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Comparative Macro- and Micro-Sized Investigation of Biocompatible Polymer Materials

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Abstract
In recent years, research and development of biocompatible polymer materials got recognition as outstanding part of human knowledge, and their applications are a matter of noteworthy interest. In this study we examined tensile strength of two thicknesses of glycolated poly(ethylene terephthalate) (PETG) for dental use and their nanoindentation elastic modulus and hardness. The mechanical behaviour of this material at the macro and micro-sized levels have been compared. It is revealed that differences in tensile and nanoindentation test values of hard and soft PETG grades might be caused by the dissimilar inhomogeneity and crystallinity along the applied tensile force.

Keywords: glycolated poly(ethylene terephthalate), tensile strength, nanoindentation elastic modulus and hardness

1. Introduction

In recent years, research and development of biocompatible polymer materials got recognition as outstanding part of human knowledge, and their applications are a matter of noteworthy interest. Importance of this behavior for the practice provokes our intention to learn and compare mechanical characteristics of such material at macro- and micro-sized levels. Using of glycolated poly(ethylene terephthalate) (PETG) for products in contact with human body gives rise of some mechanical interactions in the polymer itself not studied in detail so far [1]. Accordingly, we set our target to trace the multi-level mechanical testing of this material in order to eliminate complications that may arise as a result of materials' changes during contact with body systems and compare its behavior before and after thermoforming.

2. Materials and Methods

2.1. Material

The material used is transparent PET-G thermoplastic, DURAN grade produced by SCHEU-DENTAL GmbH, Germany in a form of circular sheets with diameter 125 ***mm*** having two thickness values, 0.5 and 0.75 ***mm***.

2.2. Methods

Investigation of the mechanical properties before and after thermoforming is performed using computerized tensile testing apparatus produced by Dongguan Lixian Instrument Scientific Co. Ltd. at a speed of 100 ***mm/min*** and Agilent Nano Indenter G200 instrument for nanoindentation testing which delivers <0.01 ***nm*** displacement resolution. The instrumented nanoindentation enables obtaining the load-displacement curve and computing of elastic modulus and indentation hardness of the material in compliance with the standard ISO 14577 using a sharp Berkovich indenter tip (**Fig. 1**). The thermoforming is completed at temperature ***T*** = 220 ***°C*** under pressure p = 6.1 ***bar*** (**Fig. 2**). The applied indentation program is under displacement control with maximum indentation depth of 2000 ***nm***.

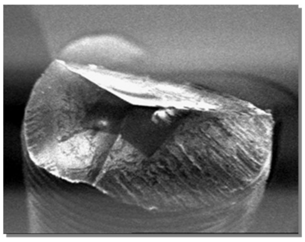

Fig. 1. Berkovich indenter tip

Fig. 2. PETG material and thermoformed sample

3. Results and Discussion

The quasi-static tensile testing of the PETG is completed according the ISO 527 standard. The true stress-strain curves of both material thicknesses are shown in **Fig. 3**. The obtained via nanoindentation load-displacement curves are shown in **Figs.4-5**.

