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The Influence of Fatigue Conditions on the Mechanical Properties of Laminated Leather and its Separate Layers

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Clothing products during wear undergo a multiplex cyclic deformation and the cracking of material during wear due to creases of upper material is very frequent reason of threadbare. The influence of fatigue cycles number and environment temperature on the mechanical properties (tensile strength and elongation) of laminated leather and its layers have been investigated. The laminated leather as well as materials of its layers (the split leather and microporous polyurethane (PU) *Permair* film were used for the investigation. The experimental results showed that mechanical properties of laminated leather after flexing in the various conditions differ from the analogous properties of separate layers. The character of dependences of tensile strength of laminated leather and PU film on number of fatigue cycles are similar, but differ from character of analogous dependence of split leather. The character of dependences of tensile strength and deformability on temperature of fatigue environment of both leathers is similar and markedly differ from characters of analogous dependences of PU film.

Keywords: fatigue, laminated leather, mechanical properties.

INTRODUCTION

The last decade is marked by a pervasion in the use of multicomponent polymeric products from the materials with different nature and properties. Various polymeric composites are used in the power generation industry and various consumer goods. One kind of those composite materials are the soft polymeric laminates used for clothing products exploited in aggressive environment. Usually such soft laminates are composed of layers of leather or textile and microporous or hydrophilic film (membrane). Advanced soft polymeric laminates often combine involved complex of various properties, for example, high long-term water impact, temperature and chemical resistance, and simultaneously a high possible permeability of water vapour [1 – 5]. On the other hand, similarly to other materials, advanced laminates age, suffer physical or chemical degradation, accumulate micromechanical damage and become weaker during exploitation. Poor fatigue performance can significantly reduce the strength of multilayer composites, decrease the life cycle and compromise safety [6]. A microscopic cracks, which emerge at the beginning of exploitation, grow later to macrostructural damage and cause failure [7].

Multilayer laminates under fatigue loadings experience a diffuse damage, consisting of a multiplicity of failure modes, such as matrix cracking, delamination and fibre breakage [8]. This results in a continuous decrease not only in the residual strength, but also in the elastic modulus with increasing the number of fatigue cycles. Consequently, the fatigue life of a multicomponent material can be determined by its loss in modulus, rather than catastrophic failure [8].

It is known that the cyclic loading stress limit is less than static stress capability [9]. Dynamic failure is a very serious problem because materials fail at stress levels much lower than under static loading [10]. The clothing products undergo a multiplex cyclic deformation during wear. Frequent reason of threadbare of clothing products is the cracking of material in the creases areas which appears during wear.

Parameters, such as environment temperature, stress amplitude, mean stress level, frequency and etc., have a great influence on the cyclic lifetime behaviour [11]. Fatigue life generally decreases as the frequency of oscillations increases [7]. Temperature also has a significant effect on the fatigue crack growth and the creep effect at elevated temperatures played a critical role in the adhesively bonded laminates behaviour [12 – 14]. One of such adhesively bonded laminates is laminated leather used for clothing products [5]. The polyurethane water-born dispersion is used for the bonding of microporous polyurethane film to the split leather surface. Microporous polyurethane coating perfectly protects leather from various external ambient negative effects. On the other hand, such coating changes leather rheology behaviour, which is very important from the technological standpoint [15].

The rheological behaviour of soft laminated polymeric materials also depends on the morphology of structure of composite and differs from the rheological behaviour of separate components. Different elastic properties of laminated materials layers influence the increase of internal stress and also determine the final properties of the multilayer material [8, 5, 14]. The mechanical behaviour of tanned leather in great deal depends on the leather structure, topographical zone, from which sample was cutted, nature and size of defects, sort and age of cattle, tanning and finishing process, etc. [16 – 18]. Due to the structure of leather and elastomeric PU film its properties differs radically [5]. High elastic deformation is characteristic to PU film. It was determined that microporous polyurethane coating film substantial changes relaxation properties of leather: the intensity and behaviour

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of stress relaxation process differ from that of leathers and are close to those of separate PU film [5].

The goal of this investigation is to investigate the influence of cyclic fatigue and temperature on the mechanical properties of laminated leather and its separate layers.

