TECHNICAL REPORT BRL-TR-2859

HIGH STRAIN RATE TESTS OF HE PROJECTILE LINER MATERIALS

ONA R. LYMAN
JOHN T. McLAUGHLIN

OCTOBER 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Several potential liner materials for HE projectiles were tested at high strain rates (in compression). Both good and poor performing materials were tested to determine what properties were important for good performance. Cellulose Acetate Butyrate (CAB), a good performer, flows at a very low pressure and maintains a thin film of material even when strained to the extreme. The poor performers tended to shatter at high strain rates, or, as in the case of polyethylene, required much higher pressures to initiate flow. Keywords:

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1. BACKGROUND

Initiation of cased explosive charges by projectile impact requires a projectile velocity equal to, or greater than, the ballistic limit of the case. In the velocity range below that which results in shock initiation of the explosive, the initiation mechanisms are not well understood. However, it has been reported by Frey et al that[1] the use of soft polymeric liners in cased munitions raised the velocity required to induce a reaction, and that, in general, reactions were less violent for the lined munitions tested. The liner materials tested in the above report were Cellulose Acetate Butyrate (CAB), and a latex rubber compound. The CAB is actually a mixture of CAB (44%), dioctyladipate (48%), and mineral oil (8%); a material used to coat metal parts to prevent corrosion. It is manufactured by Seal-peel, Inc., Detroit, MI, to specification MIL-P-149B. Since that time a few other materials have been tried but none have proven to be as effective as either of these. Without speculating as to the exact mechanism of initiation of reaction, it seems reasonable to assume that the effectiveness of the liner material is related to its ability to prevent contact between the explosive and the casing, during casing failure. The material properties required to produce effective liners have not been determined.

Swallowe and Field[2] reported in the Seventh Symposium on Detonation on work investigating the effect of polymers on the drop-weight sensitiveness of explosives. A part of this study was the effect of high strain rates on polymeric materials, and correlation of these results with drop weight sensitiveness of explosives containing these materials. In brief, they found that materials that failed catastrophically at high strain rates, such as polycarbonate, were effective in promoting ignition of the explosive. By contrast, materials such as polypropylene, which did not demonstrate catastrophic failure at high strain rates, tended to desensitize the explosive. Dr. Frey suggested that a similar high strain rate test of candidate liner materials might provide a method of predicting their performance as liners for explosive filled projectiles. The remainder of this report is devoted to a description of the apparatus used to produce high strain rates (in compression) and the results obtained for a variety of polymeric materials.

APPARATUS

The Ballistics Research Laboratory has for many years studied the setback sensitivity of explosives using apparatus developed at Picatinny Arsenal. In recent years this work, under Dr. J. Starkenberg, has expanded to other aspects of explosive sensitivity.[3] As part of this program a new test apparatus was constructed which uses drop weights as the energy source simulating setback conditions. This test vehicle has been used for this program with minor modifications and is shown in sketches in Figures 1 and 2. Three drop weights are available for tests, the heaviest is 6.44Kg, the medium weight is 3.73Kg, and the lightest is 2.41Kg. Drop heights can be as large as 1.4 meters. Impact energy up to 88Kgf*Meter and momentum up to

