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52/9, Industrial Explosives]
Gos. Nauchno-Tekhn. Izd. Lit. po Gorn. Delu, Moscow
pp. 5-10 (1963)

by

L. J. Holtschlag

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SENSITIVITY OF EXPLOSIVES TO MECHANICAL EFFECTS
AND METHODS OF INCREASING THEIR STABILITY*

by

G. T. Afanas'ev, V. K. Bobolev, and I. A. Karpukhin
(Inst. Chem. Phys., Acad. Sci. USSR)

In view of contemporary conditions for industrial use of explosives, the problem of their sensitivity to mechanical effects is receiving more and more attention. According to present-day concepts,¹⁻⁴ explosive conversion of a substance due to a mechanical effect is induced in principle as follows: the dissipation of the energy of a mechanical effect causes a substance to heat up, which then leads to self-ignition within a definite volume if the conditions of thermal explosion are fulfilled. Afterwards, a chemical reaction front is formed and can propagate throughout the charge from the induction center. Thus the induction and propagation of an explosion is of a macroscopic nature and should be described by the methods of the mechanics of a continuous medium and of the theory of a thermal explosion.

In solid explosives, explosion is induced by mechanical effects as a result of plastic deformation. The heating temperature is limited by the melting point of the substance,

* Translated from *Vzryvnoe Delo*, Sbornik 52/9, *Promyshlennye Vzryvchatye Veshchestva* [Explosives Engineering, Collection 52/9, Industrial Explosives], Gos. Nauchno-Tekhn. Izd. Lit. po Gorn. Delu, Moscow, pp. 5-10 (1963).

because the intensity of heat release during the fusion phase decreases strongly due to the low viscosity as compared with the solid phase; moreover, melting is an endothermic process.^{5, 6} However, the melting point of the majority of explosives lies much lower than their ignition temperature. On the basis of this fact, Bolkhovitinov proposed that an effective center can form only in a volume subject to uniform compression, since according to the Clausius-Clapeyron law the melting point rises with increase in pressure. In this case the melting temperature should be at least equal to the critical temperature of the hot center, which is found from the thermal explosion condition. The role played by the pressure has been well confirmed experimentally.

In estimating the critical heating temperatures of explosives due to mechanical action, particularly due to impact, we used to use methods which did not take the time up to self-ignition into account.

Let us determine the critical temperatures of heating centers, taking specific account of the time aspects of the process. In order for explosives to detonate as a result of mechanical action, the adiabatic induction period must not exceed the characteristic time of the action; that is, $\tau_{ad} < \tau_{impact}$ (1), where $\tau_{impact} = 10^{-3}$ sec. In this case the temperature of the effective centers for the majority of explosives reaches 400 to 600°C, which agrees with experiment.⁶ In order to reach such temperatures, it is necessary, as a rule, to apply a pressure of several thousand atmospheres. Is it possible to reach such high pressures with inelastic deformation of a medium whose plastic strength is several tens to several hundreds of kg/cm²; that is, one to two orders less? We have indicated that is possible due to the scale effect of deformation, which enables us to develop high pressures in thin layers. We will begin with the above necessary condition of explosion induction (1) and with the assumption concerning the role of pressure, using the experimental dependence of the melting point on the pressure obtained

by Bridgman⁸ for a number of organic compounds. Then the critical load condition is expressed as

$$\frac{c\rho RT_{crit}^2}{QEz} \rho^{E/RT_{crit}} < \tau_{impact};$$

$$T_{crit} = T_{mp} + \alpha P_{crit},$$

where P_{crit} is the critical load, T_{mp} is the melting point of explosives under normal conditions, T_{crit} is the critical heating temperature, α is a coefficient showing the influence of the pressure on the flow temperature ($\alpha = 0.02$ deg/atm), E is the activation energy, z is the preexponential factor, Q is the heat of reaction per unit volume, c is the specific heat, and ρ is the density of the explosive.

The possibility of reaching P_{crit} in a charge taking the scale effect of deformation into account depends on the plastic strength of the explosive. Therefore it was of interest to study the plastic properties of the more widely used explosives. The flow limits of various substances were determined experimentally by ram impact in a machine with free escape of the substance. The relation accounting for the scale effect of deformation under these conditions follows from solution of the problem of compression of a thin disk between the ends of absolutely rigid cylinders by the method of the theory of elastoplastic deformation.⁹ This relation has the form

$$P = \frac{\sigma_{fl} d}{3 \sqrt{3} h},$$

where P is the mean pressure upon decomposition of the disk, σ_{fl} is the flow limit of the material, d is the diameter of the disk and of the cylinders, and h is the thickness of the disk.

