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METHODS FOR DETERMINING THE DEFORMATION CHARACTERISTICS OF A NONWOVEN MATERIAL

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ANNOTATION

It has been experimentally determined that the patterns of deformation of a nonwoven material when it is stretched along the length and width is non-linear. It has been established that the manifestation of non-linear properties of a non-woven material is associated with a change in its structure during stretching to failure. Changing the structure of the material, therefore, leads to changes in the mechanical characteristics of the nonwoven material.

Keywords: deformation, nonwovens, tension, yarn, load, surface density, strength.

INTRODUCTION

The specificity of nonwoven materials is created by the technology of their production, when various types of fibers, yarn, threads, as well as fabrics, knitwear, and films are used as raw materials. In yarn, the fibers are distributed more or less evenly along its length. At the same time, if in combed yarn the fibers are straightened, which increases strength and smoothness, then in hardware yarn, the fibers are mostly entangled and slightly straightened. This is the cause of reduced strength, unevenness, greater thickness and fluffiness.

The mechanical properties of nonwoven materials are determined primarily by strength, which is inextricably linked with deformation processes through the elastic and plastic properties of materials.

Determining the boundaries of elastic and plastic deformations is a rather complicated issue. When the process of deformation is still accompanied by the viscous properties of the material, this issue becomes even more complicated. In [1], a method was proposed for determining the boundaries of elastic, elastic-plastic and plastic deformations, taking into account all stages of the manifestation of the viscous properties of a material. This method for determining the boundaries of the stages of deformation has been widely tested in the publications of the authors in prestigious journals both abroad and in our republic [2–10].

MATERIAL AND METHODS

Nonwovens are mainly tensile. In this case, it is necessary that their deformation be within the limits of elasticity, which depends on two factors: the first is the load, the second is the surface density of the nonwoven. If during the operation of the nonwoven material, the resulting loads cause deformation that does not exceed the limits of elastic deformation, then the material is deformed only elastically. If the possible loads go beyond the limits of elasticity, then it is necessary to increase the surface density of the nonwoven material. To do this, it is necessary to determine the limits of elastic deformations of the nonwoven material experimentally.

To conduct experiments on static stretching of nonwoven material, samples of three types of nonwoven were selected. These samples differ with surface density and structure:

1. Non-woven fabric, consisting of 50% cotton fiber; 30% wool fiber; 20% silk fiber with a surface density of 148.7 g/m^3.
2. Non-woven fabric with 70% cotton fiber structure; 15% wool fibers; 15% silk fibers with a surface density of 118.7 g/m^3.
3. Non-woven material consisting of 75% cotton fibers; 10% wool fibers; 15% silk fibers with a surface density of 174.6 g/m^3.

Further in the text, they were designated as nonwoven materials No. 1, 2 and 3. The experiments were carried out on an AUTOGRAPH AG-1 tensile testing machine. The general characteristics of the tensile testing machine and the methodology for conducting experiments are given in [5].

RESULTS

Let's consider the test results of non-woven materials samples No. 1, 2, 3. Figure 1 shows the tension diagram of non-woven material (hereinafter referred to as non-woven fabric) No. 1. As follows from the figure, the dependence of the relative deformation on the load is non-linear (curve 1), with an upward convexity. This means that when a nonwoven is stretched along its length, shear deformations predominate; there are shifts of the fibers that make up the nonwoven material, and they are displaced relative to each other.

In this case, the internal friction forces that resist tearing in the material predominate. The value of the tensile force increases, reaches a maximum, then there is a decline, and at a value of N=45.5 N, the material is torn. In this case, the deformation value is about 120%. The decline of curve 1 after reaching means that the material is ruptured gradually.

A completely different deformation process is observed when the same material No. 1 is stretched across the width (Fig. 2).

The stretching curve 1 in this case also has a non-linear dependence, however, with a downward convexity. This means that in the process of stretching the material across the width, the non-woven is strengthened. At the beginning of this process, with increasing strain, the value of the tensile load increases slowly. After reaching a deformation value of 25%, there is a sharp increase in the intensity of the load, which indicates that after this value of deformation, the resistance of the non-woven fabric to tensile load increases significantly.

