Ductile Iron Society

RESEARCH PROJECT NO. 26

DETERMINATION OF POISSON'S RATIO IN ADI

TESTING BY
UNIVERSITY OF MICHIGAN

REPORT PREPARED BY
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Applied Process, Inc.
Livonia, Michigan

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Introduction.

With the emerging computer technology in recent years, design criteria and techniques have changed. One of the new and widely accepted methods is the finite element design. The Poisson's ratio is part of the finite element calculations and its importance in design has increased recently.

Concurrently with the development of the computer technology, austempered ductile iron, ADI, has emerged as a new engineering material. ADI was successful in many applications in every segment of the industry. The Poisson's ratio has become a necessary but unavailable design property in ADI. Without the knowledge of the Poisson's ratio, the modern methods may not be used in designing ADI components.

The Poisson's ratio is determined as the ratio of the lateral strain to the longitudinal strain when a part is exposed to tension or compression. The Poisson's ratio is useful for isotropic materials and relatively small deformation. In un-isotropic materials the Poisson's ratio becomes a variable instead of a constant. Cast irons, including ADI, are considered isotropic and they have constant Poisson's ratios.

The Poisson's ratios of three grades of ADI were determined in this project. One, ASTM Grade 1, had high ductility and low tensile strength, another, ASTM Grade 3 with intermediate properties, and a third, ASTM Grade 5, had low ductility and high tensile strength. The three grades were referred to as ADI-125, ADI-175, and ADI-230, respectively, indicating the nominal tensile strength of the irons. The Poisson's ratio was determined both, in tension and in compression.

Experiments and Results.

The samples for the experiments were cast in a production foundry. Their nominal chemical composition is listed in Table 1. The size of the tensile bars was: 0.357 in. diameter and 2 in. gage length. The compression samples were 0.798 in. in diameter. Two lengths for the compression tests were used: 6.375 in. and 2.375 in.

The heat treat cycles of the three grades of ADI are listed in Table 2. The samples were austenitized in an atmosphere furnace, and quenched in a molten salt bath at Applied Process, Inc.

The experiments were carried out at the University of Michigan, Dearborn. The test results are summarized in Table 3, and are shown in Figures 3-22. The details of the experiments are given in the Appendix.

Discussion.

There is a great difference between the properties of grade 1 and grade 5 ADI. The hardness, the tensile strength are much higher, and the ductility is much lower in grade 5 than in grade 1. The microstructure is much finer in grade 5 than in grade 1. The density and the acoustical properties are different in the two grades.

It is surprising that the Poisson's ratio is constant in all grades of ADI, see Table 3. At least one explanation may be offered: the absence of stress risers. It is known that in gray iron the Poisson's ratio varies with the graphite morphology. The size and the shape of the graphite particles have a marked influence on the Poisson's ratio. The Poisson's ratio in gray iron may vary between 0.15 and 0.32 due to the variation in the graphite shape. The flake graphite particles are stress risers in gray iron.

Determining the Poisson's ratio in compression, two methods were used. In one the best straight line fit to the initial points was used. In the other method the actual curves were used as they were plotted. The two sets of data were given in Table 3.

The Poisson's ratio was determined in duplicates in grade 1 and grade 5 ADI. The determination of the Poisson's ratio in grade 3 was carried out in a single sample, to confirm that it was constant in all grades. The data indicate that The Poisson's ratio is constant in all grades.

A background discussion on the Poisson's ratio is given in the Appendix.

Conclusions.

1. The Poisson's ratio in ADI is independent of the heat treat cycle.

2. The Poisson's ratio in ADI is independent of the strength properties.

3. The Poisson's ratio in ADI is independent of the microstructure.

4. The Poisson's ratio in ADI is independent of the testing mode.

5. The Poisson's ratio in ADI is 0.25.

Acknowledgments.

The authors are grateful to professors Paul K. Trojan and Terry Ostrum of the University of Michigan for the experimental work and for the calculations of the Poisson's ratio.

Table 1.

Chemical Composition.

C	Si	Mn	S	P	Mg
3.60	2.60	0.30	0.01	0.02	0.04

Table 2

Heat Treat Cycles

Grade No.	Austenitizing Temperature	Austenitizing Time	Austempering Temperature	Austempering Time
1	1625 F	120 m	725 F	90 m
3	1625 F	120 m	625 F	150 m
5	1625 F	120 m	500 F	240 m

Table 3

Tensile Properties

	ADI 125 ksi		ADI 175 ksi*	ADI 230 ksi	
Property	No. 1	No. 2	No. 1	No. 1	No. 2
Tensile Str., (ksi)	141.2	145.2	192.8	212.0	190.0
Modulus, (msi)	23.5	23.8	22.6	22.2	23.8
Poisson's Ratio	0.26	0.25	0.25	0.25	0.25

Compression Properties

	ADI 125 ksi	ADI 230 ksi	
Property	No. 1	No. 1	No. 2
Buckling Stress, (ksi)	200.0	297.0	302.0
Initial Modulus, (msi)	22.5	24.6	22.6
Poisson's Ratio - Linear	0.19	0.21	0.26
Poisson's Ratio - Curve	0.24	0.26	0.26

Appendix.

1. Background.

There are four fundamental properties, or constants, in an engineering material related to stress and strain. These are the Young's modulus, E, the shear modulus, G, the bulk modulus, K, and the Poisson's ratio. When any two of these constants are known, the other two can be calculated.

The above constants are usually determined by tensile testing. When a tensile force is applied to a test sample, the force generates stresses and strains in the sample. Although the force maybe unidirectional, the stresses and the associated strains may not be. For engineering problems of experimental stress analysis it is important to know the principle stresses and strains.

The tensile tests maybe carried out in tension or compression. Figure 1. shows a schematic illustration of a tensile test.

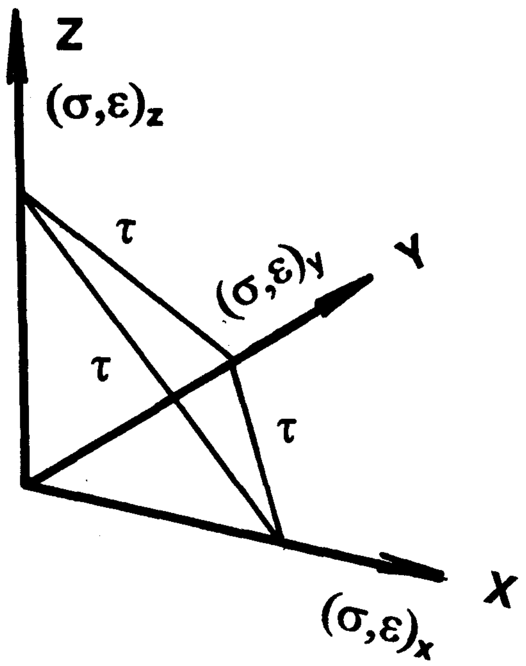


Figure 1.
Three-dimensional illustration.

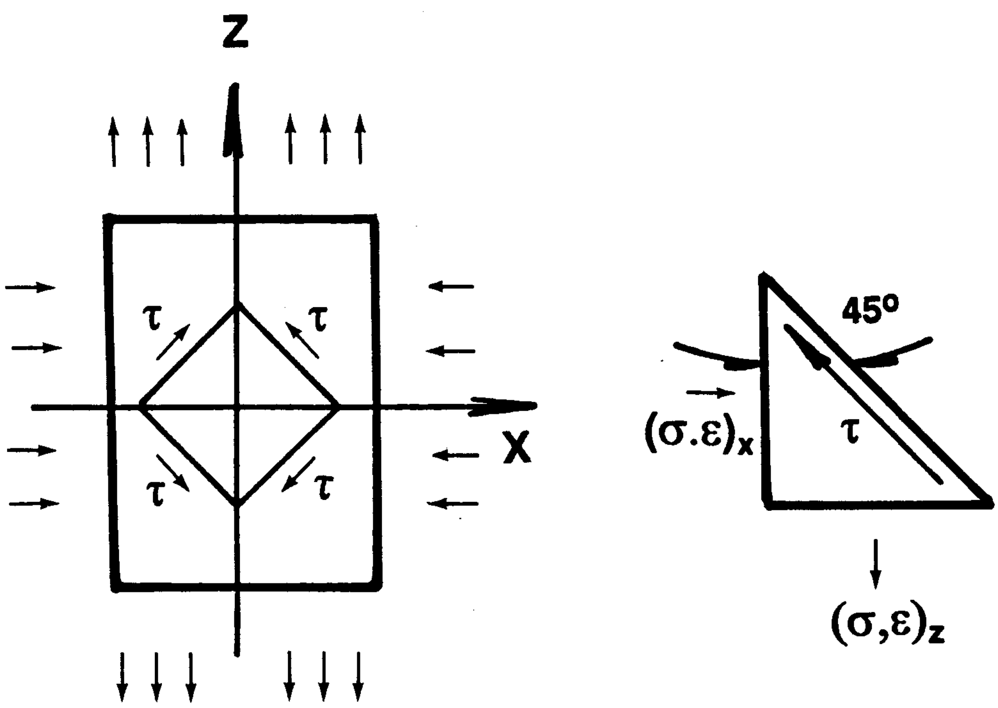


Figure 2.
Two-dimensional illustration.

Under tensional load the test sample elongates in the x direction and contracts in the y and z directions. The stress in the x direction, σ_x, and the stress in the y and z directions, σ_y and σ_z, result in a shear stress, τ, see Figure 2. In an isotropic material the shear stress, τ, points in a 45^o angle to the principle stress, σ_x.

Stress can not be measured directly. It can be calculated from the measured strain and from an elastic constant, the elastic modulus, or Young's modulus. To any stress analysis the knowledge of the elastic constant is mandatory.

Definitions of the four fundamental constants:

a. Young's modulus, E.

There are two versions of the elastic constant. One is the Young's modulus, or the engineering modulus. The other is the dynamic elastic modulus, or limit modulus.

The Young's modulus is defined as the ratio of the stress and strain. It is described by the Hooke's law:

$$E=\sigma/\varepsilon$$

Where σ is the uni-directional stress, and ε is a linear strain in the direction of the tensile force causing the stress. The Young's modulus is determined two different ways: a) from the slope of a stress/strain curve in the proportional range. The stress is calculated from the load, and the strain is calculated from the elongation. b) in the second method the yield stress, or proof stress is divided by the corespondent strain.

In either case, a marked variation exists in the determination of the Young's modulus from the fact that the proportional range in the stress strain curve is hardly ever a straight line. In most cases the initial slope of the stress strain curve is used.

The other elastic constant is the dynamic elastic modulus. The elastic modulus is strain rate dependent in cast iron. The faster a sample is pulled or compressed, the higher the modulus is. For this reason, there are standard strain rates and when the modulus is determined, the corresponding strain rate is stated. For the dynamic or limit modulus an infinitely high stain rate is assumed, therefore, it is the highest modulus in a material. Most often the dynamic elastic modulus is determined acoustically. These measurements are highly accurate. The dynamic modulus can be determined to six significant digits. The Young's modulus is typically accurate to three digits.

The simplest and the most accurate way to determine the dynamic elastic modulus is by measuring the resonant (natural) frequency acoustically and calculate the modulus through the following equation:

$$E_o= 4\rho\ell^2\omega_o^2,$$

where E_o is the dynamic elastic modulus, ρ is the density of the material, ℓ is the length of the test bar, and ω_o is the resonant frequency.

