

TESTING SMALL WOOD SPECIMENS IN TRANSVERSE COMPRESSION

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ABSTRACT

The standard test method recommended in ASTM Standard D143 for compression perpendicular to the grain does not measure pure compression. The results of small wood specimens tested in compression perpendicular to the grain may be influenced by macroscopic characteristics of the specimen or the test procedure. Pure compression tests were performed on wood and poly(methyl methacrylate) specimens measuring 0.12 to 1.56 inch in height. Young's modulus in transverse compression increased with specimen height. Yield stress was not affected by specimen height. However, an increase of specimen height resulted in a decrease of yield strain. These observations may be explained by surface roughness or non-parallelism of the specimen. The results are not unique to wood.

Keywords: Transverse compression, compression testing, surface effects, composites.

INTRODUCTION

The mechanical performance of wood components is often dependent on transverse compression properties. Large timber construction and railroad crossties are two applications for which bearing surface area and transverse compression are important considerations. ASTM standard D143 was developed because a need was recognized for compression testing of large specimens. In this standard, the load is transferred through a bearing plate that is smaller than the compression specimen. Therefore, the test combines both transverse, longitudinal, and shear stresses obtaining pseudo-transverse compression properties.

Wood-based composite materials that require mechanical pressure to promote bonding during manufacture are also dependent on the behavior of wood under

transverse compression. In products such as flakeboard, plywood, and paper, the manner in which the wood components deform will strongly influence the resulting material properties. Therefore, a complete understanding of the transverse compression behavior of wood will benefit the design of wood-based composites. The question posed is: without a suitable ASTM standard, what testing conditions can effectively evaluate transverse compression for studying the production process of wood-based composites?

Several researchers have studied the pure transverse compression behavior of wood (Bodig 1963, 1965, 1966; Kennedy 1968; Kunesh 1968). As with many mechanical tests, the compression properties are dependent on specimen size and geometry (Bodig 1963; Kunesh 1968). Contrary to intuition, both Bodig and Kunesh found that the measured Young's modulus in compression (E_c) increases with specimen height. Bodig found that the stress at the proportional limit was invariant with specimen height, whereas Kunesh noted a slight dependence that increased and then decreased. Because the influence of specimen height on E_c was far greater than on stress at the proportional limit, the size dependence of strain at the proportional limit was similar to the reciprocal of E_c .

Menges and Knipschild (1982) have documented trends for manmade cellular materials that are similar to those presented for wood. Using aspect ratio (ratio of specimen height to width) to study the size dependence, they determined that the behavior was caused by disturbing effects in the region of the applied load. For specimens with an aspect ratio greater than 2, the stress-strain relationship measured at the center of the specimen was independent of specimen size.

To effectively study this problem, the possible mechanisms for the observed behavior must be properly identified. It can then be determined whether the influencing factors occur in the specific composite manufacturing process or only in the testing situation. The following mechanisms have been proposed to account for the size dependence discussed:

1. surface quality
2. non-parallel surfaces
3. surface restraint
4. flexure in the testing apparatus
5. a weak layer in heterogeneous materials
6. load eccentricity

Theories 1–4 were proposed by Menges and Knipschild (1982) and could be present in any material. However, theory 5 (Bodig 1963) cannot be a factor in homogeneous materials.

Rough surfaces are inherent to cellular materials because any cutting technique will produce open cells on the surface of the material. In addition, both polymeric foams and wood lack the machining qualities needed to easily grind specimens flat and parallel. Both these effects can produce nonuniform stress and strain fields in the material.

Surface restraint often accompanies compression tests because frictional forces between the specimen and platen restrain the specimen from deforming laterally (Thornton et al. 1988). However, this effect alone produces the opposite trends as those seen for E_c in wood and polymeric foams. This is especially true when Poisson's ratio approaches 0.5 as in elastomers (Dillard et al. 1988).

During mechanical testing, the apparatus used to apply the load is often considered to be rigid, and crosshead movement is commonly used as a measure of specimen deflection. However, these assumptions can often lead to erroneous results when the material is stiff or the deflections are small. This behavior occurs because deflections in the testing apparatus can become a significant portion of the overall measured deflection. As specimen height decreases, the machine compliance becomes significant compared to the specimen compliance, and the apparent E_c decreases.