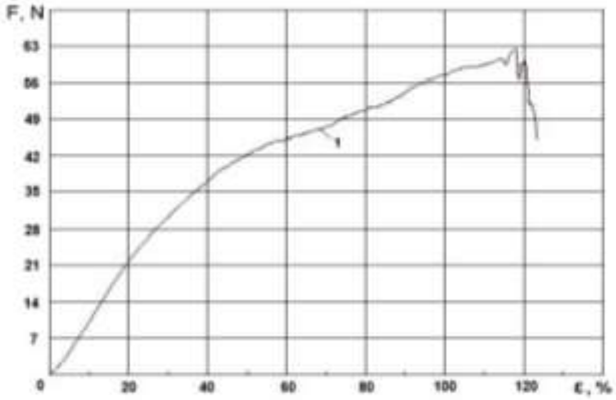

Fig.1. Stretch Chart of Nonwoven Fabric №1 Lengthwise

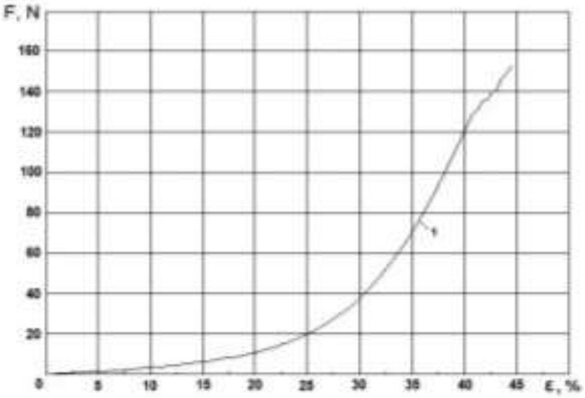

Fig.2. Stretch Chart of Nonwoven Fabric №1 in Width

At a strain value of about 45%, the material breaks. In contrast to the case of non-woven stretching along the length (Fig. 1), the rupture of the material here occurs instantly. This is due to the different structural structures of non-woven fabrics along the length and width, as well as the density of piercing in the production of non-woven materials by needle punching.

Tensile diagrams (Fig. 3-6) of non-woven materials No. 2 and No. 3 do not differ significantly from the above diagrams for non-woven No. 1 (Fig. 1 and 2). The exception is the moments of rupture of nonwoven materials.

In the case of non-woven fabrics No. 2 and No. 3, when they are stretched along the length, the rupture of materials occurs instantly (Fig. 3, 5). And when stretching non-woven fabric No. 3 in width (Fig. 6), on the contrary, at the moment of rupture, a gradual destruction of the material occurs. These exceptions are the features of the structural structure of each non-woven sample, associated with the elements of probability in the implementation of their manufacturing technology.