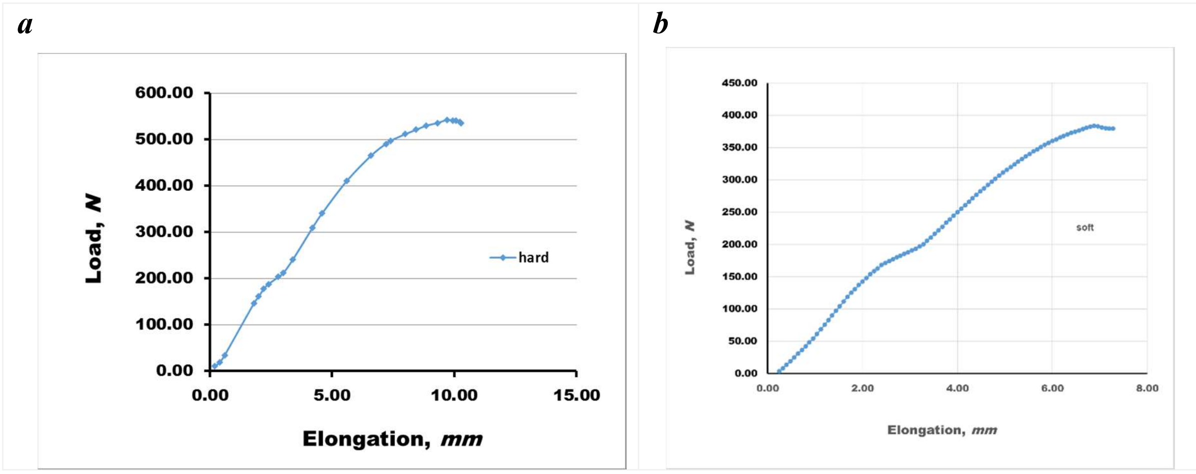

Fig. 3. Quasi-static tensile curves of dental PETG sheets of 0.75 *mm* (*a*) and of 0.5 *mm* (*b*) thickness values.

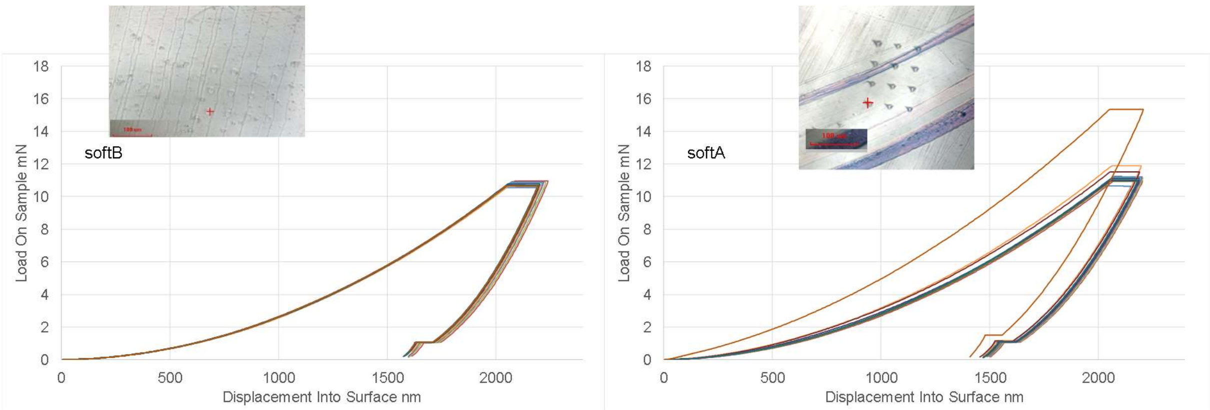

Fig. 4. Load displacement curves obtained via nanoindentation for PETG sample sheet of 0.5 *mm* thickness

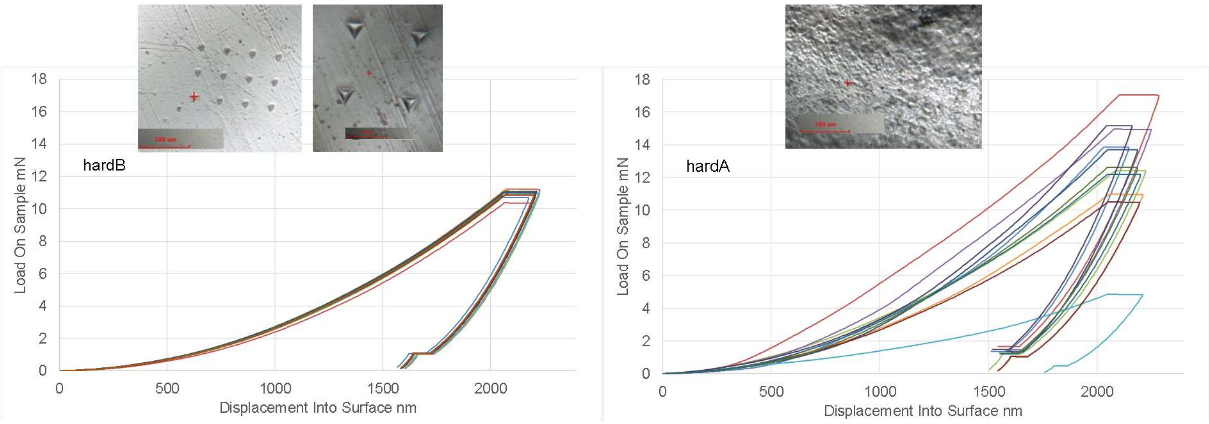

Fig. 5. Load displacement curves obtained via nanoindentation for PETG sample sheet of 0.75 *mm* thickness

