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Confined Creep Testing of Plastic-Bonded Explosives

B. J. Cunningham, F. J. Gagliardi

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Bruce J. Cunningham, cunningham1@llnl.gov
Franco J. Gagliardi, gagliardi7@llnl.gov

Lawrence Livermore National Laboratory
Energetic Materials Center
P.O. Box 808, L-282, Livermore, CA 94550, USA

ABSTRACT: A considerable amount of data has been compiled on the strain response of plastic bonded explosives to uniaxial stress. In real world applications, however, these materials are most likely to be subjected to more complex stress states. In an effort to better understand the behavior of this material under multi-axial stress conditions, a series of experiments was performed to measure the effect of confinement on the compressive creep behavior of LX-17-1, a highly filled explosive composite consisting of 92.5% crystalline energetic and 7.5% polymer binder. These experiments were conducted using our Livermore-developed creep measurement apparatus in conjunction with a gas charged confinement fixture. Measurements of axial creep were made at temperatures ranging from 24 C to 70 C, with axial stresses ranging from 1.9 MPa to 5.4 MPa gage. Confinement pressures ranged from 0 MPa gage, up to levels equal to the applied axial stress. In all, approximately 25 experiments were performed. Design details relating to the creep measurement and confinement apparatus are presented, along with experimental results and analysis. Within the range of temperatures and pressures tested, creep rates were found to correlate reasonably well with the differential between the axial and confining stresses.

INTRODUCTION

Plastic-bonded explosives (PBXs) are typically composite materials consisting of a mixture of explosive crystals and plastic binders that are compacted at elevated temperatures. The mix ratio of explosive to binder varies from one PBX to the next, but generally the explosive component comprises 80-95% of the weight of the composite [1]. In typical applications, a high ratio of energetic to binder in these materials is necessary in order to achieve a high energy density. The principle function served by the binder is to provide mechanical integrity [2]. PBX composites have notably enhanced mechanical strength when compared to compactions that are made from pure explosives. In addition to meeting the structural requirements for load bearing, binders allow parts to be machined into precise geometries. Exact geometries are important features in systems where detonation propagation needs to be precisely determined.

Many types of tests are used to characterize the mechanical properties of various PBXs, including quasi-static uniaxial compressive, uniaxial tensile, and other tests. Traditionally uniaxial tension and compression tests are used as a means of characterization for nuclear stockpile certification, for material model development, and for new lot qualification [3]. Tests such as these also provide information used in the development of material models. Such models are helpful in analyzing and predicting short-term and long-term material responses to a diverse set of possible load and temperature conditions [4].

In many applications, creep (the slow strain response, over time, to constant or changing stress conditions) is of particular interest. An ongoing objective at LLNL has been to develop a robust PBX mechanical response model that can be validated through materials testing. Requisite to the development of such a model is a detailed understanding of the long-term creep response of PBX materials.

Characterization of this particular class of materials is complicated for several reasons. One reason is that the materials are multi-phase, one phase of which is often polymeric. This causes the composite to exhibit a high degree of behavioral dependence on both temperature and strain rate. Further, as strain develops, localized decoupling and separation will occur between the binder and the energetic phases resulting in permanent damage. Consequently, the material responds in a manner that is both visco-elastic and visco-plastic.

In 2007 LLNL (Gagliardi, Cunningham) presented a paper at the SEM conference in Orlando Florida on uniaxial (unconfined) creep testing of PBXs [5]. In real world applications, stress conditions are highly likely to be multiaxial rather than uniaxial. In this paper we present follow-on work involving creep measurements on PBX materials subjected to various degrees of confinement.

The specific material upon which the experiments reported in this paper were performed is LX-17-1. This PBX consists of 92.5% triamino-trinitrobenzene (TATB) and 7.5% Kel-F 800™, by weight [6]. In the explosives world, LX-17-1 is categorized as an Insensitive High Explosive (IHE) due to its relatively high resistance to reaction when exposed to stimuli such as impact, friction, elevated temperature, or static discharge
(see Figure 1).

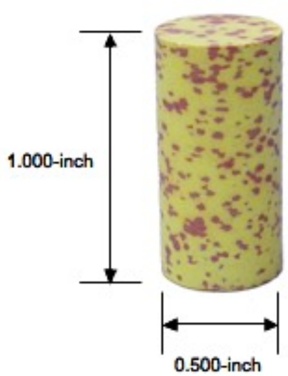

FIGURE 1: Shown left is a typical LX-17-1 compression sample. The part is made from a mixture of 92.5%triamino-trinitrobenzene (TATB) and 7.5% polymer binder (Kel-F 800™). The part has been precisely machined from a billet that was hydrostatically pressed at a temperature of 105 ˚C. TATB is an explosive that is highly insensitive to impact, friction and to thermal and electrical insult.