Material	T _{mp} in °C	σ _{fl} in kg/cm ²	Material	T _{mp} in °C	σ _{fl} in kg/cm ²
Diphenylamine	52.9	230	AN	169.6	800
Eutectic TNT-tetryl	68	350	Hexogen	201	1000
TNT	81	410	Octogen	280	1400
Picric acid	121.9	580	Sodium nitrate	308	1700
Tetryl	131	620	Barium nitrate	592	2600
PETN	141	730			

The impact pressure was recorded by the tensiometric method. A typical pressure oscillogram is shown in Figure 1;

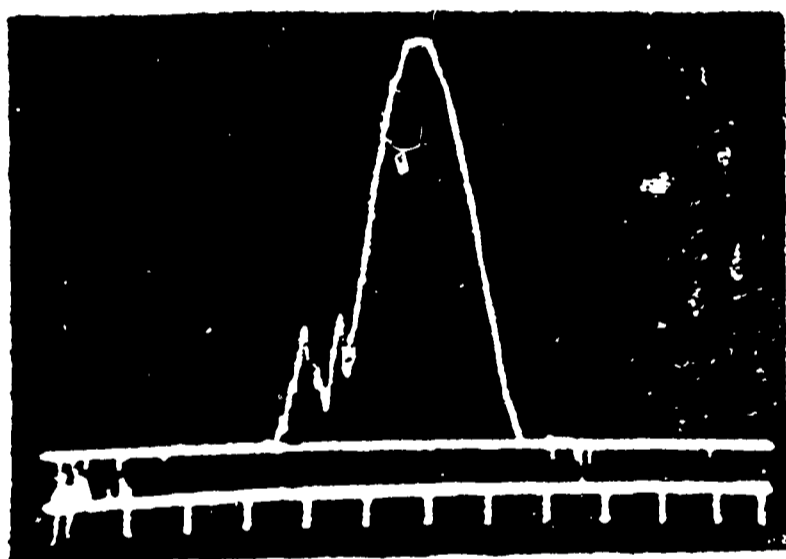


Figure 1. Oscillogram of the impact pressure (the upper trace is the process, and the lower the time scale).

the abrupt pressure drops correspond to decomposition of the sample.¹⁰ Figure 2 shows the dependence of the decomposition pressure on the initial thickness of the sample at a fixed diameter; it is well described (the measurement error is 10%) by the hyperbolic dependence. From data on the decomposition pressure we can calculate the flow limits σ_{fl} . The table and Figure 3 contain the flow limits found for a number of

explosives and some inert substances along with their melting points. All the tested substances conform well to the linear dependence of the flow limit on the melting point. The flow limits of TNT-tetryl mixtures were determined at varying concentrations of components. In this case the flow limit and melting point remained completely parallel; the flow limit was minimum at the eutectic point (Figure 4). A diagram of the fusibility of the

TNT-Te system is given in the paper by Howson, et al.¹¹

$P \times 10^{-3} \text{ (kg/cm}^2\text{)}$

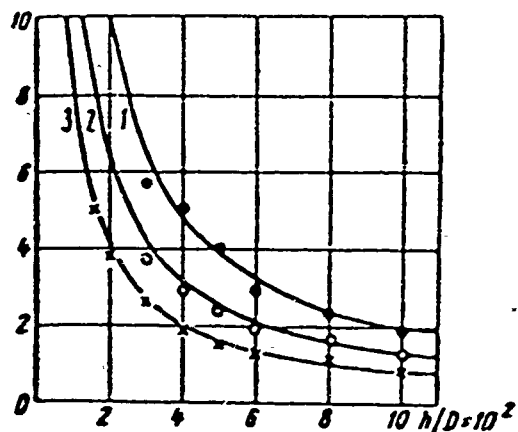


Figure 2. Decomposition pressure of the sample as a function of the initial thickness ($d = 10 \text{ mm}$):
1) hexogen; 2) PETN;
3) TNT.

$\sigma_{fl} \times 10^{-3} \text{ (kg/cm}^2\text{)}$

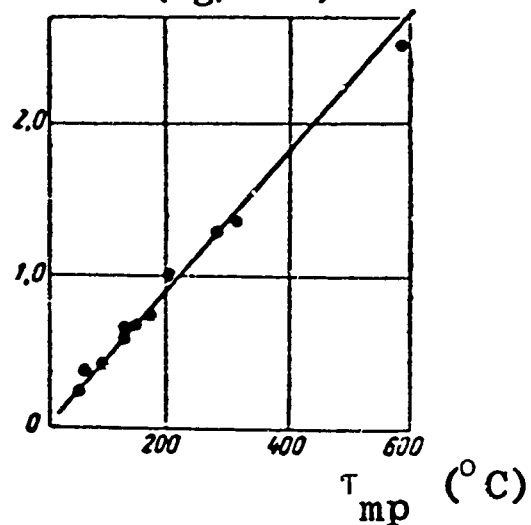


Figure 3. Flow limits of substances as a function of the melting points.