MATERIALS AND METHODS OF INVESTIGATION

The laminated leather as well as materials of its layers (the split leather and polyurethane (PU) *Permair* film (commercial grade product of "*Porvair* plc.", UK)) were used for the investigation. The characteristics of investigated materials are presented in Table 1.

Table 1. Characterisation of materials

Sample	Material	Materials characterisation
S	Split leather	Chrome-tanned bovine split leather 1.2 mm ±0.1 mm of thickness grounded with acrylic leather ground STUCO in amount of 20 g/dm^2
P	*Permair* film	Microporous PU film 0.4 mm ±0.05 mm of thickness; breathable film consists of interconnected pores with diameter not higher than 5 μm
L	Laminated leather	Hybrid leather: microporous polyurethane membrane laminated to split leather surface by adhesive layer

The laminated leather was obtained by the lamination of the PU film to the split leather surface by hot pressing using water-born polyurethane adhesive with acrylic hardener [5]. The structure of laminated leather imitates leather with natural grain however polymeric film thickness comprises about 1/3 of laminate thickness (Fig. 1) [19].

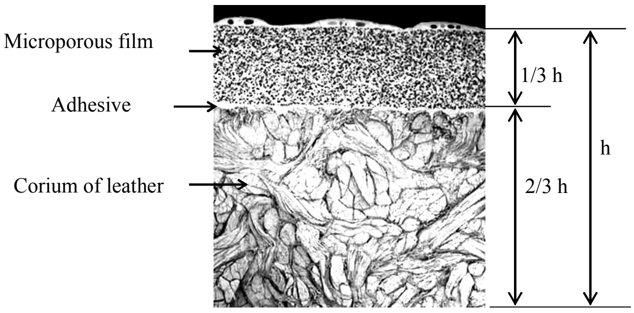

Fig. 1. Crossection of microporous PU film laminated leather (h = 0.4 mm ± 0.05 mm)

The test specimens for the flexing test were cut from the investigated materials in the shape of square, each of side 64 mm ±1 mm. Double creases in the upper of a boot during wear are generated repeatedly in specimens by means of a suitable apparatus until the test pieces survive a specified number of flexure cycles. The test was performed according to the standard LST ISO 5423:1992. The apparatus consists of pairs of V-shaped clamps suitably mounted so that the axes of each pair are in the same straight line.

The fatigue was carried out with testing "VAMP" flexing machine ("Pegasil/ZIPOR", Portugal) which has the purpose of evaluate the occurrence of cracking in the area of greater flexion which forms arises during the use of footwear. One of the clamps of each pair is capable of reciprocating at a frequency of 1.5 Hz ±0.2 Hz. This equipment is fitted inside a cold chamber so its possible to adjust the test temperature till –25 °C.

All specimens were conditioned in a standard atmosphere of 23 °C ±2 °C and relative humidity 50 % ±5 % no fewer than 48 h. The testing was carried out by two series: changing of numbers of fatigue cycles till $5 \cdot 10^5$ (temperature $T = 20$ °C ±2 °C) and changing temperature from 20 °C ±2 °C to –20 °C±2 °C (number of cycles $N_C = 10^5$).

During testing, each test piece folds with an inward crease symmetrically across it, surrounded by a diamond of four outward creases. The tensile properties were investigated with 10 mm width strips which were cut only from that area.

Mechanical properties of the samples were determined under tension by means of universal testing machine FP-10/1 (Germany). All the tensile tests were carried out with a strain rate 100 mm/min ±10 mm/min under controlled temperature at 23 °C ±2 °C and relative humidity of 50 % ±5 %. The engineering stress σ is defined as the ratio of the load to the area. The tensile strength was recorded as stress at the ultimate fracture. As result average of no less than 10 tests was assumed.

RESULTS AND DISCUSSION

The influence of number of flexing fatigue cycles on laminated leather and its separate layers strength and deformability are presented in Fig. 2 and Fig. 3.