For wood, Bodig (1963) proposed that weak earlywood layers dominated the deformation of the entire wood specimen. Considering this theory, when specimen height is increased, the deformation remains relatively constant for a given amount of stress. Therefore, the apparent E_c must increase with specimen height because the strain per unit stress is decreasing. This theory is limited to laminar, heterogeneous materials.

To determine the effect of material heterogeneity and testing technique, we conducted a series of experiments on both yellow-poplar (*Liriodendron tulipifera*) and poly(methyl methacrylate) (PMMA). The objectives of the work were:

1. To determine if a size effect could be reproduced in a homogeneous isotropic material.
2. To determine the relative contribution of machine flex to the measured deformation.
3. To determine the influence of surface roughness and parallelism on the measured stress-strain behavior.

MATERIALS AND METHODS

Specimen preparation

To study the effect of specimen height, yellow-poplar specimens, conditioned to a nominal 12% moisture content, were cut with a cross-section of 0.79×0.79 inch and heights of ca. 0.12, 0.24, 0.47, 0.79, 1.18, and 1.57 inch. Commercially obtained PMMA samples were cut 0.79×0.79 inch in cross-section and ca. 0.24, 0.36, 0.72 and 1.56 inch high.

Testing methods

Both wood and PMMA samples were tested on a universal hydraulic testing machine. A linear variable differential transformer (LVDT), attached to the crosshead directly above a movable platen, was used to measure deflection. The samples were compressed with a rate of crosshead movement that corresponded to 6% strain per minute for wood and 1% strain per minute for PMMA. Load and deflection data were acquired by computer in real time.

The samples were compressed between two $1 \times 1 \times 0.25$ inch steel plates that were ground flat and parallel to within 0.001 inch. To remove the error introduced by the inherent flexure in the testing apparatus, a compression test was conducted on the steel plates. The load-deflection relationship of the testing apparatus was found to be linear. Thus, the deflection attributable to the apparatus could be easily subtracted from the overall deflection. If this error is not considered, it would account for 30% to 50% of the measured deflection in the elastic region. This would lead to similar errors in the calculated E_c .

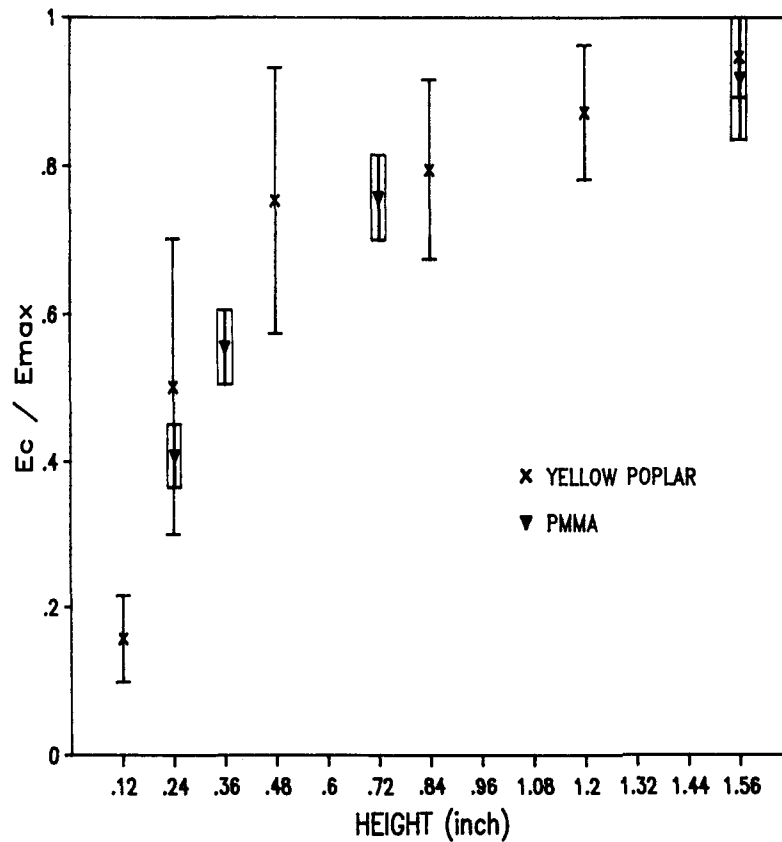


FIG. 1. Normalized Young's modulus in compression (E_c) as a function of specimen height for yellow-poplar and poly(methyl methacrylate). Error bars denote 99% confidence intervals.

