TECHNICKÁ UNIVERZITA V LIBERCI

FAKULTA TEXTILNÍ

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Anisotropy in Tensile Properties of Plain Weave Fabric
Anizotropie tahových vlastností tkaniny v plátnové vazbě

AUTOREFERÁT DISERTAČNÍ PRÁCE

Název disertační práce:	**ANISOTROPY IN TENSILE PROPERTIES OF PLAIN WEAVE FABRIC**
	ANIZOTROPIE TAHOVÝCH VLASTNOSTÍ TKANINY V PLÁTNOVÉ VAZBĚ
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1. Subject and aim of the work (Předmět a cíl práce)

Behavior of woven fabric under tensile stress is extremely anisotropic due to complex fabric configuration, yarns interaction and yarn deformation. Multifaceted deformations include of crimp-interchange, consolidation, extension and flattening are anticipated for yarns inside of fabric structure under tensile stress. To challenge anisotropy in tensile properties of plain weave fabric following two distinct aims are considered.

1.1 Fabric geometry before deformation and after bias deformation

The priority in studies of fabric under tensile stress belongs to fabric geometry due to high dependence of mechanical properties on fabric geometry. Accordingly, developing a 3D model for fabric geometry before deformation and during deformation in bias directions (±45°) would be the first scope of this study.

1.2 Tensile properties of fabric in arbitrary direction

Then, the tensile properties of woven fabric in arbitrary direction, which includes of fabric geometry and mechanical properties, would be discussed. For this purpose, a micromechanical and geometrical model of fabric deformation in arbitrary direction would be established.

2. Review of literature (Přehled současného stavu problematiky)

To interpret the deformation of woven fabric in bias direction, the concept of Weissenberg *et. al.* [1, 2] has been contemplated by most of the researchers. On the basis of this theory it is assumed that the motion of yarns at the interlacing point is pin-jointed motion and the incompressible and inextensible warp and weft yarns in a unit cell of fabric have the constant sett. Although some Weissenberg's assumptions are acceptable in ordinary fabrics under low shear deformation, however the dimension of yarns and yarns sett are subjected to change in high shear deformation. Afterward, Lindberg *et al.* [3] dealt with shear behavior of woven fabric. They found that shear deformation takes place on the basis of two levels: initial shear without sliding and shear with sliding, and then jamming. They mentioned that shear deformation is initially resisted by friction in cross-over force and then elastic forces after jamming. Kilby [4] had been suggested a formula for calculating Young's module of fabric in arbitrary direction on the basis of Young's modules of fabric in warp and weft direction. Treloar [5] demonstrated that test sample dimension has significant effect on behavior of fabric in simple shear. He mentioned that the maximum shear strain, which can be applied without the occurrence of wrinkling, is dependent on the shape of specimen and length-width ratio. Later on, several distinct modes of deformation had been put in forward by Grosberg *et* *al.* [6] depending the degree of shear imposed upon the fabric. First: deformation due to rigid intersections when the shear is too small to overcome the friction. Second: yarn slippage at the intersection. Third: an elastic deformation when slipping is complete and fourth: jamming in the structure. Accordingly they deducted a model on the basis of mechanical properties of yarns and geometry of fabric structure for predicting initial shearing characteristics. Soon after, Grosberg et al [7] tried to suggest a model to predicting mechanism of deformation of woven fabric under shear stress in elastic region. Skelton [8] studied the limitation in shear deformation of a fabric. In this study it is pointed out that the limits of shear are usually defined geometrically. For a wide range of conventional fabrics the shear limit is essentially defined by side-by-side contact of one set of yarns. Afterward, Leaf and Sheta [9] demonstrated that the Young's module of a fabric under bias stress is connected with shear modulus and fabric Poisson's ratio in warp and weft. Prodromou and Chen [10] tried to find a relationship between shear angles and wrinkling of several layers of woven fabrics that were used for composite performances. They measured angular deformation of warp and weft as shear angles by usage a trellis frame and image processing method. Moreover, buckling or wrinkling that occurred due to compressive forces was studied in this research. Critical shear angle, so called 'locking angle', was defined as the shear angle under onset of buckling in this study. Also, shear angle was predicted up to locking angle with pin-joint assumption and some geometrical parameters, such as, yarn width, space between yarns and friction were considered for modifying the model. T. M. McBride and Julie Chen [11] dealt with change in internal geometry during shear deformation.. W M Lo and J L Hu [12] tried to evaluate shear properties of fabric in all directions on the base of Kilby's model [4]. They found that there is strongly linear relationship between shear rigidity and shear hysteresis in all direction. Osamu Kuwazuru *et al.* studied anisotropy in tensile properties of plain weave fabric in arbitrary direction numerically by new concept of Pseudo-Continuum model [13-15].

