New Aspects of Polymeric Sheet Punch Deformation

V. Daukantiene, B. Bernotiene, M. Gutauskas

Kaunas University of Technology, Faculty of Design and Technologies, Kaunas, Lithuania

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ABSTRACT: Two methods of punch deformation of flat polymeric materials have been studied and compared between themselves. The areas of the method application for the determination of fabric mechanical and exploitation stability and also the suitability of methods for the evaluation of effectiveness of technological treatment with liquid chemical softeners have been analyzed. The geometrical and mechanical behavior of flat polymeric materials (woven and knitted fabrics) during pulling of a disc-shaped specimen through a central hole of KTU-Griff-Tester has been analyzed on the basis of pulling parameters. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 102: 358–361, 2006

Key words: polymeric sheet; punch deformation; pulling through a central hole; mechanical resistance; geometrical transformations

INTRODUCTION

It is already known that the mechanical properties of flat polymeric materials can be evaluated using two punch deformation methods (Fig. 1). In both cases, the disc-shaped specimens are loaded by a punch (usually spherical) perpendicular to the specimen surface.

The first method is sufficiently well-studied in aspect of theory and is widely used for the investigation of mechanical properties of materials.[1–8] In this case, a disc-shaped specimen restricted in the clamp is loaded by a punch until puncture (breaking) of specimen or until unchangeable value of punch force or punch deformation, i.e., P = const or H = const. The material strength or rheological properties (creep or stress relaxation) are evaluated on the basis of the determined parameters.

The second method is one of pulling of a disc-shaped specimen placed between parallel limiting plates (when h [tm] δ, where h −distance between the limiting plates; δ–specimen thickness) through a central hole of device. The distance between the limiting plates (h) can easily be changed. Hence, this method allows the deeper investigations of textile material properties. The well-known method of specimen pulling through a ring is realized similarly,[9–14] but the degree of constriction is unchangeable.

The first devices for constricted pulling through a central hole were designed several years ago.[15–17] The first applications were made for determination of hand parameters of textile materials (woven and knitted fabrics), based on the subjective evaluation of experts or on the sum of the parameters of other mechanical properties (softness, stiffness, hardness, roughness and others).[13] Hand in textile material science means properties such as textile softness, fineness, pleasant to handle or fabric hardness, stiffness, and roughness. These properties are best suitable for the evaluation of fabric quality and its change after fabric treatment or during fabric wear.

Usually the changes in textile properties during their wear are determined as the decrease of strength, which, in the most cases, is notable only organoleptically. Generally, the changes in the properties of polymeric textile fabrics after their dying, steaming, chemical softening, and other technological treatment can be determined on the basis of hand parameters measured during pulling the fabric specimens through a central hole. The hand parameters change significantly after fabric treatment (change in tens or hundreds of percent compared with the parameters of control specimens).[18–20]

The present work is aimed at the presentation of a method of constrictive pulling through a central hole and the application of that method.

METHODS

KTU-Griff-Tester is designed in Kaunas University of Technology. The device contains a set of changeable bottom plates with holes in radiuses r = 7.5; 10.0; 12.5; 15.0 mm, the mechanism of precise change in parameter h (with accuracy to size of ±0.05 mm) and the device working with any tension machine.[21,22] The specimens of 100 cm^2 areas (radius, R = 56.5 mm) must be used in the investigations.

The device registers the H–P (pulling deformation-force) pulling curve. The four pulling parameters:

Correspondence to: V. Daukantiene (virginia.daukantiene@ktu.lt).

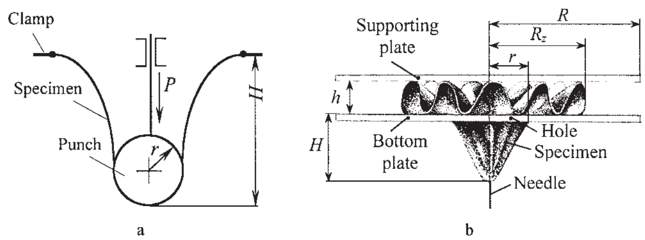

Figure 1 Two methods of punch deformation: (a) specimen restricted in clamp; (b) specimen freely placed in the space between two limiting plates.

P_{max} –the maximum pulling force; tgα–the tangent of the slope angle of the typical curve *H–P* initial part; H_{max} –the maximum specimen deformation and the pulling work *A*, which is proportional to the area lying below the typical *H–P* curve are determined from the curve (Fig. 2).

