53rd Conference on Experimental Stress Analysis
Český Krumlov, Czech Republic, June 1–4, 2015 pp. 195–202

Methods of Creating a Numerical Model of a Real Seam Based on Experimental Data

P. Kulhavý [1,*], N. Kovalova [2], J. Vosáhlo [2]

[1] *Technical University of Liberec, Faculty of Mechanical Engineering, Studentská 2, 461 17 Liberec 1, Czech Republic*

[2] *Technical University of Liberec, Faculty of Textile Engineering, Studentská 2, 461 17 Liberec 1, Czech Republic*

* *Petr.Kulhavy@tul.cz*

Abstract: In technical textiles as well as in other professions, it is important to know the exact characteristics of the behavior of materials. In the field of automotive upholstery products we are used in the same way as conventional structural materials of one- and multi-axis tensile tests, static and dynamic. There are precise numerical models of material structures of individual materials, foams and used yarns, but somewhat less in this area were taken into account the behavior of the whole. The role of a seat cover is not just to cover up the foam but also increase the rigidity of the seat cushion and have influence to a viscoelastic behavior of the foams. Also the strength of sewn seam is generally one of the main quality parameter of clothing. In reliance on seam strength of car seats we need to be sure when it comes to their deformation. In this study, four different sizes of spun polyester and polyamide threads were sewn on a material used for car seat cover through lockstitch. Based on the static and dynamic tests visually processed using high speed camera and CT tomography was constructed 3D CAD model. Due to the complexity and high difficulty on the accuracy of the model, much effort has been devoted to correct the control curves of future stitch.

Keywords: Static and Dynamic Strength; Sewing Seam; 3D Curves; Contact Numerical Model.

1 Introduction

The basic preconditions for a successful construction of a final product, is the knowledge mechanical properties of the used materials. Testing the mechanical properties of materials play an indispensable role in the control of production technology, in quality control and in acceptances or semi finished products and also in the development of new materials. Quality of sewing seams cannot be assessed unequivocally, it is determined by a set of indicators. Sewing seam strength is one of the main indicators of quality textile ready-made products, which depends on various technical and technological parameters such as: type of fabric (or material), the type of sewing thread, sewing needles, stitch type, stitch density and type of seams etc. Regarding the safety characteristics of technical ready-made products the seam strength is the most important parameter. Moreover, in some cases the human life can be in danger by the malfunction of these products (airbags, safety belts, parachutes, trampolines. . .) [1]. At present, for determining the strength of the seams conventionally used standard experimental methods, which are carried out as transversal stress in static mode [2]. For determining the dynamic strength of sewn connections is not fixed norm or method of measurement and therefore was to construct a device that allows measurement of the strength of sewn joints under dynamic stress.

During the process of product usage, sewn seams and materials are subjected to variable loads, leading to various deformations. For textile materials which show considerable anisothropi or orthotropi us generally not sufficient testing in one axis. In order to have an idea about the real strength of the seam in car seats cover should be placed in stress in two axes at the same time. For the experiment it was necessary to select and prepare samples according to ČSN EN 12751 Textiles - Sampling of fibers, yarns and fabrics for testing.

2 Used Methods

The samples were produced in Johnson Controls Company one of the main car seats part producers and were prepared according to [3, 4] the norm ČSN EN ISO 13935-1 the same about static and dynamic tests. Laboratory sample is made from material of car seat cover size 700 × 350 mm. Finally the real width of the sample (Fig. 1 and Fig. 2) will be 50 mm, the length of the investigating sample will be 340 mm.

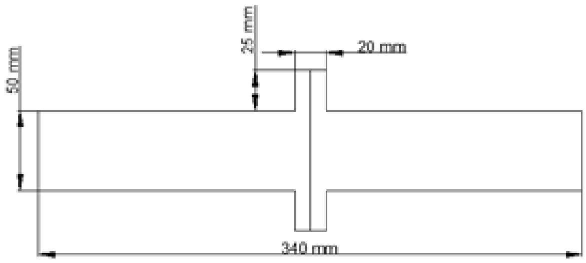

Fig. 1: Shape of the tested specimen.