RESULTS AND DISCUSSION

The effect of specimen height was determined using an analysis of variance (ANOVA). A least significant difference test (LSD) was employed to determine differences between treatment means at the 99% confidence level.

Despite corrections made for machine flexure, E_c increased with specimen height for both yellow-poplar and PMMA (Fig. 1). For PMMA samples, E_c increased for each specimen height tested. The E_c of yellow-poplar increased with heights less than 0.47 inch. No significant difference was noted for E_c of specimens 0.47 inch and higher.

In addition to E_c , the yield stress and strain were studied for yellow-poplar. Yield stress (σ_y) and strain (ϵ_y) are used to define the beginning of the plateau region in the stress-strain diagram (Fig. 4). This terminology clearly distinguishes the yielding phenomenon exhibited during the compression of cellular materials from the proportional limit that often exists prior to reaching the true yielding plateau.

The ϵ_y behaved in the opposite manner as E_c (Fig. 2). The effect of specimen height on σ_y was statistically significant as determined through an ANOVA. However, no significant differences were noted among treatment means with the LSD

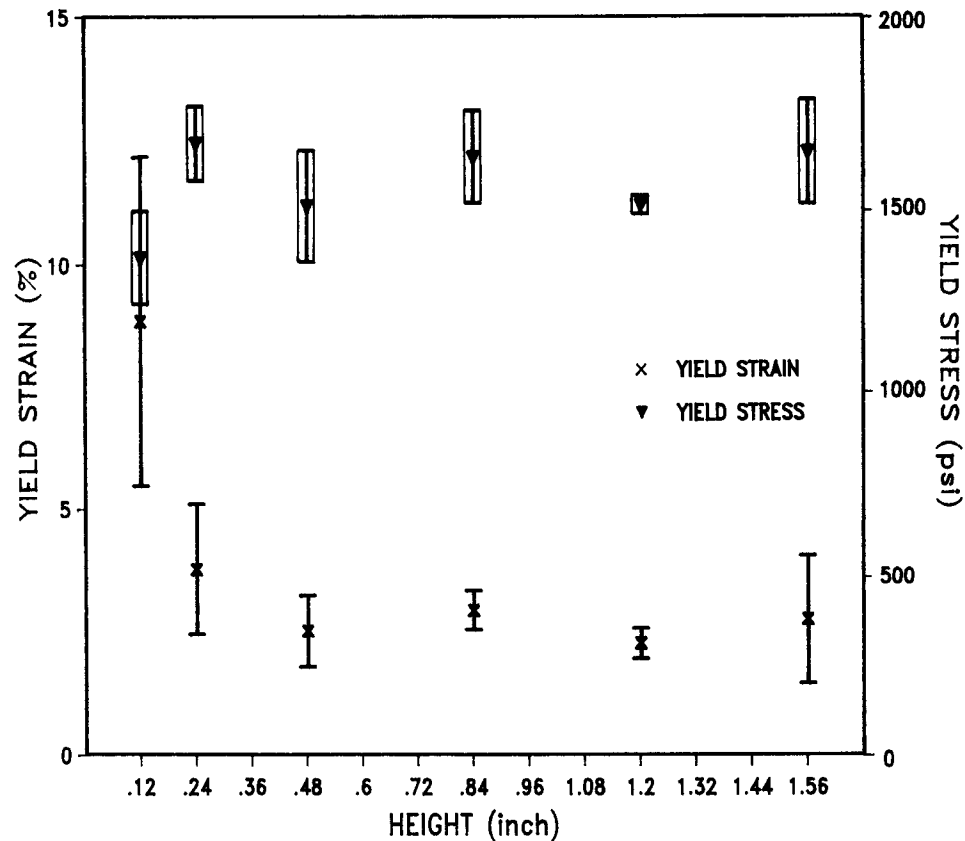


FIG. 2. Yield stress and strain as a function of specimen height for yellow-poplar. Error bars denote 99% confidence intervals.

test. In addition, no trend between the two variables was apparent (Fig. 2). Whereas the effect of height on σ_y may be statistically significant, the effect may be, in reality, small enough to ignore. The percent difference between the extreme treatment means was approximately 15%.