If the difference between Young's modulus and the dynamic elastic modulus (the modulus as a function of the strain rate) is determined the Young's modulus also can be determined accurately. Unfortunately this relationship is nonexistent for ductile iron.

b. Shear modulus, G.

The relationship between the shear modulus, G, the shear stress, τ, and the shear strain, γ, is similar to that described by the Hooke's law:

$$G=\tau/\gamma.$$

The shear stress is determined by subjecting the test bar to a torsional stressing (ASTM A260-47). The shear strain is determined by attaching a strain gage to the sample on the shear plain, a 45^o helix to the axis of the test bar. This test is somewhat difficult and the repeatability has a low degree. The shear modulus, G, is more often calculated from the Young's modulus and the Poisson's ratio through a tensile test. The relationship between the Young's modulus, the shear modulus, and the Poisson's ratio is the following:

$$E= 2G(1-\nu),$$

where E is the Young's modulus, G is the shear modulus, and ν is the Poisson's ratio. The determination of the Poisson's ratio will be discussed in a later paragraph: "Poisson's ratio".

Often there is a marked difference between the calculated and the experimentally determined G values. The calculated values are more consistent and were used in this report.

c. Bulk modulus, or volumetric modulus of elasticity, K.

The bulk modulus is defined as the ratio of the average stress, σ_m, and the volumetric strain, δ.

$$K = \sigma_m/\delta = E/3(1-2\nu),$$

where K is the bulk modulus, or volumetric modulus of elasticity, σ_m is the average of the three principle stresses, and δ is the volume strain.

Most engineering problems deal with maximum stress, therefore the bulk modulus is rarely used. It is useful when hydrostatic compression is the critical design parameter.

d. Poisson's ratio, ν.

Poisson's ratio is defined as the ratio of transverse strain to the longitudinal strain when the sample is tensile tested either in tension or compression. The Poisson's ratio can be determined two ways:
a) Measuring the transverse and longitudinal strains, or,
b) calculating it from the Young's modulus and the shear modulus if they are known:

$$\nu = E/2G-1$$

The surface strain is readily measurable by means of a strain gage. In this report the Poisson's ratio was determined by measuring the longitudinal and transverse strains simultaneously. See next chapter.

2. Experiments.

a. Material.

There were three grades of ADI tested: Grades 1, 3, and 5. First grades 1 and 5 were tested in duplicates. When no change in the Poisson's ratio was seen between grades 1 and 5, only one sample was tested in grade 3, to verify that the Poisson's ratio is indeed constant , Table 3.

b. Tensile testing.

Before tensile testing, the standard ASTM .505 diameter and 2 inches long tensile bars were equipped with four L shaped strain gages. Two of these strain gages were diametrically opposite from each other at one end of the gage section. The other two were arranged the same way at the other end of the gage section of the tensile bar. Each pair of the strain gages were connected in series to eliminate resistance due to bending of the tensile bar during testing. These L shaped strain gages were recording longitudinal and transverse strains simultaneously. From the ratio of the transverse and longitudinal strain the Poisson's ratio could be calculated.

The .505 diameter ASTM tensile bar is designed to provide a .2 square inch cross sectional area. The stress is readily determined by multiplying the load by 5 at any point of the elastic range of the load/elongation curve. The strain is determined by dividing the elongation of the test bar by the gage length. The Young's modulus, E, can be calculated by dividing the stress with the strain.

c. Compressive testing.

In the compressive testing ASTM A256-46 standard requires a .798 in. diameter (.5 square in. cross section)and 6.375 in. long cylinder for the Young's modulus determination, and a .798 in. diameter and 2.375 in. long cylinder for the compressive strength calculation. These lengths represent l/d ratios of 8:1 and 3:1 respectively.

The strain gages were mounted on both, the long and short compressive test samples, at mid-height. The Poisson's ratio was determined by measuring the transverse and longitudinal compressive strains and taking their ratio.

