AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 mm

1 2 3 4 5

Inches

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0 5.6 6.3 7.1

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

Conf-940553--78

Text for SAND94-0305C

Mechanical and Bulk Properties in Support of ESF Design Issues[1]

R. H. Price†, R. J. Martin III‡, P. J. Boyd‡ and J. S. Noel‡

†Sandia National Laboratories
Albuquerque, New Mexico 87185

‡New England Research, Inc.
White River Junction, VT 05001

Abstract

An intensive laboratory investigation is being performed to determine the mechanical properties of tuffs for the Yucca Mountain Site Characterization Project (YMP). Most recently, experiments are being performed on tuff samples from a series of drill holes along the proposed alignment of the Exploratory Study Facilities (ESF) north ramp. Unconfined compression and indirect tension experiments are being performed and the results are being analyzed with the help of bulk property information. The results on samples from five of the drill holes are presented here. In general, the properties vary widely, but are highly dependent on the sample porosity.

[1]This work was performed under the auspices of the U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Project, under contract DE-AC04-76DP00789.

Introduction

Engineering design analyses require laboratory data for utilization in realistic constitutive models to predict rock mass response to certain sets of environmental conditions. Many rock properties are needed for design of the ramps and drifts in the tuff at Yucca Mountain, Nevada, in support of the ESF. The study reported here is in the process of performing bulk and mechanical property experiments to gather bulk properties (average grain density and porosity), dynamic properties (compressional- and shear-wave velocities), elastic properties (Young's modulus and Poisson's ratio), and strength properties (unconfined and confined compression and indirect tension) for tuff samples taken from a series of drill holes designated as NRG (North Ramp Geology) along the proposed alignment of the ESF north ramp.

Samples from five of the drill holes have been tested and the results are presented. The data exhibit the large scatter expected with tuff, a naturally inhomogeneous material. However, the data are internally consistent, with the mechanical properties being highly dependent on porosity, which varies from less than 0.10 to more than 0.50 (volume fraction). The functional forms of the property versus porosity trends are very similar to those observed in earlier studies on smaller Yucca Mountain tuff samples. The differences in the fitting parameters can be explained in terms of the sample size difference and, possibly, the clay content.

Laboratory Experiments

The following is an outline of the process carried out with each set of samples tested in the laboratory for bulk and intact mechanical properties.

Raw core is collected from one of the NRG drill holes. Appropriate cores of each rock unit are selected for the determination of bulk and intact mechanical properties, packaged, and shipped to the laboratory. Each core piece is examined and a decision is made on the appropriate uses for the material. The core sample may be large enough for an unconfined compression specimen and a Brazilian (indirect tension) specimen, or just one experiment type. Only larger diameter core with relatively homogeneous tuff material are subdivided to test the effect of pressure on static moduli and strength. A specimen from every core is taken for an average grain density measurement. Each mechanical properties sample is then machined to the appropriate dimensions in preparation for testing. Following machining, the test samples are dried and then saturated, for the determination of the bulk densities and the preparation for testing under saturated conditions.

Macroscopic descriptions of all samples are performed in hand-specimen detail; however, the unconfined compression samples are also characterized by taking a CT (x-ray computerized tomography) scan of one slice through each specimen In addition, the P- and S-wave velocities are measured on the unconfined compression samples at both dry and saturated conditions. These techniques provide an analysis of the sample interior prior to testing and aid the post-test analysis of mechanical property results[1].

The unconfined compression experiments are run at a standard set of conditions for baseline testing[2]. The baseline set of conditions are as follows: a saturated sample with diameter of 50.8 mm (2 in) and a length-to-diameter ratio of 2:1 is tested under room temperature, room pressure, and drained conditions at a constant (nominal) axial strain rate of $10^{-5}s^{-1}$. The Brazilian experiments are performed using standard techniques (e.g., ASTM D3967-86).

