1080/07370659708216082

EXPERIMENTAL INVESTIGATION OF ADIABATIC SHEAR BANDS FORMATION IN TNT EXPLOSIVES UNDER IMPACT

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Abstract—Microstructure of TNT explosives column deformed under impact was observed with optical and scanning electron microscopy. The original TNT grains have the shape of coarse strip. Under impact it can be found the formation of adiabatic shear bands (ASB) in TNT samples. ASB is characterized by a river shape area, in which crystals were severely drawn out and experienced an instantaneously high temperature. Adiabatic shear is starting from the high concentration of strain in some area and the severe twist of crystals, and go up to the appearence of ASB. The emergence of ASB strongly depends on strain and strain rate. The formation of ASB is much easier in TNT explosives than in metals.

I. INTRODUCTION

Trinitrotoluene (TNT) used in both military and civilian applications are vulnerable to impact of fragments and projectiles or any other dynamic loading that could lead to ignition and premature. The safety and vulnerability of the material were investigated by many researchers. It is generally accepted that the conditions for initiation to occur in crystallines explosives is thermal in origin. Before the mechanical energy is converted into heat it must be localized within the explosives. The localized regions are called hot spots. Earlier investigaters have proposed several hot spot initiation models, these include gas compression in the cavity (or microporosity), hydrodynamic cavity collapse, friction between adjacent grains and viscoplastic cavity collapse. Bowden & Yoffe [1] demonstrated that under some conditions gas compression in pores could cause ignition. They thought that when a small volume of gas is compressed rapidly, a high temperature reservoir (hot spot) of gas can be created which may subsequently heat the adjacent explosive surface to the point of autoignition. In the hydrodynamic model developed by Mader [2], it has been suggested that when a shock wave arrives, it accelerates the upstream surface of a cavity forward, which hits the downstream side of the cavity, producing a high impact pressure that is amplified by convergence effects during the collapse process. In this mechanism, the heating is produced by compression of the solid phase material. Frictional heating in narrow regions of high shear due to material viscosity is another probable source of hot spots [3]. Cavity collapse processes have been modeled by

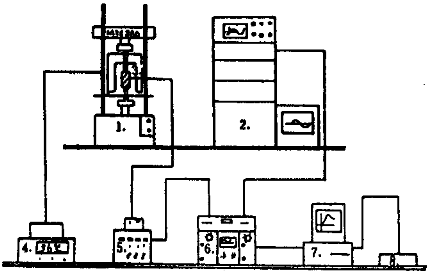
Journal of Energetic Materials Vol. 15, 185-191 (1997)
Published in 1997 by Dowden, Brodman & Devine, Inc.

Frey [4], using Carroll and Holt's viscoplastic hollow-sphere pore collapse concept [5] and studing shock initiation problem in high density explosives. Frey applied this kind of model to investigate the effects of pressurization rate, cavity size, and material parameters on hot spot formation, and concluded that the viscous heating is the most efficient mechanism and is dominant when the rise time of pressure is short, viscosity is high and yield stress is low.

Although there is general agreement that initiation is due to such hot spots there still has been much controversy about the mechanism by which the hot spots form. In most of experimental investigation about the hot spots forming under impact, the smaller samples, such as single crystals, pellets or small disc, have been used. This paper describes a study of initiation under impact and provides photographic evidence for the formation of initiation sites. A triaxial compressive apparatus has been used to simulate the loading conditions encountered by explosives during artillery launch. Microstructure of TNT explosives column deformed under impact was observed with optical and scanning electron microscopy (SEM). Adiabatic shear bands (ASB) were observed in samples and the crystals in ASB were severely twisted. Strain rate and plastic deformation are chief factors forming ASB. Under high strain rate and larger deformaton, it is much easier to form ASB in TNT than in metals.

2. EXPERIMENTAL

Experiments have been carried out using an equipment of triaxial compression illustrated in Fig.1. The samples are in the form of cylinder of lengths 38.2 mm and diameters close to 19.1mm. The density of the cylinder samples is $1.616g/cm^3$ for TNT explosives on an average. Strain rate of up to about $4s^{-1}$ can be obtained for explosive samples of the size used in this work. The impacted samples have been examined under an optical microscope and SEM.



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 set-up

The cylindrical and vertical sections were respectively removed from various locations on samples for microscopic investigation. The samples sectioned were coarse sanded on one side using 80 grit sandpaper followed by 150 grit sandpaper. The flats were again fine sanded in final preparation for polishing using 150 and 320 grit sandpaper. No fluids were used in sanding process so as to minimize the probability of contamination.

After sanding, the samples were hand polished using a wool polishing cloth saturated with distilled water. The samples being polished were rinsed with distilled water, and dried with compressed Freon.