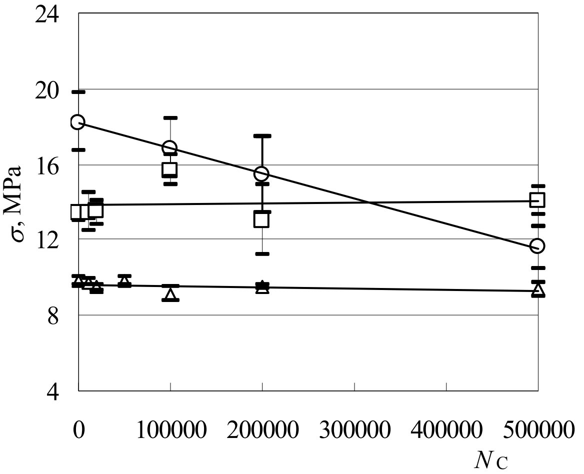

Fig. 2. Influence of number of fatigue cycles on tensile strength of laminated leather and its layers: Δ – PU film, ○ – grounded split leather, □ – laminated leather

The investigations were carried out at environment temperature $t = 20$ °C. The symbols in correspondence of $N = 0$ represent the value of the properties of non fatigue samples. As can be seen from Fig. 2, the flexing has a great influence on tensile strength of split leather: tensile strength decreases 36 % when the number of fatigue cycles increases from 0 up to $5\cdot10^5$. However, deformability increases insignificantly (Fig. 3).

It is evident that the character of curves for elastomeric PU film and laminated leather differs from the analogous curve for split leather (Fig. 2). Tensile strength of the laminated leather and PU film growth in the limits of error does not depend on the number of fatigue cycles.

The dependence of elongation of presented materials differs, too. The deformability of laminated leather decreases about 14 % (from $N_\mathrm{C} = 0$ up to $N_\mathrm{C} = 5\cdot10^5$), while this parameter of PU film is in the limits of error and does not depend on the number of fatigue cycles (Fig. 3). The low value of coefficient of determination ($R^2_\mathrm{p} = 0.014$) confirms this fact.

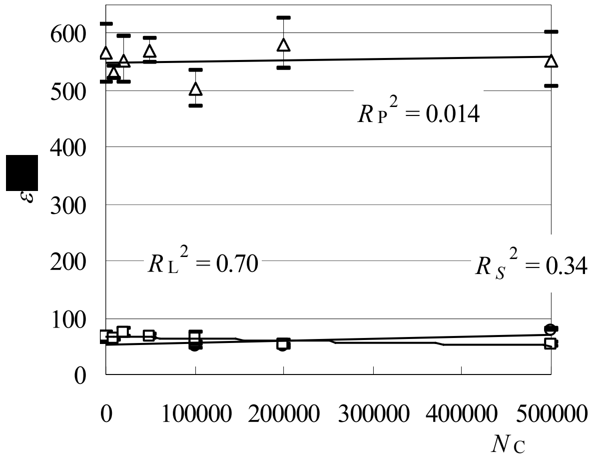

Fig. 3. Influence of number of fatigue cycles on elongation of investigated materials: Δ – PU film (*P*), ○ – grounded split leather (*S*), □ – laminated leather (*L*)

Therefore, it is possible to state that flexing up to $5\cdot10^5$ fatigue cycles (more than 7 days of non stop fatigue) does not show the endurance limit of investigated materials.

As it is known, the effect of high temperature on fatigue life of polymers and composites is to the fact that the strength of polymers generally decreases with increasing temperature, and crack growth becomes easier [14]. However, polymeric clothing products during wear are fatigue in not high positive as well as in not very low negative temperature of environment. Due to this fact the influence of environment temperature on materials properties was also carried out. Figs. 4 and 6 show dependence of tensile strength and deformability of investigated materials on temperature of fatigue environment. All test pieces survived the 10^5 flexure cycles.

It is evident that temperature of fatigue environment influences the mechanical properties of investigated materials. It was determined that when temperature of fatigue environment decreases from 20 °C ±2 °C to –20 °C ±2 °C, tensile strength of the split leather reduces by 16 % (Fig. 4).

It is evident that tensile strength of elastomeric PU film depends on temperature: tensile strength reduces twice when temperature of fatigue environment decreases from 20 °C down to 0 °C. Some samples (about 40 %) fractured when test pieces were flexing at –10 °C and all samples – at –20 °C. While in case of laminated leather tensile strength in the same width of temperature reduces only 20 %.