Results

The Young's modulus data from the unconfined experiments have been analyzed as a function of porosity. The data have a relatively linear trend on a semi-log plot. The trend is approximately parallel to the functional form that was fit to earlier data from experiments on smaller samples (25.4 mm in diameter) tested under the same set of conditions[3]. The earlier study produced the following relationship:

$$E = 85.5\ e^{-6.96n},$$

where E is the Young's modulus in GPa and n is the functional porosity in volume fraction. (NOTE: Functional porosity is defined as the volume fraction of porosity plus the volume fraction of montmorillonite[3].) The data collected in this study yield a relationship as follows:

$$E = 65.5\ e^{-7.12\phi},$$

where ϕ is the volume fraction of porosity. The new data with best fit and the fit to the earlier data are shown in Figure 1.

Poisson's ratio data have also been analyzed and there is little correlation with porosity. The Poisson's ratios are widely scattered between 0.0 and 0.5, with a mean value of approximately 0.2 (Figure 2).

A similar comparison has been made between the new and earlier data for the ultimate strengths from the unconfined experiments as a function of porosity. These data have a relatively linear trend on a log-log plot. As above, the trend is approximately parallel to the following functional form that was determined from earlier data on smaller samples[3]. The earlier study produced a relationship as follows:

$$\sigma_u = 4.04n^{-1.85},$$

where σ_u is the ultimate strength in MPa and n is the functional porosity in volume fraction. The data from this study has produced the following relationship:

$$\sigma_u = 1.22n^{-2.03},$$

where ϕ is the porosity in volume fraction. The data and two fits are plotted in Figure 3.

The indirect tension (Brazilian test) results have also been found to be distinctly related to porosity. The data collected in this study yield a relationship as follows:

$$T_0 = 65.5\ e^{-6.43\phi},$$

where T_0 is the unconfined tensile strength and ϕ is the porosity in volume fraction. The data and fit are presented in Figure 4.

Discussion

The difference in the previous fits and the recent fits are very small or can be explained in terms of the change in sample size and/or the lack of montmorillonite data for the new set of sample.

The exponent (i.e., the slope in semilog space) of the fit to the new Young's modulus/porosity data is very close to the slope for the smaller samples, indicating that the effect of porosity changes on mechanical behavior is the same for both sample sizes. In addition, the offset of the two fits is small. This result is not surprising, because no effect of sample size on this property was noted in an earlier study on size effects[4].

The variability in Poisson's ratio has been very large in both sets of data. However, all of the data from the two sample sizes have clustered around a value of approximately 0.2, with the property apparently being independent of porosity.

The fits of the unconfined compression strength data are approximately parallel. However, the fit of the larger samples is shifted downward from the earlier fit. This shift is relatively large, but can be explained in terms of the difference in sample size. The previous sample size study[4] showed a significant decrease in strength of welded tuff samples by changing the sample size from 25.4 mm in diameter to 50.8 mm.

There are a few data points on the Young's modulus/porosity plot (Figure 1) and the strength/porosity plot (Figure 3) that fall relatively far below the best fits. These offsets tend to occur at the high porosity ends of the data. Generally, the samples of non-welded tuff have a higher probability of containing some montmorillonite. As the mineralogy data becomes available and the fits are made to functional porosity instead of simply porosity, the data trend will probably become more distinct.

Conclusions

The bulk and mechanical property data discussed in this document are being collected in a detailed manner using standard laboratory procedures. The resultant data are all within expected bounds and are the result of testing reasonably sized samples for characterizing the mechanical properties in the laboratory. The analysis of these data has supported the conclusion from earlier studies that porosity is the dominant factor in determining intact-rock mechanical properties and can be measured relatively easily and used as a predictive tool for mechanical properties.