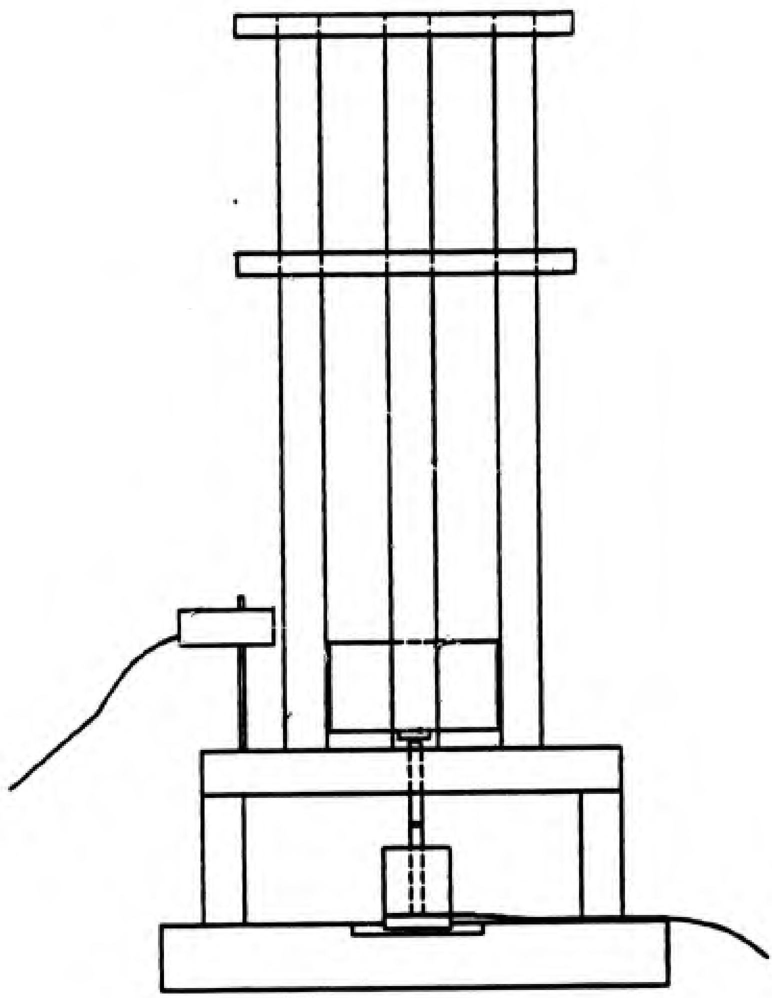

Figure 1. Sketch of Drop Weight Apparatus, Drop Weight at Impact Position

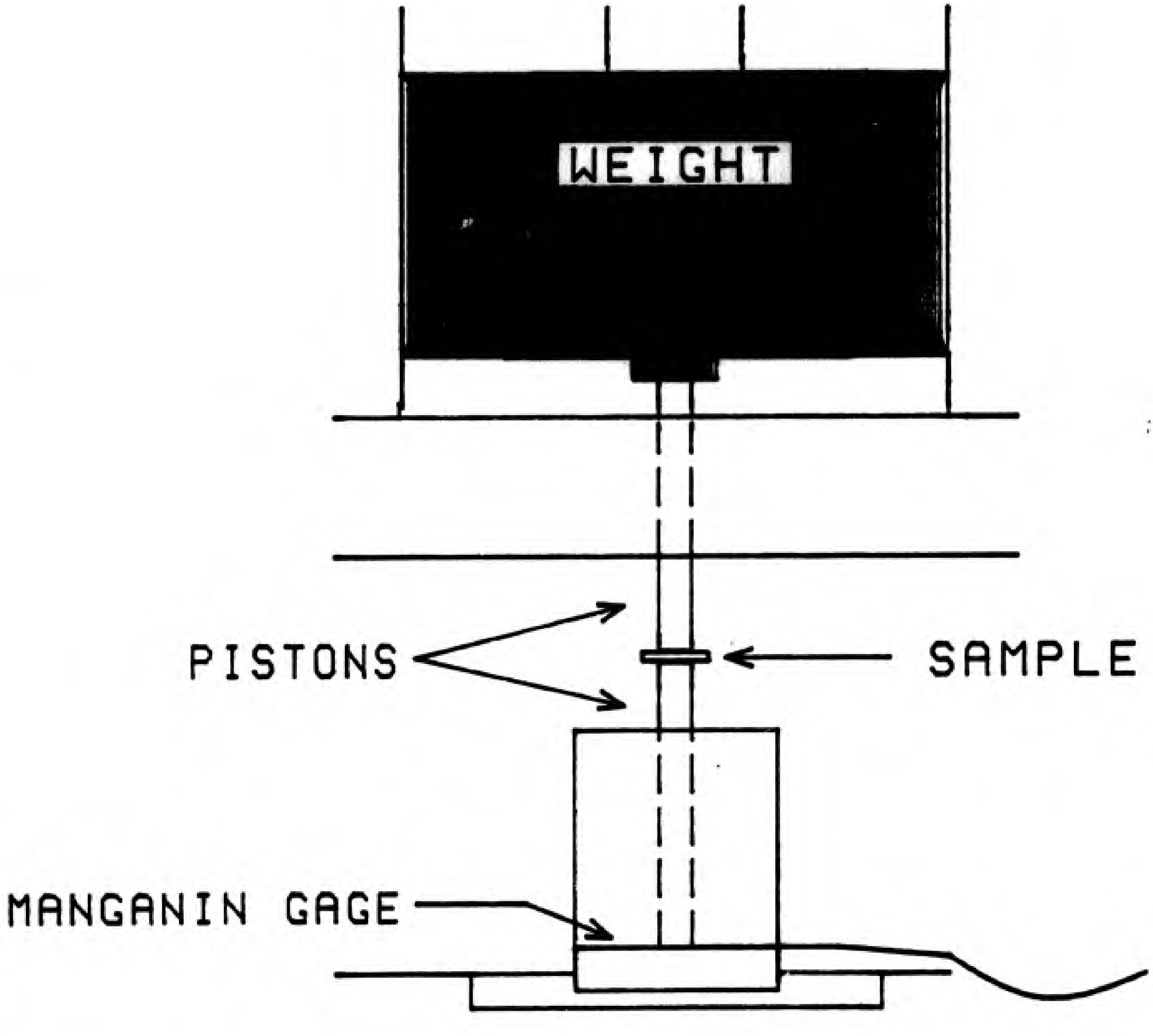

Figure 2. Close-up View of Sample, Pistons, and Drop Weight at Impact

34Kg*M/s are obtainable. A manganin gage mounted on a gage block is centered under the bottom piston of the test fixture. The bottom piston extends through the cylinder which normally provides confinement for set-back initiation experiments. The sample under test is placed atop the bottom piston and the top piston rests on it supported by the top plate of the test apparatus. When the weight is dropped, the resulting pressure on the sample produces a resistance change in the manganin gage. A constant current pulse through the gage, which is in a bridge circuit, produces a voltage recorded by a digital oscilloscope. This record can then be translated to produce a pressure vs time record or a stress vs strain record.

The diameter of the pistons used is 12.7mm. The sample lateral dimensions are sufficiently large to prevent material failure from propagating to the edge of a sample. (Samples are usually about 50mm square, although the exact dimension is not critical.) Because the sample area is larger than the piston area, the area to which the force is applied is constant throughout the test. An optical sensor and HeNe laser beam are used to provide a zero time trigger as the weight approaches the top piston. This signal is used, with appropriate delays, to both trigger the current pulse to the gage and start the data recording. The timing sequence is set to allow the gage current to stabilize before the weight impacts the piston (20 microseconds is adequate). The data obtained are a record of pressure at the gage as a function of time. Data are transferred to floppy disc storage for further analysis, and a Y vs t plot of the raw data is also made. The sampling rate used was 2 microseconds per point and the record contains 4096 points.

This apparatus produced data adequate for the purposes of this test series, however, it does have a few deficiencies. The principle problem is that manganin gages, even when pulsed at high currents, are not very sensitive at the pressures used. This is particularly true for the softer materials that yield at pressures of the order of 10 to 100 Megapascals. Fortunately, exact yield pressures are not important to the study, and the range and nature of failure can still be readily distinguished. A second problem which must be solved before the apparatus can be used with explosive samples is the bounce and second strike of the weight. Bounce occurs when there remains sufficient energy after deformation of the sample to elastically deform the other elements in the system. This energy is then returned to the weight, accelerating it vertically. This occurs long after the data recording is complete, and had no effect on these tests. In explosive testing, this would be an unacceptable occurrence. The pressure vs time records obtained had a damped oscillatory signal superimposed upon the signal of interest. This signal is a result of pressure waves oscillating between free surfaces in the system. Attempts were made to trace the source of these waves and eliminate them where possible. It was possible to eliminate, or reduce the amplitude of most of these interferences, but some still persisted. These were dependent on the sample material to some extent, but did not prevent meaningful analysis of the data.

Data reduction was performed on a personal computer using commercial software. Data are presented as stress vs strain curves. Pressures are recorded at 2.0 microsecond intervals, which are averaged over 20.0 microsecond periods to reduce the number of data points to a tractable number. A series of algebraic operations are then performed to obtain strain as a function of time, and the strain rate. Plots are then made of stress vs strain. Strain rates are maximum at impact because the velocity of the weight is decreasing after impact. Stress vs strain plots have the same general shape as the pressure vs time plots, because the strain is an increasing function of the time, and for quick analysis, pressure vs time plots can be used to determine whether or not a given material is likely to make a good liner.

RESULTS

At impact the weight has its maximum kinetic energy. It begins to lose energy from then on until all its energy is deposited in the system of pistons, sample, and steel backup plates. Initially, the sample begins to deform and some energy is used in the plastic deformation of the sample. Energy is also being used in elastic deformation of the sample (depending on its material properties), the pistons, and the remaining elements of the system. If the sample is thick, and deforms rather easily, most of the energy is used in plastic deformation. This is observable by the fact that the weight does not bounce, i.e., there is not sufficient elastic energy available to the system to accelerate the weight upward. Conversely, if the sample is thin, or a strong sample material is used, then considerable elastic energy is returned to the weight accelerating it upward. For many of the materials tested at thicknesses of interest, a typical pressure vs time plot shows a low pressure level until the sample fails or flows from between the pistons. This is followed by a steeply rising pressure which peaks at a level that depends on the material and the drop height (a drop weight of 6.44Kg was used for all data reported here). At the late time peak of the pressure pulse, the velocity of the weight has dropped to zero. This point can serve as a check point when doing your calculations. The data are quite good in this respect for strong samples such as polyethylene, but are not so good for materials with low yield strength, such as CAB. The most likely reason for this is the uncertainty of the pressure readings at low pressure levels. Figure 3 is a pressure time record for a polyethylene sample.