ADI - Tension

Proof Stress

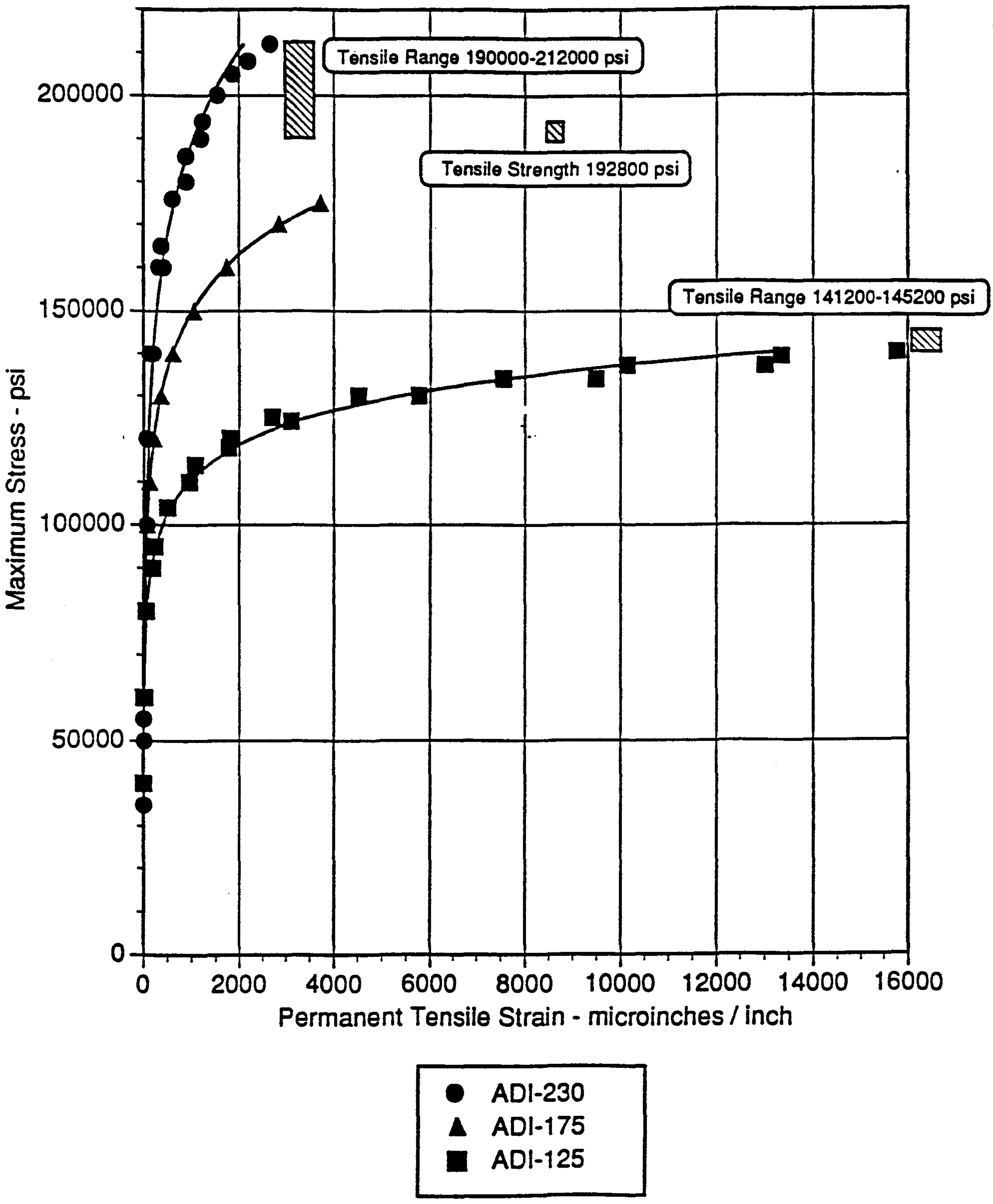


Figure 3

ADI - Tension

Proof Stress

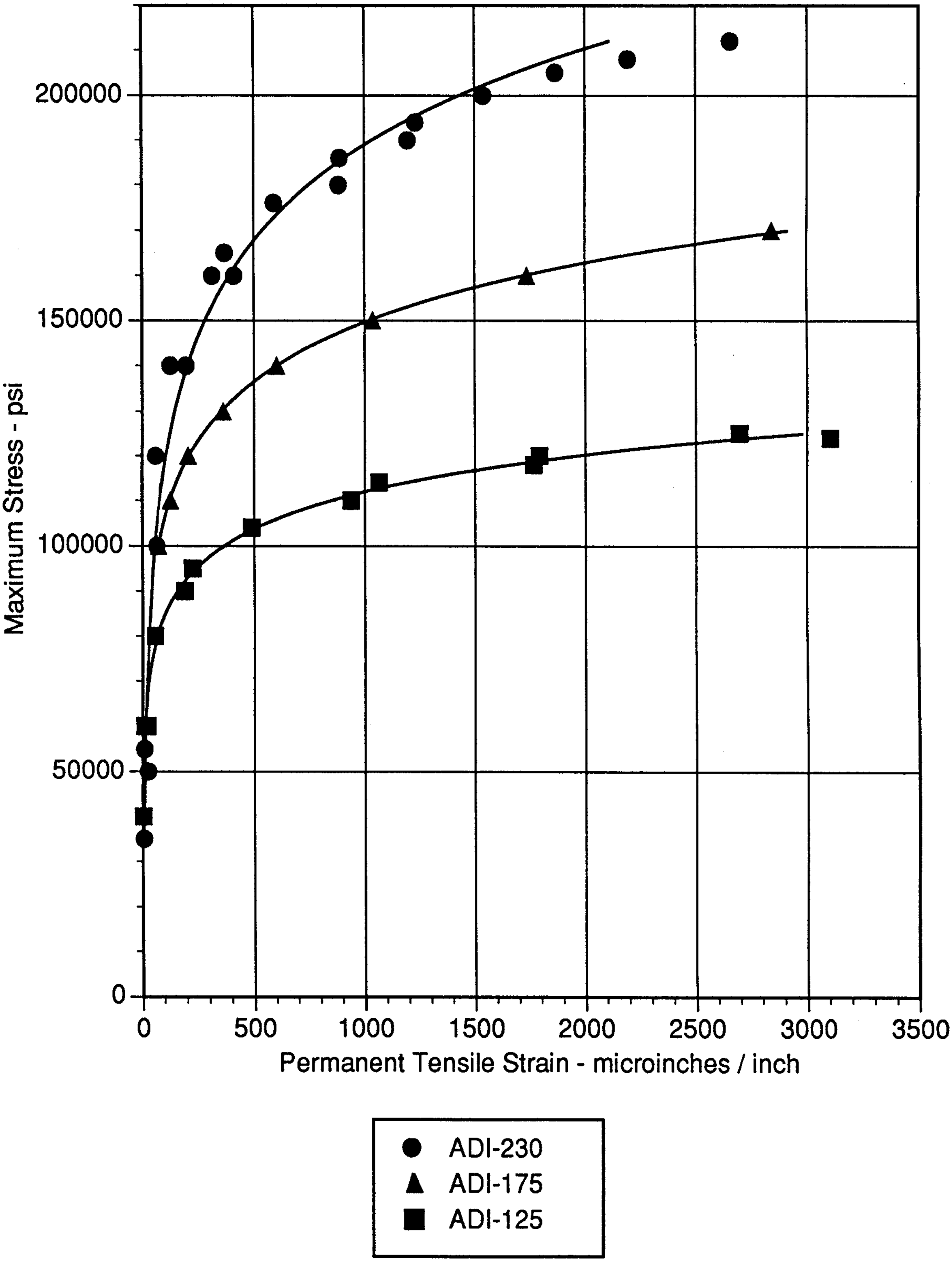
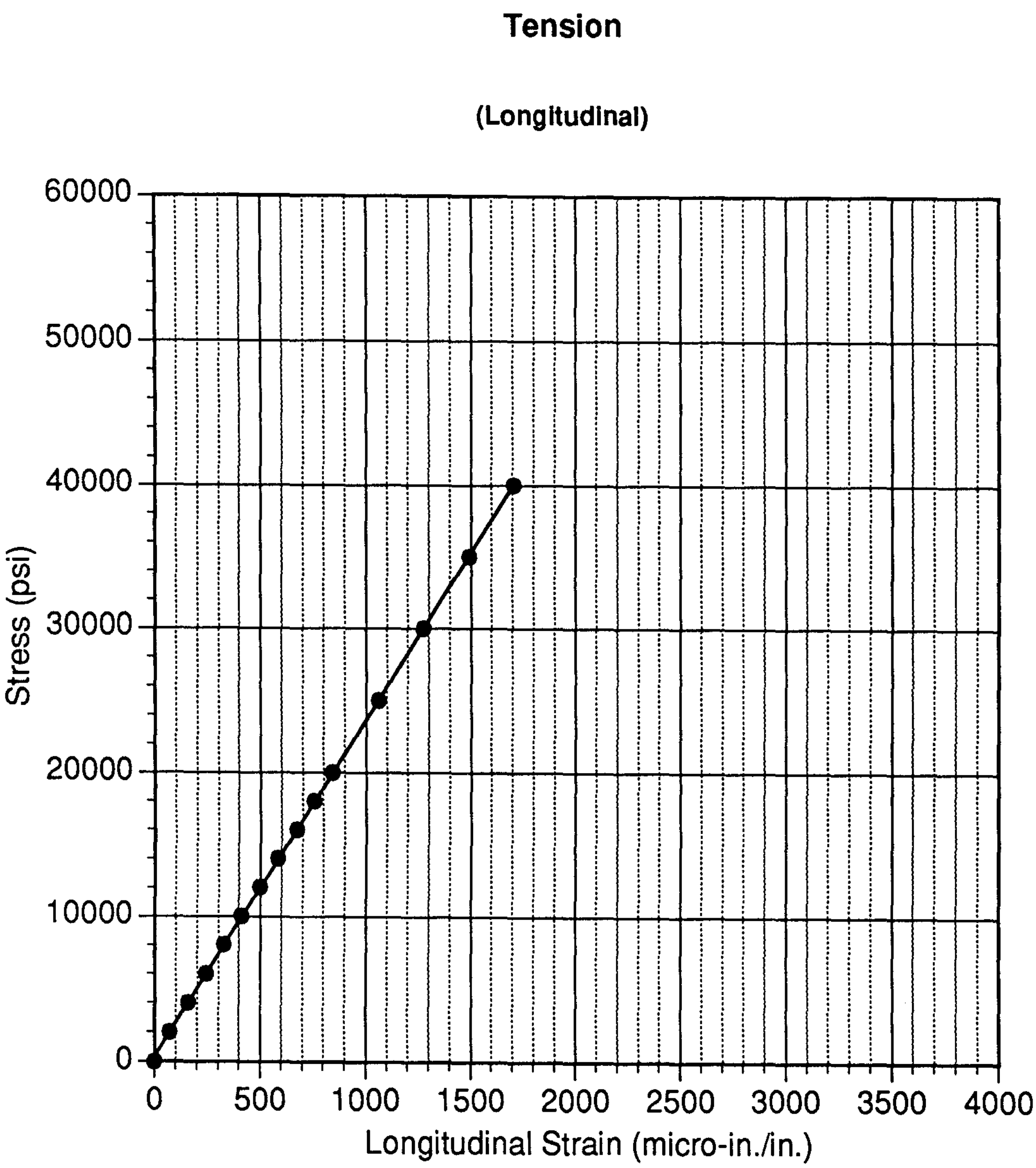


Figure 4

ADI - 125 ksi (#1)



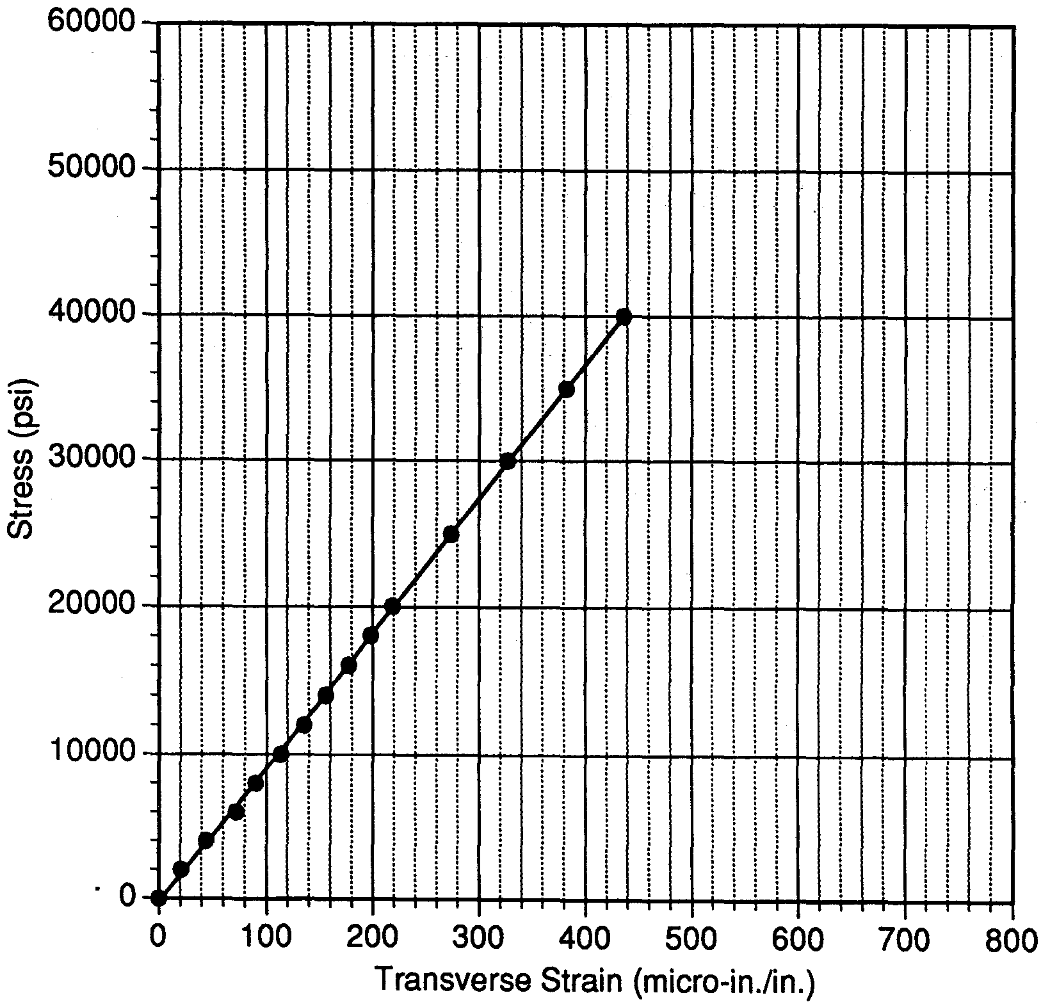
Initial Modulus = (40000 psi) / 1700 μ in./in.) = **23.5 x 10^6 psi**

Figure 5

ADI-125 ksi (#1)

Tension

(Transverse)



