OBSERVATIONS ON TYPE II DEFLAGRATION-TO-DETONATION TRANSITIONS

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Type II DDT has been observed in low density charges of ultrafine PETN and RDX. The compressive burning regime that mediates the final stages of type I DDT has been shown to be absent in this mechanism. Convective burning controls the propagation of reaction throughout the column and detonation breaks out at some point along the column. The exact features of the detonation vary between PETN and RDX. The study described here gives new details on the pressure and temperature regimes that operate within the column during the build-up to detonation. Velocity measurements of the waves (in particular the detonation waves) found in these systems have been made. It has been shown that the detonation wave velocities are anomalous for materials at the initial pressing densities, with PETN having an enhanced detonation velocity following a type II DDT and RDX having a retarded detonation velocity.

INTRODUCTION

Type II DDT was first observed in low density columns of tetryl\(^1\), picric acid \(^2,3\) and some propellants\(^4\) by researchers in both Russia and the United States. They found that in low density columns of these materials the outbreak of detonation was preceded by a rapid build-up of pressure at the point where the detonation occurs.

Previous research at the Cavendish Laboratory\(^5,6\) has shown that type II DDT can occur in widely used materials such as cyclotrimethylene trinitramine (RDX) and pentaerythritol tetranitrate (PETN). When columns of ultrafine material below about 50% of the theoretical maximum density (TMD) are thermally ignited, they do not exhibit the compressive burning stage that builds to the shock required for the SDT event in type I DDT. Instead, the convective burning reaches the end of the column. The burning then continues until detonation breaks out at some point along the column. The bulk of this early research into the type II DDT was carried out using high-speed photography.

This paper describes research that has been carried out to elucidate the nature of the events that occur in the build-up to the detonation in type II DDT. The use of strain gauges and thermocouples is described and the merits and problems associated with these diagnostics are discussed. Some observations made whilst reviewing previously obtained data are also discussed and possible explanations of the phenomena are presented.

FIGURE 1. Streak record of type II DDT event in ultrafine PETN. A - initiation; B - detonation wave.

MATERIALS USED

Both PETN and RDX were supplied in ultrafine form by ICI Nobel Enterprises, Ardeer, U.K. The powders have a primary particle size of ~1 \(\mu\)m and are produced by a proprietary process. The loose powder densities are ~15% TMD.
EXPERIMENTAL METHOD

The main tools that were used during the course of this research were thermocouples and strain gauges. Some of the discussion relates to previously reported results that were obtained using high-speed photography. This technique has been described fully in previous publications^5,6.

General

All of the experimental techniques described below relied on incrementally pressed columns in cylindrical steel confinements as shown in figure 2.

The ignition system used was based on one developed by Dickson^7. The confinement is effectively sealed against venting by the presence of polycarbonate and aluminium plugs. The pyrotechnic igniter used was an 80% potassium dichromate, 20% boron mixture. This has few gaseous products and burns at a temperature well in excess of the ignition temperature of PETN and RDX.

Prior to each experiment the calibration was checked and the results were subsequently corrected for variations in the level of amplification.

Strain Gauges

Micro Measurements strain gauges were mounted on the outside of the confinements to dynamically measure the hoop strain generated during the experiment. The gauges were used in a bridge configuration which enabled accurate and rapid monitoring of the changes in gauge resistance.

Due to the presence of a small amount of plastic deformation it is difficult to directly relate the strain on the cylinder surface to the pressure experienced by the column. As a result all traces arising from the use of strain gauges are given in terms of the strain actually measured.

RESULTS

Thermocouple measurements

Figure 3 shows the traces recorded from four thermocouples positioned in a column during the build-up to a type II DDT event in PETN. Four

![Figure 2. Schematic of confinements used. The thermocouples and strain gauges are not shown.](image)

![Figure 3. Traces from the thermocouples placed in the charge.](image)
optical fibres were also placed along the column to monitor the arrival of luminous reaction and compare it with the thermocouples’ output. The oscilloscope was triggered using the optical fibre positioned at the same point as the downstream thermocouple. The time at which the light reached this fibre corresponds to the time marked as 0 on the oscilloscope record. This occurred some 930 μs after the luminous reaction passed the optical fibre positioned at the upstream thermocouple. The temperature records began to rise some 500 μs after the reaction was first detected at the position of the upstream thermocouple.