Polyethylene is a fairly rigid material at the strain rates used for the test whose record is shown in Figure 3. The effect of the rigidity is apparent in the damped oscillation superimposed on the pressure record recorded. Because of the difference in impedance of the polyethylene and the steel components, the oscillations are spread out and damped; however, the oscillations are more pronounced than with softer materials. Polyethylene was also found not to be a very effective liner material.[4]

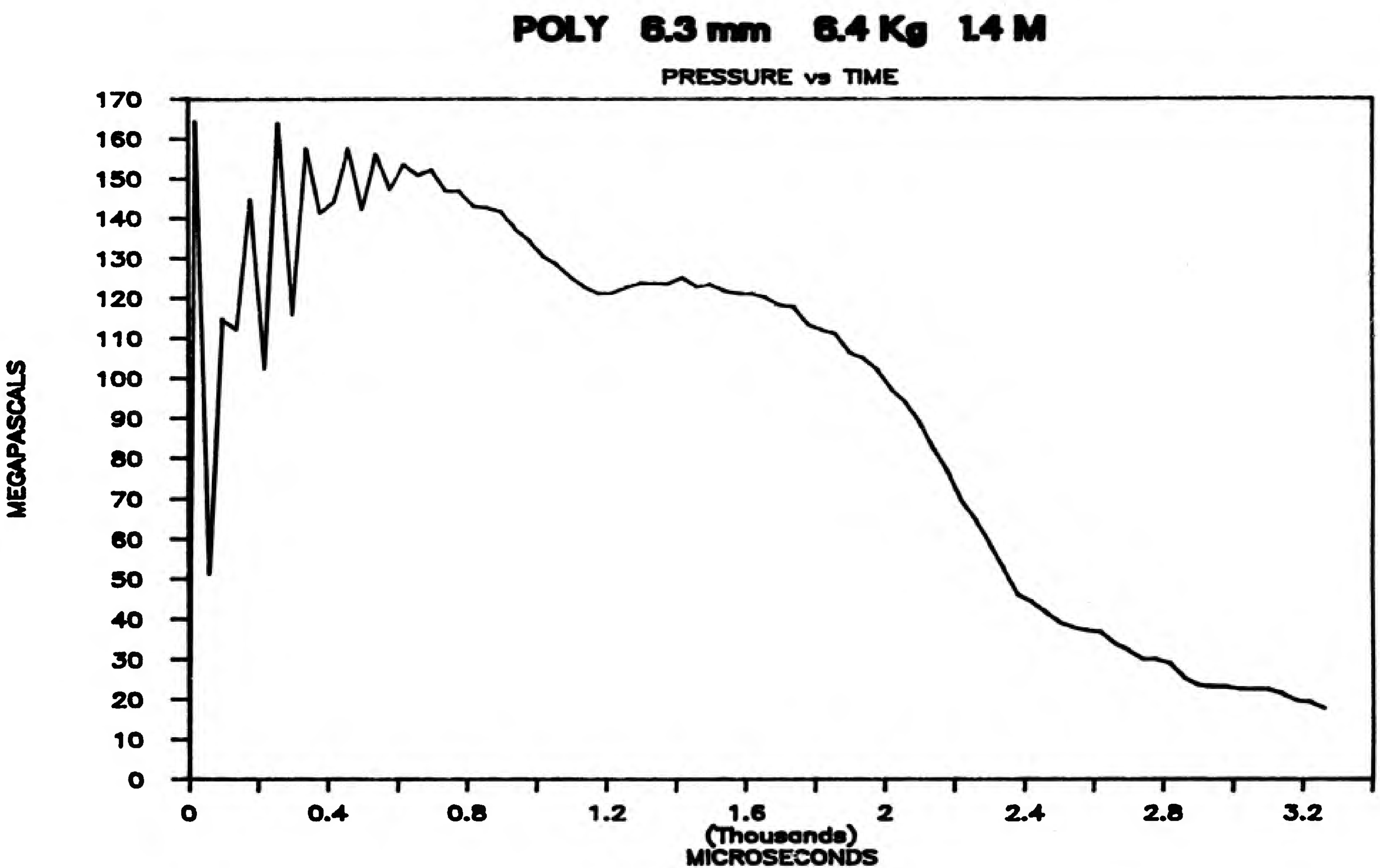

Figure 3. Pressure vs Time Record for Polyethylene Sample

A polymethylmethacrilate material was also tested. It was anticipated that this material would probably fail by shattering. The pressure vs time record for this material is quite different from that of polyethylene, as can be seen in Figure 4. For this material, the pressure rises to a fairly high value, then following one oscillation, the material fails catastrophically. The pressure remains at a low value from then on until solid contact is made between the top and bottom pistons, at this time, because the weight still has some kinetic energy to expend, the pressure rises in much the same manner that it does for tests made with no intervening deformable material. Although no tests were made to determine the efficacy of Lucite as a liner material, it is known to be unsuitable.

Teflon (tetrafluoroethylene) was tested although it was known to be a poor liner material. At these strain rates, teflon failed by shattering very soon after impact (less than 100 microseconds). The recorded pressures after that were 100 Megapascals or less until the pistons made contact. Peak pressure after contact was nearly 1,000 Megapascals. This record is shown in Figure 5.

Compare the pressure vs time record obtained for the CAB material shown in Figure 6 with the records discussed above. The test conditions were identical to those above with the exception that the CAB sample was 1.3mm thicker. For CAB, the pressure recorded was substantially less, and was maintained at a nearly constant level until the sample was penetrated. Furthermore, there is no evidence of shattering as occurred with the brittle materials. Post-test examination of the sample showed that material had been squeezed from between the pistons, and then flowed back into the hole to some degree. The fact that the sample was slightly thicker is of no significance, because other tests with variations in the sample thickness of CAB showed that the principle effect of thicker samples is to extend the duration of the low pressure region of the record. Figure 7 shows the pressure time trace for three sample thicknesses. The "long term low pressure region" indicates that the pressure experienced is nearly constant for the samples tested, within the limits of pressure recording accuracy. The duration of the low portion of the pressure trace is proportional to the thickness of the sample, which is reasonable and to be expected.

Figures 8 through 11 are the same data presented in a stress vs strain format with the strain axis limited to a maximum of 1.0. There is little to be gained from this, because the shape of the curve is the same as the P vs t curve. Strains are large as evidenced by the fact that the strain axis upper limit is set at 1.0. Strain rates are also large. For a constant sample thickness of approximately 6.2mm, strain rates were from 700 to 800/sec for the materials tested. The strain rates are maximum initially as that is the time at which the weight velocity is greatest. Consequently, for the various thicknesses of CAB, the strain rate decreases with increasing sample thickness.