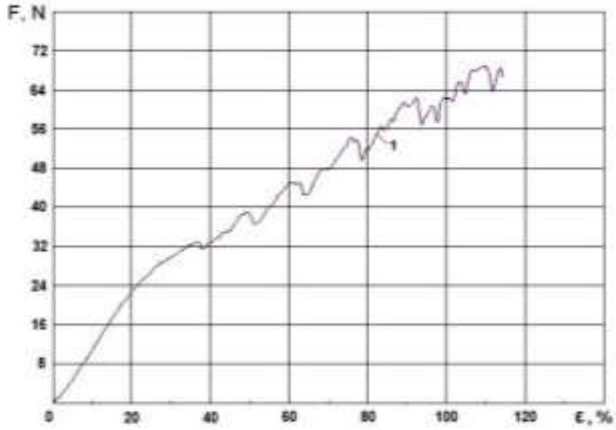

Fig. 3 Diagram of stretching of non-woven fabric № 2 along the length

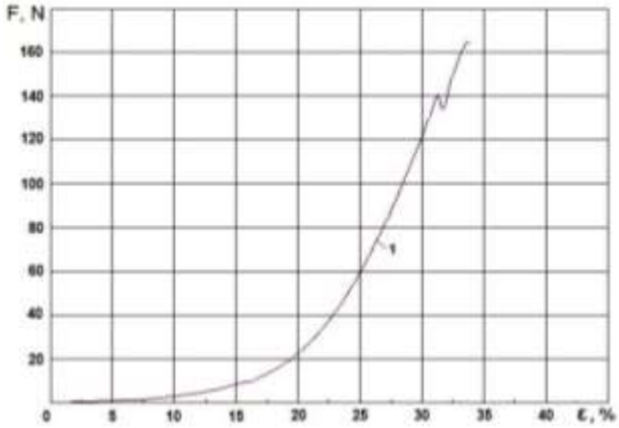

Fig. 4 Diagram of stretching of non-woven fabric № 2 in width

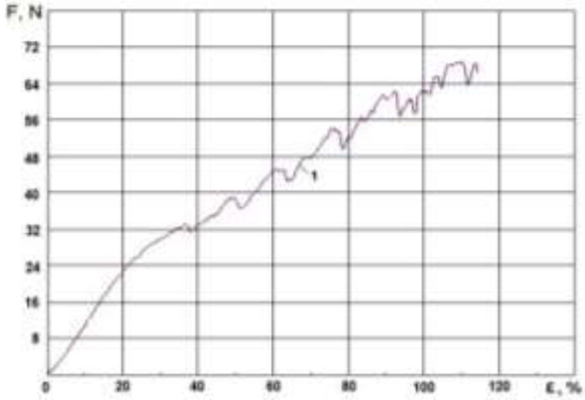

Fig. 5 Diagram of stretching of non-woven fabric №3 along the length

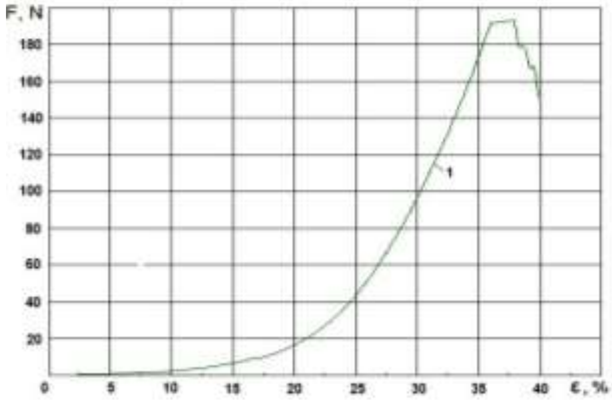

Fig.6 Diagram of stretching of non-woven fabric № 3 in width

In quantitative terms, the value of breaking loads and the values of deformation at break of non-woven fabrics do not differ significantly. They are summarized in table. one.

Table 1 Values of breaking forces and deformations of specimens nonwoven materials

№ sample	Breaking force when stretched along the length F_l, N	Tensile load in width F_S, N	Tensile strain in length ε_l, %	Tensile strain in width ε_S, %
1	60,0	150,2	123	44,5
2	68,1	165,0	113	37,5
3	68,1	150,0	115	40,0

As can be seen from Table 1, the data for samples of nonwoven materials with different proportions of cotton, wool and silk fibers for the considered options differ. Sample No. 1, which has the highest content of silk fibers (20%), is the strongest and maximum value of deformations at fracture. With a decrease in the content of silk fibers (options No. 2 and No. 3), the non-woven is torn at lower strain values (Table 1). From this we can conclude that silk fibers lead to greater extensibility of the nonwoven material.

The given experimental tension diagrams in Figs. 1-6 show that it is not possible to single out the boundaries of elastic, viscous and plastic deformations of the material from these dependences, both when stretched along the length and when stretched along the width. There are no special points in the dependences (Fig. 1-6) showing the transition from one stage of deformation to another. These stages can be determined using the method proposed by the authors [1]. To do this, it is necessary to build changes in the elastic and plasticity moduli of the nonwoven material when they are stretched to rupture.

The essence of this method for determining the boundaries of the stages of deformation lies in the fact that the nonlinearity of the tension diagrams of textile materials is a consequence of a change in their mechanical characteristics during tension. In the process of stretching, the initial structure of the material changes, therefore, the density, modulus of elasticity, plasticity, etc. change. From these characteristics, it is more unambiguously possible to determine changes in the modulus of elasticity, viscoelasticity and viscoplasticity of the textile material. In this case, the viscous properties of the material manifest themselves in all stages of deformation [2–6].

From the dependences $F(\varepsilon)$, shown in Figs. 1-6, we determine the change in the secant deformation moduli of nonwoven materials from the tensile diagram of samples №1-3. The change in the deformation moduli of non-woven fabrics, determined from the tensile diagrams shown in Figs. 1, 3 and 5, i.e. when stretched along the length, shown in Figs. 7-9. As can be seen from these figures, the functions $E(\varepsilon)$ are essentially non-linear and a general pattern is revealed. So, in all cases, in the process of stretching the non-woven along the length, the initial modulus E_N begins to decrease to E_*. Further, there is an increase in the deformation modulus to the maximum value . After that, there is a slow decline and at the $E = E_k$ non-fabric breaks off (Fig. 7).

