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ANALYTICAL ASSESSMENT OF THE SIGNIFICANCE OF SINGLE-CYCLE MECHANICAL DEFORMATION OF FABRICS PRODUCED FROM BLENDED TEXTILE MATERIALS

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Abstract:

This article presents a theoretical and analytical study of the single-cycle deformation process of textile materials under external mechanical action. The mechanical state of the fabric is primarily determined by the interaction between warp and weft yarns, the degree of yarn crimp, friction, inter-yarn slippage, and the viscoelastic properties of the fibrous material. Hysteresis arises during the single-cycle deformation process due to the difference in force-deformation relationships between the loading and unloading stages. The article provides analytical expressions for determining relative deformation, mechanical stress, deformation energy, residual deformation, and hysteresis energy.

Keywords: tissue, mechanical deformation, single-cycle deformation.

Introduction

The transition of Uzbekistan's economy from the export of raw materials toward the production of competitive finished goods has created new objectives for textile manufacturers. Product quality, dimensional stability, durability, comfort, and predictable performance are especially important for fabrics intended for clothing and technical applications. These requirements make the mechanical characterization of woven materials a practical production and design task [1].

Textile fabrics are subjected to mechanical forces that differ in magnitude, direction, duration, and frequency. Loading may occur along the warp, along the weft, or at an angle, producing tensile, bending, shear, and torsional deformation. Fabric performance also depends on fibre composition, yarn structure, weave, density, finishing, and environmental conditions [2].

Textile fabrics are complex fibrous structures whose mechanical behaviour is governed not only by the properties of the constituent fibres but also by yarn linear density, twist, crimp, fabric construction, inter-yarn friction, thread density, and loading direction. Consequently, fabric deformation cannot be predicted from fibre properties alone [3].

Under tensile loading, woven fabrics generally exhibit a nonlinear force-deformation response. At low strain, much of the deformation is associated with yarn straightening and crimp reduction. At higher strain, yarn and fibre extension become increasingly important. The loading-unloading curve additionally describes recoverable deformation, residual strain, hysteresis, and energy dissipation [4].

When a force is applied to the fabric, processes such as tension, bending, displacement, and mutual friction occur within the warp and weft yarns. The mechanical deformation of a textile fabric differs from the deformation of a homogeneous solid material. The primary reason for this is that fabric is a structural material composed of a system of yarns. During the initial stage of loading, a portion of the external force is expended on straightening the yarns and altering their relative arrangement. Subsequently, the process of deformation within the yarns themselves becomes dominant [5].

Initial length of the fabric specimen: L_0

Length under the influence of external force: L_L

if so, relative deformation is determined by the formula: $\varepsilon = (L - L_0) / L_0$.

In percent: $\varepsilon(\%) = [(L - L_0) / L_0] \times 100$.

This expression indicates the extent of elongation of the fabric sample relative to its initial dimension.

According to the classification by Professor G.N. Kukin, the mechanical properties of fabrics are categorized into three types of deformation: semi-cyclic, single-cycle, and multi-cycle. Single-cycle tensile deformation comprises elastic, viscoelastic, and plastic (residual) components [6]. Elastic and viscoelastic deformations are reversible, whereas plastic deformation is irreversible (residual). Viscoelastic deformation arises under the influence of external forces, resulting in an increase in yarn dimensions. The recovery of viscoelastic deformation occurs at the speed of sound. Viscoelastic energy accumulates in the yarns within the fabric; upon the removal of the load, the viscoelastic deformation recovers at the aforementioned speed [7].

In the case of plastic deformation, the fabric's shape changes; elongation occurs due to the shifting or straightening of loosely arranged yarns within the fabric structure, and this is determined using the following formulas:

1. Perfectly elastic deformation:

$$l_q = L_1 - L_2 (mm)$$

2. Relative elastic deformation:

$$E_k = \frac{l_k}{L_o} \cdot 100 = \frac{L_1 - L_2}{L_o} \cdot 100 \quad (\%)$$

3. Perfectly elastic deformation:

$$l_e = L_2 - L_3 \ (mm)$$

4. Relative elastic deformation:

$$E_э = \frac{l_э}{L_o} \cdot 100 = \frac{L_2 - L_3}{L_o} \cdot 100 \quad \%$$

5. Absolute plastic deformation:

   $l_n = L_3 - L_0$ (mm)