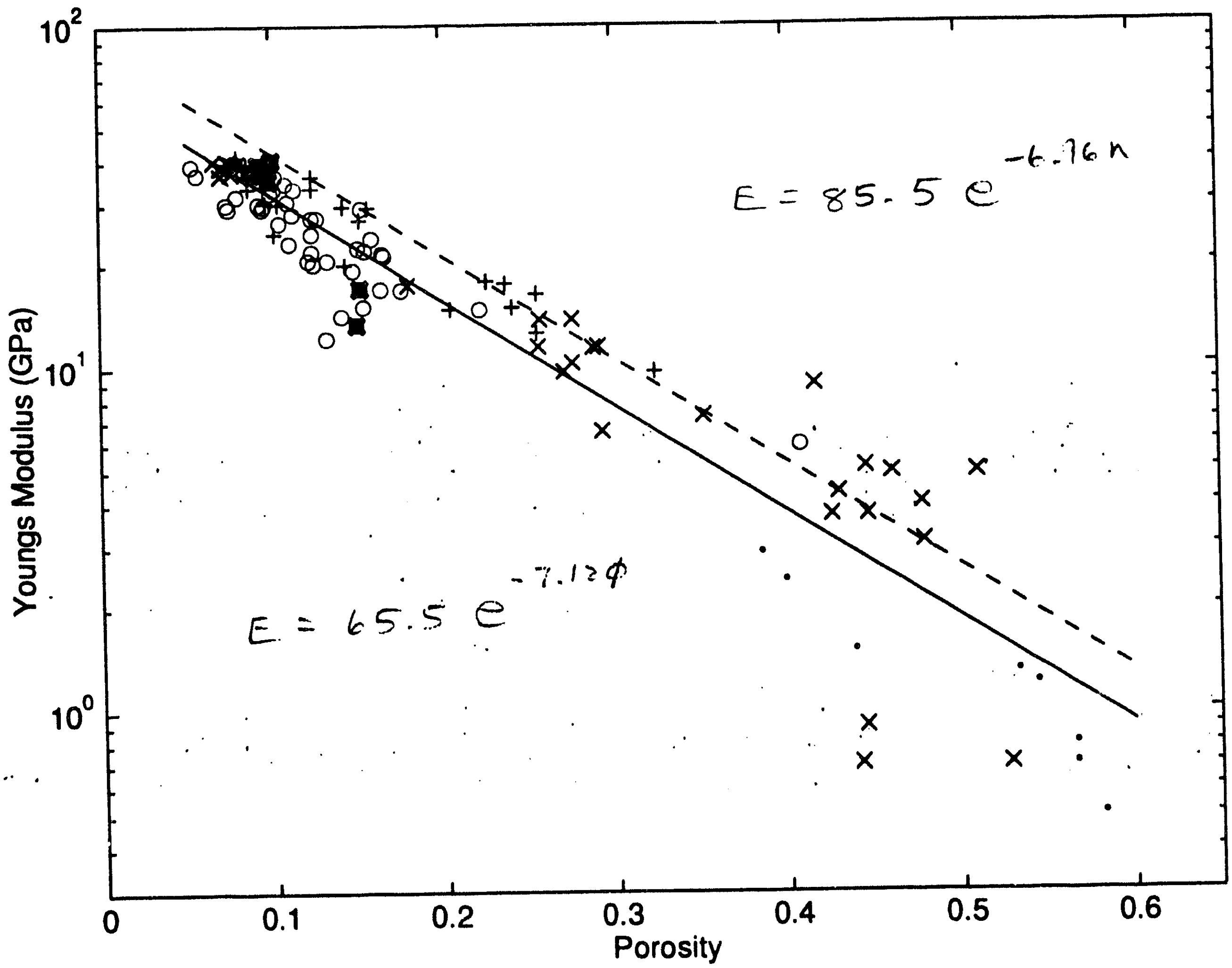
References

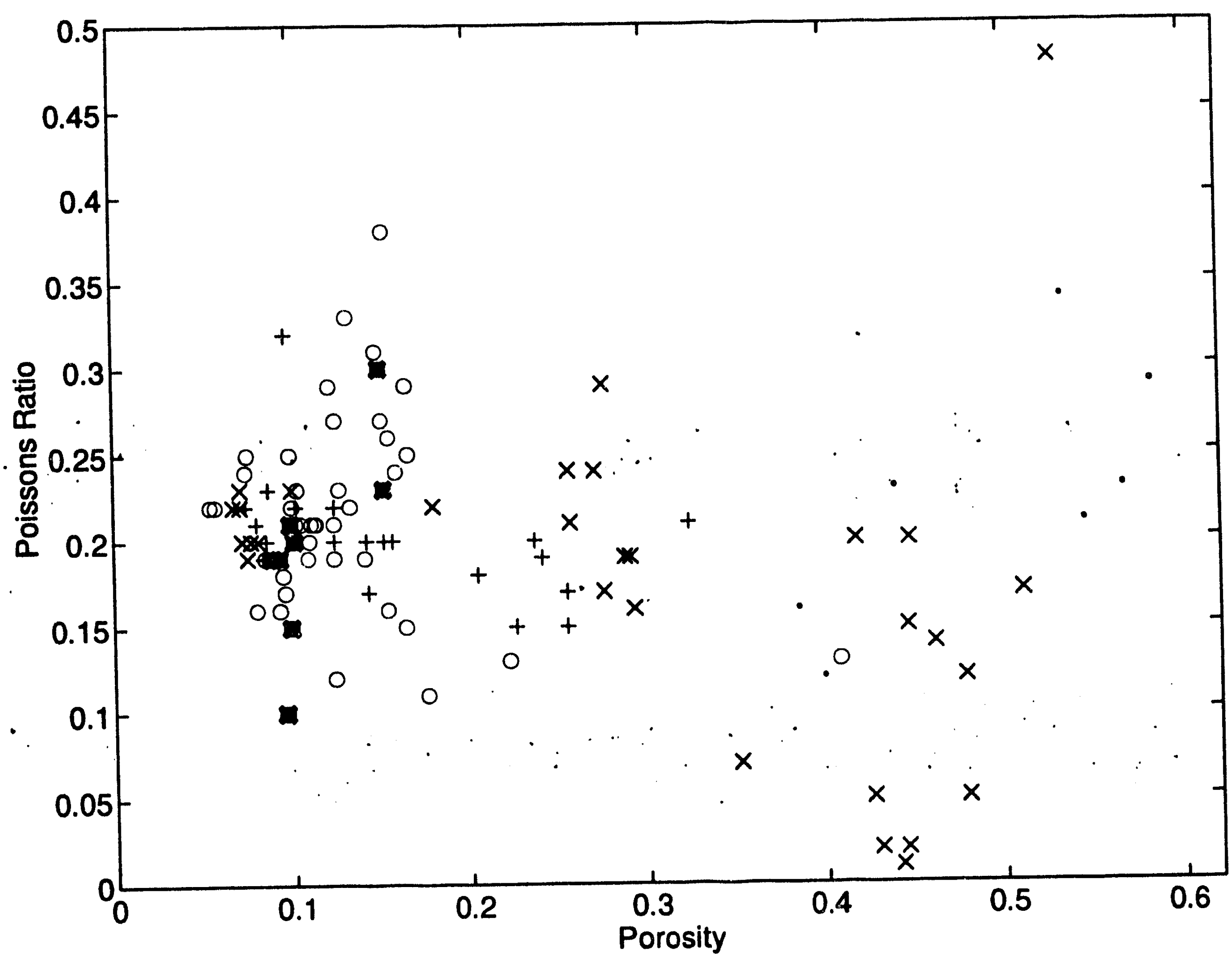
[1] R. Price, R. Martin III, and P. Boyd, Characterization of Porosity in Support of Mechanical Property Analysis, In: Proc. of the 4^{th} Annual International Conference on High-Level Radioactive Waste Management, Las Vegas, NV, 1993, Vol. 2, p.1847-1853.