This process of changing the modulus of deformation is qualitatively repeated for all three samples of nonwoven material with different structural content of cotton, wool and silk fibers (Fig. 7-9). However, with an increase in the content of cotton fibers, the process of changing the deformation modulus E becomes more pronounced and approaches the change $E(\varepsilon)$ in cotton yarn [1]. The given dependences $E(\varepsilon)$ in Figs. 7-9, obtained from experimental data $F(\varepsilon)$ (Figs. 1, 3, 5), make it possible to determine the boundaries of the stages of deformation of a nonwoven material when stretched along the length.

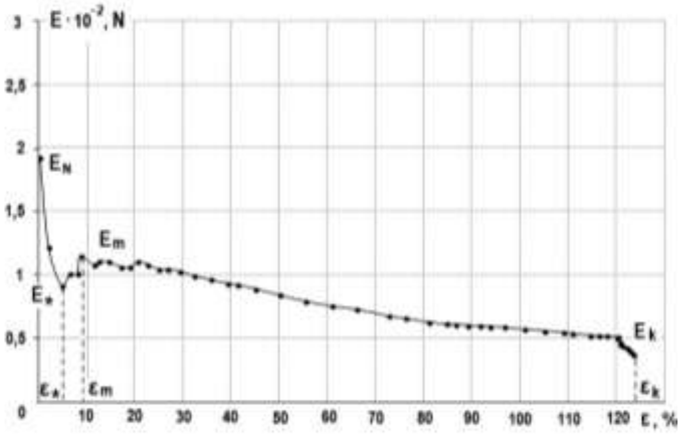

Fig.7 Dependence of the modulus of deformation on the relative deformation when stretching nonwoven fabric № 1 along the length

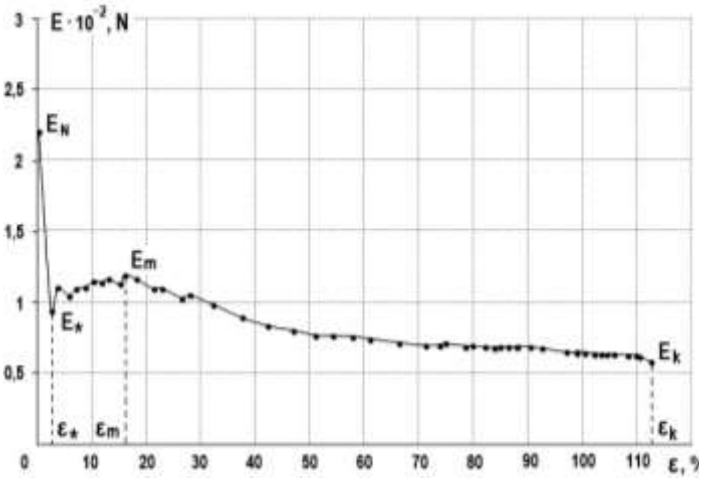

Fig.8. Dependence of the modulus of deformation on the relative deformation tensile for nonwoven fabric №2 in length

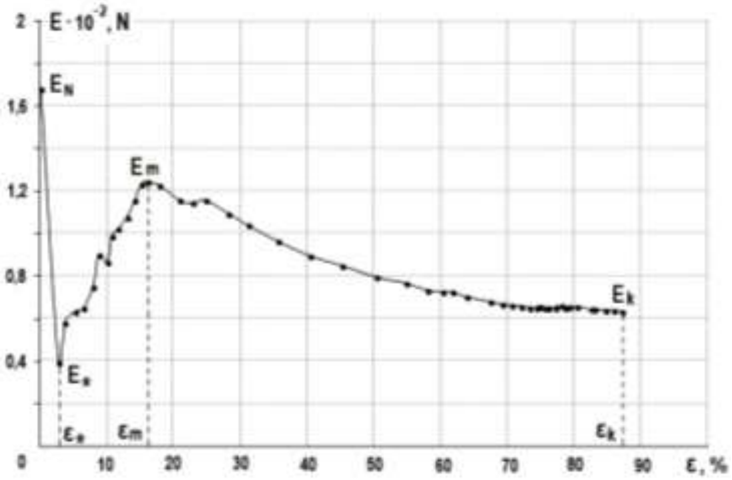

Fig.9. Dependence of the modulus of deformation on the relative deformation when stretching nonwoven fabric No. 3 along the length

In the cases considered in Figs. 7-9, in the areas $E_N E_*$ with a change in strain from 0 to ε_* some compaction of the material occurs during tension. In this area, even looser non-woven material, the value drops. This section is completely reversible and here the material is deformed E elastically. In the section $E_* E_m$, when the deformation changes from ε_* to ε_m, the process of compaction of the material continues under tension and the value E increases.