The relationship of increasing E_c with increasing specimen height has been shown for wood, PMMA, and foams (Menges and Knipschild 1982). These corroborative findings certainly suggest that this phenomenon is an anomaly of the testing technique and not unique to wood. The interpretation of these results does not suggest a clear reason for the observed relationship between E_c and specimen height. However, the effect of surface quality and load eccentricity can be examined using a mechanics of materials approach.

Surface quality

Both surface roughness and nonparallel mating surfaces result in a nonuniform stress field. In an attempt to approximate these effects, we considered the model shown in Fig. 3. The surface asperities or nonparallelism are modeled as triangular to simplify the mathematics. The frequency of asperities does not enter the formalism; therefore the model applies to localized or global deviations from perfect

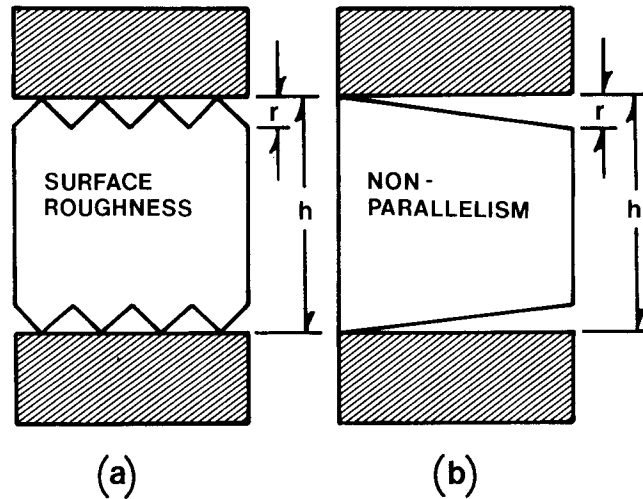


FIG. 3. Model of compression specimen with (a) surface roughness and (b) nonparallel mating platen-specimen surfaces.

contact between the platens and specimen. An elastic-perfectly plastic constitutive model was assumed. In addition, a densification region that is exhibited in cellular materials was imposed (Fig. 4). A simple mechanics of materials approximation that considers progressive collapse of the triangular asperities was derived for this study. The total deformation of the test specimen (δ) may be written as:

$$\delta = \frac{\sigma}{E}(h - 2r) + 2r\epsilon_d \frac{\sigma}{\sigma_y} \quad [1]$$

where:

- h = specimen height (inch)
- r = height of the asperities (inch)
- ϵ_d = fully densified strain

Therefore, the ratio of apparent modulus (E_{app}) to actual modulus (E) would be:

$$\frac{E_{app}}{E} = \frac{h}{(h - 2r) + 2r\epsilon_d(E/\sigma_y)} \quad [2]$$

Because the asperities are triangular, the progressive collapse results in linear-stress-strain curves with a reduced slope from the actual modulus.

The results of this analysis clearly indicate the significance of specimen height on E_{app} when some characteristic roughness is present. Because the deformation in the solid portion of the specimen is small during the elastic region, even slight roughness can lead to substantial errors with short specimens. The asperities are totally collapsed when the stress is equal to σ_y . Therefore, the yield stress exhibited by the specimen is independent of specimen height as is seen in the experimental results. This also implies that ϵ_y will vary with the inverse of the E_{app} .

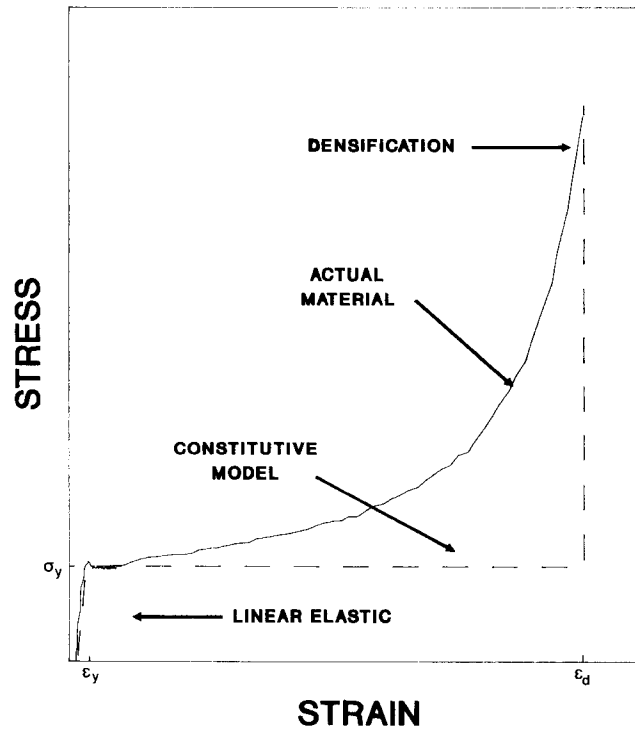


FIG. 4. Assumed constitutive model for cellular material and actual stress-strain diagram for yellow-poplar.