$\sigma_{fl} \times 10^{-3} \text{ (kg/cm}^2\text{)}$

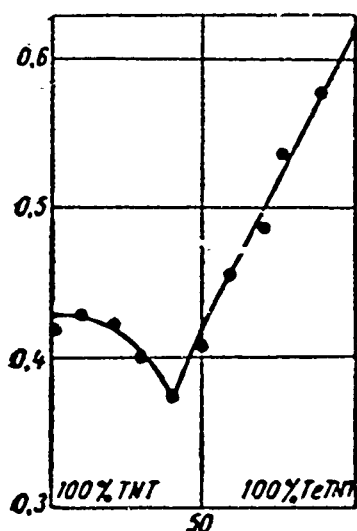


Figure 4. Flow limits of TNT-tetryl mixtures as a function of the concentration of components.

In connection with the above, let us consider methods of decreasing the sensitivity of explosives to mechanical effects, especially to impact. Problems associated with increase in stability have already been partially treated in Ref.10. The sensitivity can be lowered by increasing the critical load P_{crit} necessary for inducing explosion or by decreasing the plastic strength of explosives.

In turn P_{crit} can be increased by lowering the melting point (preparing eutectic mixtures of explosives) or by raising the critical temperature T_{crit} of the induction explosion centers (addition to the explosives of mixtures which will slow down the reaction rate). There are many and various ways of decreasing the plastic strength of explosives: first, by introducing low-strength additives, that is, additives whose melting point is as low as possible; secondly, by preparing a eutectic; thirdly, by using surface-active substances, etc.

It appears that the preparation of a eutectic is the most effective method of reducing the sensitivity. Here the sensitivity of the eutectic should be considerably less than that of any one of the individual explosives forming the eutectic. Even higher stability can be achieved by preparing ternary eutectic mixtures.

Another widely used method of reducing the sensitivity is by introducing low plastic-strength fluid additives into the explosive. Figure 5 gives the measured flow limits of mechanical hexagen-TNT and hexagen paraffin mixtures as a function of the percentage of the concentration of components. It is note-

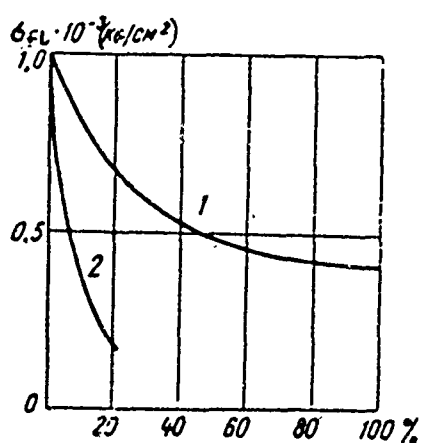


Figure 5. Flow limits of mechanical hexagen-TNT and hexagen-paraffin mixtures as a function of the ratio of components: 1) TNT; 2) paraffin.

worthy that even a small percentage of additive sharply decreases the plastic strength. Another important aspect is the effect of concentrating deformations in the layers of the additive, which we demonstrated in connection with the problem of stabilizing explosives by plasticizers.¹⁰ The stabilizing effect of the fluid additive is apparent in the extremely low sensitivity of the water-filled explosives developed in the Inst. for Phys. Chemistry of the Acad. Sci. USSR, and elsewhere (see the

articles by A. Ya. Apin, B. Ya. Svetlov, et al. in this publication).

From the example of the TNT-hexogen system (see Figure 5) we see that a low percentage of additive (hexogen) with a higher plastic strength than the base explosive (TNT) has almost no effect on the strength of the mixture. However, if the melting point of the additive is higher than that of the base explosive, the sensitivity may increase. The sensitivity increases particularly strongly if the melting point of the additive exceeds T_{crit} , as defined by relation (1), which has been established experimentally by Bowden.⁶ It is a generally known fact that the sensitivity increases when sand is added. Obviously, the mechanism of explosion induction in the presence of an inert additive is the heating to the melting point of the particles interacting when the charge deforms in addition to conductive ignition of the explosive. However, a detailed consideration of this problem requires special study.

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