

1972

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Fang, H. Y. and Chen, W. F., "Further study of double-punch test for tensile strength of soils, 1972" (1972). *Fritz Laboratory Reports*. Paper 1969.

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FURTHER STUDY OF DOUBLE-PUNCH TEST FOR
TENSILE STRENGTH OF SOILS

by

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TENSILE STRENGTH OF SOILS

H. Y. Fang¹ and W. F. Chen²

ABSTRACT

This paper presents the theoretical and experimental studies of the newly developed double-punch test method for determination of the tensile strength of compacted soils. Some factors that may effect the double-punch test are studied. These factors include sample-punch size, rate of loading, compressive strength, and soil types. The comparisons of tensile tests determined from double-punch and split tensile tests for various materials including concrete, mortar, rock, and stabilized materials are also presented.

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I. INTRODUCTION

The importance of the tensile characteristics of compacted soils can best be demonstrated from the following observations: Winterkorn (1955) uses the tensile strength data to compute the surface energy of various clay minerals for soil stabilization purposes. Leonards and Narain (1963) use tensile-bending stress of soil to predict the cracking behavior of earth dams. Suklje (1969) points out that dangerous tensile fissures can appear in cohesive layers at the base of open excavations subjected to artesian water pressure, and the critical hydraulic gradients in the cohesive base may also depend on the shearing strength and tension resistance of soil. Spencer (1968) and Suklje (1969) indicate that the effect of tensile strength is related to the slope stability analysis, especially in cohesive slopes where creep and critical stress states with tensile principal stress appear in the upper parts of the slopes. George (1970) and Sih and Fang (1972) apply the fracture mechanics theory to evaluate the tensile characteristics and cracking growth on various highway materials.

Currently, there are four methods available for measuring the tensile strength of soils. Tschebotarioff (1953) and Winterkorn (1955) use the Briquest-Gang model type modes for measuring the direct tensile strength. Leonards and Narain (1963) use the beam-type test, and Narain and Rawat (1970) use split-tensile test for measuring the indirect tensile strength. Recently, a double-punch tensile test for measuring the indirect tensile strength of soils was developed (Fang and Chen, 1971).

The purpose of the work discussed herein is to investigate the effect of several variables upon the observed strength and the uniformity of the new test results. These factors include sample-punch sizes, rate of loading, compressive strengths, and soil types. The comparisons of tensile tests determined from double-punch and split-tensile tests for various materials including concrete, mortar, rock, and stabilized materials are also presented.

II DOUBLE PUNCH TEST

The double-punch test may be briefly described as follows: using two steel discs (punch) centered on both top and bottom surfaces of a cylindrical soil specimen, the vertical load is applied on the discs until the specimen reaches failure. The tensile strength of the specimen can be calculated from the maximum load by the theory of perfect plasticity. The test set is shown in Fig. 1a, and the typical mode of failure of the specimen under the tensile test is shown in Fig. 1b.

III THEORETICAL ANALYSIS

The plasticity developed previously for computing the bearing capacity of concrete blocks or rocks (Chen 1970a, 1970b) has been extended recently to soils and other stabilized materials (Fang and Chen 1971). Further evaluation of the effects of the compression-tensile strength ratio, friction angle of soil, and sample-punch size related to the formula used for computing the tensile strength of soils will be discussed briefly in this section.

Two major assumptions are made in the theory (Chen and Drucker, 1969). The first is that sufficient local deformability of soils in tension and in compression does exist to permit the application of the generalized theorems of limit analysis to soils idealized as a perfectly plastic material. The second is that a modified Mohr-Coulomb failure surface is postulated as a yield surface for soils.

Figure 2 shows an ideal failure mechanism for a double-punch test on a cylinder specimen. It consists of many simple tension cracks along the radial direction and two cone-shaped rupture surfaces directly beneath the punches. The cone shapes move toward each other as a rigid body and displace the surrounding material sideways. The relative velocity vector δ_w at each point along the cone surface is inclined at an angle φ to the surface. The compatible velocity relation is also shown in Fig. 2c. The rate of dissipation of energy is found by multiplying the area of each discontinuity surface by σ_t times the separation velocity $2\Delta_r$ across the surface for a simple "tensile" crack or $q_u (1 - \sin\varphi)/2$ times the relative velocity δ_w across the cone-shaped rupture surface for simple "shearing". Equating the external rate of work to the total rate of internal dissipation yields the value of the upper bound on the applied load P,

$$\frac{P}{\pi a^2} = \frac{1 - \sin\varphi}{\sin\alpha \cos(\alpha + \varphi)} \frac{q_u}{2} + \tan(\alpha + \varphi) \left(\frac{bH}{a^2} - \cot\alpha \right) \sigma_t \quad (1)$$

where

- P - load
- b = radius of specimen
- a = radius of punch
- H = height of specimen
- φ = friction angle of soil
- q_u = unconfined compression strength
- σ_t = tensile strength

in which α is the as yet known angle of the cone.

