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Test Equipment

In situ materials characterization using the tissue diagnostic instrument

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ABSTRACT

An understanding of the mechanical behavior of polymers is critical towards the design, implementation, and quality control of such materials. Yet experiments and method for the characterization of material properties of polymers remain challenging due the need to reconcile constitutive assumptions with experimental conditions. Well-established modes of mechanical testing, such as unconfined compression or uniaxial tension, require samples with specific geometries and carefully controlled orientations. Moreover, producing specimens that conform to such specifications often requires a considerable amount of sample material. In this study we validate a micromechanical indentation device, the Tissue Diagnostic Instrument (TDI), which implements a cyclic indentation method to determine the material properties of polymers and elastomeric materials. Measurements using the TDI require little or no sample preparation, and they allow the testing of sample materials *in situ*. In order to validate the use of the TDI, we compared measurements of modulus determined by the TDI to those obtained by unconfined compression tests and by uniaxial tension tests within the limit of small stresses and strains. The results show that the TDI measurements were significantly correlated with both unconfined compression ($p < 0.001$; $r^2 = 0.92$) and uniaxial tension tests ($p < 0.001$; $r^2 = 0.87$). Moreover, the measurements across all three modes of testing were statistically indistinguishable from each other ($p = 0.92$; ANOVA) and demonstrate that TDI measurements can provide a surrogate for the conventional methods of mechanical characterization.

1. Introduction

Polymers are commonly used materials for many design applications due to their relatively low thermal and electrical conductance, ease of surface modification, and compatibility with biological materials [1–5]. In order to effectively and optimally utilize polymers, the accurate characterization of material behavior of polymers is necessary for design processes. One of the industry standards for polymer testing is the use of a durometer as specified, for example, in ASTM D2240 [6]. The durometer, which measures the depth of an indentation in the material created by a given force on a standardized indenting platen, is an inexpensive and convenient instrument for mechanically characterizing these polymers. However, the resulting durometer reading, although numerical, does not directly provide a constitutive relationship between load and deformation in the same manner that parameters such as elastic modulus do. Although durometer numbers typically increase with increasing elastic moduli, substantial variability exist in the conversion of the durometer number

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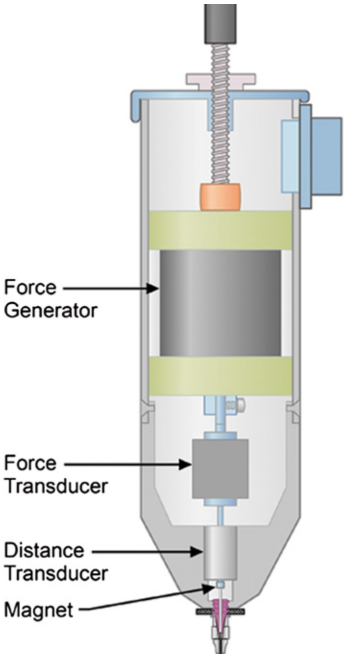

Fig. 1. A cross sectional view of the TDI head unit. A flat-punch indenter, is held by a magnet to a shaft that transmits force from the Force Generator. The Force Generator is powered from an electronics box that is controlled by a computer running a custom LabView program. The resulting force vs. distance plots are analyzed to obtain material parameters.

to elastic modulus [7], and the accuracy of conversion depends considerably on scale [8,9] and material [10].

Standard material test devices deploying tensile or compressive modalities are often used to characterize polymer materials. However, because rubbers and other polymeric materials exhibit non-linear material behavior and may depend on temperature, frequency, and scale [11,12], it is difficult to fully characterize material behavior across the full range of environmental and loading conditions. Simplifications are frequently made to obtain material behavior at a specific set of conditions. For example,

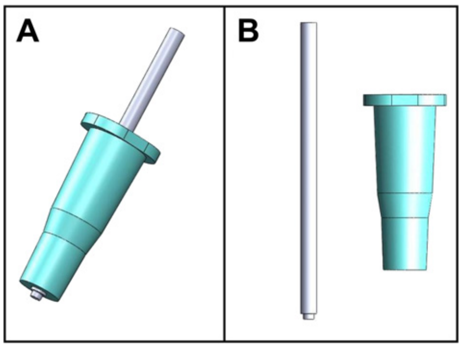

Fig. 2. A close up view of the probe assembly, which consists of a test probe and a reference probe shown assembled (A) and disassembled (B). The reference probe (right in B), is made from a hypodermic needle. It rests on the material's surface and provides a reference point for the indentation distance. The flat-punch test probe (left in B), manufactured from high-speed steel, indents into the material during testing. Its diameter is turned down to approximately 1 mm near the end to minimize the effects of stress concentration.

Table 1
List of polymer samples used for testing with the corresponding manufacturer's Durometer number. They are commonly used in a variety of design applications involving low deformation situations.

Sample	Manufacturer's Durometer number
Latex	38–40A
Natural gum rubber	–
Polyurethane	40A
Santoprene	55A
BUTYL	60A
EPDM	60A
Epichlorohydrin	60A
Neoprene	60A
Polyurethane	60A
Silicone	60A
Red Rubber	–
Hypalon	65A
Viton	75A
Polyurethane	80A
Polyurethane	90A
Polyurethane	95A

since polymers are commonly used in low deformation design situations, it is convenient and practical to determine the material properties from the linear region of the curve in the limit of low stresses and strains [13]. Furthermore, accurate mechanical characterization requires carefully controlled sample shapes to allow the derivation and validation of constitutive relationships. However, the preparation of conforming samples for typical mechanical testing modalities is laborious, costly, and may not directly reflect the *in situ* mechanical behavior of the polymer. Thus, the ability to non-destructively evaluate material behavior at the site of polymer deployment may alleviate experimental efforts to provide a more accurate assessment of the polymer's real-world performance.

The indentation testing of materials is widely used to characterize the material properties of polymers under quasi-static and dynamic conditions because of its non-destructive nature, ease of computation, and minimal requirements on sample dimensions [14,15]. The Tissue Diagnostic Instrument (TDI), a new developed instrument developed in our laboratory, uses a cyclical indentation method to non-destructively determine the material behavior of polymers and tissues.

The overall goal of this study is to compare the material measurements made using the TDI with those measured using well-established methods of mechanical testing, and

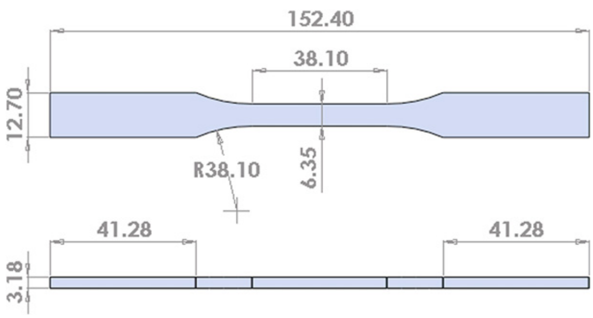

Fig. 3. The geometry of the dumbbell-shaped used for tensile testing (mm). The dimensions above have been converted to SI units from English units; resulting in apparently arbitrary decimal values.