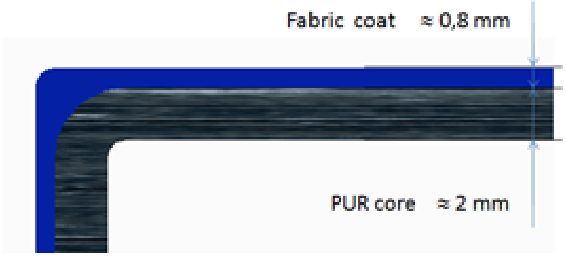

Fig. 2: Layers of the tested sandwich composite.

2.1 Static

The static test using the Strip method – it's a tensile test in which the full width of the test specimen is gripped in the jaws of the testing machine. Pneumatic tensile-testing machine provided with one clamp which is stationary and another clamp which moves with a constant speed throughout the test, the entire testing system being virtually free from deflection. The set feed speed of the jaws was 100 mm/min. Maximum force recorded when a test specimen with a seam perpendicular to the direction of extension is taken to seam rupture during a tensile test.

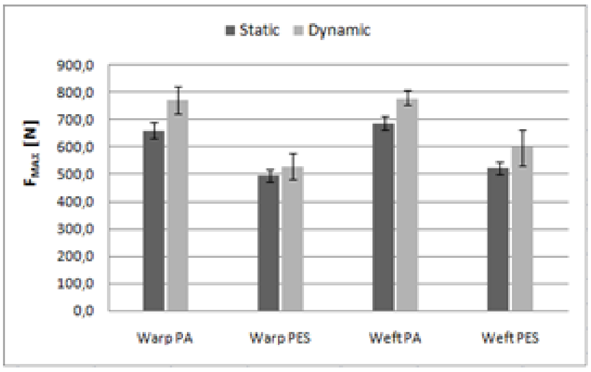

Fig. 3: Comparison of loading of the whole assembly.

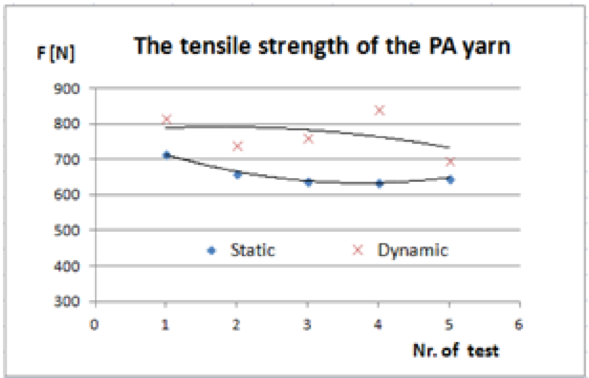

Fig. 4: Strength of the PA yarn.

2.2 Dynamic

Dynamic tests are used to detect the behavior of the material during a sudden increase in loading. During this kind of tests the force acts on experimental sample of a certain speed. For a dynamic test with a similar character is possible to use a hydraulic or a pneumatic circuit. The air is a very available medium, but before using must be pressed, then filtered or dried. After working process air is discharged into the environment. Therefore, the pneumatic systems called open systems and their suitability particularly in applications where it is not possible to allow pollution, for example hydraulic oil. In the pneumatic circuit during compression varies the air volume and creates tension forces, in this way leads to inaccurately controlled movement and a sudden increase in strength. By contrast, the main advantages of hydraulic systems include the required stepless speed control under great strength and shock attenuation [5].

For the dynamic test was used the high speed hydraulic cylinder Inova AG 25_100 that is able to reach an extremely velocity almost 15 ms^{-1}. Used speed was set to 500 mm/sec. To be able measure the actual size of the force was applied an axial force transducer GTM KAK 2.5 kN.

2.3 Results

According to Kovalova [6] between the results of static and dynamic loading can be observed correlation Fig. 3 and 4, however, the value of dynamic strength of the seam is about 10 % higher. The differences between static and dynamic strength of the sewing seams in warp and weft directions are shown below in Fig. 5.