The samples can be chemically etched after polishing to enhance the grain boundries. A number of solvents and mixtures of solvents were evaluated. It appeared that acetone/water mixture (1 : 1.5) gave good results. Etching of TNT grains with acetone has been found to be rapid, and hence had to be carefully controlled. The time etched was taken as 4—6 seconds. Dissolution was quenched after 4—6 seconds by immediate immersion in distilled water. The samples were rinsed with distilled water, and dried with compressed Freon. Acetone/water mixture in a 1:1 ratio was also tried and etching has been done in 2—4 seconds.

Samples for SEM were prepared by sputtering a conductive coating of gold or gold/palladium onto the surface. The sputter coating for this work was done in a denton vacuum. A gold/palladium coating was applied at an argon pressure of 75 mtorr, and a current of 15 mA for 2 minutes. These sputter conditions provide a conductive film thickness of about 500 angstroms. A film of this thickness has been found to be the minimum thickness suitable for SEM work on an explosive sample.

3. RESULTS AND DISCUSSION

Examination of sections of TNT explosive column subjected to impacts reveals several phenomena which appear to be important to the initiation process. The formation of ASB have been found in impacted samples with optical microscopic and SEM.

Photographs of the original crystals obtained from TNT samples are given in figures 2 and 3.They show that the typical TNT crystals have the shape of coarse strip without loading. At quasi static loading and at room temperature, the crystals in TNT column ruptured crisply, even breaked to pieces, as shown in figures 4 and 5.

Extruding between crystals, strain concentrations and severe twist for crystals at local regions can be observed in explosive column under impact, as

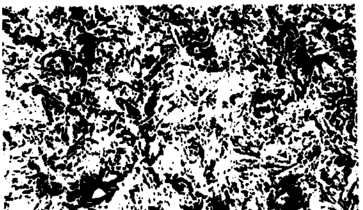


Fig.2 Original crystal pattern in TNT column


Fig.3 Original crystal pattern in TNT column (local region)

Fig.4 Brittle rupture or crush of crystals

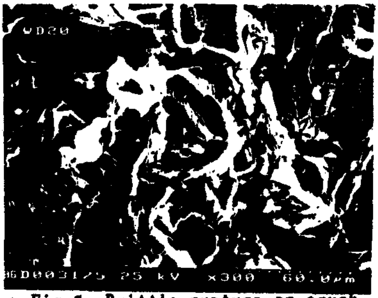


Fig.5 Brittle rupture or crush of crystals

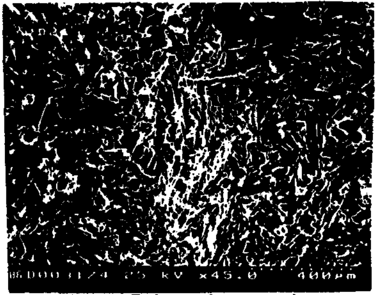


Fig.6 Twist of crystals

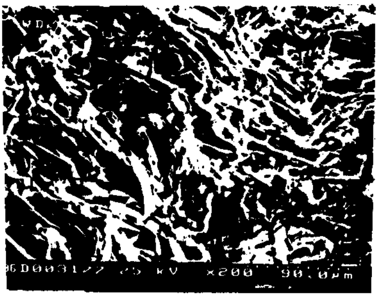


Fig.7 Twist of crystals(local region)

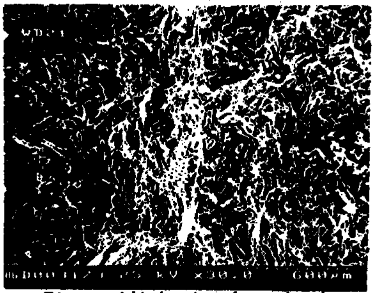


Fig.8 Adiabatic shear bands in TNT column

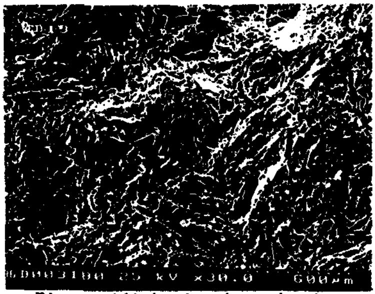


Fig.9 Adiabatic shear bands in TNT column

illustrated in figures 6 and 7. Figure 8 shows when the deformation is quite large under impact,crystals were severely drawn out at local regions and a river *shape region—shear bands were formed.The crystal tissues in bands were severely* drawn out along the band, but the deformation of crystals outside the band is far less. At some regions the intersection by several bands can be seen (Fig.9). From Fig.9 it can also be seen the characteristic of developing from the severe twist of crystals through the forming of bands, such as partial crystals within bands have been obviously drawn out and partial grain boundaries left in bands can still be found.