In this area, the deformation process is also reversible and the material is deformed elastically. After reaching the value $E = E_m$ at, $\varepsilon = \varepsilon_m$ the value of the deformation modulus begins to fall in the area $E_m E_k$ at values of deformation $\varepsilon = \varepsilon_k$ from $\varepsilon = \varepsilon_k$ to . When there $\varepsilon = \varepsilon_k$ is a rupture (destruction) of the nonwoven material.

The decrease in the deformation modulus in the area occurs due to $E_m E_k$ the destruction of structural bonds in the material. The beginning of the destruction process means the appearance of irreversible deformations $E_m E_k$. But this irreversible deformation is not yet predominant at the beginning of the section. It follows that the deformation process in the section is elastic-plastic. The viscous component $E_m E_k$ of the process of deformation of the nonwoven material is present in all sections of the dependence $E(\varepsilon)$.

As can be seen from Table. 2, an increase in the content of cotton fibers in the structure of the nonwoven material from 50% to 70% leads to an increase in the values of the parameters E_N, that is, the initial value of the deformation modulus of the nonwoven. Further, reducing the content of wool fibers from 30% to 15% leads to a decrease in the value of E_N. Similarly, reducing the content of silk fibers also leads to a decrease in the initial value of the modulus of deformation E_N at the initial value of the tensile strain $\varepsilon_N \approx 0$.

Table 2 Values of the modulus of deformation at different stages of deformation of the nonwoven material when stretched along the length

Deformation parameters and their values	Nonwoven Samples		
	№1	№2	№3
E_N, N	190,0	225,0	163,0
E_*, N	180,0	180,0	40,0
ε_*, %	5,0	3,1	3,0
E_m, N	120,0	120,0	121,0
ε_m, %	14,0	17,0	18,0
E_k, N	40,0	52,0	61,0
ε_k, %	124,0	112,0	89,0

Qualitatively, a slightly different picture is observed in the process of deformation of a nonwoven material when stretched across the width (Fig. 10-12). In this case $E(\varepsilon)$, the changes occur along a different curve shape than in Fig. 7-9. Here, in the process of stretching, as well as during stretching along the length, the value of the modulus of deformation drops to E_*. Further, an increase E in tension along a curvilinear dependence is observed. After reaching $E = E_k$ at $\varepsilon = \varepsilon_k$, the material is torn.

When stretching the non-woven material across the width, also at the beginning of the deformation process, the loose structure of the non-woven fabric is compacted without much resistance, so the value of the deformation modulus decreases rapidly to a value $E = E_*$ at deformation from 0 to ε_*. Further, during stretching, the structure of the nonwoven material is compacted, the value of the deformation modulus increases, and destruction occurs at $\varepsilon = \varepsilon_k$ and $E = E_k$. This change $E(\varepsilon)$ is explained by the peculiar structural structure of the nonwoven material in width. Here it is obvious that the process of deformation along a curve $E(\varepsilon)$ is viscoelastic.

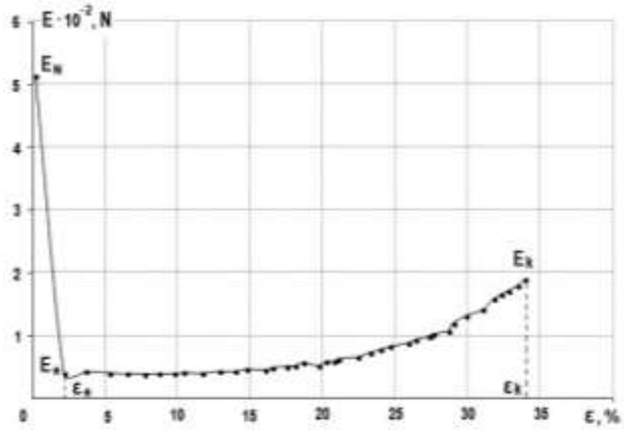

Fig.10 Dependence of the modulus of deformation on the relative deformation when stretching nonwoven fabric №. 1 in width