The upper bound has a minimum value when α satisfies the condition $\partial p^u / \partial \alpha = 0$, which is

$$\cot\alpha = \tan\varphi + \sec\varphi \left[1 + \frac{\frac{bH}{a^2} \cos\varphi}{\frac{q_u}{\sigma_t} \left(\frac{1 - \sin\varphi}{2} \right) - \sin\varphi} \right]^{1/2} \quad (2)$$

valid for

$$\alpha \geq \tan^{-1} \left(\frac{2a}{H} \right)$$

and the upper bound solution of Eq. 1 can be reduced to

$$P \leq P^u = \pi (k bH - a^2) \sigma_t \quad (3)$$

or

$$\sigma_t = \frac{P}{\pi (k bH - a^2)} \quad (4)$$

where $K = \tan (2\alpha + \varphi)$

The value of k depends not only on the angle of friction, φ , but also on the compression-tensile strength ratio, q_u/σ_t , and sample-punch dimension ratio, bH/a^2 as can be seen from Eq. 2. The variations of the value of k are shown in Fig. 3. Two sizes of specimens were used: Proctor and CBR molds. Two values of φ were assumed 0° and 20° . The following values of k are recommended for practical use:

Table 1 Recommended Values of k

	k Value	
	Soil	Stabilized Materials
Proctor Mold 4" x 4.6"	1.0	1.2
CBR Mold 6" x 7"	0.8	1.0

IV EXPERIMENTAL STUDY

(a) Specimen

Silty clay with liquid limit = 29 and plasticity index = 5 was chosen and samples were passed through a No. 10 sieve and air dried. The 4 by 4.6 in. specimens were used for double-punch, split-tensile and unconfined compression tests. The specimens were prepared at optimum moisture content as determined by Standard AASHO compaction (ASTM, 1971). In some cases, however, the silty clay was mixed with various percentages of sand and bentonite in order to establish the relationship between compression-tensile strength ratio and plasticity index.

(b) Test Results

The tensile strength was computed from Eq. 4 with P = load at failure in lab., H = 4.6 in., b = 2.0 in., k = 1.0, and a = punch radius in inches.

Figure 4 shows the variation of tensile strength with loading rate varying from 0.03 to 2.00 in. per minute. The load-deflection curve for various loading rates is shown in Fig. 5.

It was previously shown by Hampton and Yoder (1960) that in general there is a tendency for the unconfined compressive strength of compacted soil to increase when the loading rate is increased from 0.55 to 1768 in. per minute. For the range of loading rates investigated in this study, however, no definite trends in tensile strength variation or deformation at failure can be observed. It is, therefore, suggested that the double-punch test for soils be run at the ASTM loading rate for the unconfined compression test. The ASTM recommendation for the axial strain at a ratio of 0.5 to 2 percent of height per minute is recommended.

Punch size significantly affects both tensile strength as shown in Fig. 4, and strain at failure, illustrated by representative curves in Fig. 5. Tensile strength increases with increasing punch size. Strain at failure, however, decreases sharply as punch size increases.

The cracking pattern for the double-punch test is shown in Fig. 1b. Samples generally cracked into 2 or 3 pieces with cone formations at both ends. For punch diameters of 0.50 and 1.50 inches no visible cones were formed. This indicates that the punch diameter should be within these limits.

Figure 6 shows the comparisons of the tensile strength of soils and other materials determined by double-punch and split-tensile tests. These materials include concrete (Chen, 1970b) mortar, bitumen and cement treated base, and rock (Dismuke et al, 1972). Good agreement between the two tensile strength results is observed.

Figures 7 and 8 show the relationship between tensile strength, compression-tensile strength ratio and plasticity index. The double-punch data as shown in the figure is the averaging of two tests. The test specimens were molded at optimum moisture content (OMC). It can be seen that the tensile strength increases and the compression-tensile strength ratio decreases as plasticity index increases. A somewhat similar result was reported by Narain and Rawat (1970) using the split tensile test.

The range of compression-tensile strength ratio varies from 6 to 13 for soils. Winterkorn (1955) pointed out that compression-tensile strength ratio will decrease significantly if tensile strength is tested in a dry state. Similar indications were found by Fang and Chen (1971) that higher moisture content increases the tensile strength slightly as density increases, however, at lower moisture content as density increases, the tensile strength increases sharply.

V SUMMARY AND CONCLUSIONS

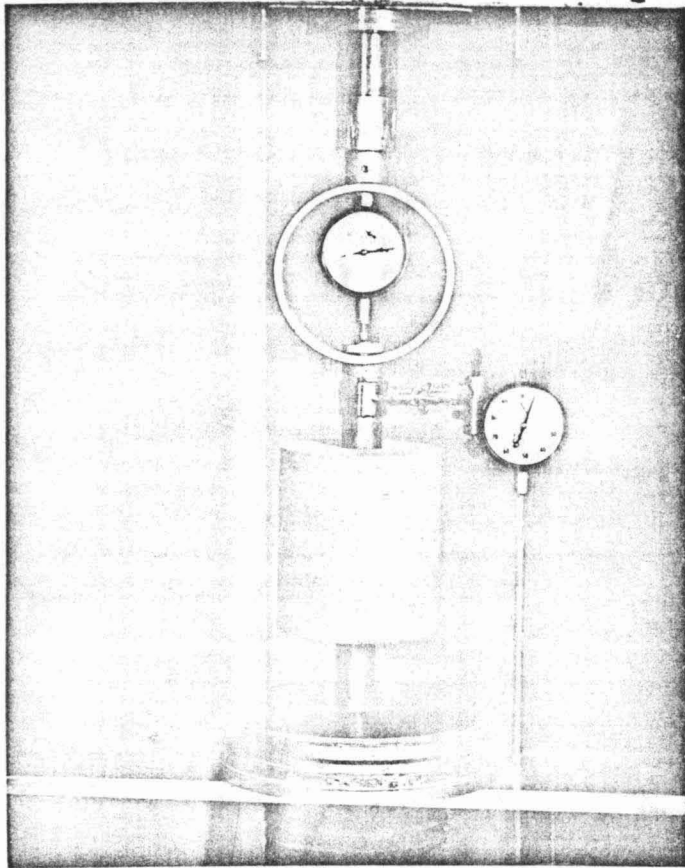
1. There is good agreement between double punch and split-tensile tests.
2. A table is proposed as a guide for selecting the value of k . $k = 1.0$ for soil and $k = 1.2$ for stabilized materials are recommended.
3. The tensile strength is not sensitive to the rate of strain within the range of 0.03 to 2.0 in. per minute.
4. The tensile strength increases but the compression-tensile strength ratio decreases as the plasticity index increases.