Photographic evidence from TNT explosive column presented in Fig.2 to 9 have

Fig.10 Original crystal pattern in TNT column (1cm=100μm)

Fig.11 Original crystal pattern in TNT column (local region) (1cm=20μm)

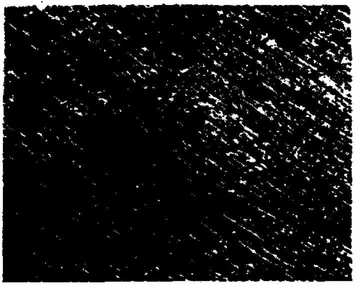


Fig.12 Twist of crystals (1cm=200μm)

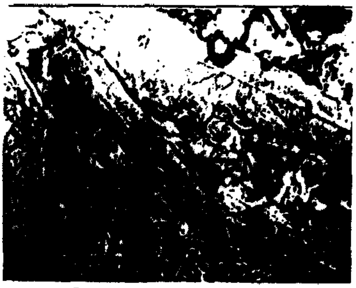


Fig. 13 Brittle rupture of crystals (1cm=20μm)

clearly demonstrated that its dominant plastic deformation is after the form of the evolution of shear bands under impact. When the plastic deformation is large enough, the heat transformed from plastic work leads to the change of crystal tissues. Adiabatic shear is starting from the high concentration of strain and the severe twist of crystals in some area, and go up to the appearence of ASB.

The critical condition for emergence of ASB at certain temperature depends on simultaneously strain and strain rate. At quasi static rate even if there was larger plastic deformation in samples adiabatic shear did not emerge. At high rate, if plastic deformation is less, we have not observed ASB.

ASB is characterized by a river shape region in which crystal tissues are different from those out of bands. The above photographs give a clear idea that the stream shape area experienced an instantaneously high trmperature, then by shear stress thermal softening grains were forced to flow at high speed and finally it resulted in grains in a band being severely drawn out.

The time experienced for loading is very short under impact so the case is nearly adiabatic. Based on energy equilibrium principle for adiabatic deforming process, temperature increasing is calculated from the following formula, i.e.

$$dT=\frac{\beta}{\rho C}\sigma d\varepsilon \qquad (1)$$

where β, ρ, C are respectively mechanical equivalent of heat, mass density and specific heat. When strain rate is high enough, a very high value of β can be obtained. As larger plastic deformation takes place in samples, the larger plastic work was produced, and it could lead to substantial temperature rising.

For TNT explosive column, $\rho = 1.616\ g.cm^{-3}$, $C = 1.29 \times 10^{3}\ J.Kg^{-1}.K^{-1}$ [6], the product of ρ and C is much less than that for metals. From this point it can be thought that at high rate and large deformation the formation of ASB is much easier in TNT explosives than in metals. Moreover, the less heat conduction coefficient K is, the easier is the formation of ASB in samples. The value of K for TNT is very little ($K = 0.262 W.m^{-1}.K^{-1}$ [6]), comparing with metal. We combine equation (1) to form the following idea; a TNT explosive column under dynamic loading may experience thermo-mechanical instability if sufficient heat is generated at localized regions during deformation. This heat diffuses very slowly corresponding to loading rate and tends to melt the grains in the localized regions. As this process continues, these regions, which are warmer and softer than neighboring material, can absorb greater amounts of strain, causing unstable flow of material and localized thermal softening in explosives and finally ASB may occur.

The optical microscopic examinations were shown in figures 10 to 13. Figures 10 and 11 give a typical original crystal pattern of TNT column. From figures 12 and 13, it can be seen the crystal tissues pattern of extruding between crystals, twisting and rupturing of grains.

4. CONCLUDING REMARKS

1. Examination of TNT explosive column with optical microscope and SEM shows that original TNT grains have the shape of coarse strip.

2. Under impact it can be found the formation of adiabatic shear bands in TNT samples. ASB is characterized by a river shape region, in which crystals were severely drawn out and experienced an instantaneously high temperature.

3. The dominant plastic deformation for TNT explosive column is after the form of the evolution of shear bands under impact. Adiabatic shear is starting from the high concentration of strain in some area and the severe twist of crystals, and go up to the appearence of ASB.

4. The emergence of ASB at certain temperature depends greatly on strain and strain rate.

5. Under impact the deforming process of TNT explosive column is nearly adiabatic, so from energy equilibrium equation, $dT = (\beta / \rho C) \sigma\, d\varepsilon$, a substantial temperature rising can be calculated from plastic work.

6. The formation of ASB is much easier in TNT explosives than in metals.

5. ACKNOWLEDGEMENTS

This work was partly supported by the state key laboratory of mechanical structural strength & vibration of Xi'an Jiao University (P.R.C). Thanks are also

due to Xi'an Modern Chemistry Research Institute (P.R.C) for the preparing of samples.

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