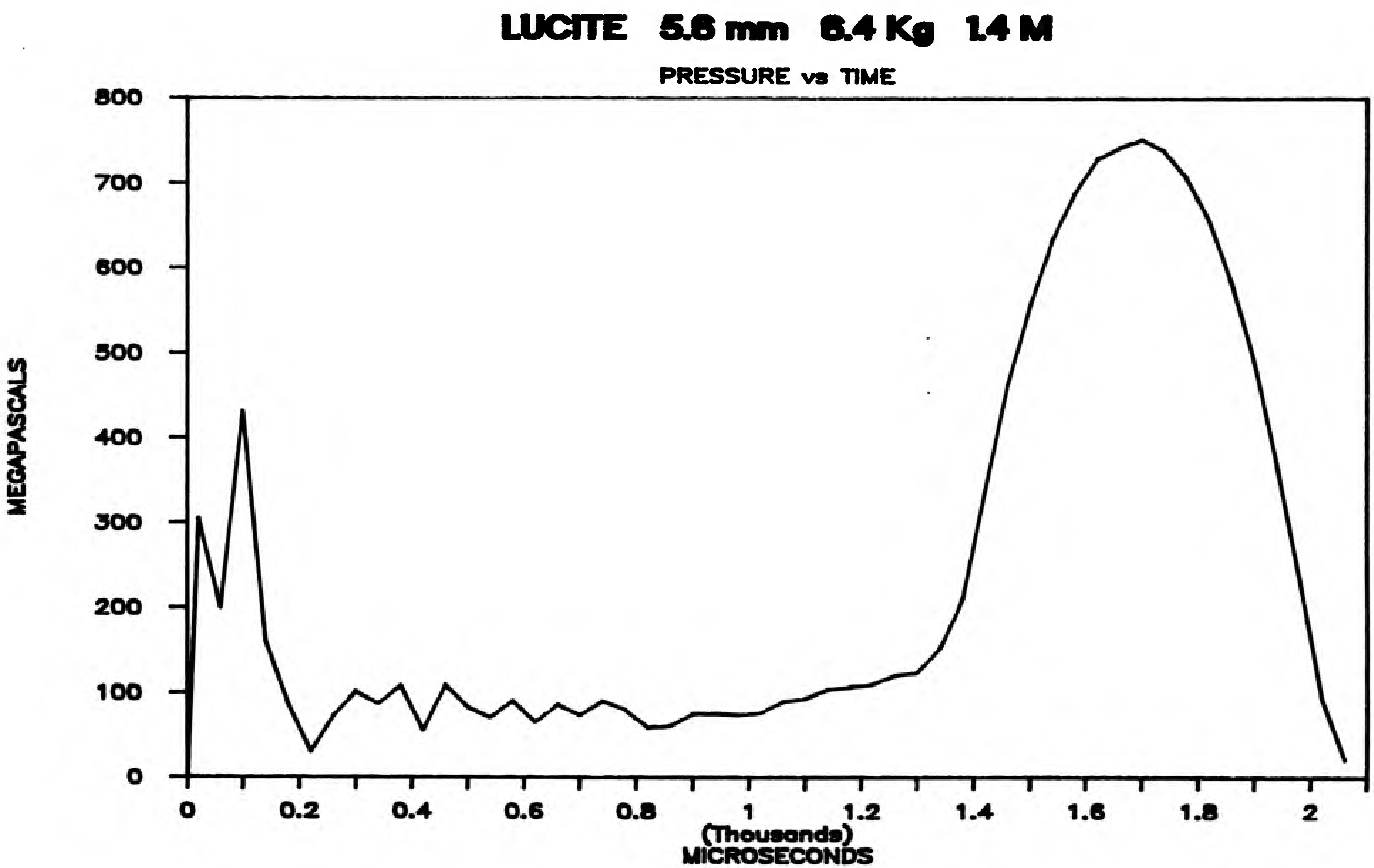

Figure 4. Pressure vs Time Record for Methylmethacrylate Sample

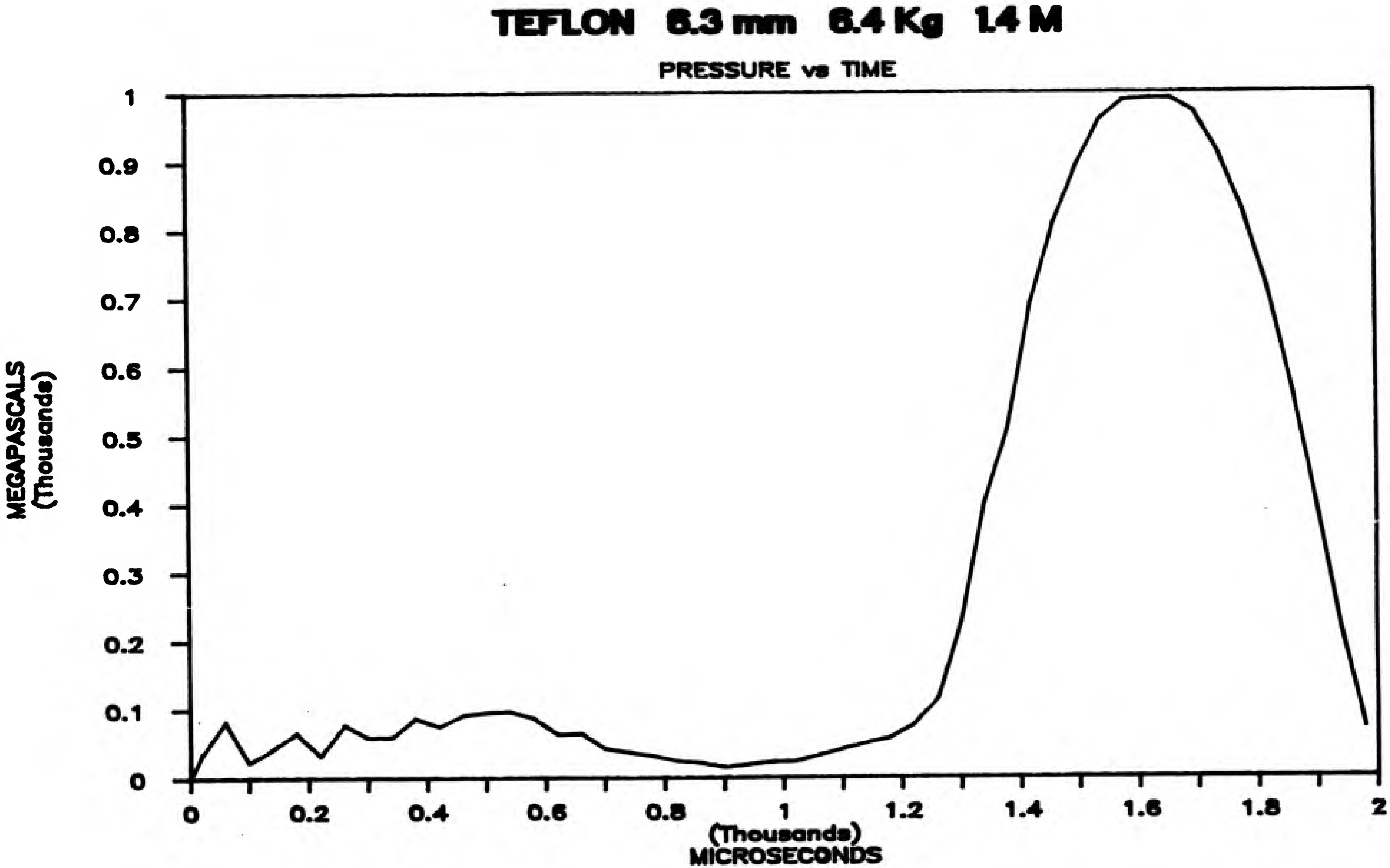

Figure 5. Pressure vs Time Record for Tetrafluoroethylene Sample

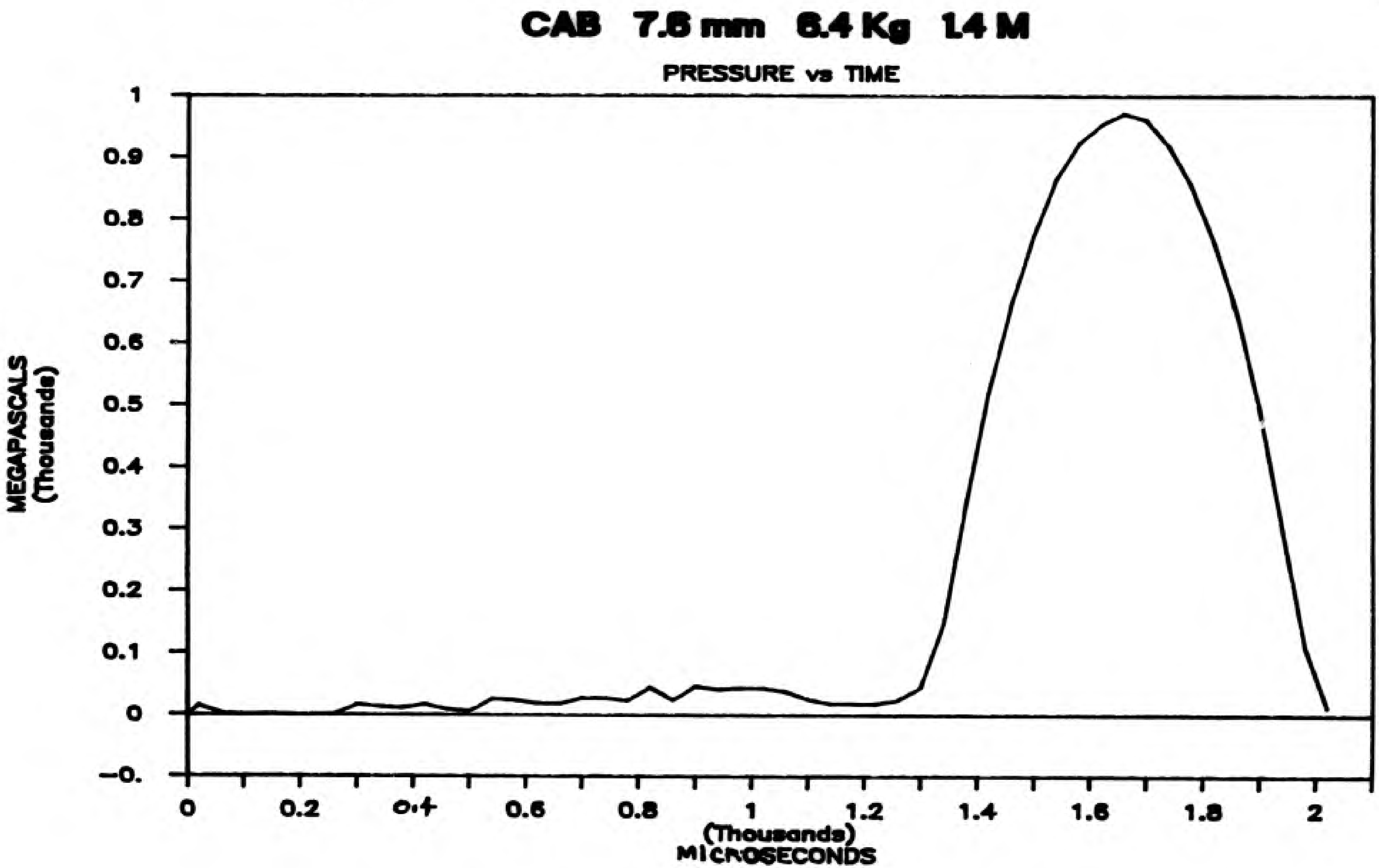