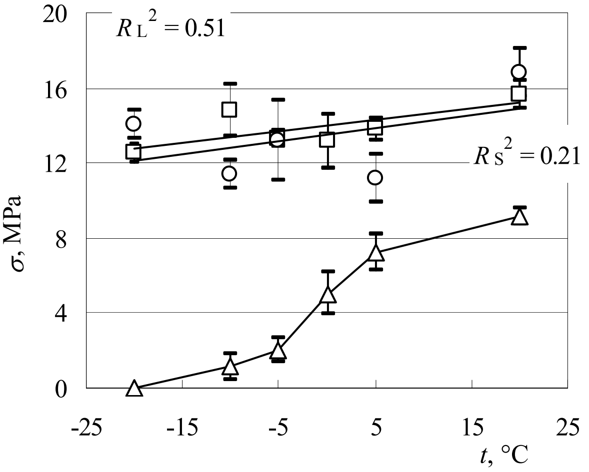

Fig. 4. Influence of fatigue environment temperature on tensile strength of laminated leather and its layers ($N_\mathrm{C} = 10^5$): Δ – PU film, ○ – grounded split leather, □ – laminated leather

The same tendency is observed in the case of dependence of elongation of elastomeric PU film on temperature of fatigue environment (Fig. 5).

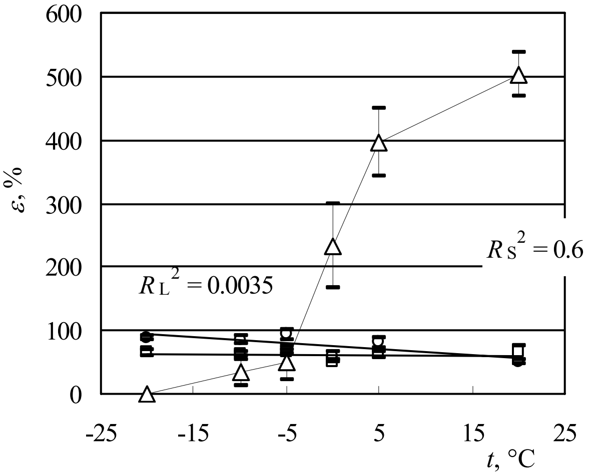

Fig. 5. Influence of fatigue environment temperature on elongation of investigated materials ($N_\mathrm{C} = 10^5$): Δ – PU film, ○ – grounded split leather (S), □ – laminated leather (L)

It is very important to note that decreasing of temperature of fatigue environment does not influence the deformability of laminated leather: $\varepsilon = 64.9\ \% \pm 10\ \%$ at $t = 20\ ^\circ\mathrm{C} \pm 2\ ^\circ\mathrm{C}$ and $\varepsilon = 64.9\ \% \pm 4\ \%$ at $t = -20\ ^\circ\mathrm{C} \pm 2\ ^\circ\mathrm{C}$ (low value of coefficient of determination ($R^2_\mathrm{L} = 0.0035$) confirm that). On the other hand, elongation of split leather marginally increases when temperature of fatigue environment decreases. High value of coefficient of determination ($R^2_\mathrm{s} = 0.8$) confirm existing of such dependence.

It is well known that such self-action of heating arises in polymeric materials in the cyclic fatigue process and is very important for polymers fatigue limit [7, 12]. In the laminate the self-heating depends on nature and structure of all layers of laminate and their interrelationship in the interface of layers. The reason of such differences of laminated leather and PU film can be the different heating intensity of material during the process of flexing. The self-action of heating is different for separate PU film and multilayer laminate.

CONCLUSIONS

The number of fatigue cycles at temperature of fatigue environment $t = 20$ °C ranging over $5 \cdot 10^5$ cycles only has slight influence on tensile strength and deformability of laminated leather and its layers. For the future investigations of influence of fatigue cycles it is necessary to increase number of fatigue cycles up to few millions.

The environment temperature has a great influence on tensile strength and deformability of PU film. The influence of environment temperature on analogous characteristics of laminated and split leathers is not so high but is detectable.

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