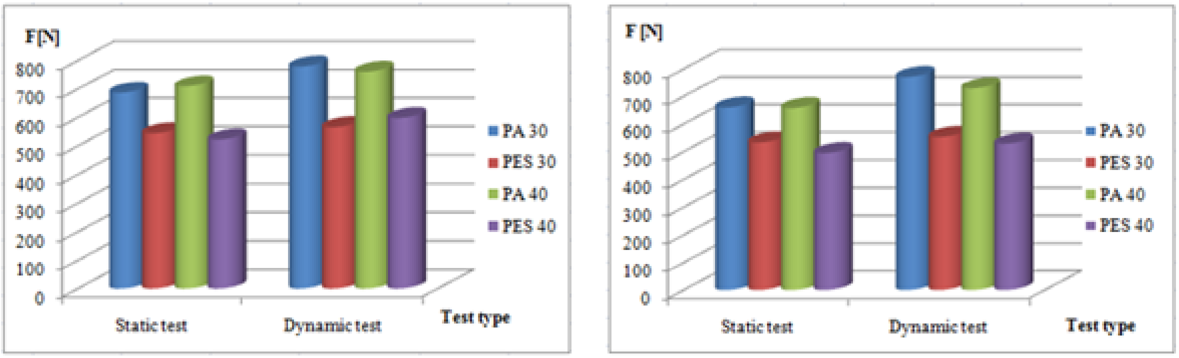

Fig. 5: Changes of seam breaking forces depending on thread and test type (left – in warp direction, right – in the weft direction).

3 The Model Section

As already mentioned in Chapter 2, the basic shape of sewing seam was given the standard norm for static tests. By means of macrograph with added scale were determining basic dimensions of sample (Fig. 6). The next step was to explore how actually appears the penetration of individual threads in the seam and shape of the binding points Given that using conventional means cannot be simply to get binding point of the seam has been used so-called computed tomography CT [7]. The principle of CT is based on fact that the density of individual components of tested material passed through by the X-ray can be measured from the calculation of the attenuation coefficient. It was possible to get an idea of the principle of connection, however, the display format does not allow the transfer of graphical data for possible publication and therefore Fig. 7 viewed the middle of the sewn material rather illustrative.

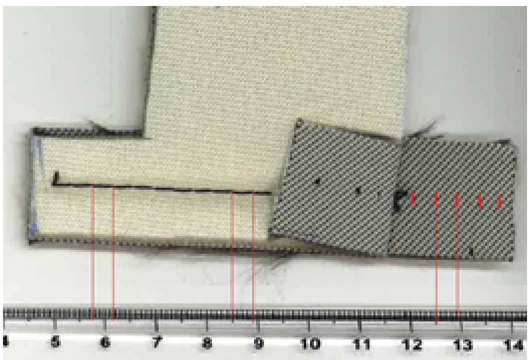

Fig. 6: First measure of the seam dimensions.

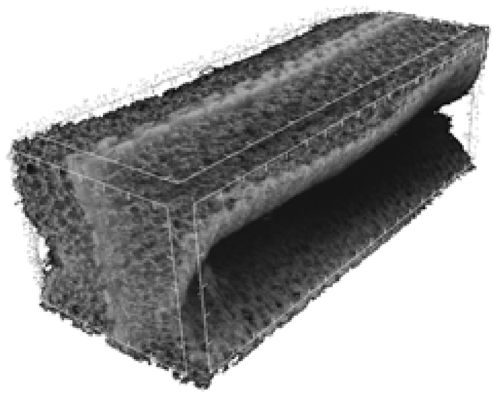

Fig. 7: Demonstration of stitched materials with CT.

3.1 The Control Curve

For creating a CAD models with the similar complexity is the main parameter find out the most appropriate forming and carrier curve, that will be able to respond to a sudden changes in the direction vectors and in the radius of curvature. Generally, it is according to [9] possible to express a curve in a space using the explicit expression $z = f(x, y)$ or implicitly by $F(x, y, z) = 0$. In a computer graphics we encounter with the parametric curves expressed by a point equation $P(t) = [x(t); y(t); z(t)]$ or alternatively with the steering vectors $\vec{p}(t) = [x(t); y(t); z(t)]$.

In our case the design concept was verified using the B-spline curves and using the Bezier curves. The B spline is actually a generally controlled modification of the piecewise polynomials functions and their approximations. The B-spline is in fact a curve passing through the specified points, which still seeks to achieve the lowest values of the radii of curvature. In contrast of the Bezier curves that is firmly made up of the end and start points, called control polygon and other (internal) points that indicate and control the internal curvature as is shown in Fig. 8. Currently, it is one of the most popular curves used e.g. on the font styles [10]. By changing the level of the Bezier curve parameters, it's possible to make and check for example the main characteristics of a lines, ellipses, parabolas or hyperbolas. The common feature of the two curves is that by changing the any one points cause a variation of the entire curve shape.