The initial conditions of experiment are chosen according to the thickness δ of fabric and the peculiarities of specimen jamming in the hole of bottom plate and in the space between the limiting plates,[17] i.e.:

$$r \geq \sqrt{2\delta R}; \quad h \geq \frac{R}{r}\delta \tag{17}$$

The behavior of the specimen pulled through the central hole is throughout different from the specimen constricted in the clamp and deformed by the punch.[23,24] Thin-walled shell has two typical parts: a section of sphere and a section of cone is formed during punch deformation by spherical punch. Though, the specimen extracted through a central hole forms the wrinkled shell with two different parts: a wavy (pleated) surface between the limiting plates and a pleated cone under the plates. At the first deformation stages the number of specimen waves can

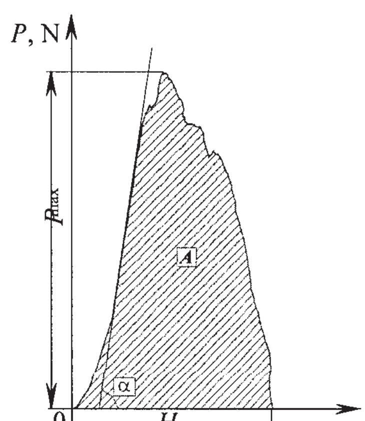

Figure 2 Typical *H–P* pulling curve of a specimen extracted through a circular hole.

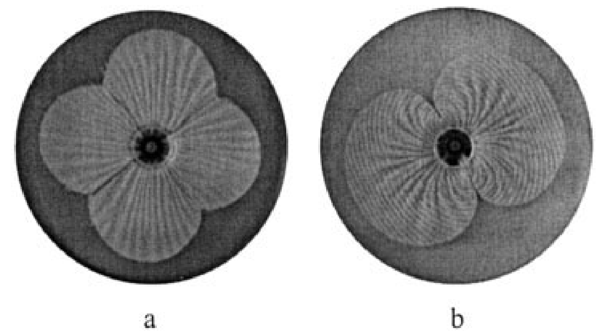

Figure 3 Geometrical shapes of the specimen of (a) woven and (b) knitted fabrics.

be calculated from the mathematical equations.[25] Later, the outer contour of the specimen nears to the hole edges. The sinusoid-shaped waves of specimen change the shapes, nestle to each others, and "break" covering the lying nearby waves. This deformation stage could be illustrated by the stepped top part of the typical *H–P* pulling curve.

The geometrical shapes of deformed specimens depend on the anisotropy of fabric properties. The flat shapes similar to Cassini ovals or "four-leaved clovers" (Fig. 3) are formed from the specimens. The contours of the shapes can been reliably described by the equations of shortened epicycloids.[18,24–26]

RESULTS AND DISCUSSION

The typical *H–P* curves of the investigated fabrics are presented in Figure 4. The figure shows that the max-

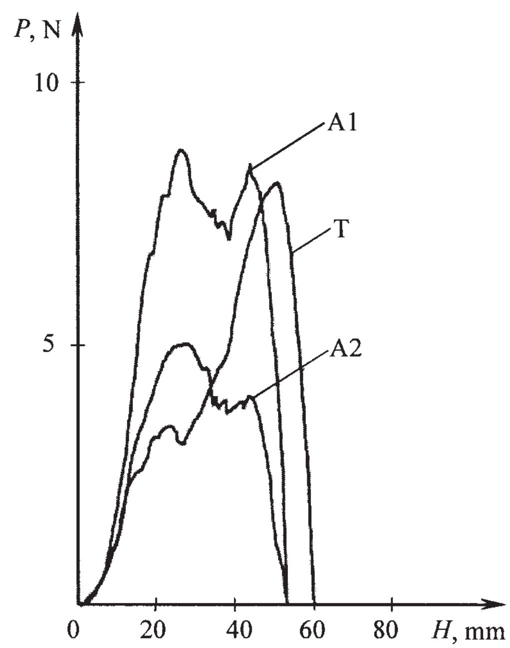

Figure 4 Pulling curves of woven (A1, A2) and knitted fabric (T), when $r = 10$ mm and $h = 5.6$ mm.

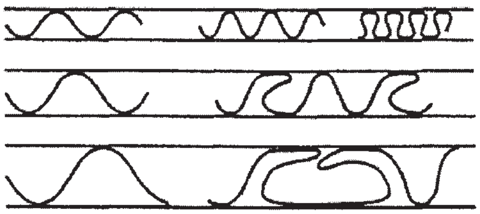

Figure 5 The shapes of specimen waves (wrinkles) in the space between limiting plates.

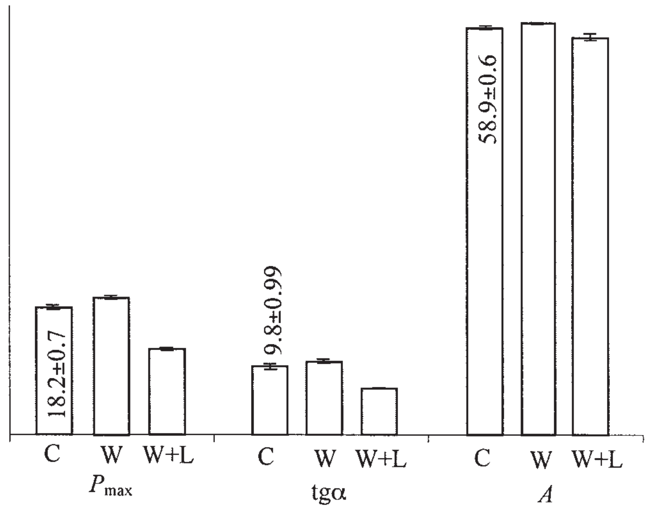

Figure 6 The changes in pulling parameters for knitted polyester fabric after its washing (W) and rinsing with LENOR chemical softener (W+L).

imal pulling force (P_{max}) of woven fabrics is usually on the first part of *H–P* curve, and in the case of knitted fabric the maximum force is reached only at the end of pulling process.

