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Stress Distribution in Soft Polymer Laminates

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The influence of the mechanical properties of the adhesive on the stress distribution in the polyurethane film laminated leather layers was investigated. The finite elements method was used for the 3-D model evaluation. Laminate models consisted of three layers: split leather, adhesive film and polyurethane film. The elastic modulus of adhesive layer was varied from 40 MPa up to 110 MPa. The models were loaded in two different ways, i.e. constant strain of 3 % and constant force of 100 N. The relationships of adhesive elastic modulus and principal stress in the layers of the laminate on the loading condition of constant strain or constant force were obtained. The results showed that the increase of adhesive elastic modulus increases stress only in the adhesive layer of laminate. In the case of loading by constant force it was obtained that the increase of adhesive elastic modulus increases stresses in its layer and insignificantly decreases stresses of split leather and microporous polyurethane layers. Layers orientation also influences the deformability and stress distribution of the laminate. The highest deformability was reached as each split leather or PU film were orientated in the direction of the lowest elastic modulus.
Keywords: laminated leather, elastic modulus, stress, strain, finite element analysis, modelling.

INTRODUCTION

A wide variety of polymer coated materials is used in clothing and footwear industry. Frequently it is crucial to match quite different properties in such systems. It is preferred that the materials allow the transfer of perspiration vapour and at the same time blocked the entry of liquid water, had high elastic, thermoinsulational properties and high resistance to other external effects. The laminated leather combines all these properties. Such leather consists of the layer of split leather coated with microporous film. These two layers are bonded using a thin layer of adhesive (Fig. 1).

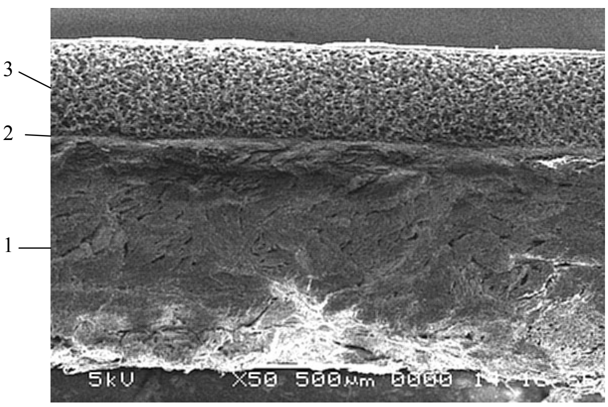

Fig. 1. Laminated leather: 1 – split leather, 2 – adhesive, 3 – microporous PU film

The stress-strain behaviour of such laminated leather can be influenced by the appearance of the highly stressed regions at the interface of different nature and properties materials layers. Due to this, the stress concentration at the interface may lead to crack formation and propagation [2].

Plenty of various experiments were carried out in which mechanical properties of polymeric films [3 – 5] and different kinds of leather were investigated [6 – 10]. It was obtained that the leather backing mainly influences mechanical behaviour of the hybrid system, while polymeric film – deformability [8, 9]. The influence of adhesive thickness, mechanical properties upon the mechanical behaviour of layered structure have been studied too [11 – 14]. However, the majority of these researches are not oriented to the soft polymer laminates investigation.

It is also very important to determine the location of highly stressed regions in the laminate and the stress values in all the layers of the system. This procedure is quite complicated using regular experimental methods but this problem can be easily solved by the finite elements analysis (FEA). The FEA is increasingly being used since it has proven to be effective a tool for obtaining either 2-D or 3-D stress and strain distributions along the loaded and bonded structure [2 – 11, 15 – 18]. Another advantage of numerical analysis application is that this method may also be applied for the determination of internal stress values in each layer under different loading conditions.

The goal of this study was to determine the influence of the adhesive mechanical properties and layers orientation on the mechanical behaviour of the soft polymer laminates.

EXPERIMENTAL

Laminated leather was used in the studies. Such leather is obtained by hot pressing of microporous

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polyurethane membrane to split the leather surface. Typical view of the investigated structure is given in Fig. 1.The bonding of the layers is performed using water-born polyurethane adhesive. The mechanical properties of the separate layers are presented in Table 1. The elastic modulus of the adhesive layer varied from 40 MPa up to 110 MPa.