VI REFERENCES

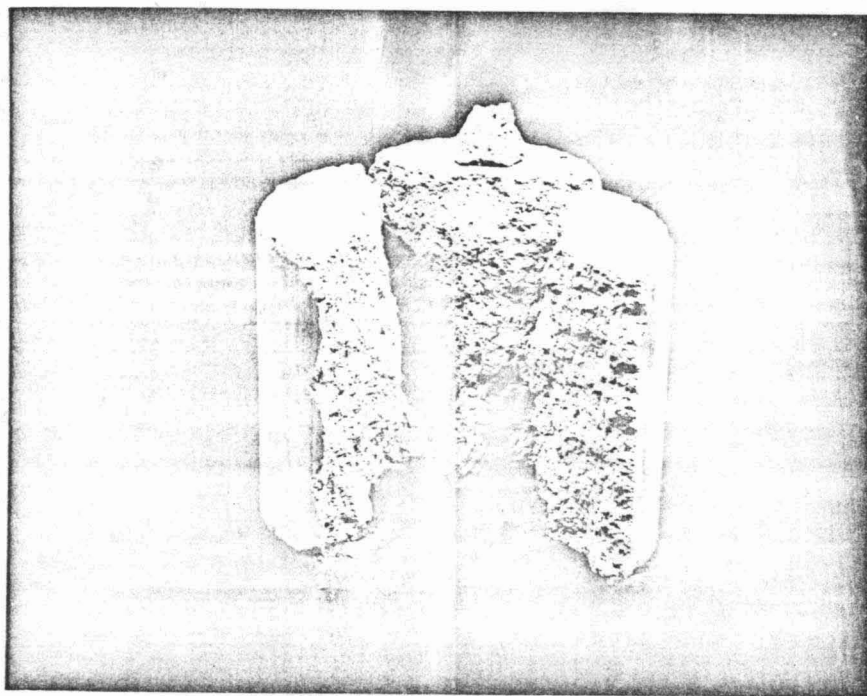
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(a) Test Set-up