The temperature reading at the thermocouple 20 mm downstream from the ignition point rose considerably faster than the other three thermocouples reaching around 40 °C at the time when the luminous reaction passed the downstream fibre (0 s on figure 3). This thermocouple remained at a higher indicated temperature than the others as they all rose slowly until 466 μs after triggering at which point the upstream thermocouple reading jumped from 36 °C to around 120 °C in 2 μs. As the others continued to rise steadily and quite slowly this upstream thermocouple continued to go up and down erratically indicating temperatures as low as -5 °C. Between 483 and 486 μs after triggering all of the thermocouple readings rose rapidly as the detonation event occurred. Prior to that event the two downstream thermocouples only reached indicated temperatures of 40 °C while the thermocouple 20 mm from the ignition point reached nearly 200 °C.

**Strain gauges**

The strain gauge traces in figure 4 are from the outside of the confinement during a type II DDT event occurring in ultrafine PETN. The distances indicated on the figure refer to the distance between the position of the gauge and the ignition point of the charge.

The oscilloscope was triggered using an optical fibre located at the downstream end of the column. 0 s refers to the time at which luminous reaction was visible through the fibre.

The strain gauge records show no evidence of significant pressure build-up within the column until 650 μs after the luminosity reached the optical fibre. At that point the outbreak of detonation caused all three gauges to jump to strains between 0.005 and 0.02. The traces in this region are quite noisy due to both electrical disturbance associated with the detonation and waves travelling through the confinement.

![FIGURE 4. Strain gauge traces during a type II DDT event. Ignition occurred at approximately -0.9 ms](image)

2.5 ms after the detonation event, the strain gauges settle to the strain level that remains in the confinement due to plastic deformation.

**Observations from reviewing previously obtained data**

As has been previously reported the detonation velocity following a type II DDT event in PETN pressed to 30% TMD is typically 5-5.5 mm μs⁻¹. This is higher than the 3.7 mm μs⁻¹ that is found when charges of this density are directly detonated.

What has also been found from reviewing data obtained prior to the recent thermocouple and strain gauge investigation is that the detonation velocity following a type II DDT event in ultrafine RDX is around 2 mm μs⁻¹ which is slower than would be found in an equivalent pristine charge of that density were it directly detonated.

**DISCUSSION**

The thermocouple readings must be considered in the main to be only indicative of the temperatures in their vicinity. The relatively large heat capacity of the metal junctions when compared to the low...
density materials present within the columns will mean that there is some discrepancy between the actual temperatures and the measured temperatures\(^9,10\). Despite this, thermocouple readings of no more than 40 °C on three of the four thermocouples prior to the detonation breaking out seem very low.

A possible explanation of this which is consistent with the previous high-speed photographic studies is that the reaction only occurs in close proximity to the channels along which the hot product gases permeated. The photograph in figure 1 shows high luminosity reaction occurring only in some of the regions of the column in contact with the viewing window.

The higher reading given by the thermocouple 20 mm from the ignition point may well have occurred due to a reacting region being in close proximity to the thermocouple junction.

The strain gauge measurements serve to support the hypothesis that the portion of the charge that is actually reacting prior to detonation is very small when compared to the total amount of material in the charge.

**CONCLUSION**

The results of these studies point to the type II DDT transition being preceded by an early conductive burning that leads to a convective burn as hot gases are given off. The lack of any detectable pressure build-up within the column reinforces the previous hypothesis that no compressive burning stage such as that mediating the final stage of the type I transition is present in the type II mechanism.

It seems that convective burning is localised around the channels through which the gases are permeating and that temperature rises in other regions of the column are modest.

The enhanced detonation velocity in PETN is possible because little material is consumed in the pre-transition period and a channel is created within the column. The presence of a channel in a charge has been shown by Woodhead\(^11\) and Bakirov\(^12\) to lead to large increases of the detonation velocity through the gas filled channel and initiate material as it passes.

The retardation of the detonation velocity in the case of RDX may be due to more material being consumed in the pre-reaction part of the transition and hence less material is available to support the detonation. Further research involving columns of RDX with embedded thermocouples and strain gauges may be able to shed some light on this problem.

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**REFERENCES**