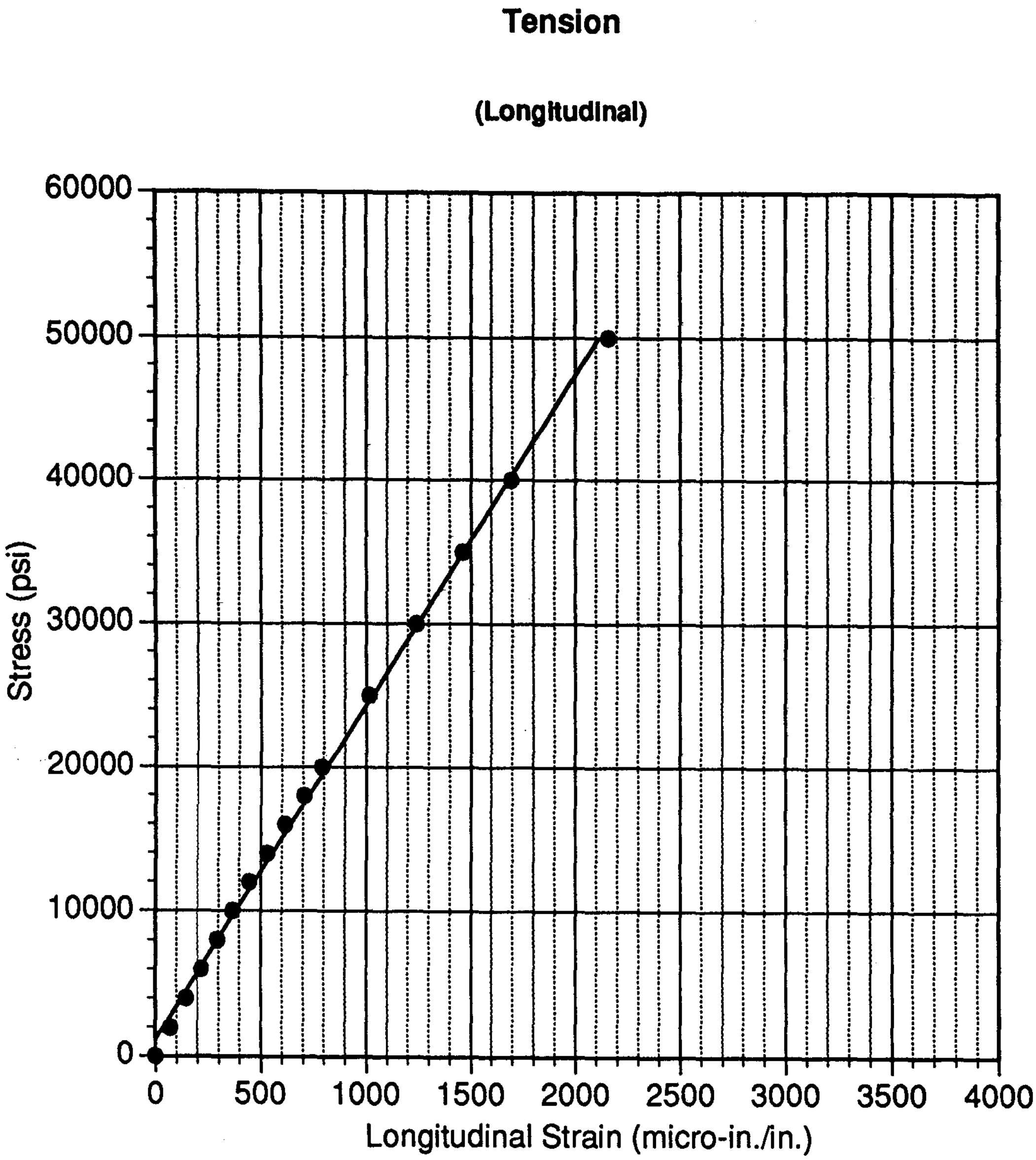
Poisson's Ratio

At 40000 psi: transverse / longitudinal strain

= (435 / 1700) μ in./in. = **0.26**

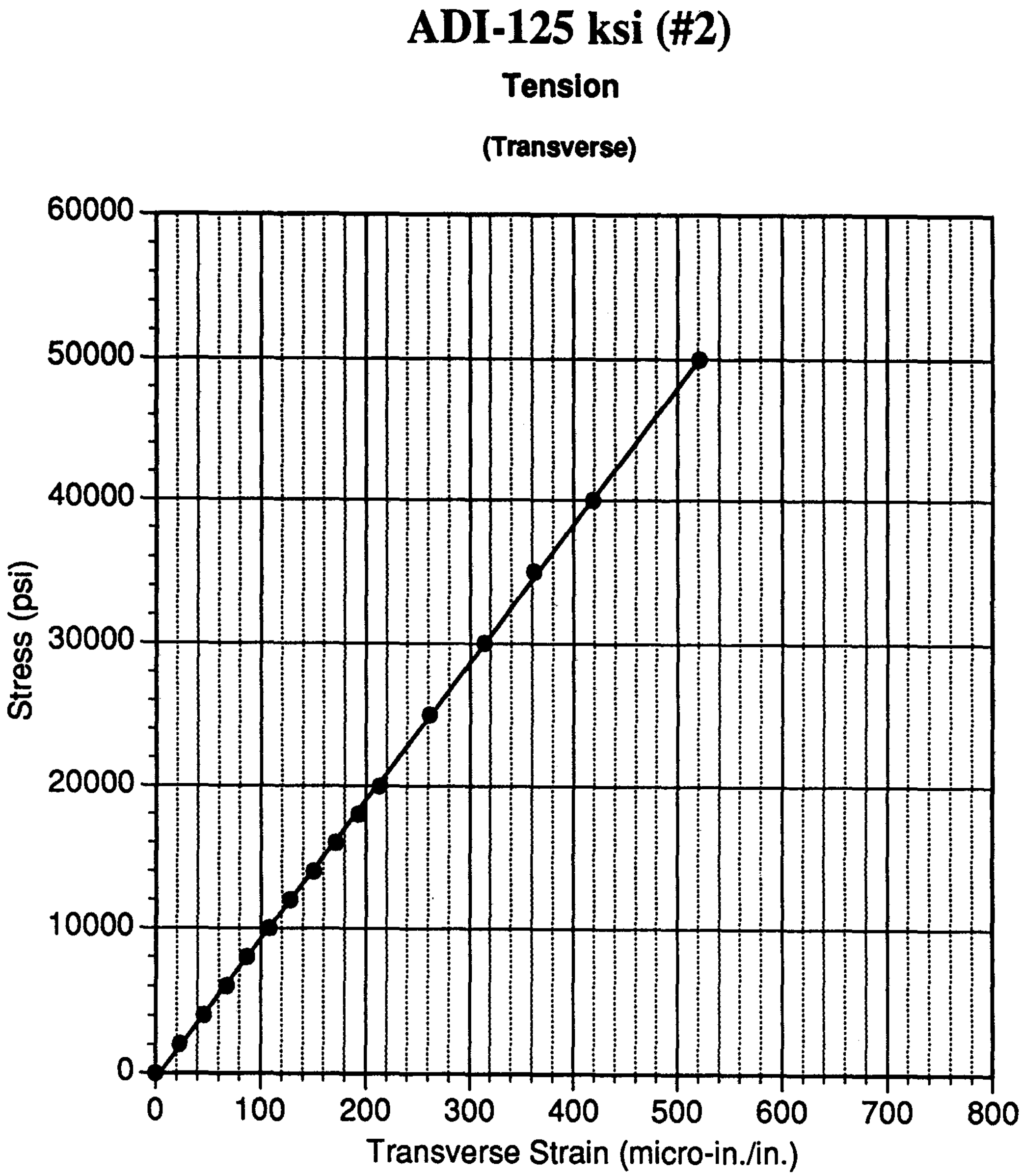
Figure 6

ADI - 125 ksi (#2)



Initial Modulus = (40000 psi) / 1680 μ in./in.) = **23.8 x 10^6 psi**

Figure 7



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain

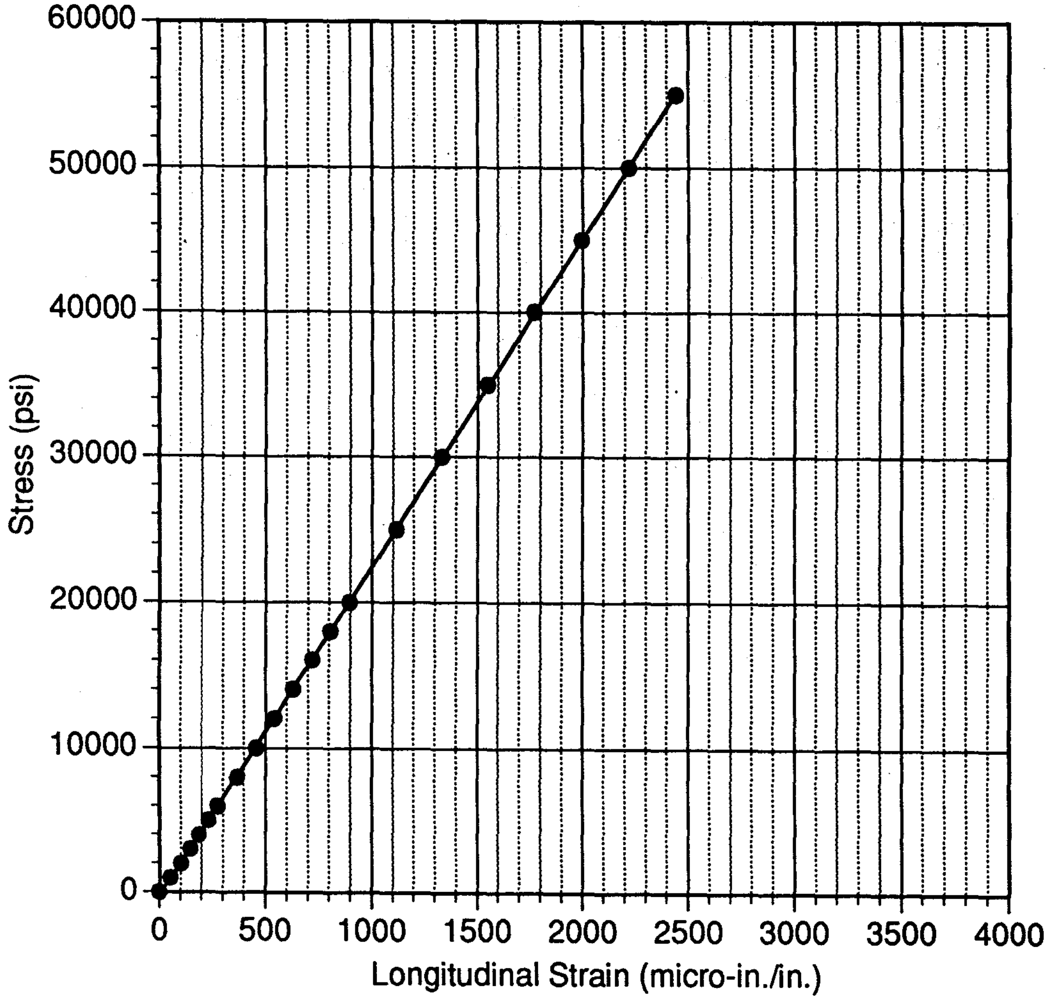
= (415 / 1680) μ in./in. = **0.25**

Figure 8

ADI - 175 ksi (#1)

Tension

(Longitudinal)



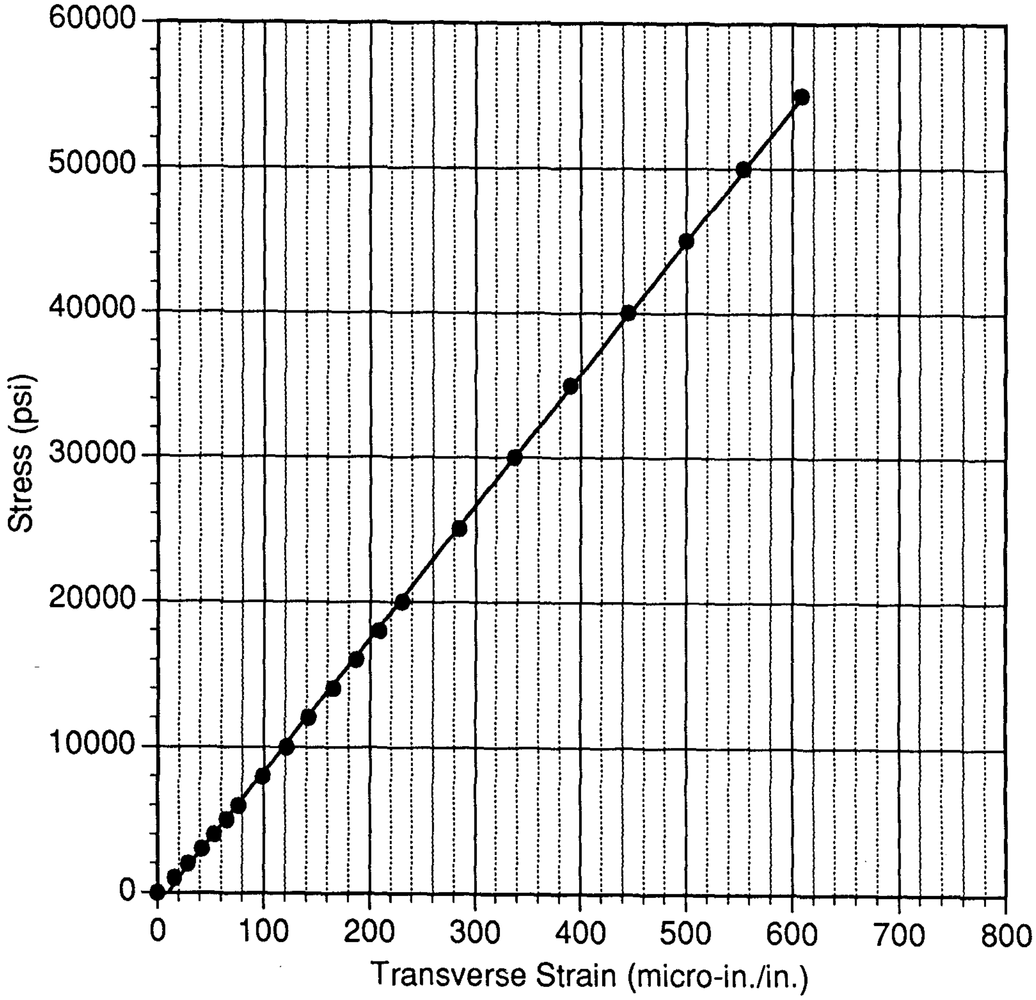
Initial Modulus = (40000 psi) / 1770 μ in./in.) = **22.6 x 10^6 psi**