Table 1. Mechanical properties of laminated leather layers

Layer	Thickness, mm	Elastic modulus	
		E_X, MPa	E_Y, MPa
Split leather	1.2	21.9	38.9
Adhesive	0.2	40 – 110	40 – 110
Microporous PU film	0.4	12.7	44.3

Two different kinds of 3D models were applied in this study. One group of models was loaded by the constant force of 100 N, another – by the constant strain of 3 %. One end of the models was firmly fixed, i.e. all degrees of freedom were equal to zero, while another end was allowed to deform under tension at transversal directions. Length and width of the models were 50 mm × 34 mm, respectively (Fig. 2). The exact number of elements in each model was 425.

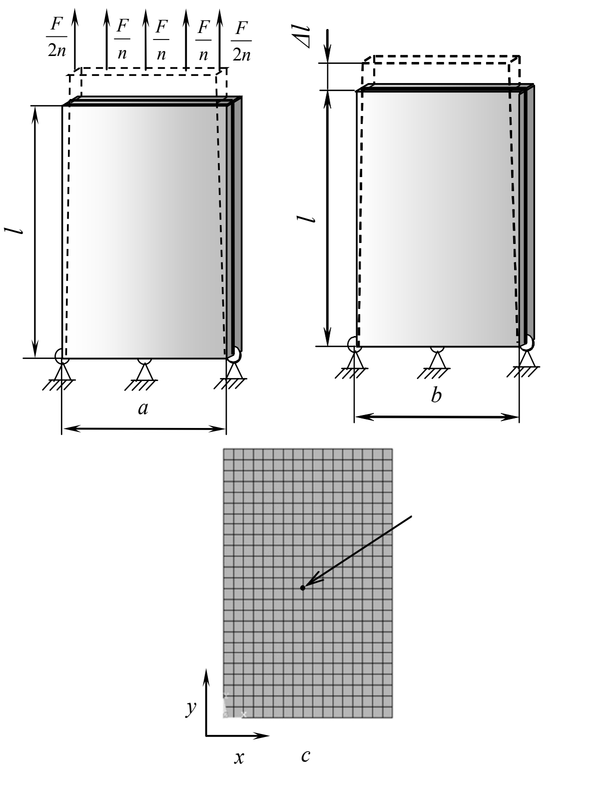

Fig. 2. Loading conditions of the models: a – constant force, b – constant strain, c – location of stress measuring (F = 100 N, n – number of elements in transversal direction, x – crossectional direction, y – longitudinal direction)

The FEA was used to identify the influence of the adhesive layer elastic modulus and laminate layers orientation on mechanical behaviour of the laminated system. The analysis was performed by finite element code ANSYS, which allows to get the stress values in each layer. For this purpose multilayer 3D SHELL91 elements were used. After solving the problem maximum principal stress σ_1 values were obtained (Fig. 2, c).

As the split leather and microporous PU film are orthotropic materials, it was interesting to determine the influence of the layer orientation on the stress and strain distribution. For this purpose layer orientation angle of the split leather and PU film was changed by step of $\theta = 15°$. The longitudinal axis was assumed as the countdown position for rotation. The split leather orientation was changed in the model A and PU film – in model B (Fig. 3).

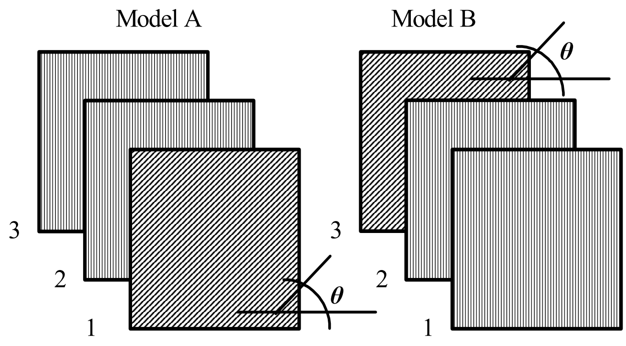

Fig. 3. Layer orientation: 1 – split leather, 2 – adhesive, 3 – PU film, θ – layer orientation angle

RESULTS AND DISCUSSIONS

The influence of the adhesive elastic modulus E on the maximum principal stress in each layer of the soft laminate at constant strain is presented in Fig. 4.