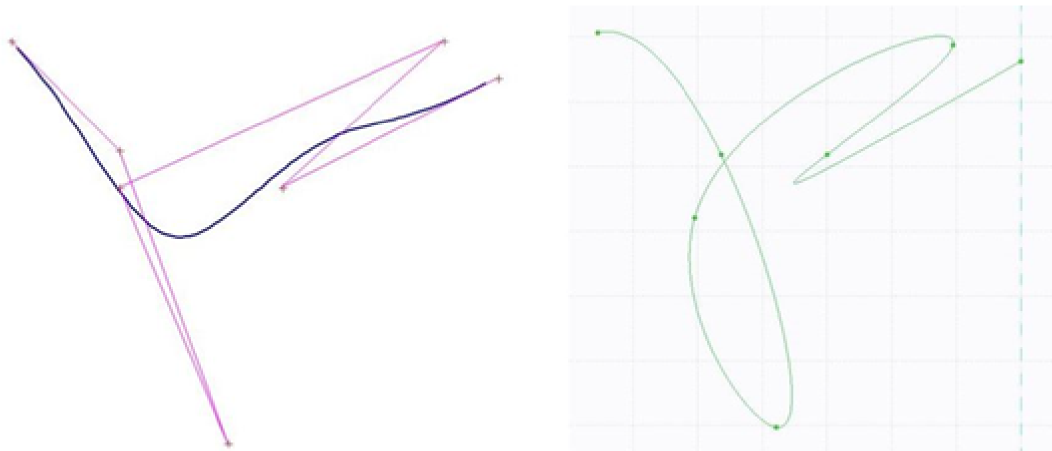

Fig. 8: Comparison of the shape of Bezier (left) and B Spline curve (right) interlaying them through the identical points.

As unsuitable for our model has been the Bspline curve [7]. During the model creation are the individual parts connected together and it causes changing of their curvature when even an only slight local variations caused occurrence of errors during the FEM computation. The Bezier curve has been found a very suitable because of firmly specified start / finish points and also a management of curvature independent of the adjacent segments connected to the curve. For the required connection was possible to simply use the adjustable parameters of normality, tangentiality or parametric settings of the transitions. As has been already mentioned a very important parameter for the model is settings of the parametric classes n of the continuity transitions between individual segments that defines us continuous derivative in 3 classes. Connection C0 means in common point two arbitrarily passing vectors and two curves with different radius of curvature. Continuity C1 is characterized by the one common tangent vector $\vec{t_i}$ in the transition point, but different radii of curvature. Completely analogously then the last class C2 provides a common tangent vector and value of the radius of curvature in the transition point.

3.2 CAD Model

As the first attempt were assembled the interconnections of yarns and consequently its implementation to the model with fabric materials (Fig. 8). For a connection of the yarns were used merged surfaces and a formation of the holes geometry was performed with using the assembly cut-off with offset surfaces (Fig. 9). For a creation of the models has been used system Creo_2 which is the one of only a few CAD modelers that allows with using manual and parametric input direct support for creation of 3D curves, including their transition parameters and direct control of their polygons.

3.3 Numerical Model

All of the tested material layer has orthotropic hyper-elastic properties [7]. Due to uniaxial orientation the vessel has predominant strain in one direction only. According to (my) this can be mathematically described by the energy-conjugated pairs, which together constitute the deformation work. For large deformation energy the pair of conjugate Green-Lagrange strain tensor **E** and 2. Piola-Kirchhoff stress tensor **S** is appropriate. This behaviour may be considered as predominantly hyper-elastic and we can use mathematical description of the strain energy of hyper-elastic anisotropic material, which is divided into two parts by an elastic part and configuration (deformed) part, which describes a change of volume (where the Jacobian of the deformation $\mathbf{J} = \det(\mathbf{F})$ is in the range $0 < J < 1$).

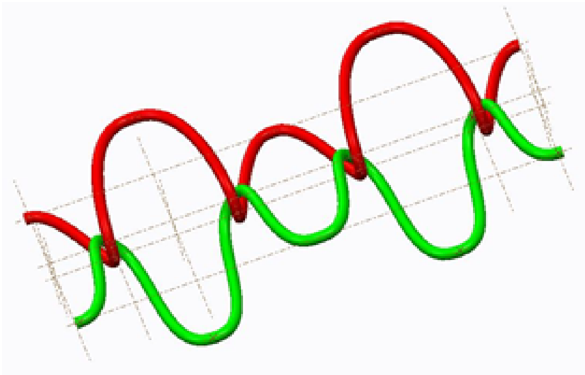

Fig. 9: CAD model of the stitches.