TEST HARDWARE

The additional hardware used to provide confinement on compressive creep specimens was designed to work specifically with our existing uniaxial creep measurement hardware (See Figures 2, and 3). The confinement fixture (see Figures 4 and 5) consists of a hollowed out aluminum box to which an elastic tube with a 0.5 inch (12.7 mm) inner diameter has been fitted. The tube ends have been pinched to provide a gas-tight seal. Surrounding the tube is a cavity with a port. In testing, a lubricated specimen is inserted into the tube. After bringing axial loading rods into contact with the specimen, confining gas pressure is applied to the specimen via a 1/16-inch (1.6 mm) diameter stainless steel tube connected to a high-pressure manifold and gas-bottle. For safety reasons, testing is usually conducted behind a barrier whenever the confinement device is charged to levels exceeding 150 psig (approximately1 MPa). The gas pressure is measured and monitored using dial gages and a digital readout.

PRELIMINARY TESTING

Before experiments were conducted on explosives, testing was first performed on a number of inert substitute materials. The purpose of these initial experiments was both to determine whether functional problems might exist with the apparatus, and also to provide a preliminary means to evaluate the data being generated. Figure 6 shows a plot of data that was produced by subjecting an 0.5 inch (12.7 mm) diameter by 1 inch (25.4 mm) long black Delrin® specimen to a series of step changes in confinement pressure. For this test, there was no applied axial load. As is seen in the plot, the specimen responds to steps in increased pressure by growing axially (in effect, extruding), with additional time-dependent growth occurring during the periods of constant pressure. For stepped decreases in pressure, rapid shrinkage occurs during unload, followed by creep recovery during subsequent periods of constant pressure.

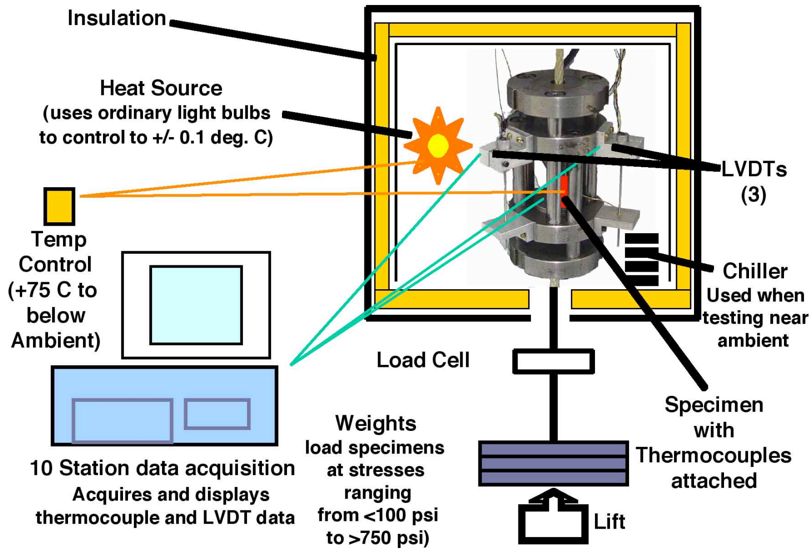

FIGURE 2 : A schematic of the basic creep measurement system.