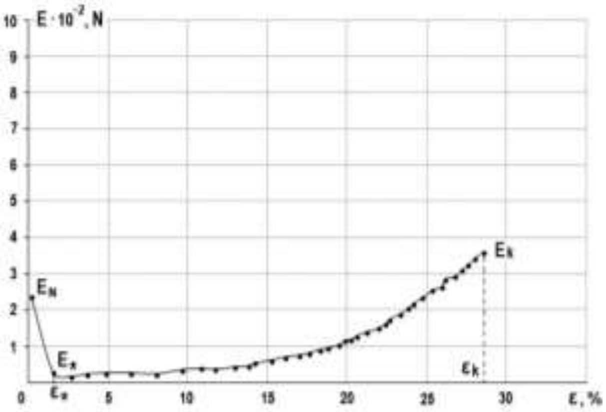

Fig.11 Dependence of the modulus of deformation on the relative deformation when stretching nonwoven fabric №. 2 in width

Changes in the values of the parameters of the function $E(\varepsilon)$ when the non-woven is stretched along the width are shown in Table 3, which also shows the value $\varepsilon_N \approx 0$ at which E=EN is determined.

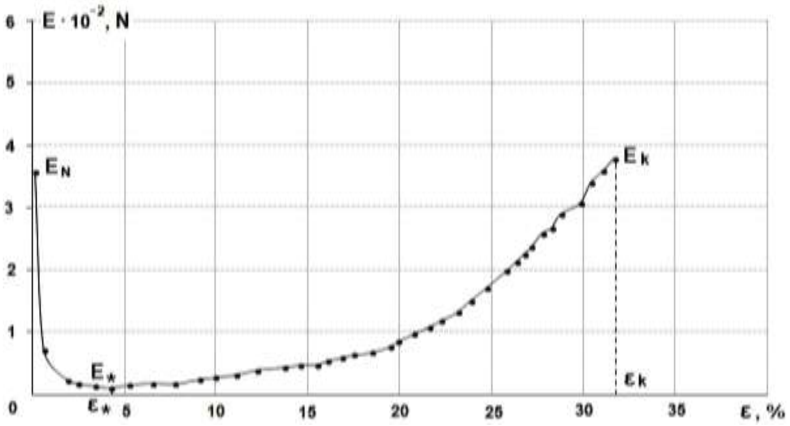

Fig.21 Dependence of the modulus of deformation on the relative deformation when stretching nonwoven fabric No. 3 in width

Table 3 The values of the modulus of deformation at different stages of deformation of the nonwoven material when stretched across the width

Deformation parameters and their values	Nonwoven Samples		
	№1	№2	№3
E_N, N	510,0	230,0	360,0
E_*, N	35,0	20,0	15,0
ε_*, %	4,0	2,0	4,0
E_k, N	190,0	340,0	380,0
ε_k, %	34,0	28,2	33,0

As can be seen from Table 3, an increase in the content of cotton fibers in the structural composition of the nonwoven material leads to an increase in the deformation modulus at the moment of rupture at $\varepsilon = \varepsilon_k$ and $E = E_k$. In all nonwoven samples, the values of parameters ε_* and ε_k within the scatter of experiments remain approximately the same.

The results shown in Figures 10-12 and Table. 3 show that non-woven materials, when stretched across the width, exhibit higher strength and deform non-linearly elastically throughout the deformation process.

As can be seen from the above results, the dependences obtained from $E(\varepsilon)$ the experimental diagrams $F(\varepsilon)$ more clearly and accurately reflect the stages of deformation of the nonwoven material. It should be noted that the method for determining and evaluating the elastic, elastoplastic and viscous stages of deformation is an effective and demonstrative method for studying the mechanical properties and behavior of textile materials during deformation.

FINDINGS

It has been experimentally determined that the patterns of deformation of a nonwoven material when it is stretched along the length and width is non-linear. It has been established that the manifestation of non-linear properties of a non-woven material is associated with a change in its structure during stretching to failure. The change (destruction) of the structure of the material, therefore, leads to changes in the mechanical characteristics of the nonwoven material.

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