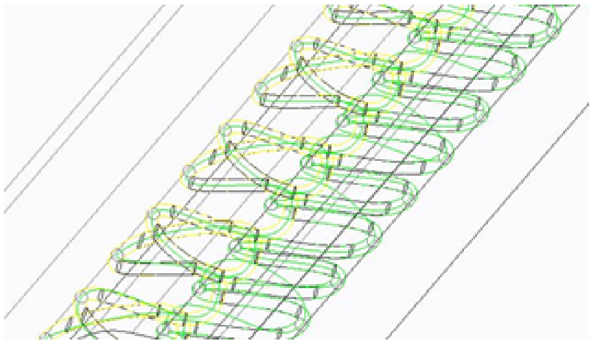

Fig. 10: Labyrinth of the cut holes through the fabrics.

The first task of analysis of the assembly of the threads connection was to determine the static strength. In software ANSYS 14.0, have been found the first information about the distribution of stress field in the places of interaction of the threads. Using the finite element method allows the determination of the the most stressed interconnected threads. The created CAD geometry was imported into the commercial numerical software ANSYS and with regards to the speed of solving has been the model symmetrically split. Into the thus prepared model were inserted the measured orthotropic material properties of the tested sample of yarn. Between the individual yarns bundles, based on the previous experiments, were established frictional contacts with the friction coefficient of 0.3.

The automatic tools typically used for meshing of the solid models proved as unsuitable. The generated network has been optimized by reducing size the edge to 0.8 mm, and with using the sweep and body sizing methods. From the original 53 168 nodes and 25 318 elements has been the mesh adequately optimized to 37 176 nodes and 17 810 elements. After the creation and optimization of this mesh was the next step to introduce the real boundary conditions. In the upper part of the model of the bunch of threads, the model was firmly fixed in all directions and rotation. In the bottom part the bundle of yarns was the feed allowed up to a maximum length of 0.86 mm.

The determined value correspond to mean values of the measured displacements at which occurred the yarn rupture of the real samples. As an output of the test (Fig. 10) have been observed the maximum stress at the critical points of connections of the threads with the found value 790 MPa.

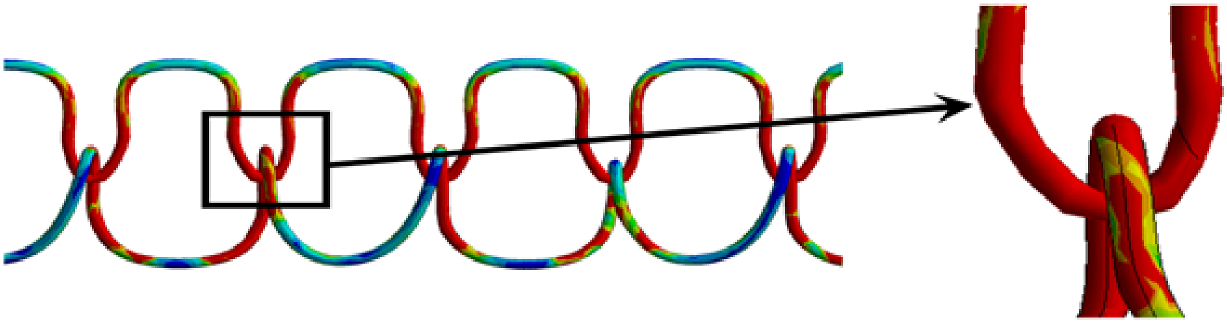

Fig. 11: The observed maximum stress in the contacts of the yarns.