6. Relative plastic deformation:

$$E_n = \frac{l_n}{L_o} \cdot 100 = \frac{L_3 - L_0}{L_o} \cdot 100 \quad (\%)$$

7. Complete absolute deformation:

   $l_t = l_k + l_e + l_n$ (mm)

8. Total relative deformation:

$$E_T = \frac{l_T}{L_0} \cdot 100 = \frac{L_1 - L_0}{L_0} \cdot 100 \quad (\%)$$

At times, a portion of the deformations is determined.

$$\Delta_k = \frac{l_k}{L_T}; \qquad \Delta_э = \frac{l_э}{L_T}; \qquad \Delta_n = \frac{l_n}{L_T}$$

The sum of these is equal to 1. $\Delta_k + \Delta_э + \Delta_n = 1$

The initial tensile modulus can be estimated from the initial slope of the stress–strain curve:

$$E_0 = \frac{\Delta\sigma}{\Delta\varepsilon}$$

For the loading part of the cycle, the absorbed deformation energy per unit volume is:

$$W_L = \int_0^{\varepsilon_{max}} \sigma_L \, d\varepsilon$$

The recoverable energy during unloading is:

$$W_U = \int_{\varepsilon_r}^{\varepsilon_{max}} \sigma_U \, d\varepsilon$$

The hysteresis energy is therefore:

$$W_H = W_L - W_U$$

The energy-loss coefficient can be expressed as:

$$\eta_H = \frac{W_H}{W_L} \times 100\%$$

Residual strain after unloading is:

$$\varepsilon_r = \frac{L_r - L_0}{L_0}$$

where $L_r$represents the specimen length after unloading and an appropriately defined recovery interval.

The recovery ratio can then be expressed as:

$$R = \left(1 - \frac{\varepsilon_r}{\varepsilon_{max}}\right) \times 100\%$$

These parameters allow the mechanical response to be interpreted more comprehensively than by tensile strength alone [8].

The deformation of a blended yarn differs from that of a simple single-component yarn because the constituent fibers do not deform to the same extent when subjected to external force [9]. For instance, in a yarn composed of cotton and polyester fibers, the polyester component's superior mechanical stability and the distinct deformation characteristics of cotton influence the resulting load-elongation relationship. When the yarn is stretched by an external force, a sequence of processes may occur: fiber straightening → fiber slippage → partial twist alteration → fiber elongation → fiber breakage under high load. Consequently, the mechanical properties of the yarn are not merely the simple sum of the properties of the individual fibers [10].

The objective of this study is to develop a transparent analytical framework for assessing the single-cycle mechanical deformation of woven fabrics made from blended yarns. The framework integrates stress-strain response, initial modulus, residual strain, recovery ratio, hysteresis energy, and energy-loss coefficient, and demonstrates how these indicators can be interpreted without confusing illustrative calculations with measured experimental findings.

Methodology

The study used an analytical and demonstrative design to evaluate the single-cycle tensile behaviour of woven fabrics produced from cotton/polyester blends. The framework combined standard mechanical definitions, a hypothetical four-group dataset, and the interpretation of one supplied force-deformation record. The hypothetical values were used only to demonstrate calculations and comparative interpretation; they are not presented as measurements from manufactured specimens [11].

Four illustrative fibre compositions were considered: 100% cotton (C100), 70% cotton/30% polyester (C70/P30), 50% cotton/50% polyester (C50/P50), and 30% cotton/70% polyester (C30/P70). For a future laboratory validation, specimens should have comparable weave structure, yarn linear density, fabric mass per unit area, warp and weft density, crimp, finishing history, and test direction. Conditioning and testing should follow the applicable standard atmosphere and constant-rate-of-extension procedures [12].

The proposed test sequence includes specimen conditioning, mounting without slack, loading at a constant crosshead speed to a predefined strain or rupture criterion, controlled unloading, and recording of the complete loading-unloading curve. Relative strain, stress, initial modulus, absorbed energy, recoverable energy, hysteresis energy, energy-loss coefficient, residual strain, and recovery ratio are then calculated from consistent specimen dimensions and curve areas.

For the supplied force-deformation record, the maximum load, extension at break, elongation at break, and tenacity were taken from the values summarized in Table 3. Because the underlying raw instrument file, replicate measurements, specimen dimensions, and uncertainty estimates were not available, inferential statistics were not performed. Pearson correlation and multiple regression are proposed only for a future measured dataset with adequate replication [13].

For methodological demonstration, four fabric groups with different cotton/polyester compositions are considered.