Figure 6. Pressure vs Time Record for Cellulose Acetate Butyrate Sample

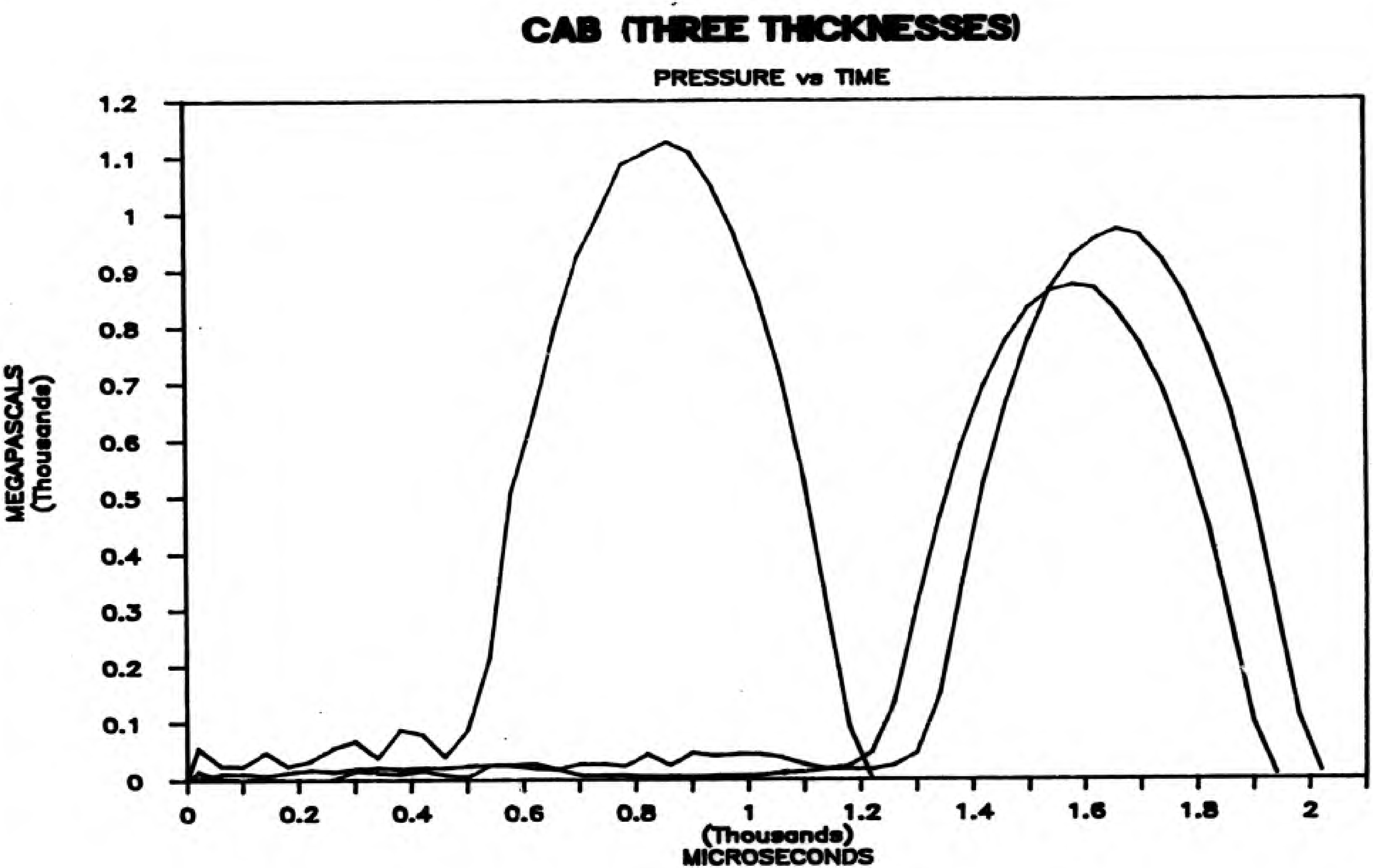

Figure 7. Pressure vs Time Records for Three Samples of CAB With Thicknesses of 2.5mm, 7.6mm, and 10.6mm