The successful testing of threads connection led to a further solving of the overall problem of the model of entire assembly. Into the Imported CAD geometry has been created a new axial symmetry. For next computations has been used a model with orthotropic material properties. The generated network has been optimized by reducing size the edge to 0.2 mm. The creation of a mesh of textile materials had to be optimized with using the mapped meshing.. The optimized mesh structure after the performed adjustment counted 59 812 nodes and 26 348 elements. In the place of interconnection between the fabric and threads it was necessary to define a new contact area Between the individual yarn bundles have been established frictional contacts with the friction coefficient 0.3 (Fig. 11). In the thus prepared model have been introduced the boundary conditions. From one side was the model supported and deprived of motion and rotation in all directions. The other boundary conditions were introduced into the end surface of the model, where the maximum displacement was set 113 mm (Fig. 10) due to the maximal founded displacement during the carried tests.

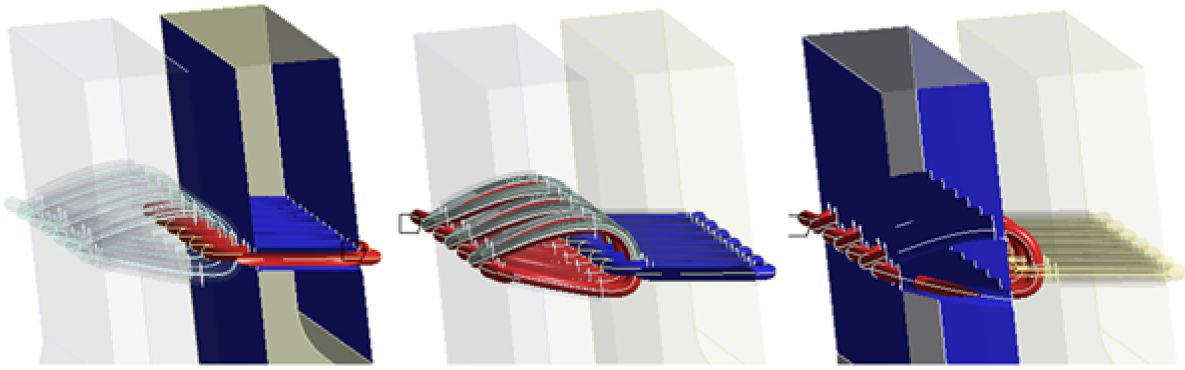

Fig. 12: Scheme of the solved numerical contact model.

Fig. 13: The defined boundary conditions.

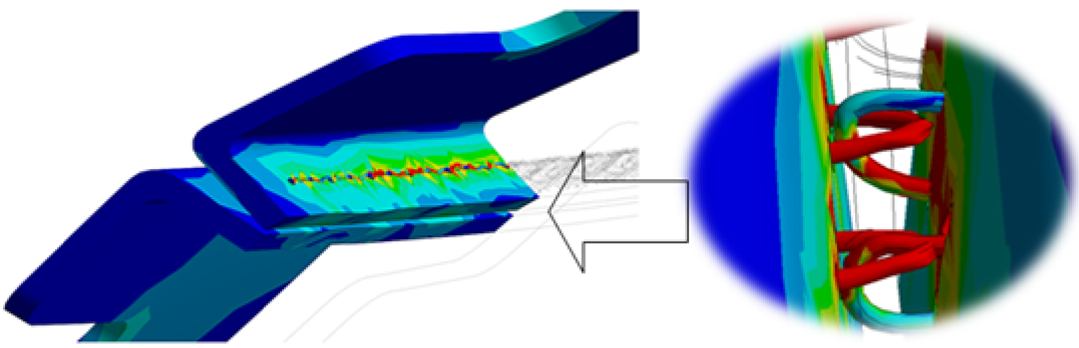

Fig. 14: Sectional view and detail of the observed von-Mises stress in the symmetric half of model.

As a result of the carried simulations has been observed the maximum stress (von Mises) and the deformation in the thread lockstitch arrangement with the added textile materials how can be seen in the Fig. 12.

4 Conclusion

Based on the carried experimental measurements have been determined the mechanical properties of the used materials, the yarns and fabrics. For the verification of the calculations, simulated tensile tests were