(b) Mode of Failure

Fig. 1 Double-Punch Tensile Strength Test

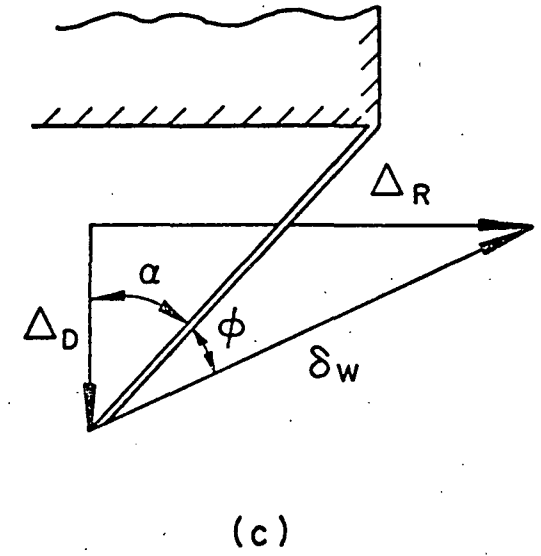
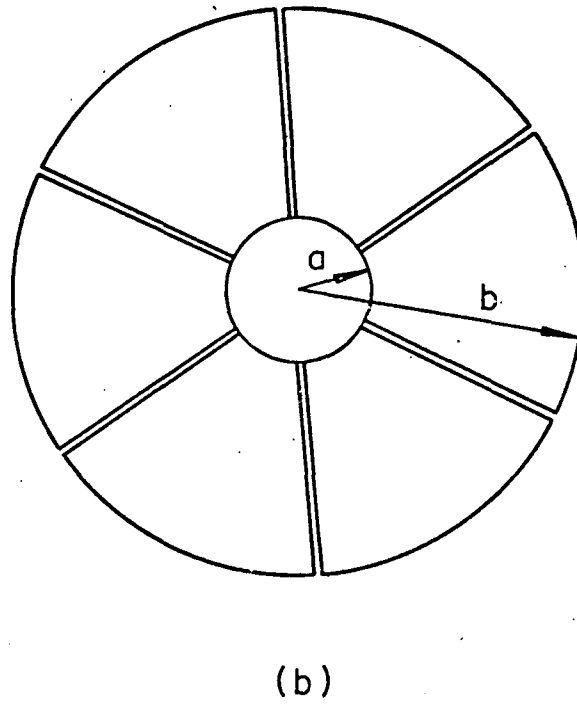
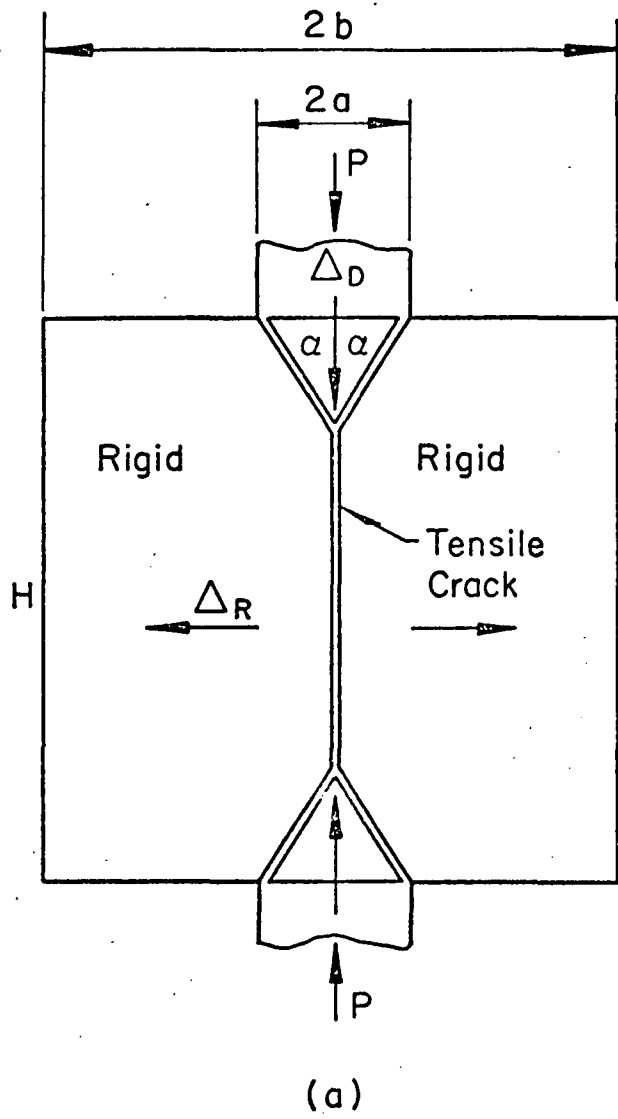