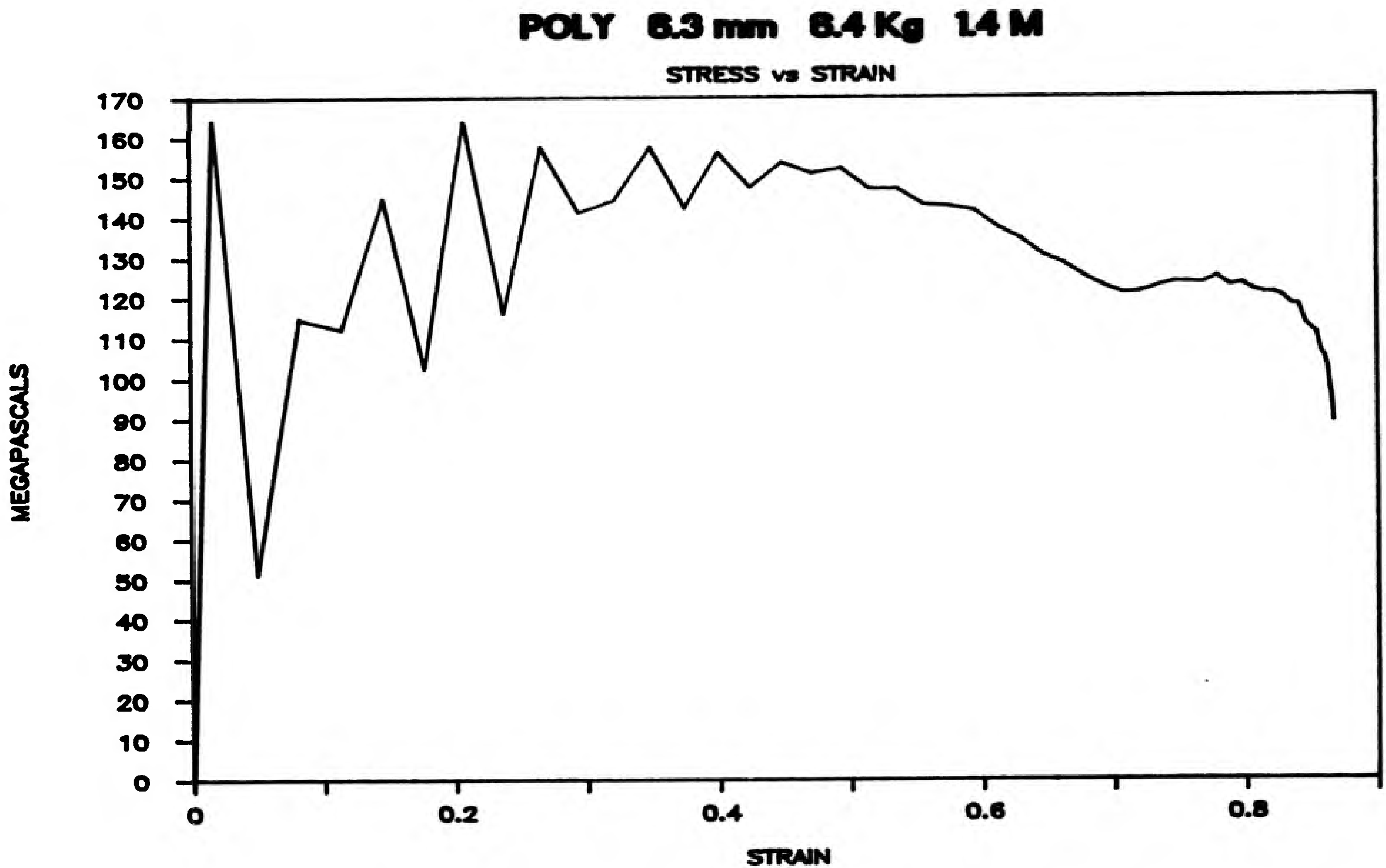

Figure 8. Data From Figure 3 Displayed as Stress vs Strain

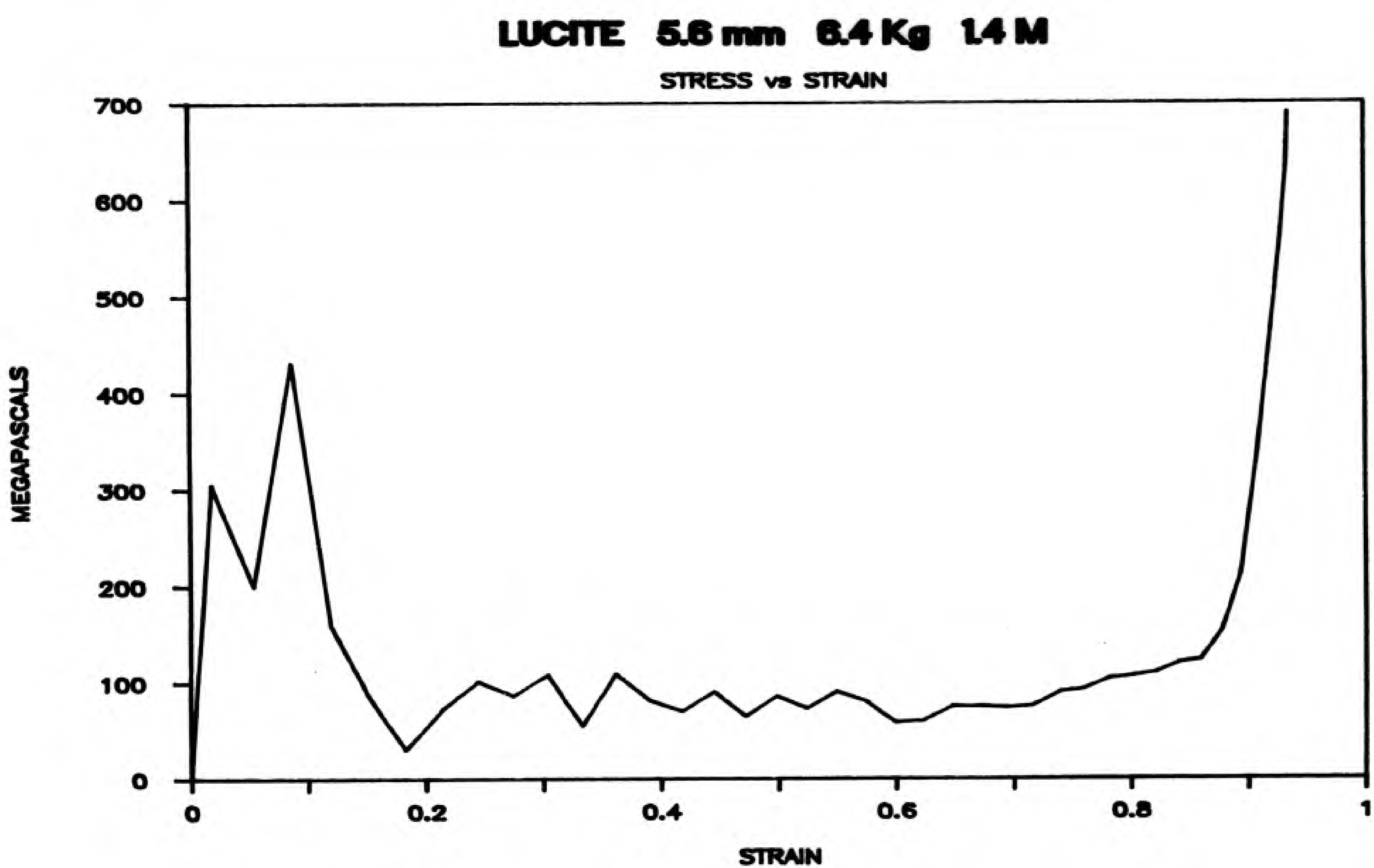

Figure 9. Data From Figure 4 Displayed as Stress vs Strain

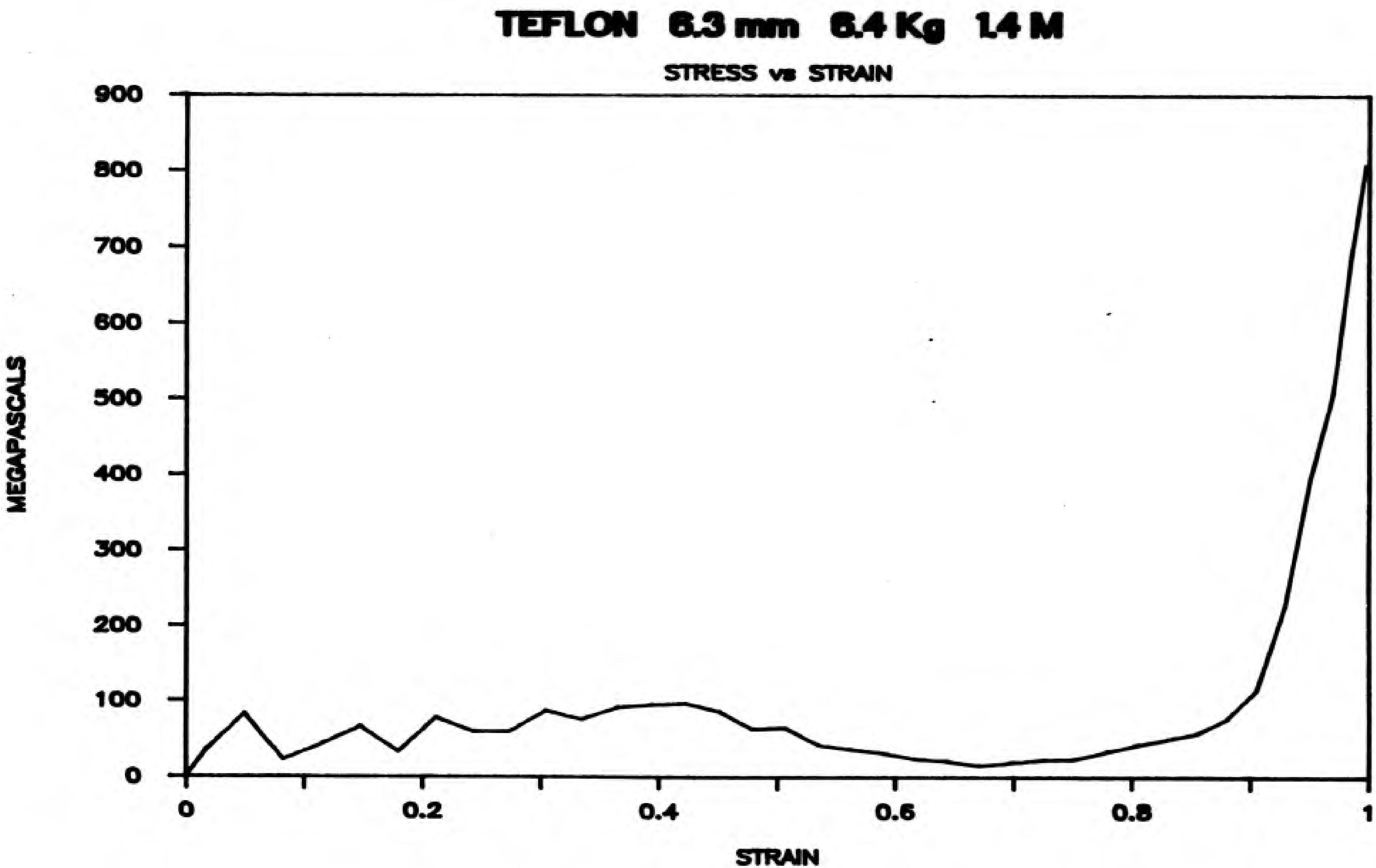

Figure 10. Data From Figure 5 Displayed as Stress vs Strain

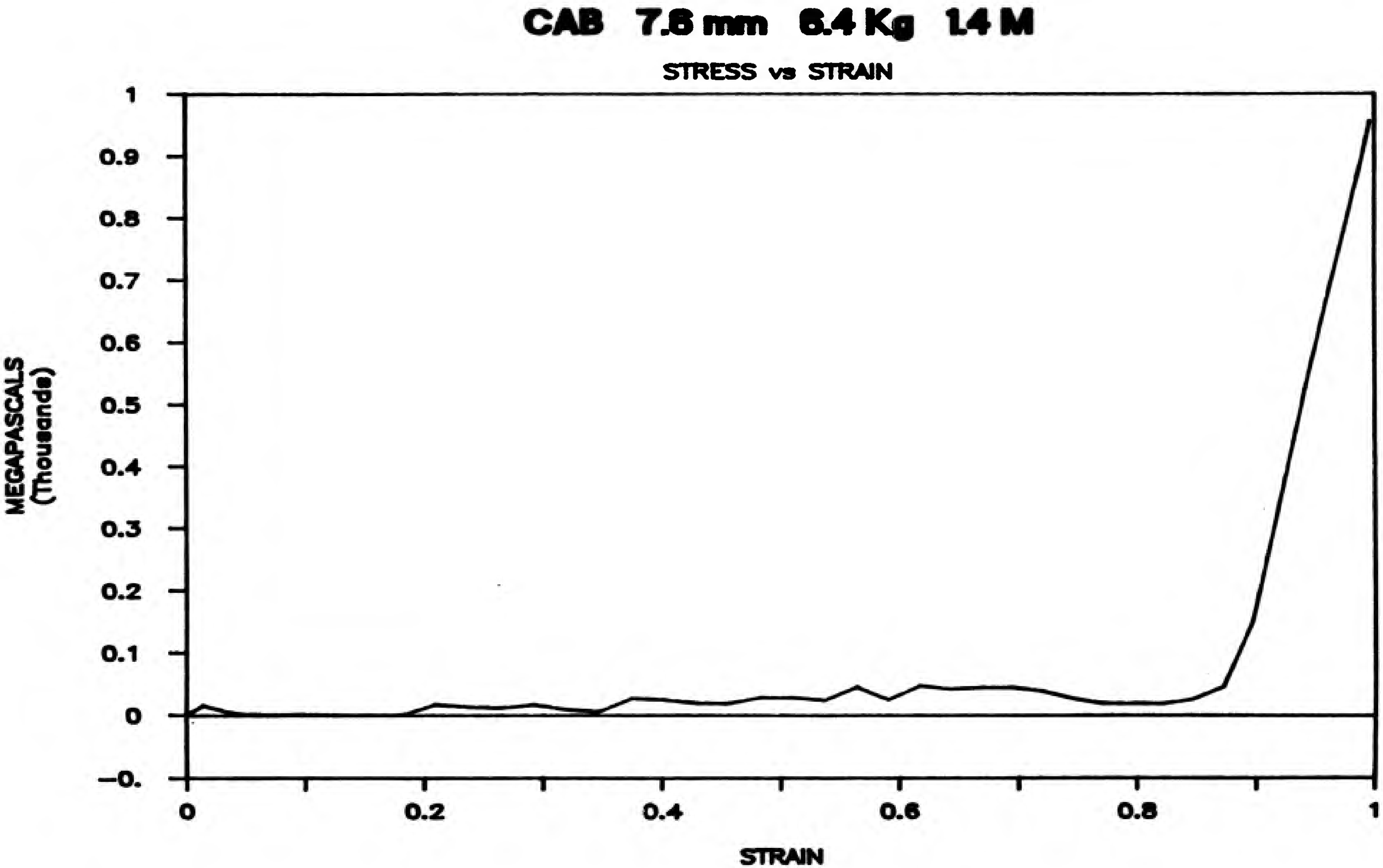

Figure 11. Data From Figure 6 Displayed as Stress vs Strain

A soft epoxy material was also tested. There was insufficient material available to do a complete test series, but for the tests performed, it was apparent that its performance was not very different from that of CAB. Although the data are not included in this report, it is mentioned to indicate that CAB is not the only material that appears to have potential as a liner material.

At the time this program was drawing to a close, Dr. Philip Howe provided some samples of latex rubber that he had been using in some related work. A few tests were made with these materials. The results were not significantly different from those obtained with the CAB material. Dr. Howe reports, however, that he has some evidence that the CAB material has a tendency to fail by plugging at high strain rates, and that the latex material is possibly a better liner material from this aspect.[5] The strain rates available from the apparatus used here were not large enough to make any determination about these properties.