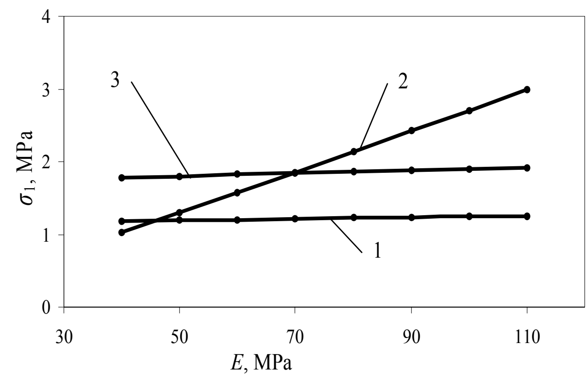

Fig. 4. The influence of the elastic modulus E of adhesive on principal stress σ_1 distribution in the layers of the laminate at constant strain: 1 – split leather, 2 – adhesive layer, 3 – microporous PU film

This investigation showed that the increase of elastic modulus of the adhesive layer significantly increased the stress values in the adhesive layer. About 2.7 times higher elastic modulus E caused 3 times higher stress values in the adhesive layer. It may be explained by the linear stress dependence upon elastic modulus in the case of loading within the limits of Hook's low validity. As it was expected, the change of adhesive elastic modulus has no influence on the stress of split leather and PU film as the loading mode under axial tension is the constant strain (Fig. 4, curve 1, 3). From the layered composite mechanics it is known [19] that in this case the stress changes can occur only in the layer which elastic modulus varies.

After loading the model by constant force of 100 N, another effect on the adhesive layer stress was achieved (Fig. 5). As in the case of constant strain loading, the increase of adhesive elastic modulus also causes the increase of adhesive stress values. On the other hand, the decrease of stress of both the split leather and PU film layers was observed. Maximum principal stress of split leather decreases by 12 %, while in PU film stress decrease of 10 % was observed.

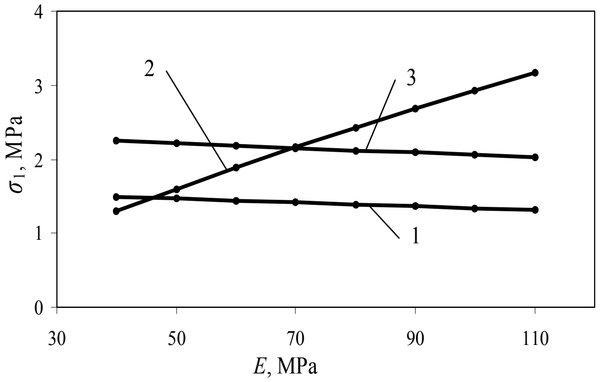

Fig. 5. The influence of the elastic modulus E of adhesive on principal stress σ_1 distribution in the layers at constant force: 1 – split leather, 2 – adhesive layer, 3 – microporous PU film

This can be explained by 20 % of strain decrease at 110 MPa E value compared with the strain value at 40 MPa (Fig. 6). As the total stiffness of the model is higher, the system is deformed at lower degree at the same loading condition. Lower strain causes lower stress values.

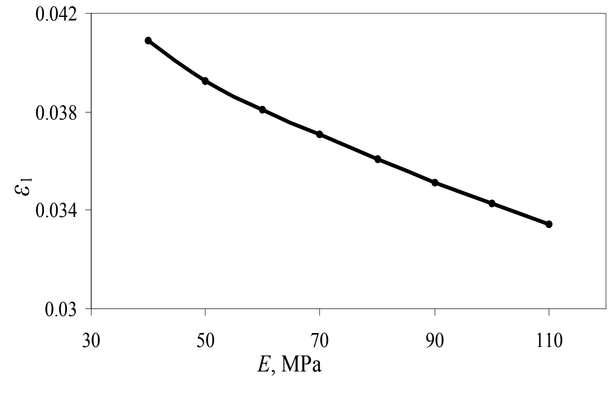

Fig. 6. The influence of the elastic modulus E of adhesive on total strain ε_1 of the laminate

The influence of split leather and PU film orientation angle upon the principal stress of split leather, adhesive, and microporous PU film is presented in Fig. 7 and Fig. 8, respectively.

As it is known, the orthotropic layer orientation influences on the stress and strain values of the system. It was found that changes of both, split leather or PU film orientation cause the stress decrease in the layer to be rotated. The highest decrease is obtained as the layer is orientated at θ = 90°. In this case the orientation of the split leather layer by 90° causes the stress decrease in 37 %. The opposite effect was obtained in the other layers, i.e. adhesive and PU film. The stress increases by 47 % and 40 %, respectively, compared to that of the stress values of the orientation at 0°.

Changes of the orientation angle of PU film also cause its stress decrease of 63 %. In this case the opposite effect, stress increase, was obtained in split leather and adhesive layers. The change of stress values was equal to 48 % in the adhesive layer and to 46 % in PU film (Fig. 8).