Figure 9

ADI-175 ksi (#1)

Tension

(Transverse)



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain

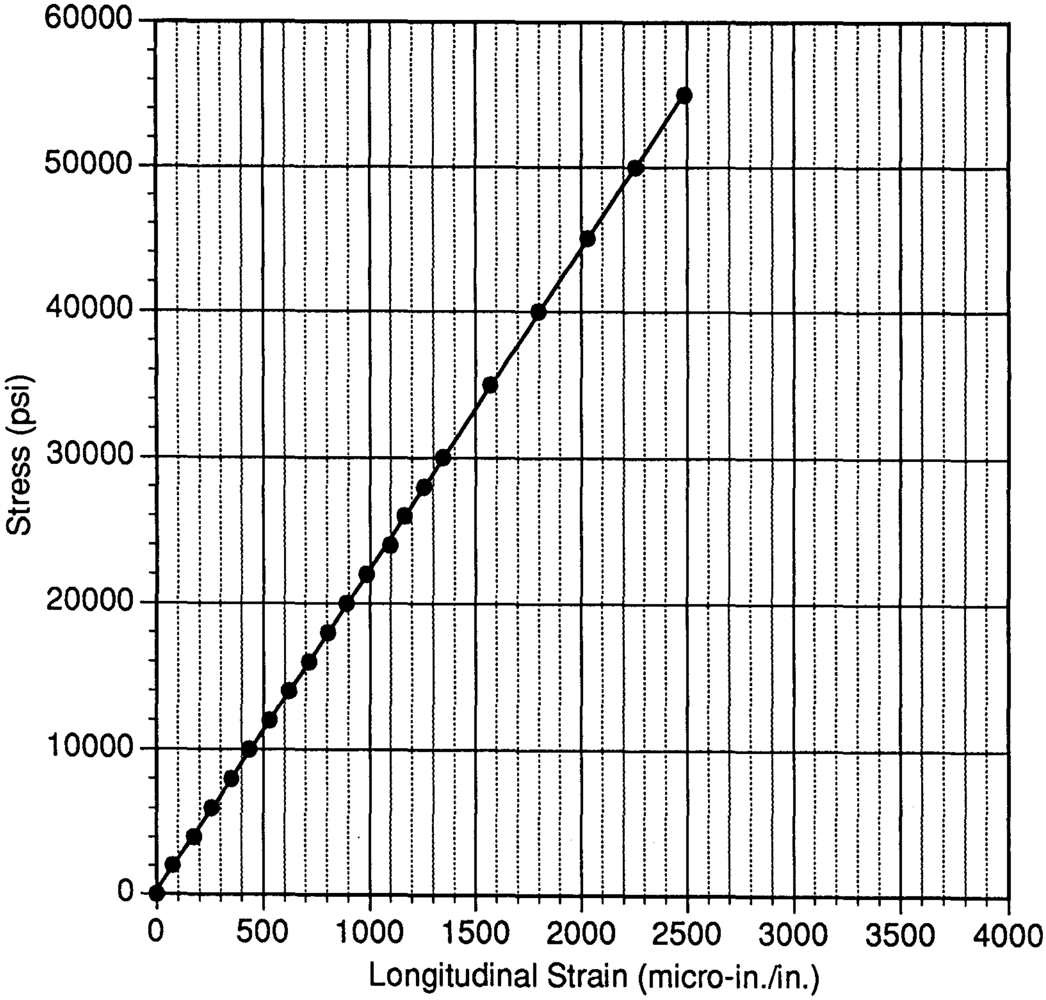
= (445 / 1770) μ in./in. = **0.25**

Figure 10

ADI - 230 ksi (#1)

Tension

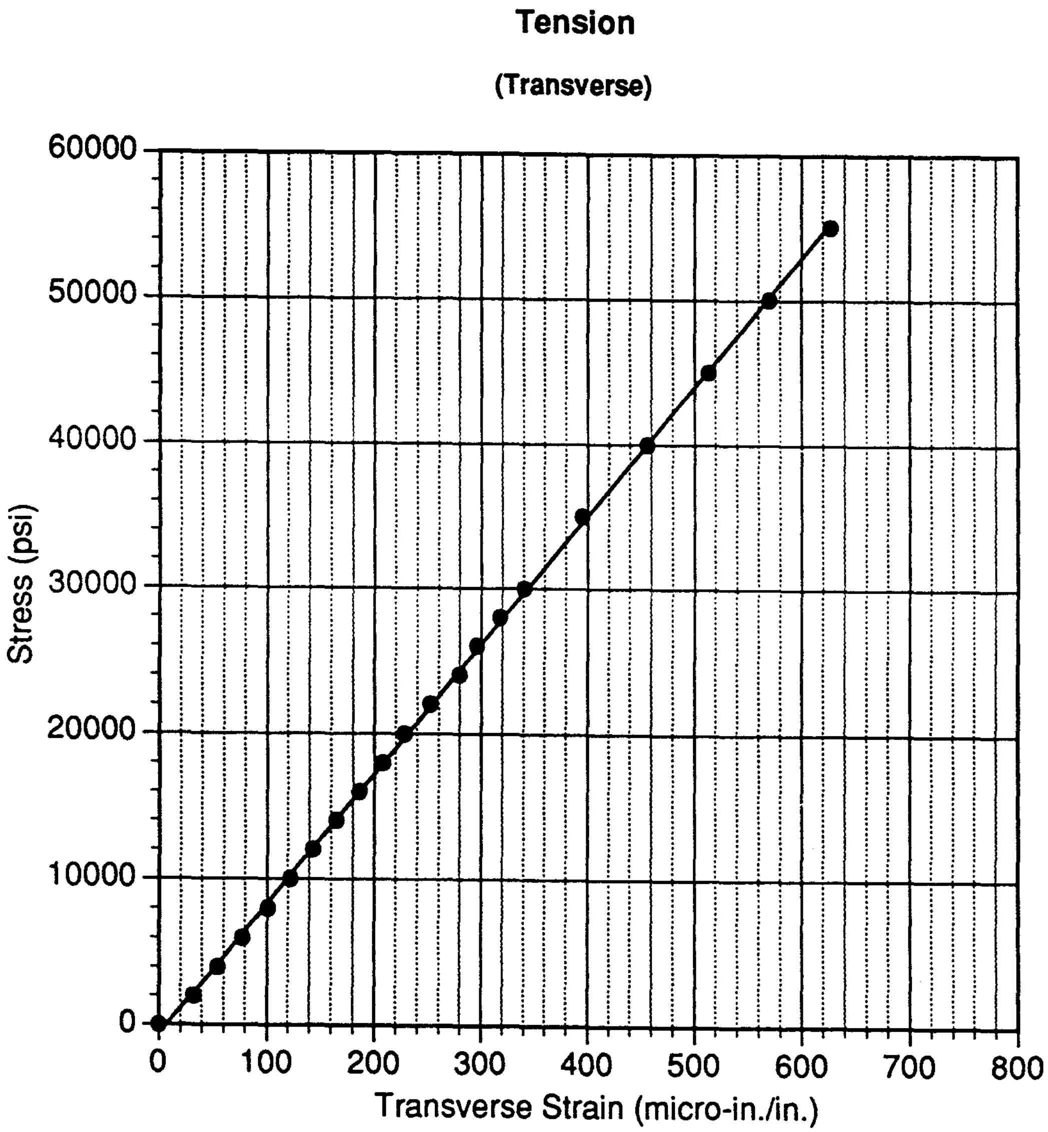
(Longitudinal)



Initial Modulus = (40000 psi) / 1800 μ in./in.) = **22.2 x 10^6 psi**

Figure 11

ADI-230 ksi (#1)



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain

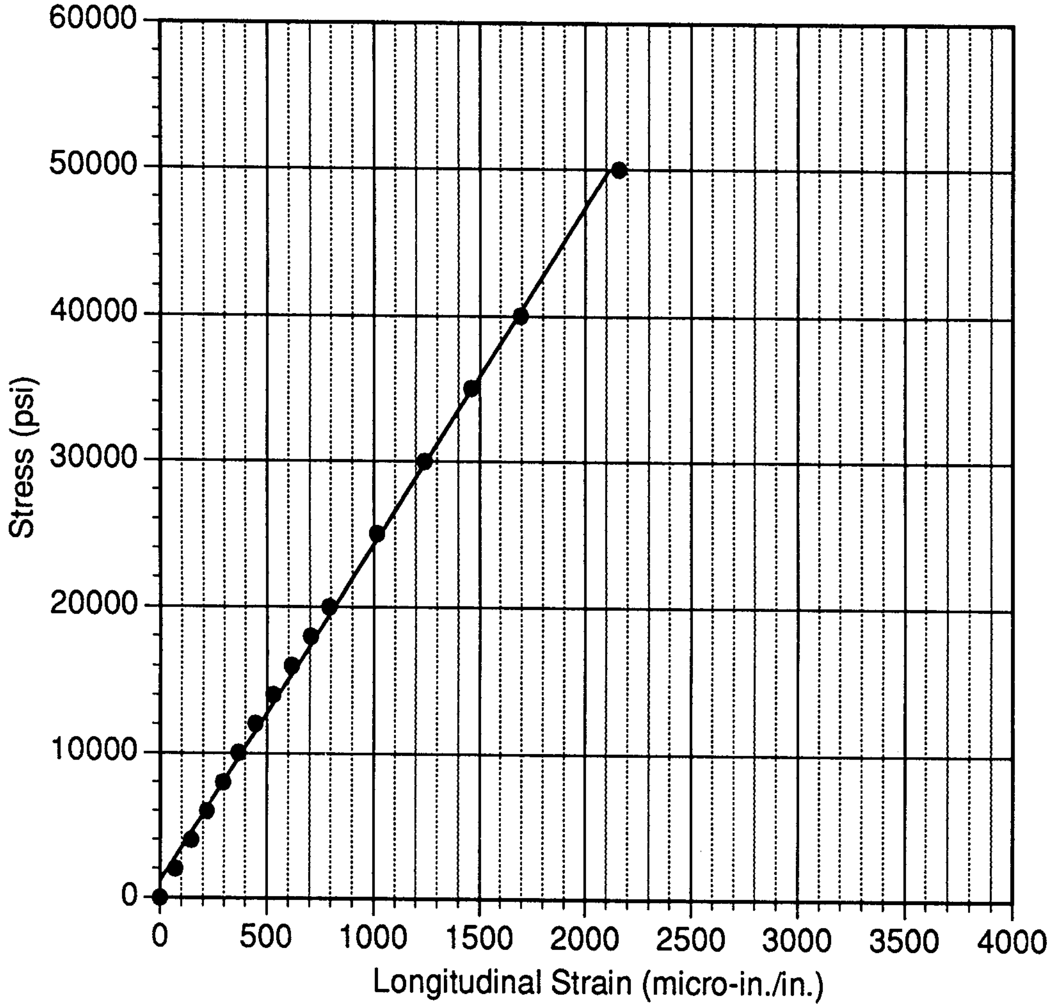
= (455 / 1800) μ in./in. = **0.25**

Figure 12

ADI - 230 ksi (#2)