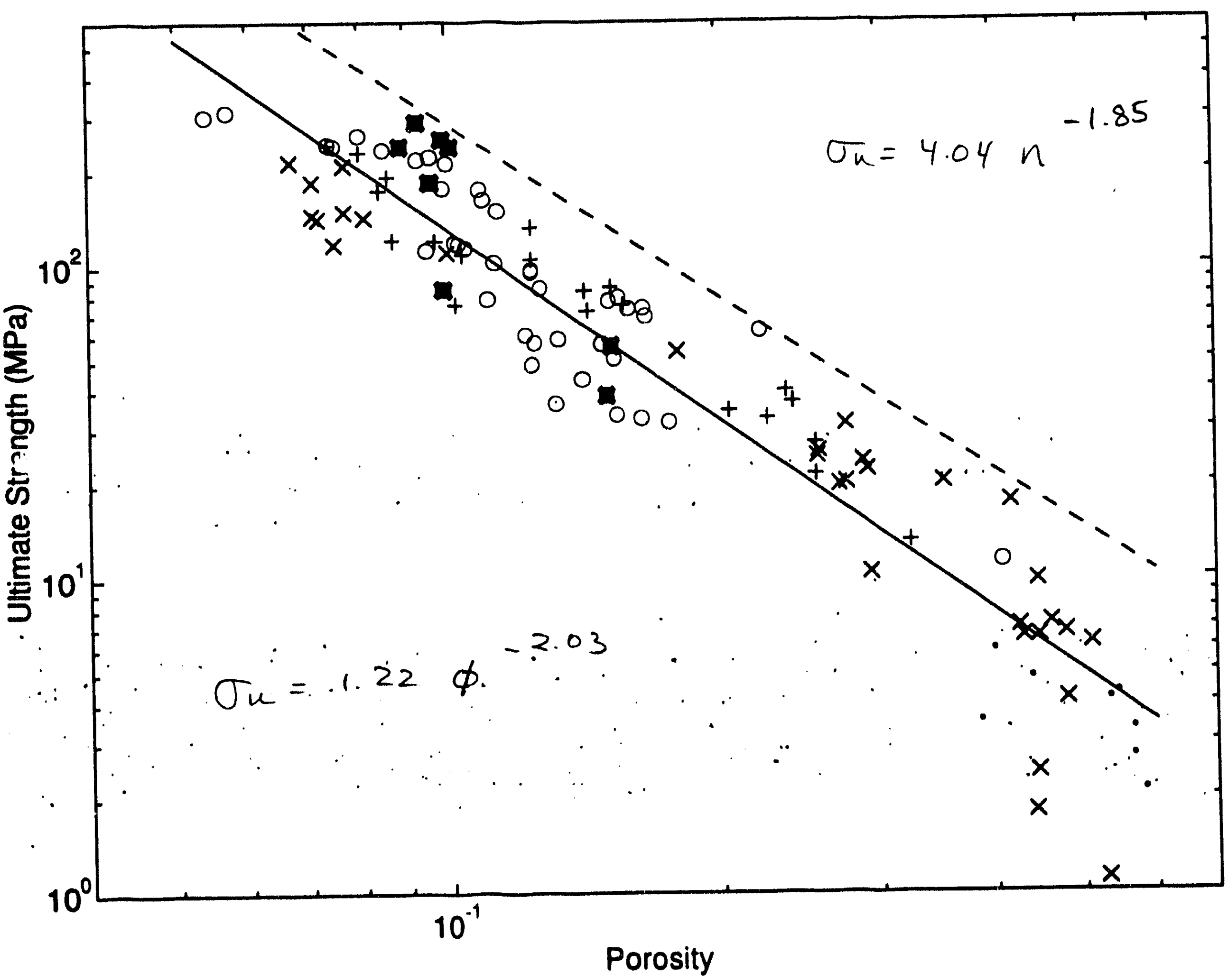
[2] R. Price, Laboratory Determination of the Mechanical Properties of Intact Rock, Study Plan for YMP Study 8.3.1.15.1.3, OCRWM, DOE, Washington, June 1991.

[3] R. Price and S. Bauer, Analysis of the Elastic and Strength Properties of Yucca Mountain Tuff, Nevada, In: Research and Engineering Applications in Rock Masses, Proc. 26^{th} U.S. Symposium on Rock Mechanics, Eileen Ashworth (ed.), Rapid City, SD, 1985, Vol. 1, p.89-96.