To examine the predictions, typical properties for wood were considered: $E = 130$ ksi, $\sigma_y = 1.4$ ksi, and $\epsilon_d = 55\%$. Figure 5 shows the effect of surface roughness on E_{app}/E . Note that for a short specimen with a height of 0.20 inches, a roughness of only 0.002 inch gives approximately a 50% drop in E_{app} . The effect of block height on E_{app}/E for several asperity heights is shown in Fig. 6. The trends are similar to the experimental results presented in Fig. 1.

If the asperities are not triangular or if the collapse process is not as simple as assumed, the initial portion of the stress-strain curve could deviate from linearity. However, similar trends should continue to exist. This allows us to hypothesize that localized surface irregularities, nonparallel contact surfaces, or small foreign particles on the platens could all give rise to the types of specimen height dependencies observed.

Load eccentricity

Another factor that should be considered in experimentally determining the compressive modulus is the load eccentricity. If the platens are free to rotate, the apparent modulus determined using platen displacement will decrease as the specimen is shifted away from center. Consider a square specimen with the load applied off center by an amount e . The eccentricity is nondimensionalized by expressing it in terms of the width of a square specimen (a) as $\Phi = e/a$. Because the moment of inertia of a square cross-section is invariant with rotation, the

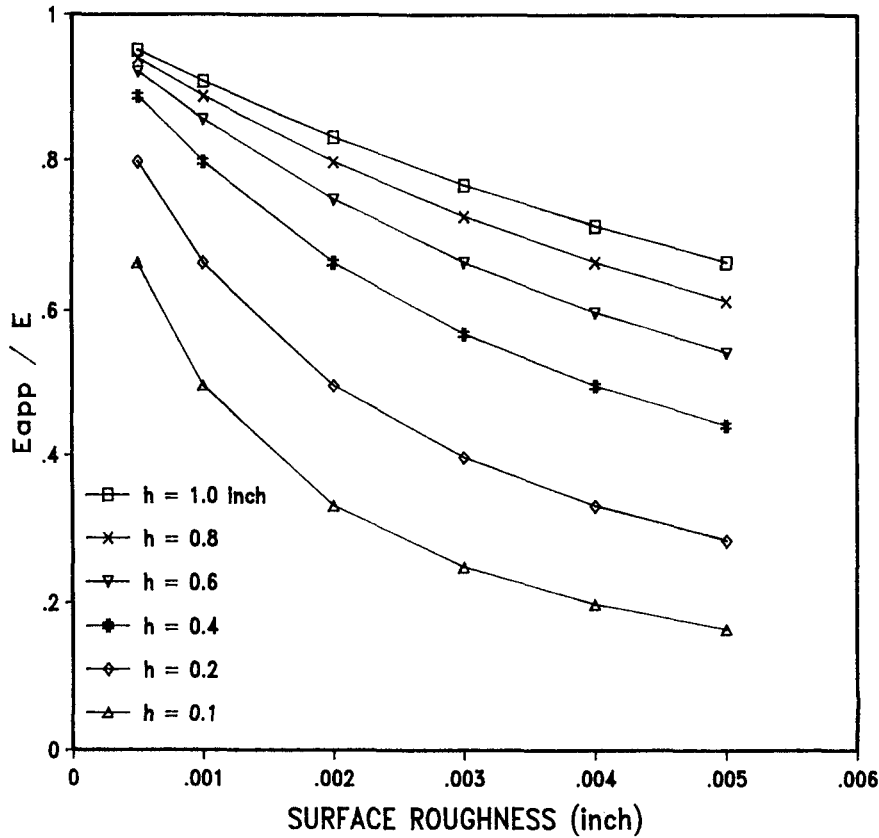


FIG. 5. Predicted ratio of apparent modulus (E_{app}) to actual modulus (E) expressed as a function of surface roughness (r) for different specimen heights (h).