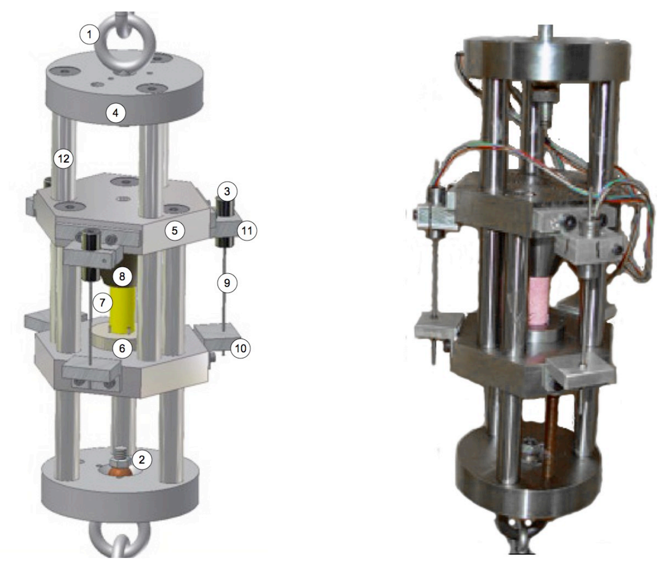

**FIGURE 3: The creep fixture, shown as a solid model on left and a photograph on right. 1) An eyebolt serves to connect the fixture to the top of the chamber. 2) Brass spheres are used to create a low friction pivot coupling between the eyebolts and the outer cylindrical plates 3) Three LVDTs (Linear Variable Differential Transformers) are used as the long-term creep measurement displacement gages. They are spaced 120˚ degrees apart and measurements from the three gages are averaged. 4) Cylindrical plates.
5) Two hexagonal plates transmit the compressive load to the sample as the outer plates are pulled apart. 6) The lower plate with sample positioning pins. 7) The sample (yellow). 8) A conically-shaped connector with a flat end applies load to the top of the sample. 9) One of three LVDT core-mounting rods. 10) A lower bracket to which the core mounting rods are attached. 11) An upper LVDT mount bracket. 12) Six 0.5-inch rods are used to connect the outer cylindrical plates to the inner hexagonal plates creating the pull-push frames used to apply the compressive load to the sample. The short-term load-up strain is measured using a directly applied extensometer pair. Long-term creep strain is inferred from the relative motion of the loading surfaces as measured by the LVDTs.**

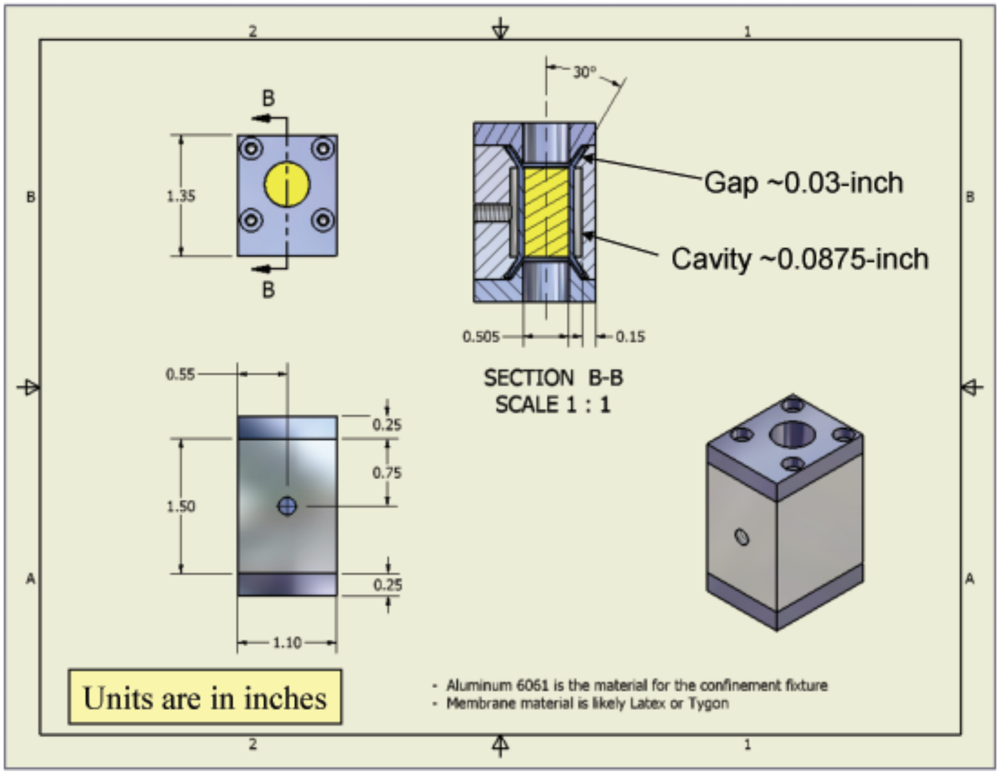

FIGURE 4: The confinement hardware.