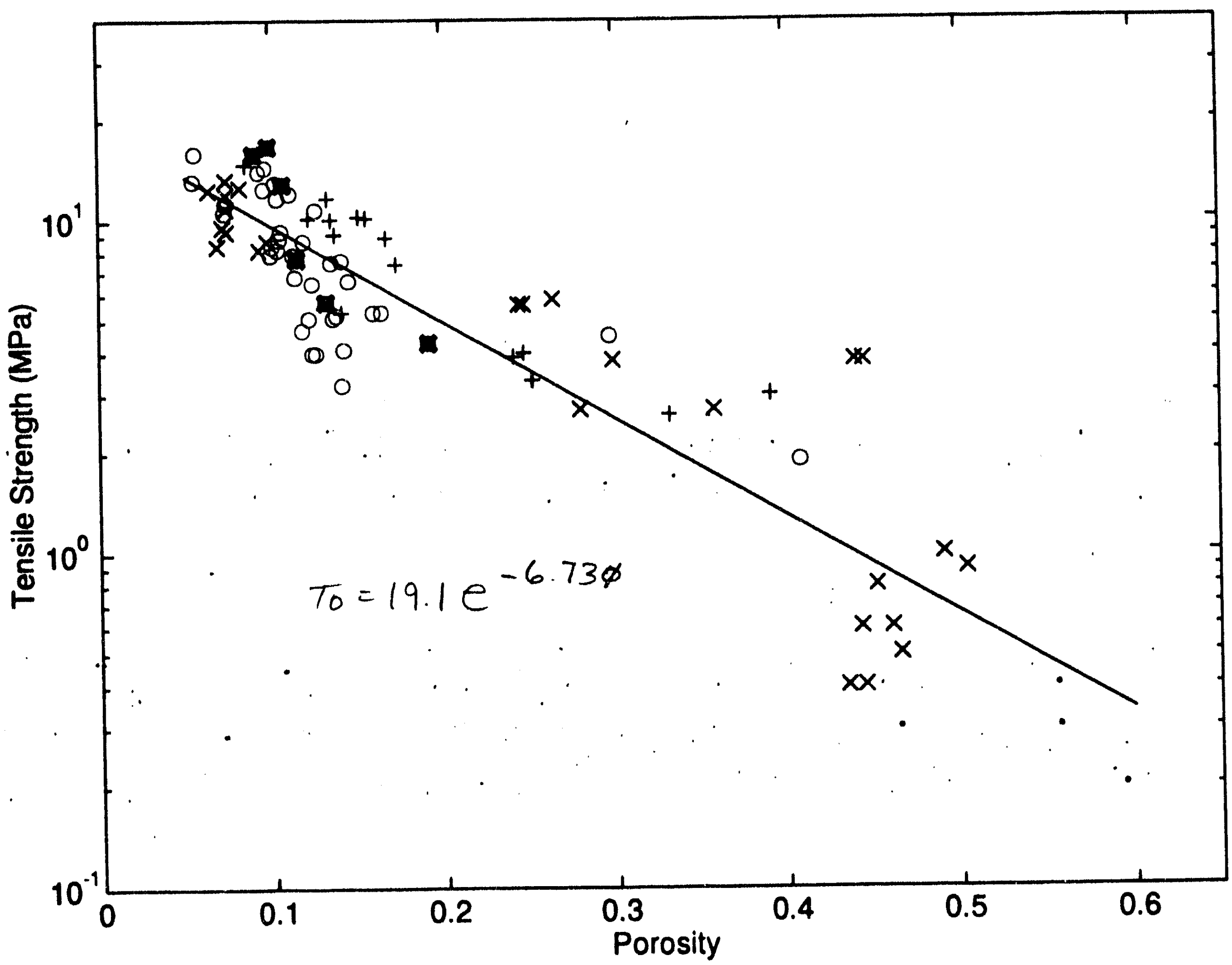
[4] R. Price, Effects of Sample Size on the Mechanical Properties of Intact Welded Tuff, (ABSTRACT): Transactions of the American Geophysical Union, Volume 67, Number 16, April 22, 1986, p.373-374.


Youngs Modulus (GPa)
Porosity
E = 85.5 e^-6.76n
E = 65.5 e^-7.12φ


Poissons Ratio
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
Porosity



$\sigma_u = 4.04\ n^{-1.85}$
$\sigma_u = 1.22\ \phi^{-2.03}$
10^2
10^1
10^0
10^-1
Ultimate Strength (MPa)
Porosity


Tensile Strength (MPa)
10^1
10^0
10^{-1}
0
0.1
0.2
0.3
0.4
0.5
0.6
Porosity
$T_0 = 19.1 e^{-6.73\phi}$

DATE FILMED

10/18/94

END