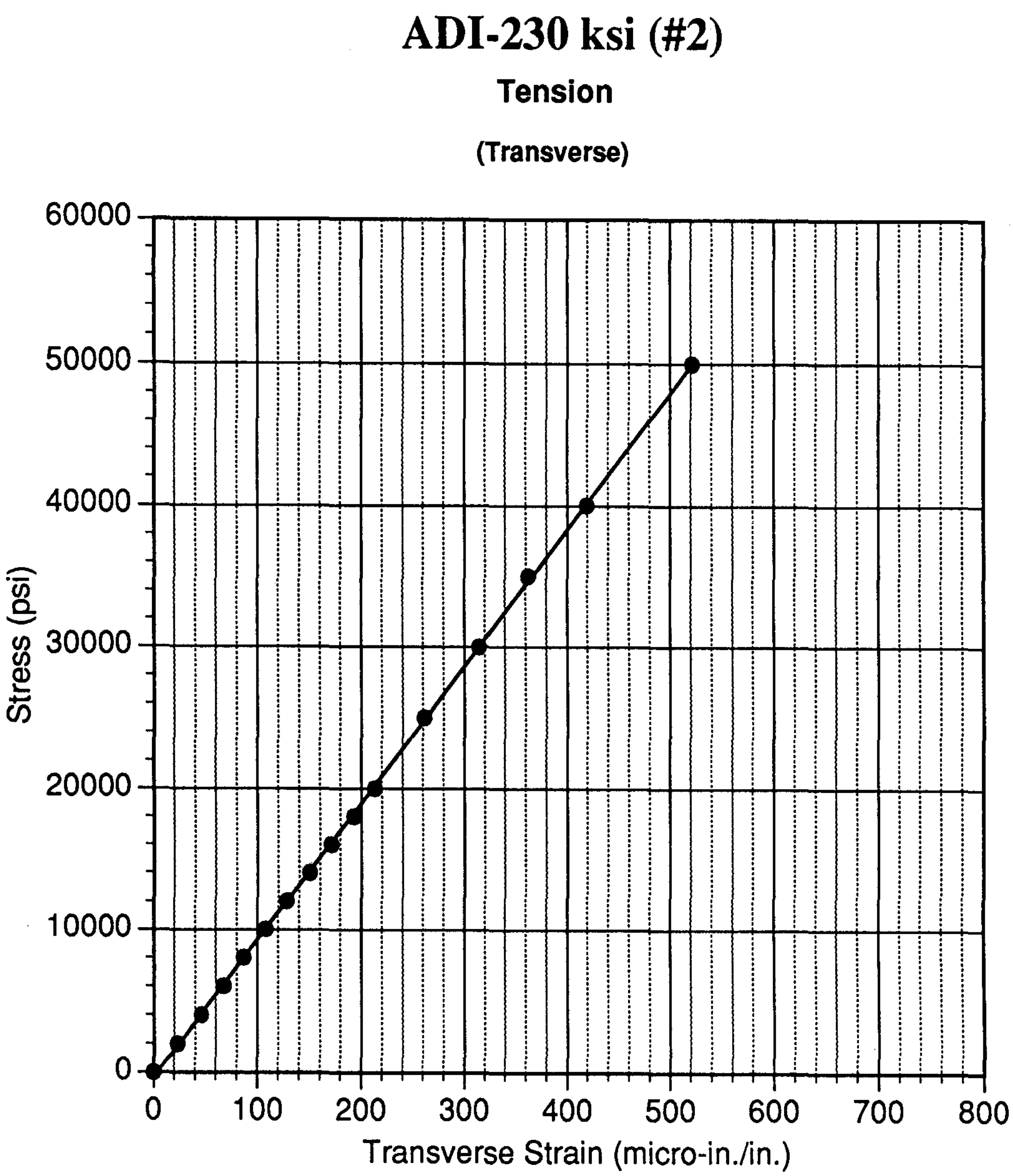
Tension

(Longitudinal)