analysis is valid for an eccentricity in any direction. The stress at the point that the load is applied can be written as:

$$\sigma_e = P \left[\frac{1}{A} + \frac{e^2}{I} \right] = \frac{P}{a^2} [1 + 12\Phi^2] \quad [3]$$

where:

P = load

A = area

I = cross-sectional moment of inertia

The apparent modulus can be determined by assuming that $\epsilon_e = \sigma_e/E$. The resulting form is given by:

$$\frac{E_{app}}{E} = \frac{1}{1 + 12\Phi^2} \quad [4]$$

Because tensile stresses cannot be sustained across the interface, the analysis is valid only when the eccentricity is within the kern (Seely and Smith 1952). Because

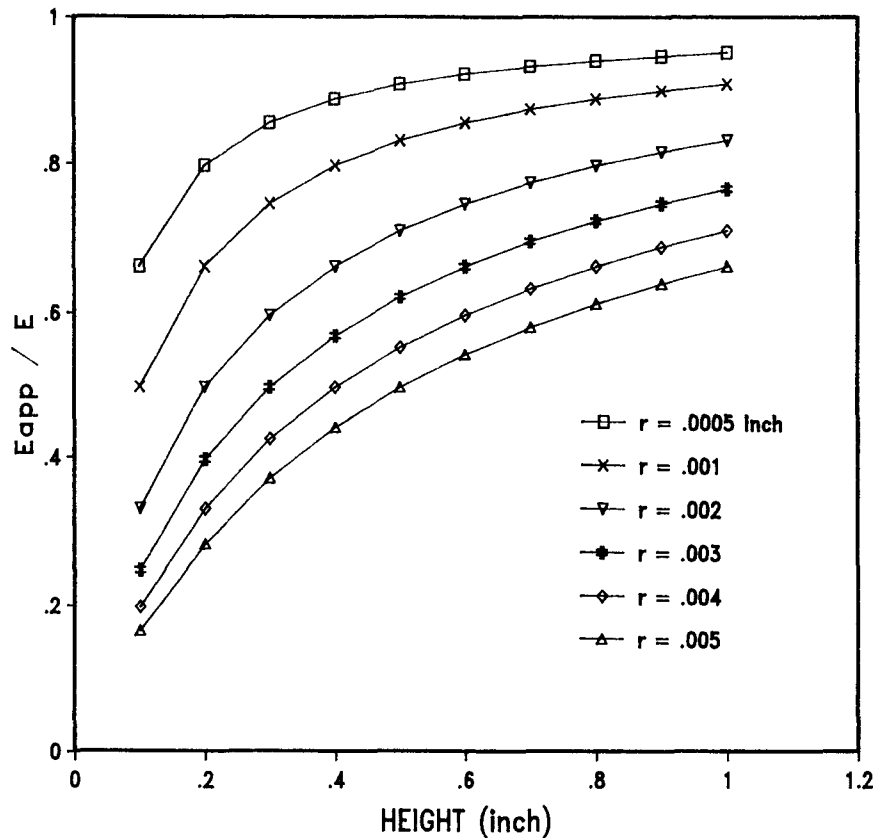


FIG. 6. Predicted ratio of apparent modulus (E_{app}) to actual modulus (E) expressed as a function of specimen height (h) for different values of surface roughness (r).

eccentricity is a second order effect, small amounts will result in negligible changes in apparent modulus. An eccentricity of $\Phi = 1/6$ corresponds to loading at one corner of the kern and gives an apparent modulus that is 75% of the actual modulus. Interpretation of the second order effects suggests that precise alignment is not essential; however, gross eccentricities must be avoided.

SUMMARY AND CONCLUSIONS

The mechanical properties of yellow-poplar and PMMA were tested in compression and found to be highly influenced by specimen size. Young's modulus has been observed to increase with specimen height, whereas, yield stress remains invariant with specimen height and yield strain decreases similar to the reciprocal of modulus.

Neglecting deflections from the testing apparatus can give rise to the observed behavior. However, the experimental trends remained after accounting for machine compliance. A mechanics of materials solution of a surface roughness model exhibited similar trends for E_c , σ_y , and ϵ_y to those observed experimentally. Therefore, surface roughness and nonparallel mating surfaces for specimen and platens can account for the observed behavior. Given the strong influence of specimen

surface quality, the observed behavior is likely to be exhibited in any situation where the material is not ground to tolerances substantially less than 0.0005 inch.

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