Table 1. Fabric compositions

№	Sample	Fibre composition	Abbreviation
1	F1	100% cotton	C100
2	F2	70% cotton / 30% polyester	C70/P30
3	F3	50% cotton / 50% polyester	C50/P50
4	F4	30% cotton / 70% polyester	C30/P70

A uniaxial tensile test can be performed using a universal testing machine equipped with a calibrated load cell.

A recommended experimental sequence is:

1. specimen conditioning under standard atmospheric conditions;
2. mounting the specimen without initial slack;
3. applying tensile deformation at a constant crosshead speed;
4. increasing strain to a predefined maximum strain;
5. unloading the specimen to the initial force level;
6. recording the complete loading and unloading curves;
7. determining residual strain and hysteresis parameters.

For a real experimental study, all specimens should preferably have comparable fabric mass per unit area, weave structure, yarn linear density, thread density, and finishing conditions. This is important because fabric construction itself can strongly influence tensile and hysteretic behaviour. Earlier studies have shown that weave construction, yarn linear density, yarn crimp, and fabric structural parameters can substantially affect tensile properties [14].

Results and Discussion

Table 2 presents an illustrative dataset constructed to demonstrate the analytical procedure. These values must be replaced with measured replicate results before journal submission and must not be interpreted as experimental evidence [15].

Table 2. Illustrative single-cycle deformation parameters

№	Fabric	Initial modulus, MPa	Maximum stress at 10% strain, MPa	Residual strain, %	Recovery ratio, %	Hysteresis energy, MJ/m³	Energy-loss coefficient, %
1	C100	85	6.8	3.10	82.1	0.24	32.6
2	C70/P30	98	7.1	2.15	85.3	0.22	27.3
3	C50/P50	114	7.4	2.33	87.1	0.18	21.4
4	C30/P70	131	8.2	1.45	92.1	0.14	17.6

Within the illustrative dataset, the initial modulus increases from 85 MPa for C100 to 131 MPa for C30/P70. Over the same modeled comparison, residual strain decreases from 3.10% to 1.45%, the recovery ratio rises from 82.1% to 92.1%, and hysteresis energy falls from 0.24 to 0.14 MJ/m³. These internally consistent model values show how an increased polyester fraction could be associated with greater stiffness and recovery, but they do not demonstrate a causal material effect because the dataset is hypothetical and contains no replicates.

The single-cycle framework is useful for separating immediate elastic recovery, delayed recovery, residual deformation, and dissipated energy. In production, however, yarns and fabrics are also exposed to repeated loading. High breaking strength therefore does not automatically guarantee resistance to cyclic deformation or fatigue. Single-cycle results should be interpreted together with repeated-load testing when the intended application involves recurrent mechanical stress.

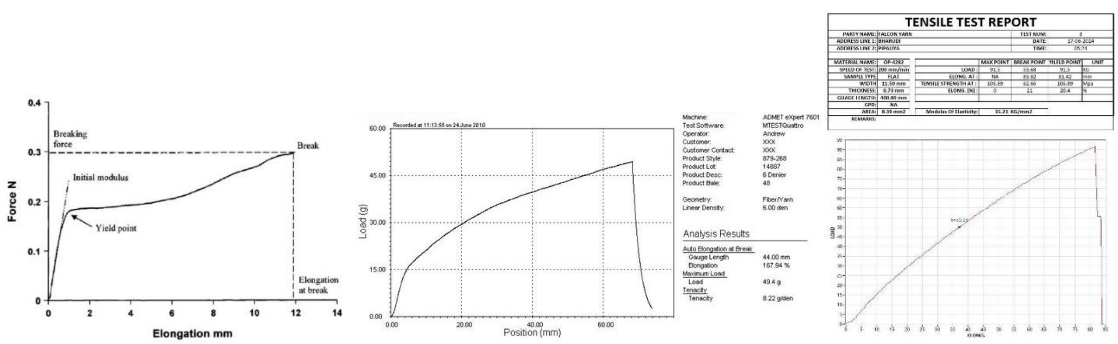

Figure 1. Force-deformation diagram for the investigation of blended yarns.

The supplied force-deformation record summarized in Table 3 shows a maximum tensile load of 59.2 gf (approximately 0.581 N), an extension at break of 54.8 mm, an elongation at break of 77.14%, and a tenacity of 0.32 gf/tex. These values characterize the recorded specimen only; the absence of replicate curves and specimen metadata prevents estimation of variability or generalization to all blended fabrics.