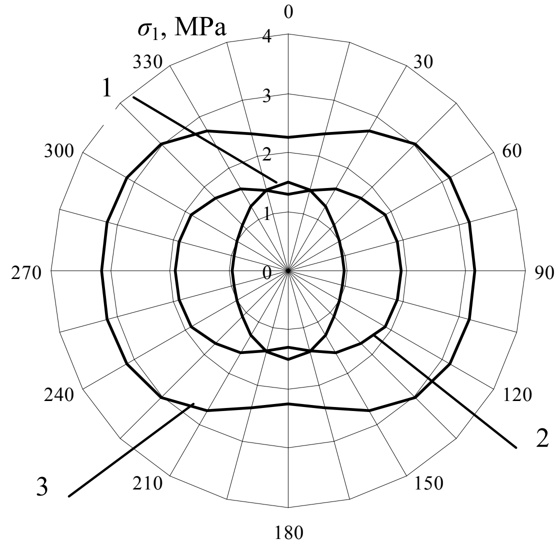

Fig. 7. The influence of split leather layer orientation upon principal stress σ_1: 1 – split leather, 2 – adhesive layer, 3 – microporous PU film

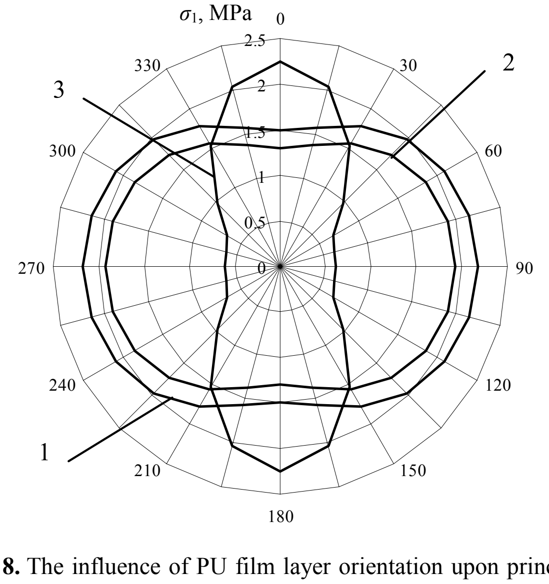

Fig. 8. The influence of PU film layer orientation upon principal stress σ_1: 1 – split leather, 2 – adhesive layer, 3 – microporous PU film

It can be seen that the orientation of both split leather and PU film layers up to 90° reduces the system stiffness (Fig. 9). The system obtains higher deformation capability. Orientation of split leather layer at 90° causes almost 30 % higher total strain. Though PU film has a lower elastic modulus in the transversal direction, it has 1/3 lower thickness than split leather. Thus, the influence of PU film orientation is significant. This fact explains why PU film orientation by 90° increases strain by only 22 %.

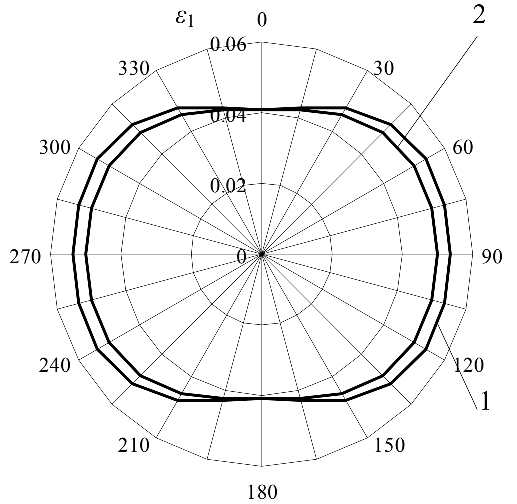

Fig. 9. The split leather (1) and PU film (2) layer orientation influence on total strain ε_1

CONCLUSIONS

Finite element simulation is efficient method to study the influence of the adhesive mechanical properties on stress distribution in laminated leather layers. The relationships of adhesive elastic modulus and principal stress in the layers of the laminate at the loading of constant strain and constant force were obtained.

The increase of adhesive elastic modulus increases the stress only in adhesive layer of laminate in case of constant strain. The increase of adhesive elastic modulus increases the adhesive stress and insignificantly decreases stress of split leather and microporous polyurethane layers when loading condition of constant force is used.

Orientation of the layers influences the deformability and stress distribution in the laminate. The highest deformability is reached as either split leather or PU film is orientated in the direction of the lowest elastic modulus.

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