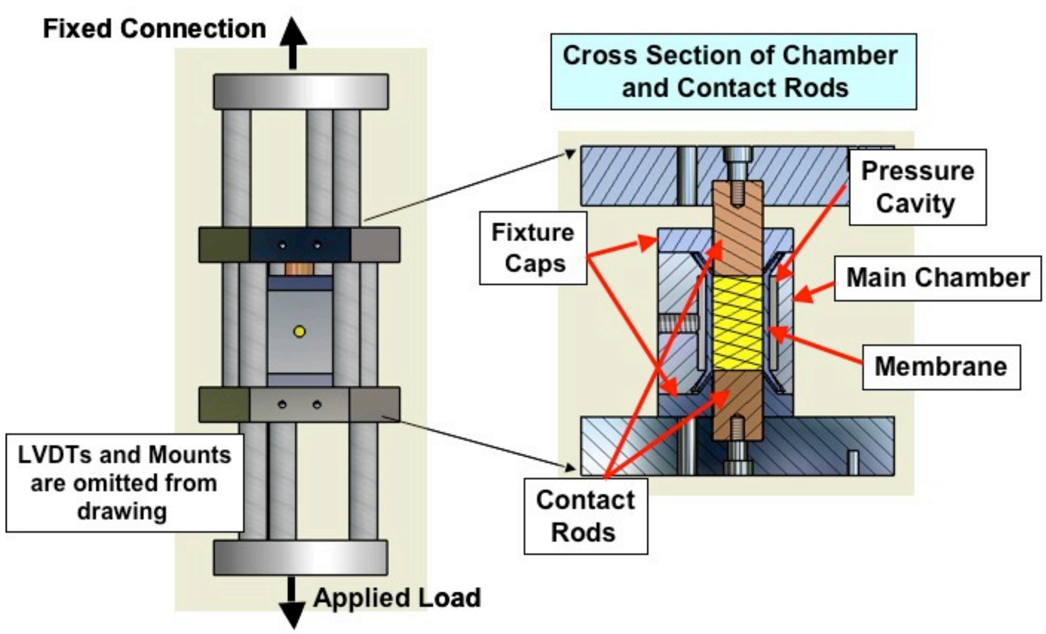

FIGURE 5: An illustration of the confinement hardware situated in the creep fixture.

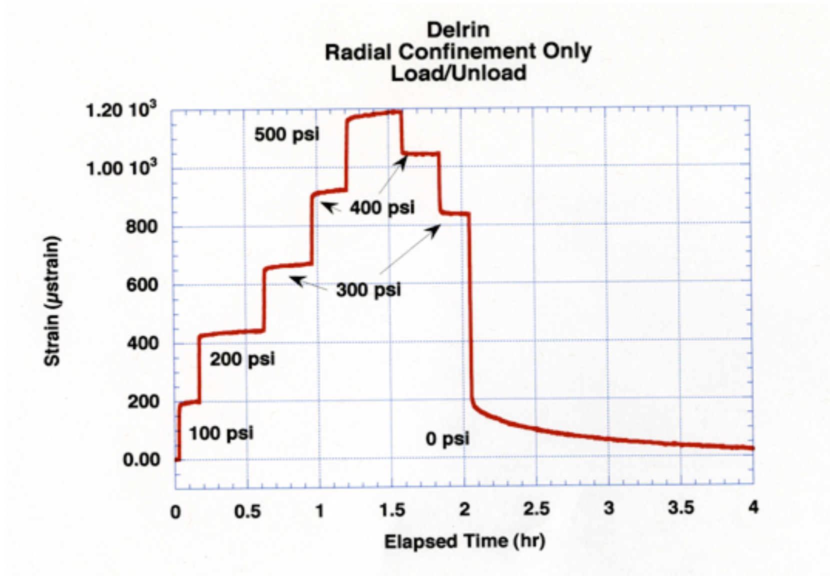

Figure 6: Preliminary confinement pressure measurements on black Delrin®. The strain shown (vertical axis in microstrain) is in the axial direction. There was no applied axial load.

To examine the possibility that the pressurized tube might cause an artificial stiffening of the specimen due to frictional coupling to the walls of the sample, we performed some simple experiments in which we measured the force necessary to axially displace a rod that was being confined by the fixture (see Figure 7). Measurements showed that, at worst case, slippage between the rod and confining tube ensured at applied axial forces that were quite small - on the order of a pound (.45 kg). This suggested that in testing, we would expect the tube to be nearly axially decoupled from the smooth walled, lubricated sample, and this was the desired condition.