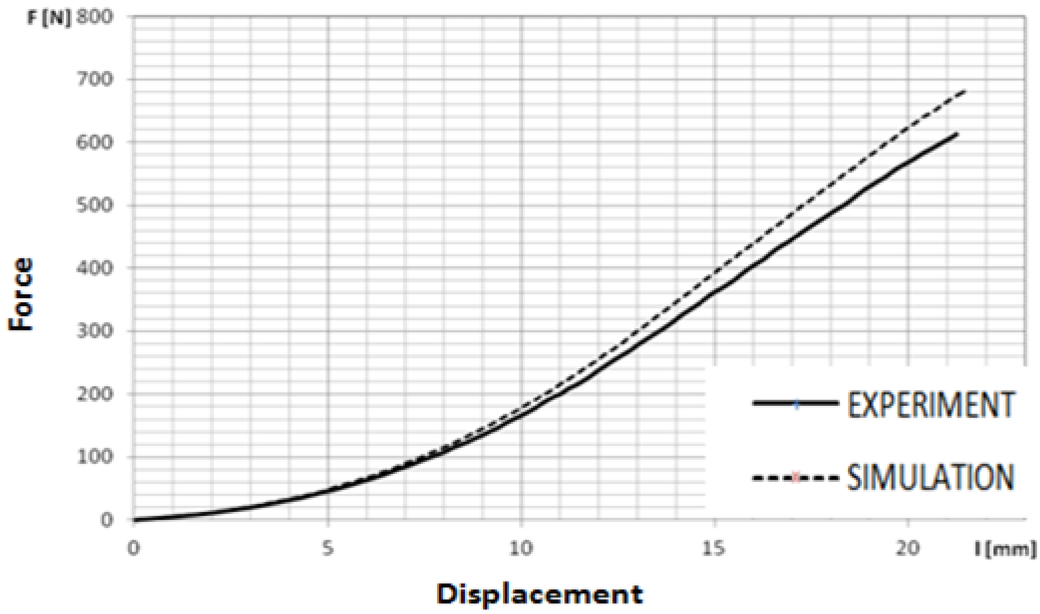

Fig. 15: Graph of dependence of the force F [N] and deformation Δl [mm].

performed. The achieved values of simulation correspond quite well to the real tensile test. Designed CAD model with the lockstitch threads connections was imported to software Ansys 14.0, where the model has been subjected to a simulation of static pull test. The results led to the fact that a given yarns has exceeded the limit of proportionality 790 MPa and this led to their rupture. Furthermore, it was examined the maximum stress in the contacts with the textile materials. The results observed that the textile material has reached the maximum stress of 2845 MPa that approximately corresponds to 630 N as is possible to see in Fig. 13. Another task will be the modification of used materials which consists of a composite parts. The newly created material models will be again subjected to testing in order to observe the maximum stress at the seams.

Acknowledgement

This work was supported by the Ministry of Education of the Czech Republic within the SGS project no. 21007 on the Technical University of Liberec.

References

[1] Kržová, J.: Vliv parametrů šicích nití a tvorby stehu na pružnost šitých spojů u pletenin, DP, TU Liberec 2003.

[2] Dosedělová, I., Analysis of the properties of the seam of technical readymade products with respect to the method of straining. Liberec, 2010. DP. TUL.

[3] ČSN EN ISO 13935-1. Seam tensile properties of fabrics and made-up textile articles: Determination of maximum force to seam rupture using the strip method. 2014 Český normalizační institut, Praha, 2014.

[4] CSN 800 00 73. Pojmy používané při zkoušení textilií tahem. 1992.

[5] Cerha, J, Hydraulické a pneumatické mechanismy.Liberec: Technická univerzita v Liberci, 2008, 189 s. ISBN 978-80-7372-297-5.

[6] N. Kovalová, P. Kulhavý, A. Havelka, Static and dynamic strength of sewing seams for a special application, Clotech 2015, to be printed.

[7] P. Kulhavý, N. Kovalova, J. Vosáhlo: Numerical Model of the Static Loading of a Stitched Seam in the Composite Cover of Car Seat, EAN 2015, 53th, Journal, to be printed.

[8] O. Kunz, K problematice vlastností švů ve vztahu k vlastnostem šitého materiálu. Informativní přehled. VÚP Brno, 1979, č.1, s. 41.

[9] Matoušek, I., Computer modeling in the automated production of molded glass: Liberec: Technická univerzita v Liberci, 2005, 28 s. ISBN 80-708-3988-0.

[10] Žára, J., Beneš, B., Moderní počítačová grafika. Vyd 1. Brno: Computer Press, 2004, 609 s. ISBN 80-251-0454-0.

[11] Jirásek, M., Bažant, Z. P. (2002) Inelastic analysis of structures, Wiley, p. 463 ISBN 0-471-98716-6.