Table 3. Main tensile characteristics obtained from the experimental curve

№	Parameter	Experimental value	Interpretation
1	Maximum tensile load	59.2 gf	Maximum load-bearing capacity
2	Maximum tensile load	≈0.581 N	SI-unit equivalent
3	Extension at break	54.8 mm	Absolute deformation at rupture
4	Elongation at break	77.14%	Relative deformation
5	Tenacity	0.32 gf/tex	Strength relative to linear density
6	Test type	Uniaxial tensile loading	Loading-to-break regime

The recorded elongation at break indicates that the tested structure underwent substantial deformation before rupture. This response is consistent with a fibrous assembly in which deformation initially includes yarn straightening, crimp reduction, inter-yarn movement, and friction, followed by a larger contribution from yarn and fibre extension as loading increases.

At the beginning of loading, the slope of the curve is comparatively low. This region represents the structural accommodation of the textile material. The applied load is initially consumed by yarn straightening, reduction of crimp and redistribution of the fabric structure.

Mathematically, the local stiffness can be expressed as:

$$K = \frac{dF}{dL}$$

where $F$is tensile load and $L$is extension.

The initial value of Ktherefore characterises the resistance of the fabric structure to small deformation.

The curve can be interpreted in three stages. The initial region is dominated by structural accommodation and yarn rearrangement; the intermediate region increasingly reflects yarn and fibre extension; and the high-deformation region develops local stress concentrations that precede rupture. Standard tensile methods permit the determination of maximum force, elongation, tenacity, modulus, and work-related parameters from such records when specimen preparation and instrument settings are controlled. Analysis of blended materials should therefore distinguish fibre composition from structural variables.

D=f(C,M,S)

where: D is total deformation; C is blend composition; M represents the mechanical properties of the fibers; and S is the yarn structure.

Proposed Correlation Analysis. For a full experimental article, the following correlations should be calculated:$r(E_0, \varepsilon_r)$; $r(E_0, R)$; $r(E_0, \eta_H)$

$r(\text{polyester content}, \varepsilon_r)$; $r(\text{polyester content}, R)$

where $r$represents Pearson's correlation coefficient.

A multiple regression model may also be used:

$$\varepsilon_r = \beta_0 + \beta_1 C + \beta_2 \rho + \beta_3 T + \beta_4 K + \epsilon$$

where:

- C= polyester content;
- ρ= fabric mass per unit area;
- T= yarn/fabric density;
- K= yarn crimp;
- β_i= regression coefficients;
- ϵ= residual error.

In a measured study with sufficient replication, correlation and multiple regression could help distinguish the contribution of polyester content from fabric mass, density, crimp, and related structural variables. Model assumptions, collinearity, residual behaviour, confidence intervals, and effect sizes would need to be reported. This extension would make the analysis stronger than a simple comparison of group averages.

The analytical comparison supports the expectation that blend composition can influence stiffness, recovery, and dimensional stability, while also showing why composition cannot be evaluated in isolation. Twist, spinning method, fibre distribution, weave, crimp, finishing, and friction may modify or even reverse an apparent blend effect. The theoretical prediction of improved recovery with higher polyester content must therefore be tested experimentally under controlled structural conditions.

The practical implication is that tensile strength alone is insufficient for characterizing blended fabrics. Initial modulus, recovery ratio, residual strain, hysteresis energy, and energy-loss coefficient provide complementary information about service behaviour. Together, these indicators can support fibre-blend selection, fabric engineering, quality control, and the design of clothing or technical textiles.

Conclusion

The study establishes an analytical framework for evaluating the single-cycle deformation of woven cotton/polyester fabrics. The framework links the loading-unloading curve with relative strain, stress, modulus, recoverable and dissipated energy, residual strain, and recovery ratio. This combined assessment describes structural and viscoelastic behaviour more fully than breaking strength alone.

The illustrative comparison suggests that increasing polyester content may be associated with higher modulus and recovery and lower residual deformation and hysteresis. Because Table 2 contains hypothetical demonstration values, this pattern should be treated as a testable expectation rather than a verified experimental finding. The force-deformation values in Table 3 describe only the supplied record and cannot establish group-level differences.

Future work should apply standardized conditioning and tensile procedures to replicated specimens whose weave, density, crimp, yarn count, and finishing are controlled. Reporting mean values, dispersion, curve-derived energy measures, and multivariable analysis would allow the separate effects of fibre blend and fabric structure to be evaluated and would improve the practical value of the method for textile design and production.

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