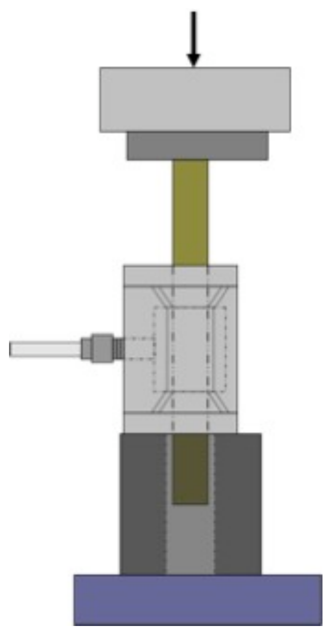

Figure 7: The confinement fixture placed on a hollow stand with a long, greased rod inserted through the fixture. Measurements were made of the force necessary to slide the rod through the tube, at various confinement pressures.

PBX MATERIAL DATA

A matrix of experiments was performed under different conditions of temperature, axial stress, and confinement pressure. Figure 8 shows representative strain-time data derived from a subset of the matrix. For all the data shown in the figure, the applied axial stress was nominally the same - 510 psi (3.5 MPa) - and the test temperature was 50 ˚C. Each of the curves plotted represents a different level of confinement, ranging from no confinement (lower curve), to 510 psig (see upper curve). For this test set, 510 psig confinement represents, essentially, a "hydrostatic" pressure condition for the sample, because the axial and confinement stresses are the same. Note that as the level of confinement increases, the PBX material stiffens and the creep rate decreases. Also note that, even under the condition of "hydrostatic" confinement pressure, small amounts of creep still occur, suggesting a slow densification is taking place. Densification is possible because, when the material is initially compacted, maximum theoretical densities are not achieved, which is to say that voids are present. This circumstance allows for the possibility of further void closure, and therefore a reduction in volume.

Figure 9 plots all the data for all the experiments performed. In these experiments, three different nominal levels of axial stress levels were used - 270, 510, and 780 psig (1.9, 3.5, 5.4 MPa) – as well as three test temperatures – 24, 50, and 70 ˚C. To allow comparisons to be made between all experiments, the data is plotted as a function of confinement pressure, where confinement pressure is expressed as a percent of "hydrostatic". "hydrostatic" is defined as the condition where the applied confinement stress is equal to the applied axial stress. The vertical axis in these plots represents creep rates normalized to rates measured at the zero confinement condition.

Figure 10 re-plots the same data as that plotted in Figure 9, only in this case, the data is shown as a function of the difference between the axially applied stress and the confinement stress. Here creep rates are defined as the "b" coefficient in fits to the data of the form shown in the equation:

$$\varepsilon(t) = a + b * Log(time) \tag{1}$$

Note that, although there is some scatter, the data indicates a general correlation between the creep rate and the stress differential. An apparent violation of this principle exists for the data gathered at the "hydrostatic" condition, which shows some creep taking place, in spite of the fact that, under these circumstances, the difference between axial and confinement stress is zero.

SUMMARY

Hardware to allow the effects of lateral confinement on the creep rate of plastic bonded explosives was designed and subsequently tested. More than two-dozen LX-17-1 tests were performed under different conditions of axial stress, temperature, and confinement pressure. For a given axial stress and temperature, creep rates were found to diminish with increasing levels of confinement. It was observed that, even under circumstances where the confining stress was equal to the axial stress (the "hydrostatic" condition), small amounts of creep were still present, suggesting some densification was occurring. With qualification, the data indicates that over the temperature and stress regimes for which tests were performed, creep rates for this material appear to be largely a function of the difference between the axial and confining stresses.

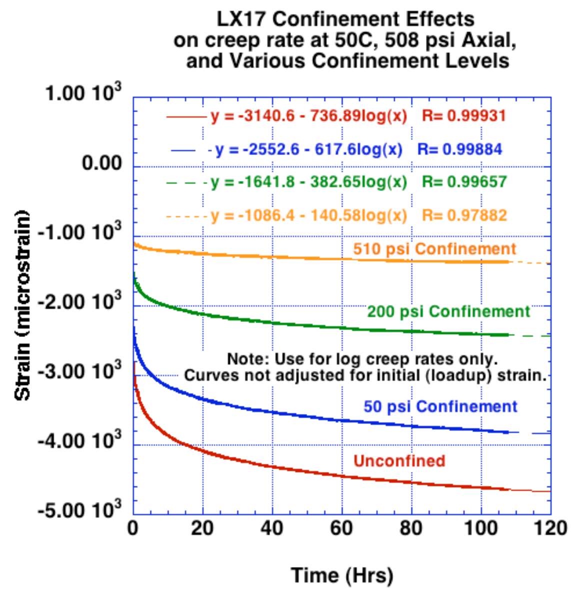

Figure 8: Effects of lateral confinement pressure on axial creep of LX17-1. The equations shown are fits to the data of the form strain = a + b*log(time), so that the "b" values are an indicator of the rates of creep. Creep rates for the four plots shown vary by a factor slightly greater than five. We are not able to measure initial strain at load-up when using our confinement fixture, and consequently the relative axial position of the curves is not accurate. Initial load-up strains are normally measured using sample-applied extensometer pairs. LVDTs are not used to measure load-up strains due to errors that are attributable to slight closure between the sample ends and the loading surfaces as the load is being applied.