The shapes of the typical curves depend on fabric flexibility. It is known that the woven fabrics are stiffer when compared with knitted fabrics. Hence, the formation of specimen waves from woven fabrics is more complicated because of sliding resistance of fabrics even at the beginning of pulling process. The soft knitted fabrics are deformed easily only at the beginning of pulling process, and later the sliding resistance of fabric increases when the edges of the outer contour of the specimen near to the edges of the hole of plate. It was noticed that the *H–P* curves are step-shaped (particularly in the top part of curve). The reasons for such shapes of the curves could be the changes in the shapes of waves (Fig. 5). The waves of specimens slide against each other or "break," influencing the pulsation of *P* force when the outer contour of the specimen nears to the edges of the pad hole.

Table I presents the pulling parameters of woven cotton fabric (flannel). The analysis of the results has shown that the pulling parameters P_{max}, tgα, H_{max}, and A changed significantly when compared with the ones of control (unwashed) fabric (in the most cases the sum of the statistical errors does not exceed the differences between the values of determined parameters) after the fabric washing or rinsing with the cationic chemical softener. KTU-Griff-Tester could also be used for the evaluation of the influence of the number of technological treatment cycles on textile hand. The used testing equipment allowed us to determine the changes in fabric properties after the first and the fifth washing and rinsing.

Figures 6 and 7 present the pulling parameters for knitted fabrics after their washing and rinsing with LENOR chemical softener.

The results presented in Figures 6 and 7 show that the main pulling parameters (P_{max}, tgα, and A) significantly changed. The hand parameters for polyester fabric became better in 1.5–1.6 times after the fabric treatment with cationic chemical softener and in the case of the acetate fabric ↑ in 1.7–1.9 times. These changes could not be determined by using the other well-known mechanical tests. Hence, from the obtained results it could be stated that the method of a disc-shaped specimen pulling through a central hole is suitable for the deeper characterization of mechanical behavior of thin polymer sheet during punch deformation and for the quality control of technological processes of different polymer materials.

CONCLUSIONS

Constantly sophisticated testing method of punch deformation based on pulling of a disc-shaped specimen placed between two limiting plates through a central hole presents the new possibilities for the more reli-

TABLE I
The Pulling Parameters of the Woven Fabric

Treatment mode	P_{max} (N)	tgα	H_{max} (mm)	A (N cm)
Control	29.6 ± 0.4	3.58 ± 0.27	59.4 ± 0.3	104.2 ± 2.0
Washed 1 time	38.7 ± 1.1	3.89 ± 0.19	61.4 ± 0.3	139.9 ± 4.1
Washed 2 times	40.3 ± 1.2	3.79 ± 0.14	62.4 ± 0.9	143.7 ± 2.2
Rinsed with chemical softener (SILAN) after the 1st washing	29.8 ± 1.3	3.11 ± 0.01	61.6 ± 0.6	111.4 ± 3.6
Rinsed with chemical softener (SILAN) after the 5th washing	27.5 ± 0.6	3.02 ± 0.10	60.9 ± 0.6	100.6 ± 2.9

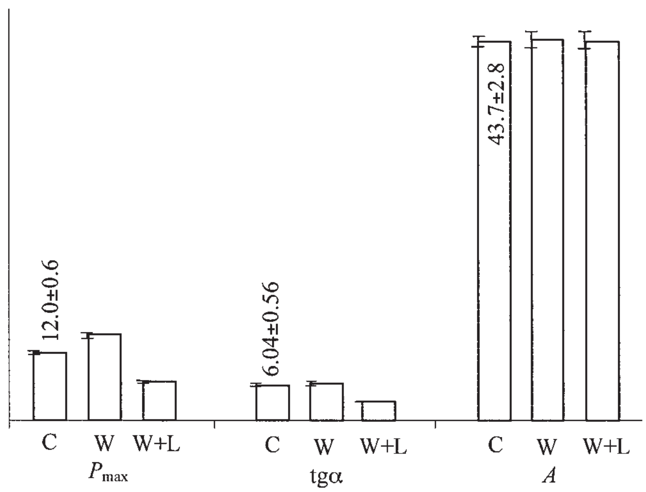

Figure 7 The changes in pulling parameters for knitted acetate fabric after its washing (W) and rinsing with LENOR chemical softener (W+L).

able control of polymer material surface quality and its changes.

The method of a disc-shaped specimen pulling through a central hole is informative. The mechanical and geometrical parameters can be quantifiably evaluated. The slight changes in the properties of soft material could be determined after the simple operations of technological treatment. The anisotropy of material properties could be evaluated on the basis of the geometrical parameters determined even only for one investigated specimen.

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