Initial Modulus = (40000 psi) / 1680 μ in./in.) = **23.8 x 10^6 psi**

Figure 13



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain

$= (420 / 1680)\ \mu$ in./in. = **0.25**

Figure 14

ADI - Compression

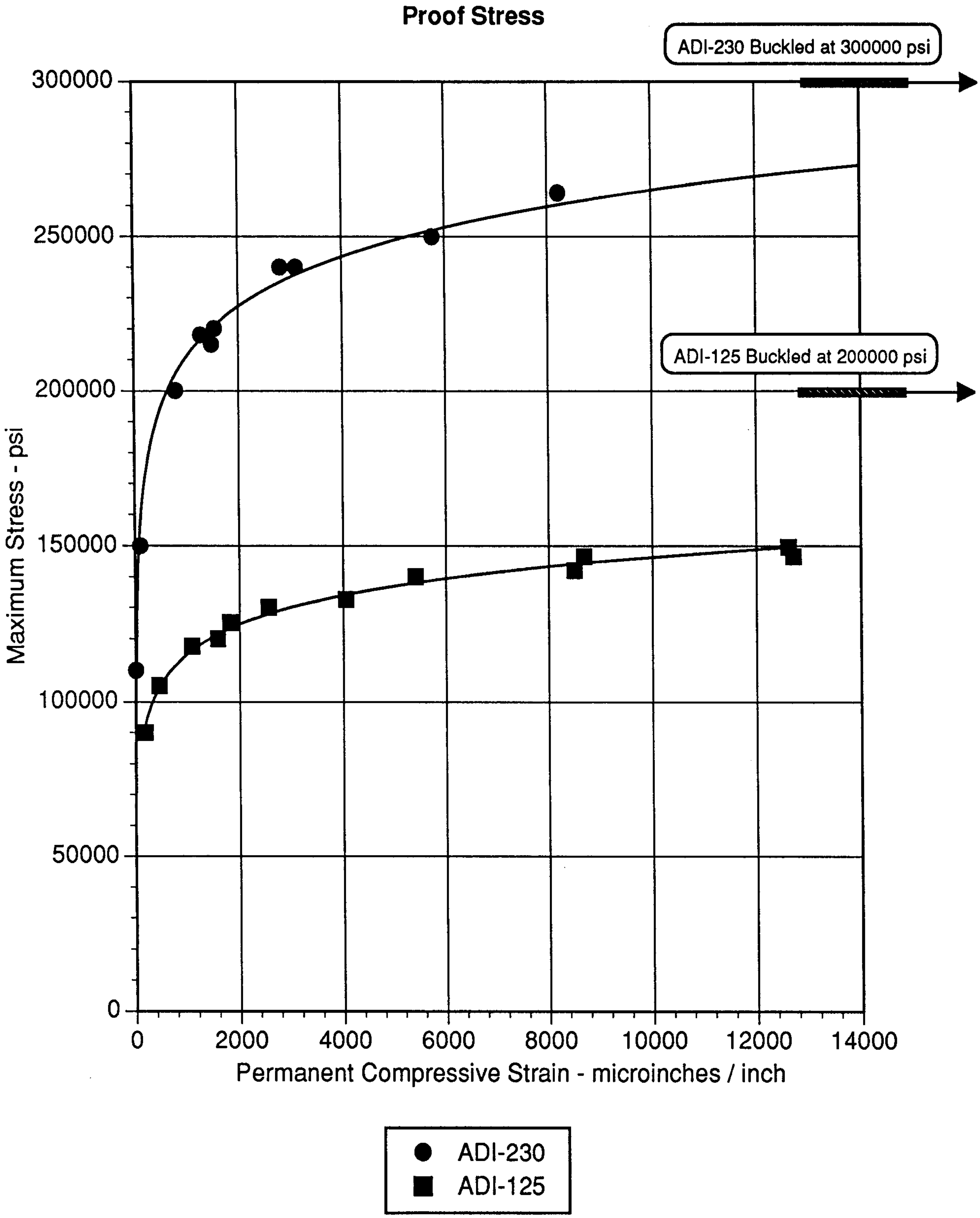


Figure 15

ADI - Compression

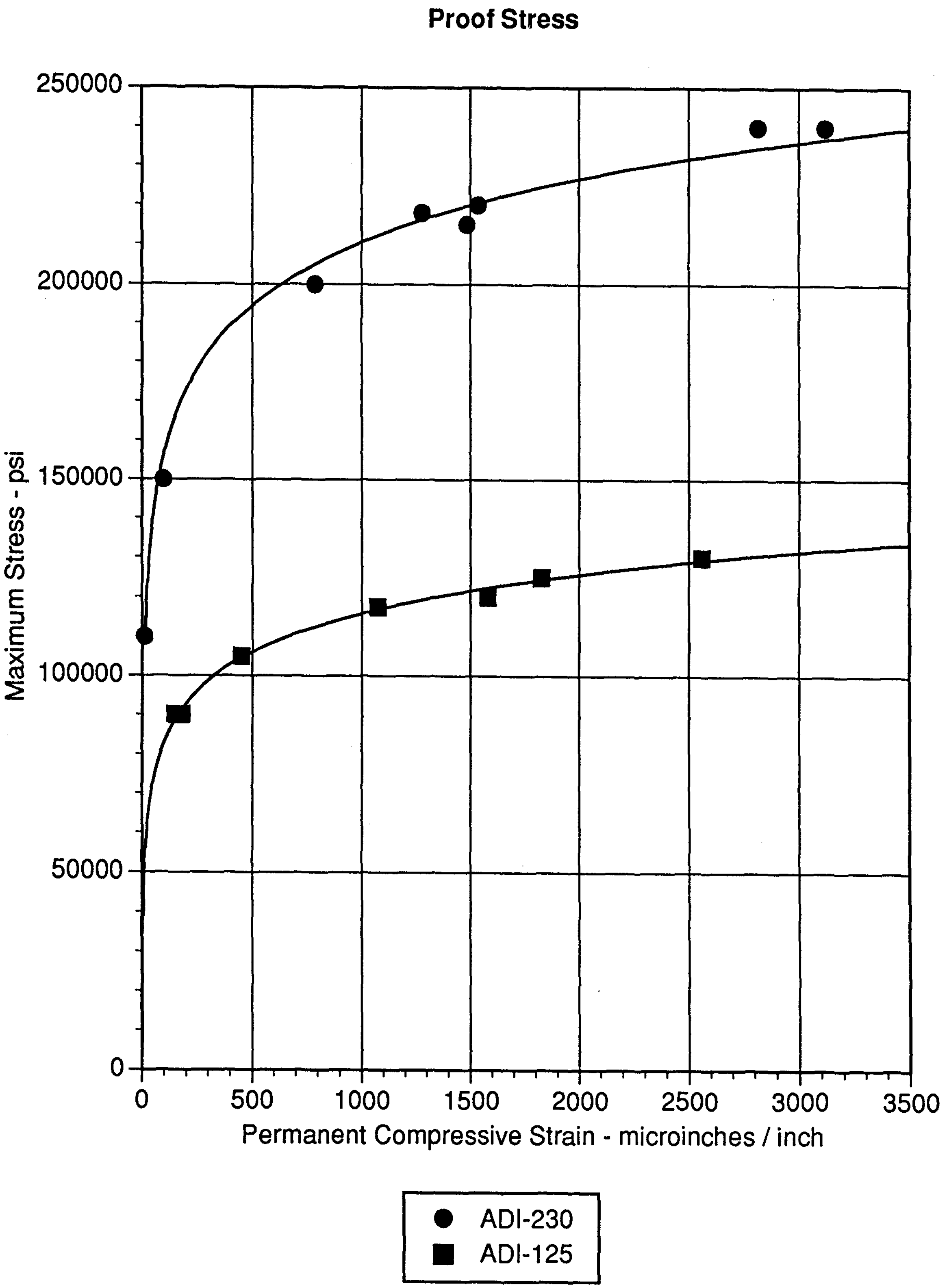
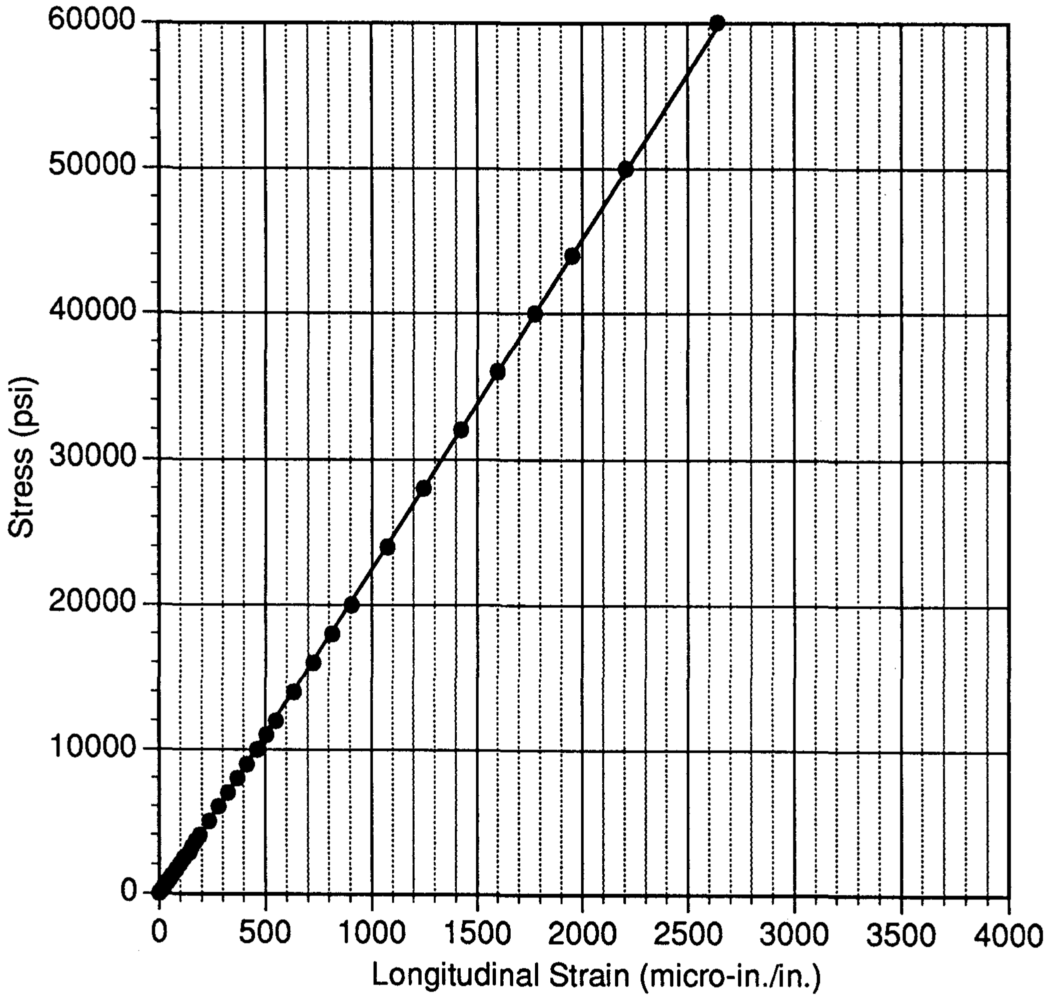


Figure 16

ADI - 125 ksi (#1)

Compression

(Longitudinal)



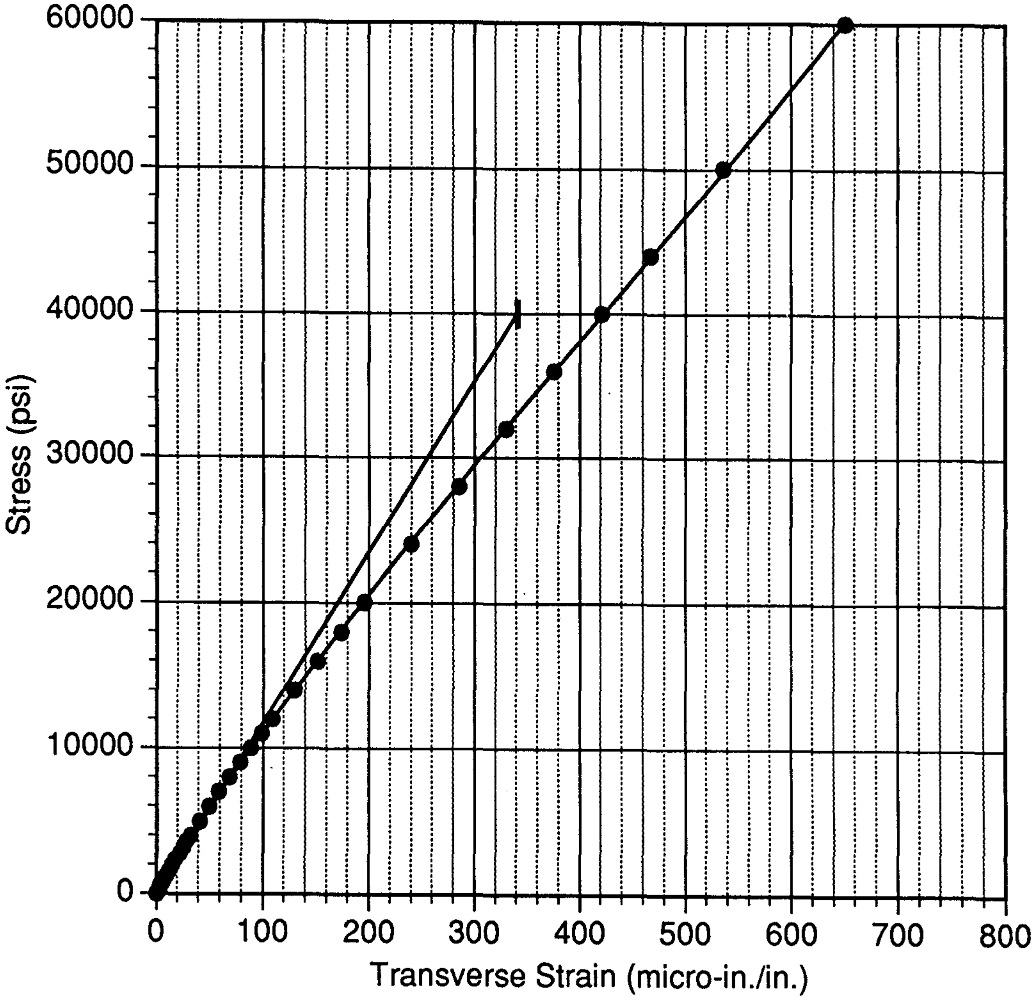
Initial Modulus = (40000 psi) / (1775 μ in./in.) = **22.5 x 10^6 psi**

Figure 17

ADI - 125 ksi (#1)

Compression

(Transverse)



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain (straight line fits)

= (340 / 1775) μ in./in. = **0.19**

If use actual curves at 40000 psi:

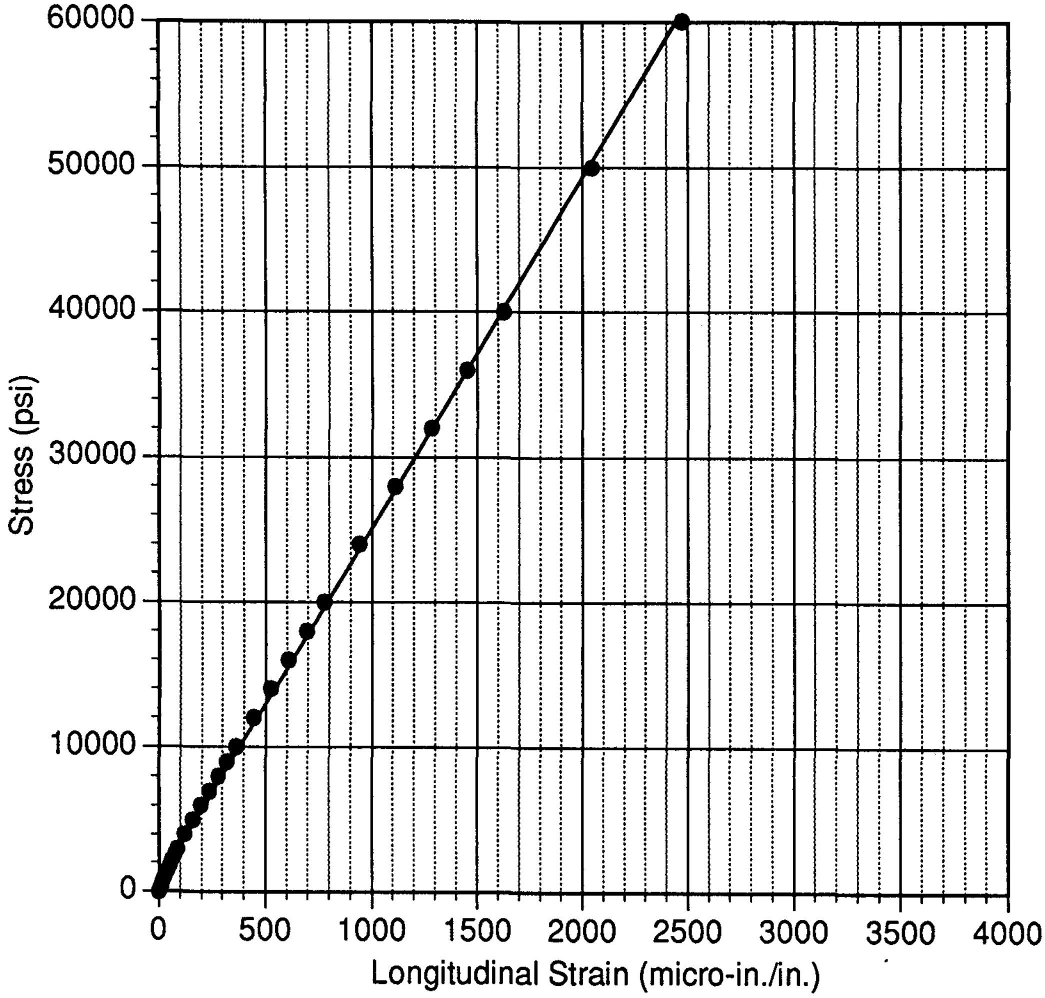
= (420 / 1775) μ in./in. = **0.24**

Figure 18

ADI - 230 ksi (#1)

Compression

(Longitudinal)