Fig. 2 Failure Mechanism of a Double-Punch Test

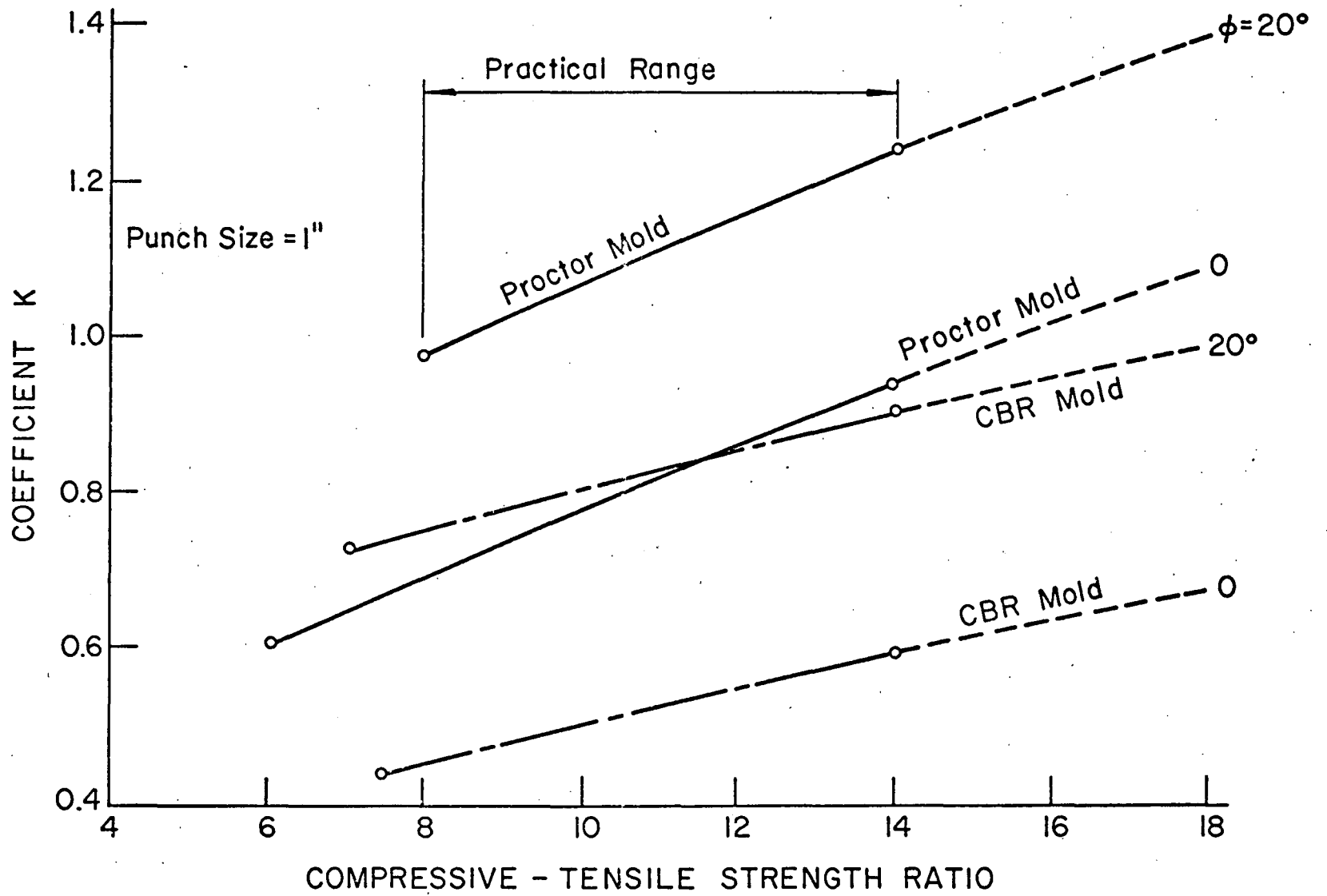


Fig. 3 Coefficient, K vs Compressive-Tensile Strength Ratio