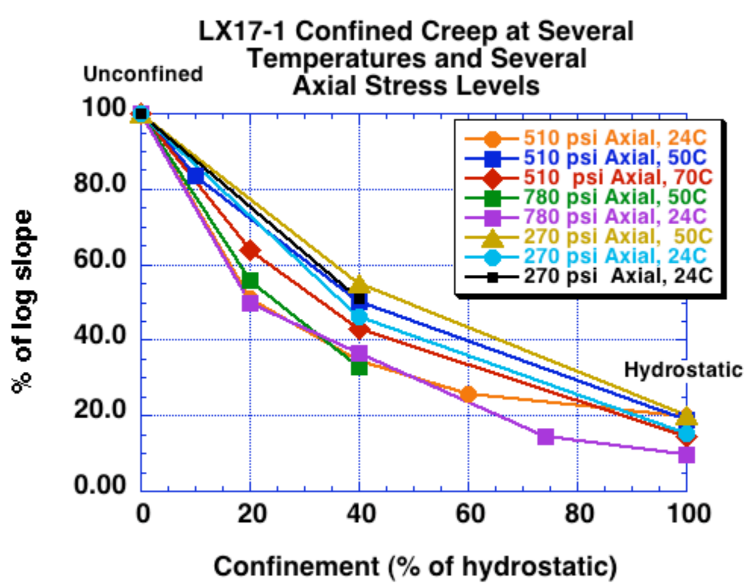

FIGURE 9: Data from all tests. Confinement (the x-axis) is expressed as a percent of the pressure that would create, in effect, a hydrostatic loading condition (confinement pressure = axial stress). The vertical y-axis expresses the creep rate as a percent of the creep rate measured with no confinement is present.

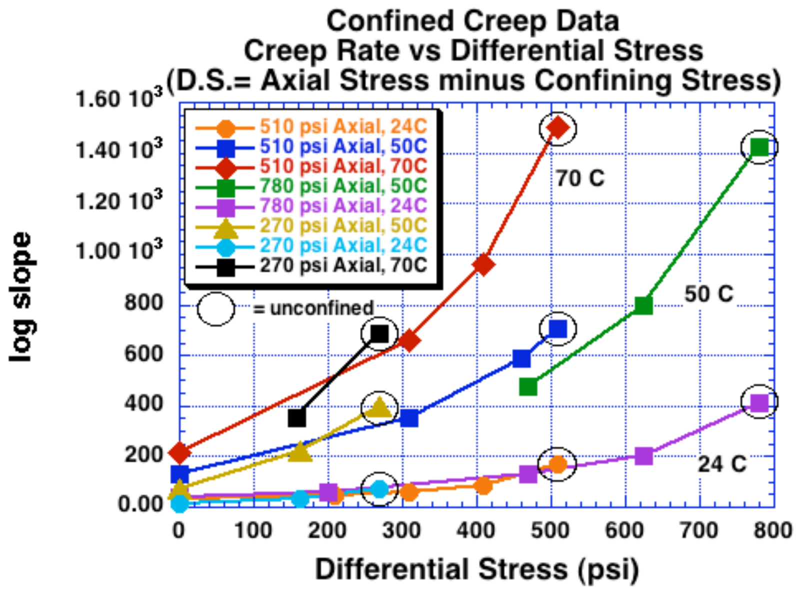

FIGURE 10: The data shown in Figure 9, re-plotted. Shown are the log slopes as a function of the difference between the axial and confining stress. The data suggests that, generally, for a fixed temperature, creep rates are largely a function of the stress differential (the axial stress minus the confinement pressure). However when the axial stress is equal to the confinement pressure (the "hydrostatic" condition), creep rates are not zero due to the presence of small voids in the PBX. These voids can slowly close when the material is under hydrostatic load, resulting in a creeping volumetric reduction.

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