Figure 6 compares the indentation modulus and indentation hardness for the investigated “soft” and “hard” PETG sheet samples before and after thermoforming. In **Fig. 7** the elastic modules obtained by tensile testing are compared with indentation modules of the corresponding PETG sheets before thermoforming. The difference in absolute values could be caused by the material effective stiffness shown in **Table 1**. The effective stiffness value (Young’s modulus × thickness A_0), S_{eff}, of the thinner polymer exceeds those of the thicker one. It is well-known that the effective stiffness to a great degree depends on orientation of macromolecules and the side groups branching attaining different orientation along the applied tensile force [1 - 3].

Table 1. Tensile properties of soft and hard grades PETG for dental use

Measure / Type	**Elastic Modulus, *E, MPa***	**Specific Elongation, *A, %***	**Effective stiffness, $S_{eff} = E \times A_0$**
Soft	1047.72 ± 26.6	10.36 ± 0.13	6176.31
Hard	574.87 ± 22.04	13.19 ± 1.34	5405.69

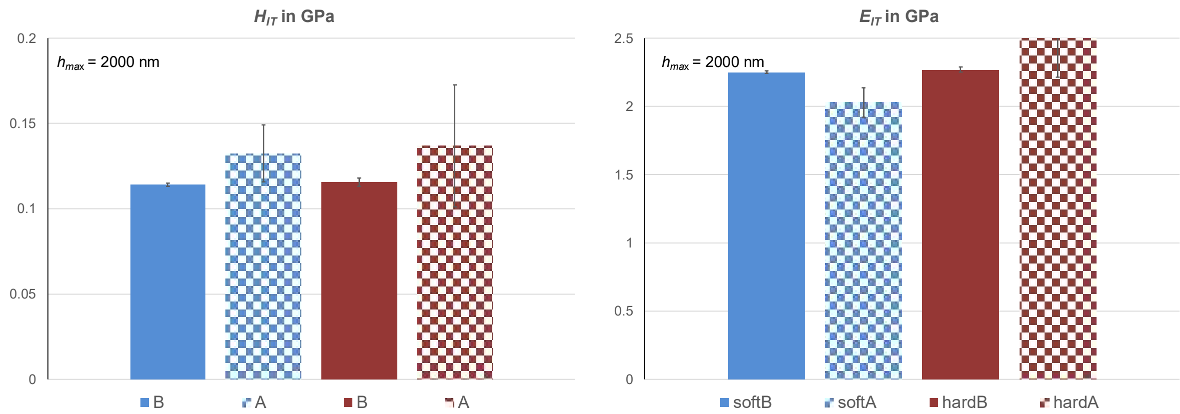

Fig. 6. Nanoindentation hardness and elastic modules of PETG before (denoted as B) and after (denoted as A) thermoforming

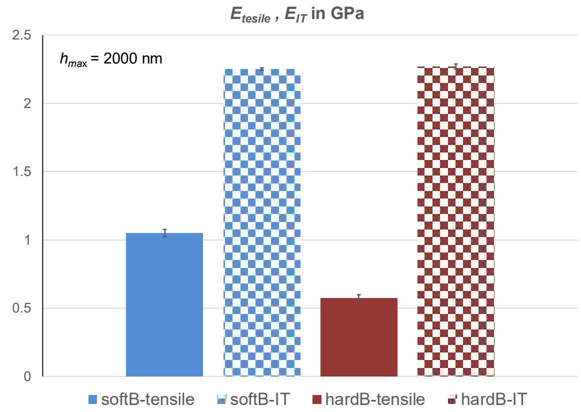

Fig.7. Comparing the tensile test results *vs.* nanoindentation (IT)

Conclusions

There is a significant difference between polymer micro- and macro-deformation behaviour. The micro-level mechanical behaviour of the “soft” and “hard” thermoplastic sheets does not defer statistically while tensile test results show dependence of the elastic properties on material thickness. After thermoforming the thermoplastic samples demonstrate certain inhomogeneity at micro-level. More enhanced interpretation of the experimental data obtained by instrumented indentation test and tensile test should be additionally done to make a wide-ranging conclusion about the mechanical characteristics of the PETG thermoplastic.

Acknowledgments
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