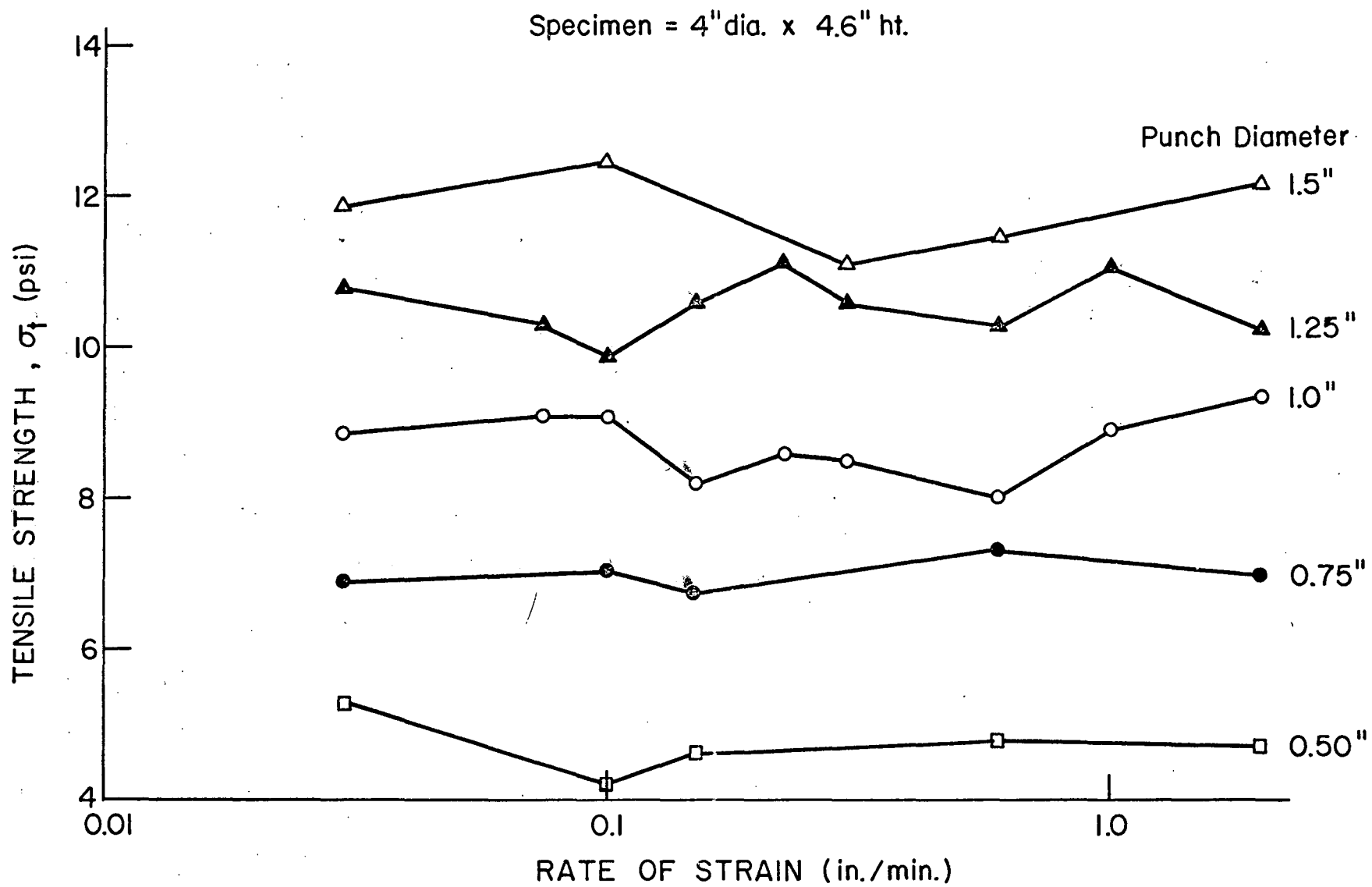


Fig. 4 Effect of Strain Rate and Punch Size on Tensile Strength

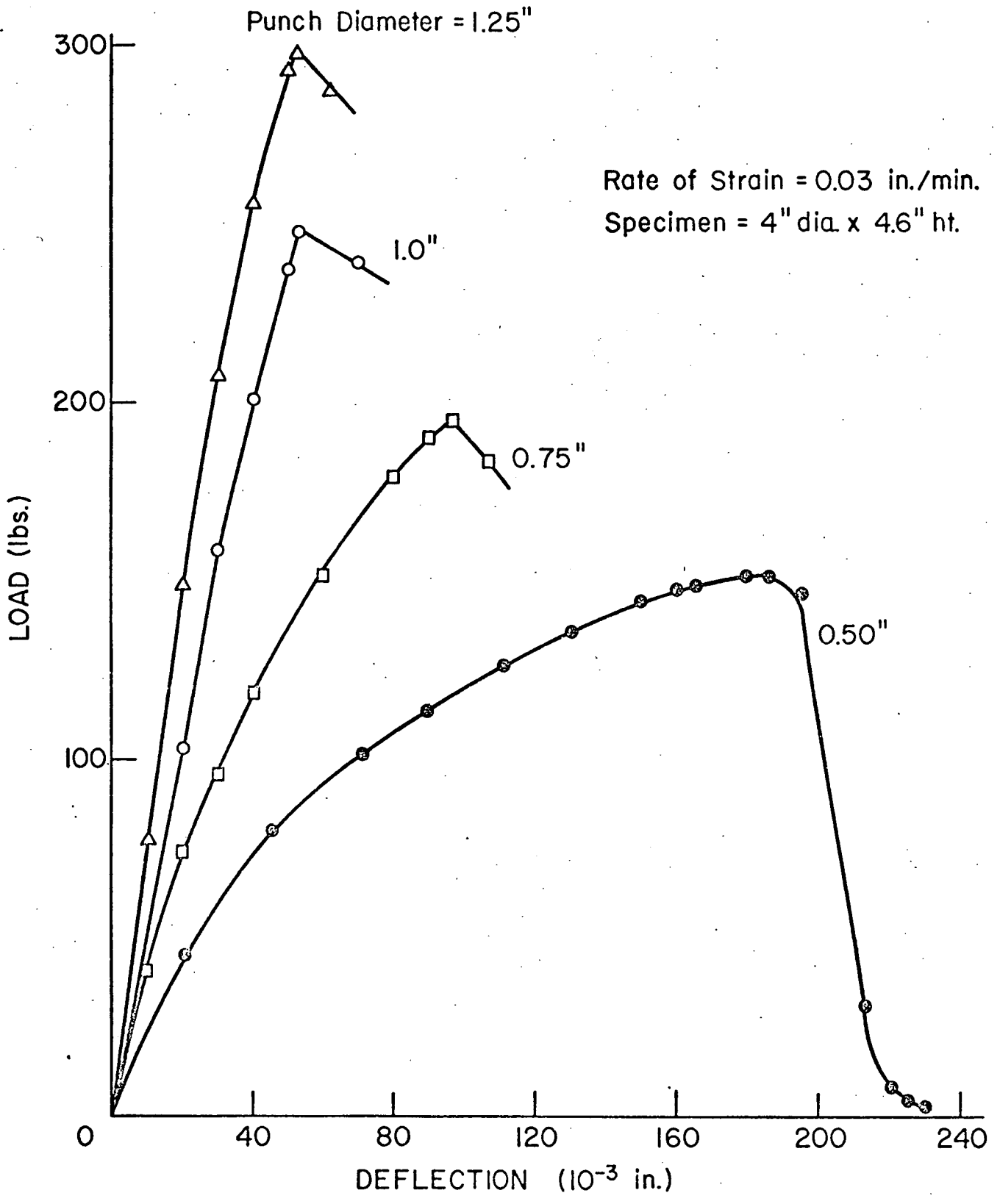


Fig. 5 Load-Deflection Curves