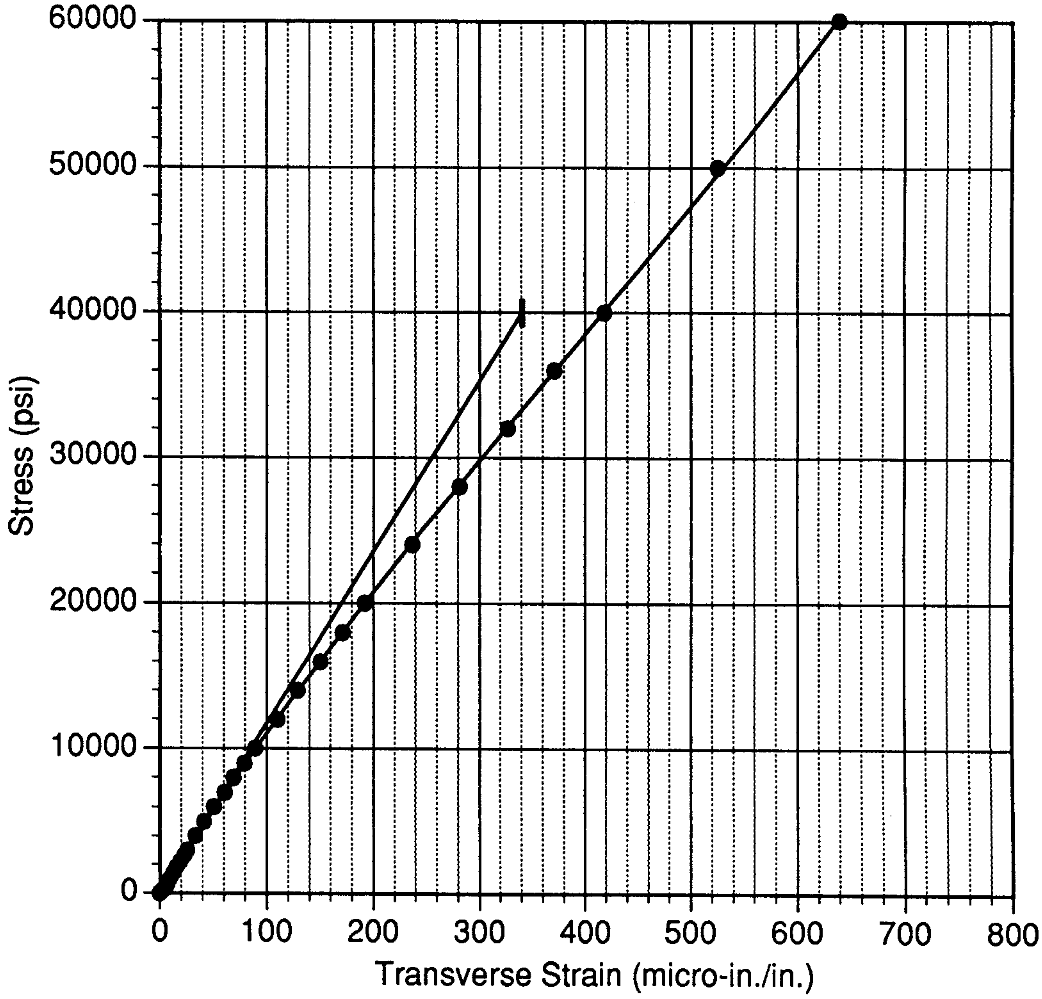
Initial Modulus = (40000 psi) / (1625 μ in./in.) = **24.6 x 10^6 psi**

Figure 19

ADI - 230 ksi (#1)

Compression

(Transverse)



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain (straight line fits)

= (340 / 1625) μ in./in. = **0.21**

If use actual curves at 40000 psi:

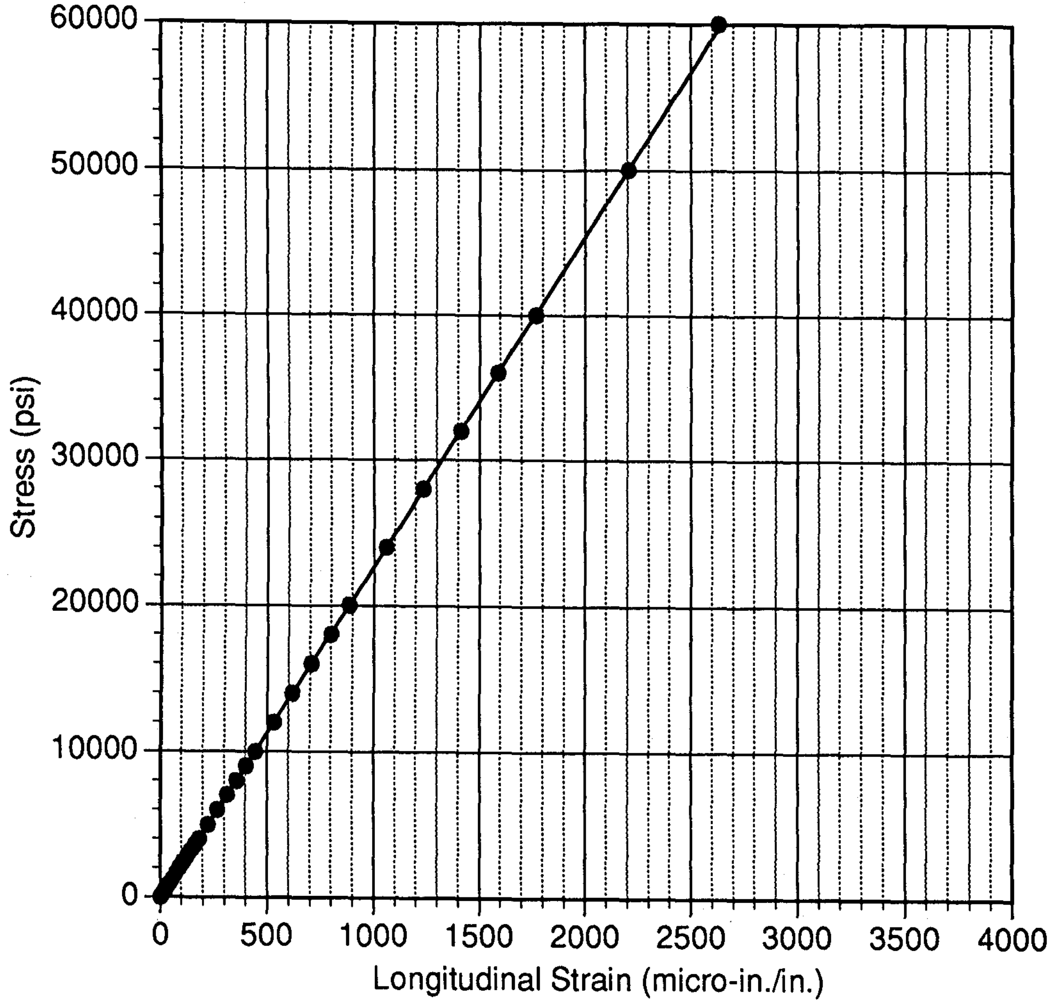
= (420 / 1625) μ in./in. = **0.26**

Figure 20

ADI - 230 ksi (#2)

Compression

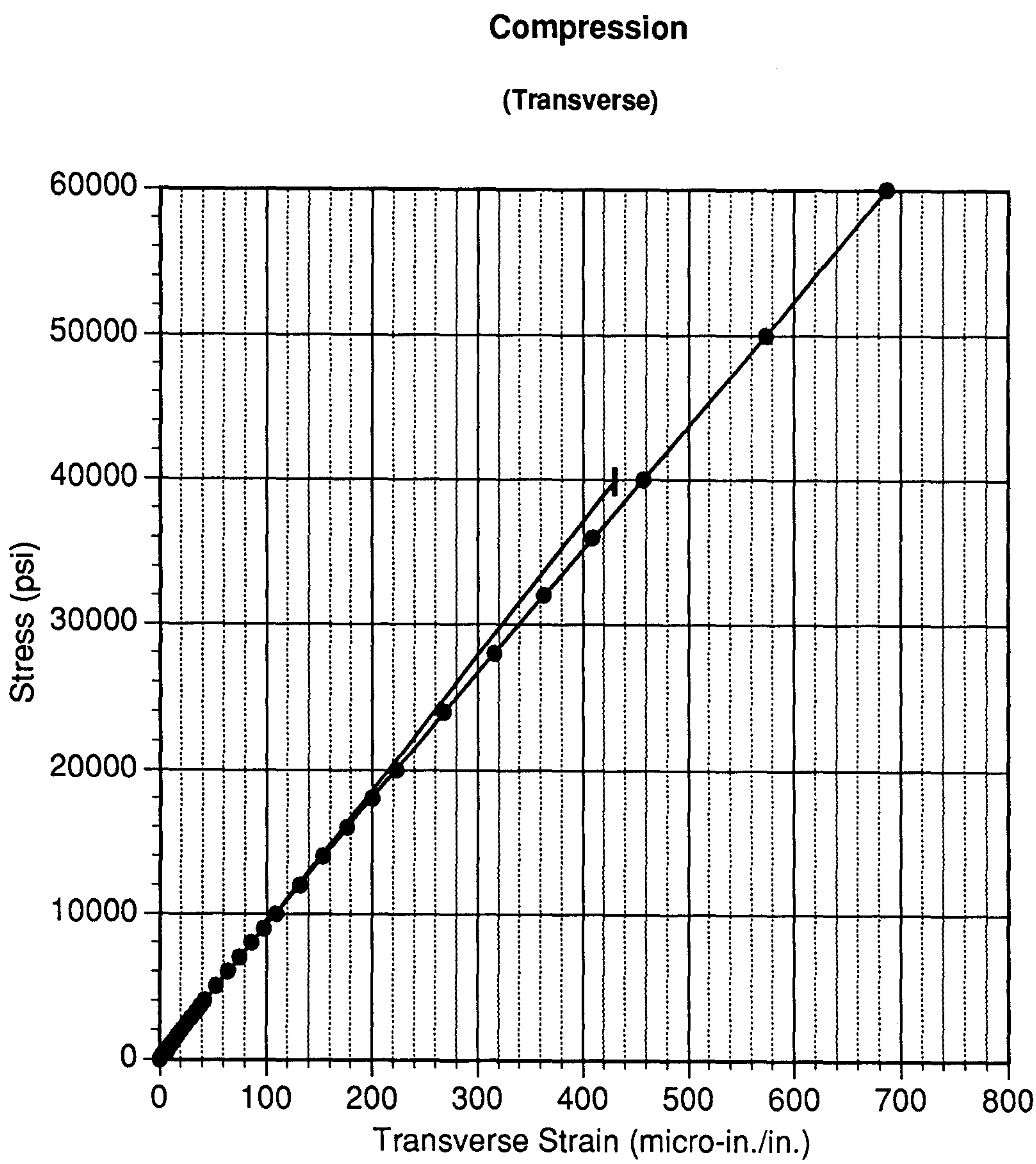
(Longitudinal)



Initial Modulus = (40000 psi) / (1770 μ in./in.) = **22.6 x 10^6 psi**

Figure 21

ADI - 230 ksi (#2)



Poisson's Ratio

At 40000 psi: transverse / longitudinal strain (straight line fits)

= (430 / 1770) μ in./in. = **0.24**

If use actual curves at 40000 psi:

= (460 / 1770) μ in./in. = **0.26**

Figure 22