CONCLUSIONS

Frey et al[1] have shown that CAB liners for explosive filled projectiles can significantly increase the fragment velocity required to produce violent reactions. This study shows that the material properties that are important for this application are the ability to flow at low pressures (of the order of 50 megapascals), and the ability to remain cohesive under large strains, i.e., not shatter. The CAB samples examined after impact still had a thin layer of material between the piston faces. It is believed that this is important because it provides a layer of material between the explosive and the casing in HE projectiles. This thin layer insulates the explosive from the hot fracture surfaces of the case, and prevents the extrusion of explosive into casing cracks.

Some impact energy of a fragment striking a lined cased explosive will be expended in forcing the liner material to flow as the case is deformed. If the pressure required to do this is small, then the explosive will experience a smaller force. Perhaps, and equally important, the strain rate experienced by the explosive will be reduced. This leads one to the conclusion that thick liners should be more effective than thin liners. There are practical reasons why a liner should not be too thick. However, Frey[1] has shown that thicknesses as small as 1.5mm are effective.

The work reported here is not an exhaustive study of all potential materials that might make suitable liners. Material known to be effective (CAB) and material known to be ineffective were tested and their responses observed. The CAB material, as was mentioned earlier, a mixture of CAB, dioctyladipate, and mineral oil, is a readily available commercial product, and is easily applied. More tests at larger strain rates should be made with CAB, soft epoxy, and latex compounds. A more sensitive measurement system for the low pressure range of the data is also needed in order to make more than a qualitative evaluation of materials. More and different tests need to be done before any of these materials could be recommended for inclusion in the manufacture of HE projectiles; such as long term compatibility, performance in a launch environment, etc. In addition to testing each of these seemingly appropriate materials, variations in the ratios of additives should also be examined, particularly for the CAB. Lastly, if interest in this technology develops, it would seem wise to include the addition of outgassing agents, such as calcium formate, to the liner material as they have been shown to be effective in reducing reaction violence during fast cook-off tests.[6]

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