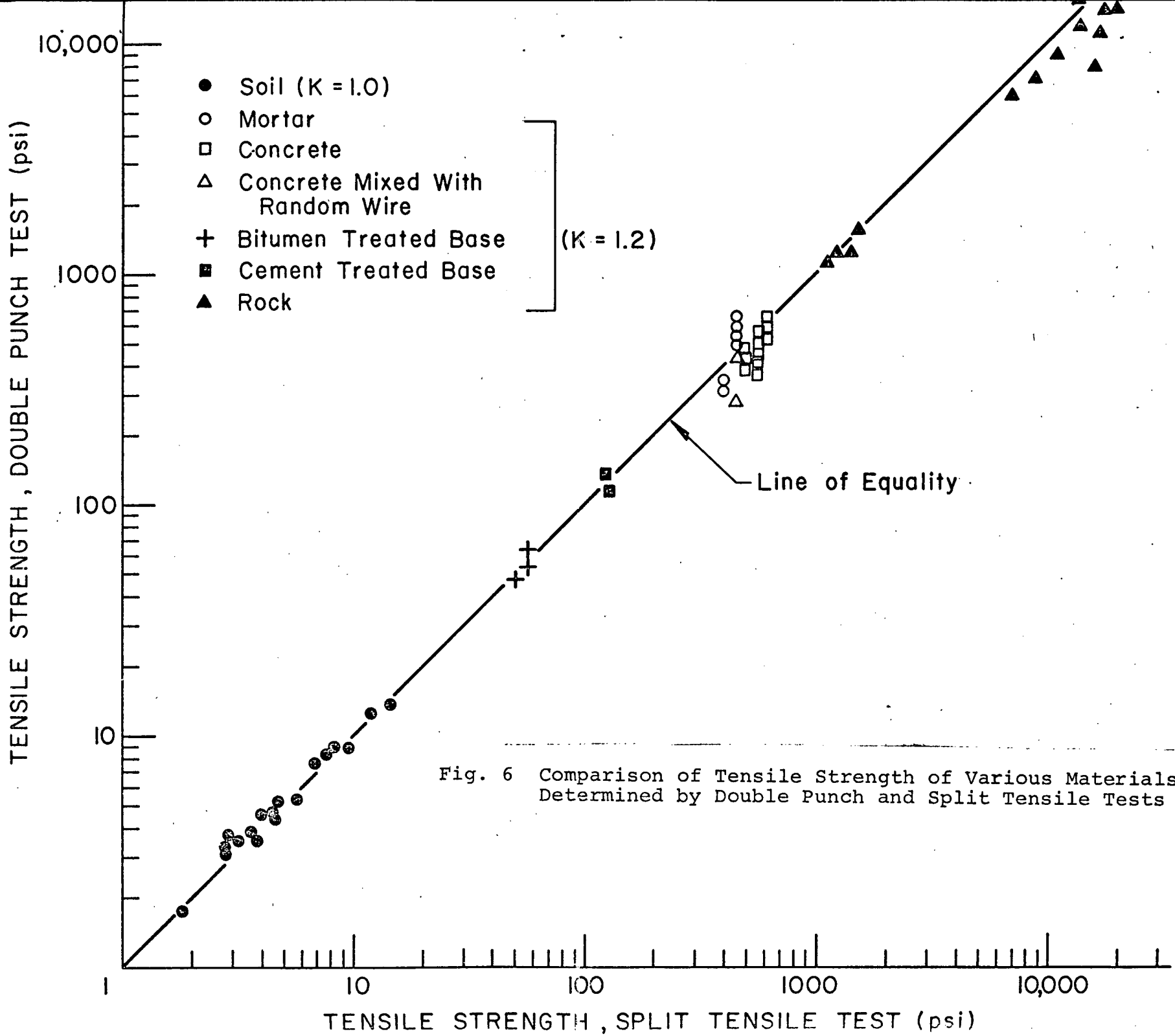


Fig. 6 Comparison of Tensile Strength of Various Materials Determined by Double Punch and Split Tensile Tests

