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The Effect of High Mechanical Stress on Certain Solid Explosives

P. W. BRIDGMAN
The Physics Laboratories, Harvard University, Cambridge, Massachusetts

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Eleven different solid explosives have been subjected at room temperature to stresses of the order of those which prevail in the detonating front. Two types of stress were applied. The first consisted of a hydrostatic pressure of 50,000 kg/cm², on which was superposed a shearing stress sufficient to produce shearing deformations of the order of 60 radians. The second type consisted of a hydrostatic pressure of 100,000 kg/cm², with a comparatively small superposed shearing deformation. Seven of the eleven explosives survived stress of the first type without detonation. Only four of the explosives were subjected to the second type of stress; three of these survived without detonation. It is probable that in those cases where detonation occurred secondary effects were responsible, such as striking of sparks by fractured fragments of steel. The general conclusion is drawn that stresses of these magnitudes, without the cooperation of high temperature, cannot be counted on to produce detonation.

Incidentally it was found that yellow ammonium picrate is transformed irreversibly to the red form by the first type of stress. Values were obtained for the plastic flow stress as a function of hydrostatic pressure. The strength increases approximately linearly with pressure.

IN November, 1940, when it seemed probable that the United States would be eventually drawn into the war, I made, at the request of Professor G. B. Kistiakowski, some orienting experiments on the effect of high mechanical stress on various solid explosives. These experiments have not yet been published, and it is perhaps worth while to put a brief account of them in permanent form. The immediate problem was to determine whether detonation could be initiated by the action of stresses alone without the cooperation of high temperature. The particular point of the experiments was that it was possible to reach, in the cold, impressed stresses of the same order of magnitude as those which are supposed to prevail in the detonating front. The application of the results to the ultimate problem of determining the conditions of detonation in the detonating front is obvious.

The following explosives which were provided by Professor Kistiakowski were investigated. Alpha-, beta-, and gamma-T.N.T., alpha- and beta-nitroguanidine, picric acid, ammonium picrate (yellow and red forms), tetryl, cyclonite, and P.E.T.N. (penta-erythritol-tetra-nitrate).

Two types of test were applied. In the first, the explosive was exposed to an average hydrostatic pressure of 50,000 kg/cm², on which was superposed a shearing stress sufficient to produce a drastic shearing deformation of the order of magnitude of 60 radians. This shearing deformation might be several times repeated, with reversal of direction. In the second type of test, average hydrostatic pressure up to 100,000 kg/cm² was applied, but without explicitly applied superposed shearing deformation. The conditions were such, however, that a comparatively small amount of plastic shearing deformation was the incidental accompaniment of the pressure.

The general arrangements for the first type of test were exactly like those which I have previously employed in determining the effect of combined pressure and shear on a large number of substances.[1] The material to be tested is in the

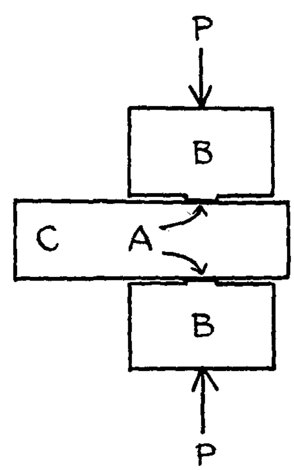

FIG. 1. General scheme of an apparatus for combining shearing stress with pressure.

[1] P. W. Bridgman, Proc. Am. Acad. 71, 387–460, 1937.

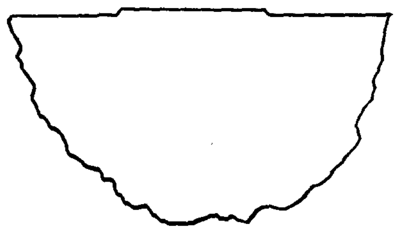

FIG. 2. Scale drawing of part of the "piston," modified so as to minimize the possibility of detachment of shearing wedges at the edges.

form of two thin disks, *A*, placed between the hardened rectangular steel "anvil" block *C*, and short "pistons," which are cylindrical bosses 0.250 inches in diameter on the cylindrical blocks *B*. The blocks *B* are squeezed together in a hydraulic press until an explosion occurs, or until the desired maximum average compressive stress of 50,000 kg/cm^2 is reached. This application of pressure is accompanied by lateral extrusion of the material of the disks until equilibrium thickness is attained, which is of the order of a few thousandths of an inch. If the desired pressure maximum was successfully reached without explosion, pressure was then released to zero, and then reapplied in steps of 10,000 kg/cm^2, shearing stress now being applied by rotating the block *C* between *B* and *B* after each pressure increment, and while pressure was maintained constant by a dead weight gauge. The rotation was back and forth through an angle of about 60°. A rotation of 60° gives a shearing deformation on the periphery of a disk 0.250 inch in diameter and 0.002 inch thick (an average thickness) of 65 radians. Rotation was repeated after each pressure increment until detonation occurred or the maximum was reached. The rotating force was also always measured, so that the data exist for a determination of the shearing strength of these materials as a function of hydrostatic pressure.

There were two subdivisions of the first type of test. In the first, exactly the same dimensions of the various steel parts were used as in my previous work. The bosses which constituted the pistons had a height of 0.030 inch. With these dimensions all eleven explosives were tested. All but one of these (red ammonium picrate) survived the initial application of 50,000 kg/cm^2 without explosion, but only two, alpha- and beta-nitroguanidine, survived the subsequent combination of shearing and pressure, the explosion occurring in most cases at the top pressures. Several repetitions with alpha-T.N.T. under ostensibly identical conditions did not lead to consistent results. The most probable explanation of the capricious results appeared to be that, under the shearing stress, minute steel wedges sheared off the edges of the pistons, struck a spark and so initiated the explosion by the high temperature.

In order to eliminate this factor, the second subdivision of the first type of experiment was made. In this the pistons were redesigned to have a height of only 0.009 inch and with a 45° bevel, as indicated in the figure, in order to eliminate minute shearing failures of the steel at the edges. With this modified arrangement shearing was applied at 50,000 kg/cm^2 to alpha-T.N.T., tetryl, cyclonite, picric acid, and P.E.T.N. The other explosives were not tried in the modified arrangement, but repeat experiments were made with alpha-T.N.T. and P.E.T.N. The first attempts with these two resulted in explosions and the second attempts did not. The other three successfully withstood the maximum stress without explosion on the first attempt. It is difficult to know whether the capriciousness in the results is to be ascribed to the explosives themselves, or is the result of secondary factors. The existence of such factors is to be recognized. If, for instance, the film of explosive between piston and anvil gets so thin as to allow the steel parts to rub directly on each other, splinters of steel might be detached with high local temperatures. It did indeed seem to be true that explosions occurred in a number of cases when the initial quantity of explosive was less than normal, and therefore the disk unusually thin.

The maximum shearing stress at 50,000 kg/cm^2 has thus been applied without explosion to seven of the eleven explosives, namely, alpha-T.N.T., tetryl, cyclonite, picric acid, P.E.T.N., and alpha- and beta-nitroguanidine. In view of the capricious character of the results and the fact that one could never have absolute assurance that no sparks were struck, it did not seem worth while to continue to repeat the attempts with the other four in the effort to reach maximum stress without explosion. In my opinion the probability is that this would have been possible.

The explosions which did occur varied greatly in character; some of them were detonations of extraordinary violence, and some were mild decompositions with a puff of black smoke and a sooty residue.

The yellow ammonium picrate was found to be irreversibly transformed into the red form.

The shearing strength of all these explosives is approximately a linear function of pressure, increasing, if anything, a little more rapidly than linearly with pressure. This is, in general, characteristic of organic substances and in sharp contrast to the metals, the shearing strength of which increases less rapidly than linearly with pressure. Within the limits of repeatability, there is no significant variation in the shearing strength of the different explosives, but all are contained within a range of ± 30 percent. In this range the largest shearing strength was shown by alpha-T.N.T. and the smallest by beta-T.N.T. Under a mean hydrostatic pressure of 50,000 kg/cm^2 the average shearing strength of all these explosives was close to 4000 kg/cm^2. This is not far from the shearing strength of metallic copper at the same pressure. At lower pressures, the shearing strength of copper is, of course, higher than that of the explosives.

In the second type of test Carboloy pistons, pressed directly against each other without the intermediate anvil block, were used. It was not possible in this type of test to apply shearing explicitly, but a small amount of shearing was the incidental accompaniment of the lateral extrusion of the wafer of explosive from between the pistons. The Carboloy pistons were only 0.125 inch in diameter on the face instead of 0.250 as were the steel pistons, and their average height was 0.006 inch. The advantage of the Carboloy over the steel is that much greater pressures can be applied. In preliminary tests a mean pressure of over 150,000 kg/cm^2 on the face of the pistons was applied without completely destructive failure. The first tests with explosives were made with alpha-T.N.T. On the first attempt, there was an explosion with black residue on reaching 57,000 kg/cm^2. On the second attempt there was a similar explosion with black residue on reaching 49,000 kg/cm^2. Neither of these explosions was of sufficient violence to do any perceptible damage to the pistons. On the third attempt, pressure was increased much more slowly than on the first two, waiting several minutes after every increment of 8000. On this third attempt a maximum of 77,000 was reached with no explosion and no apparent alteration in the explosive. The fourth attempt, also with slow application of pressure, reached the full 100,000 kg/cm^2 with no explosion. Similar tests with slow increase of pressure were then made on ammonium picrate (yellow) and alpha-nitroguanidine, reaching the full 100,000 without explosion. Picric acid was then tested. The increase of pressure was not made as slowly as with the three preceding. On reaching 93,000 kg/cm^2 there was an explosion, with black residue, of sufficient violence to destroy the pistons. Since the preparation of new pistons was a matter of some difficulty, the experiment was terminated at this point.

In view of the various possible secondary effects, such as minute local fractures in the metal parts and local elevations of temperature, it would seem legitimate to ascribe a greater significance to the reaching of a given stress condition without explosion than to explosions on other occasions produced by the same or lower stresses. The general conclusion of these experiments would seem to be that mechanical stresses of themselves of the magnitudes of those reached in these experiments cannot be counted on to initiate explosion in explosives of the type of those investigated.