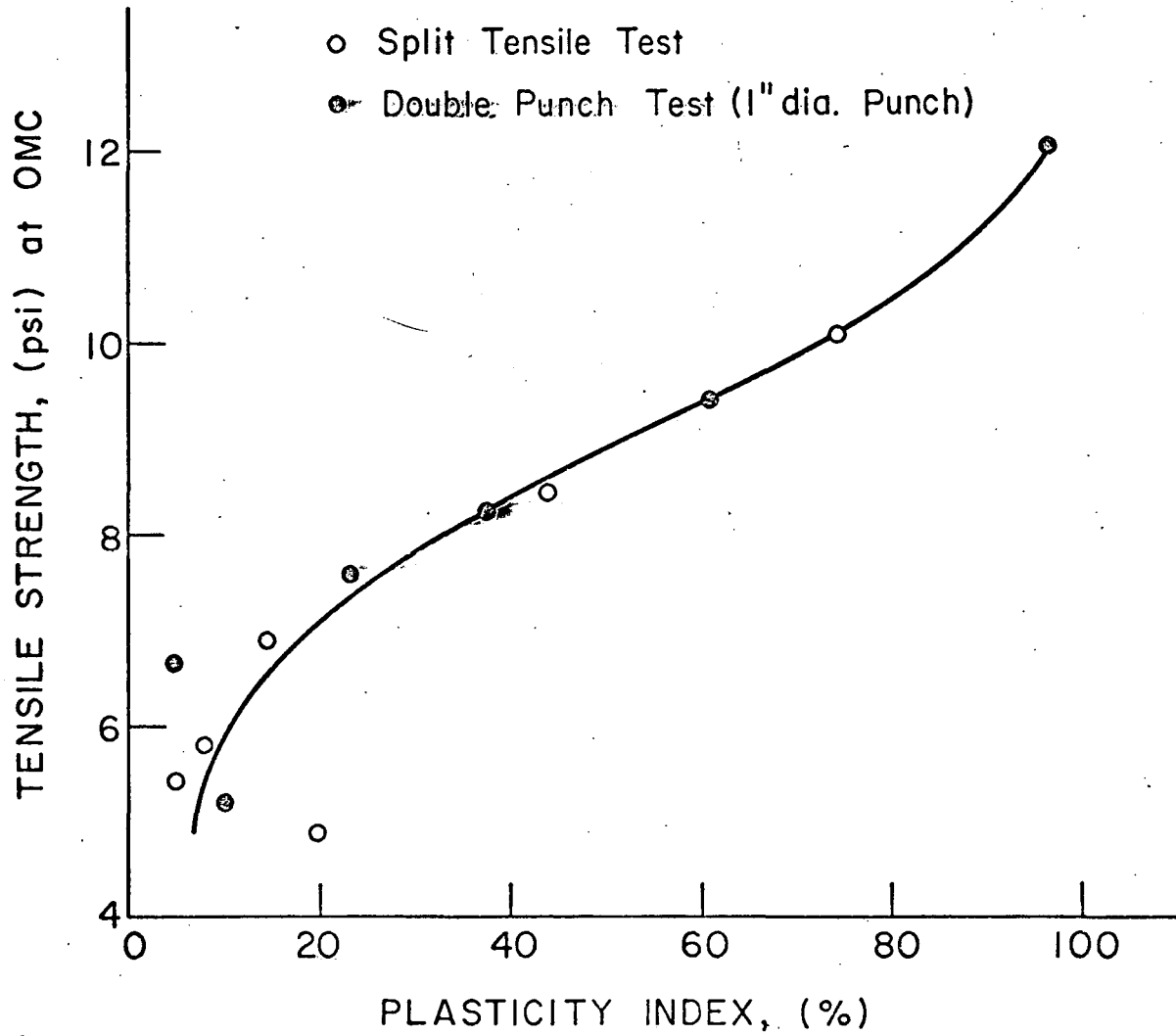


Fig. 7 Relationships Between Tensile Strength and Plasticity Index

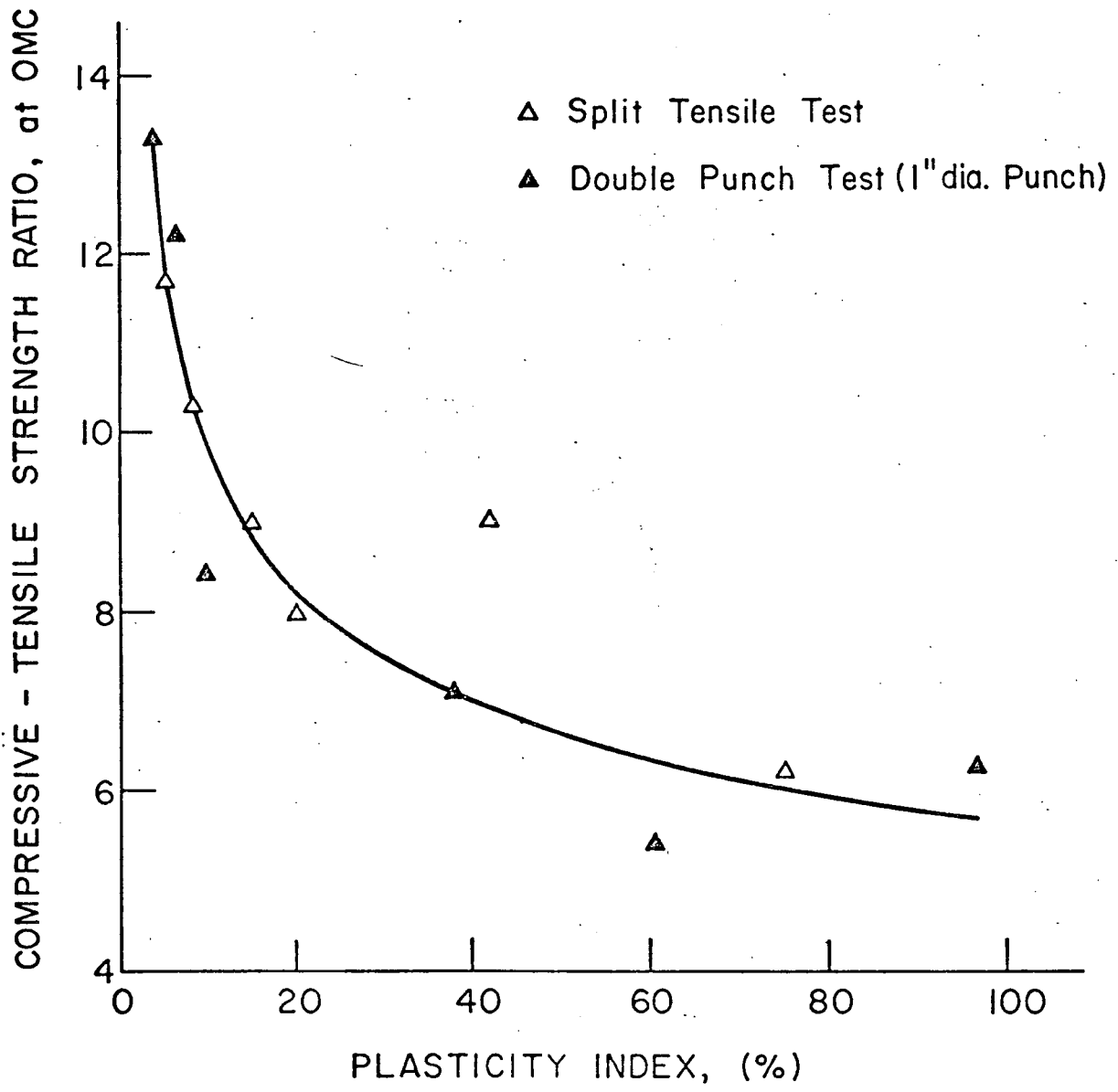


Fig. 8 Relationships Between Compressive-Tensile Strength Ratio and Plasticity Index