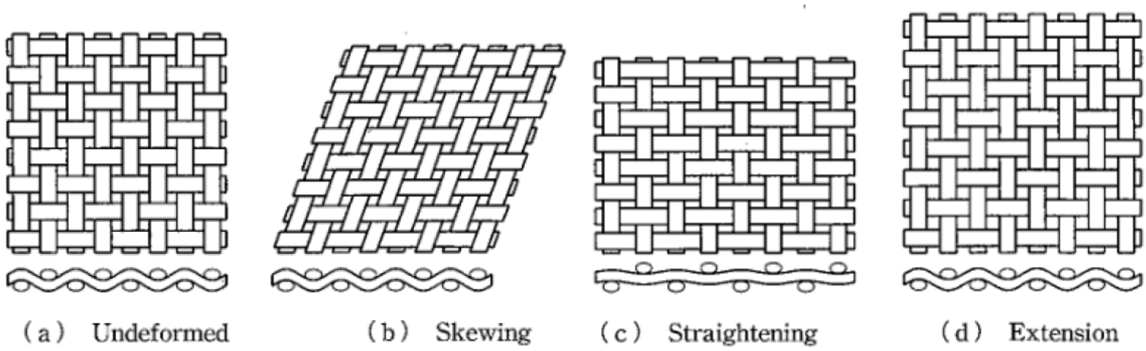

Figure 1- Modes of woven fabric deformation [13]

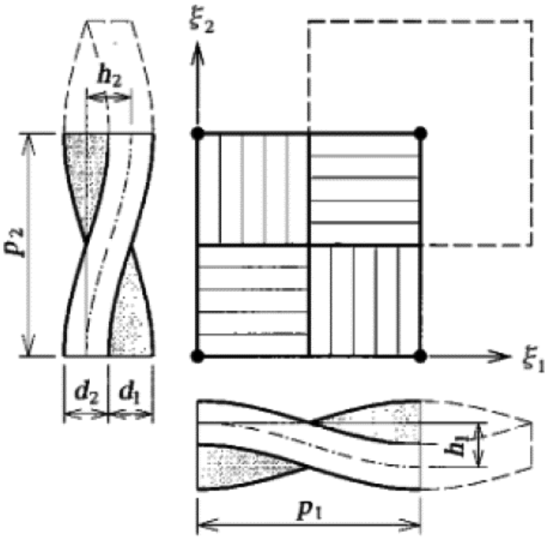

Figure 2- Unit cell of weave structure [13]

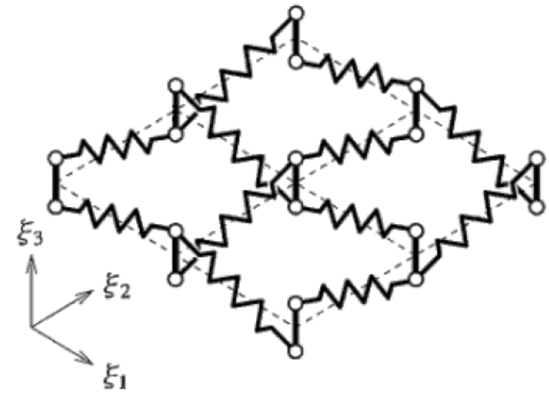

Figure 3- Strut-Spring model [13]

This model is constructed on the basis of three modes of deformation of fabric and Strut-Spring concept (figures 1-3). The obtained outcomes of this model in anisotropy of ultimate strength and strain by numerical solution of an imaginary fabric are presented in figures 4 and 5 respectively.

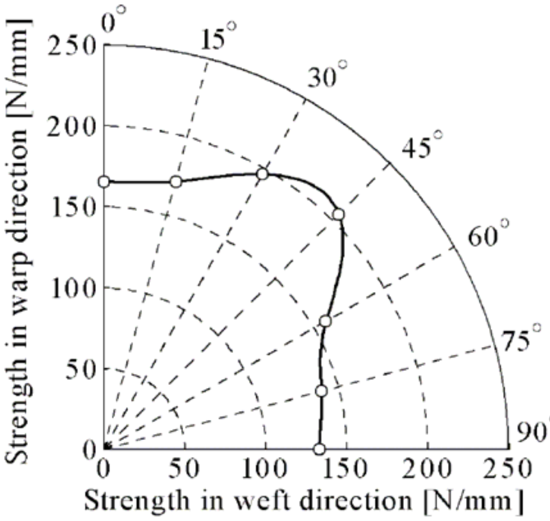

Figure 4- Anisotropy of tensile strength [15]

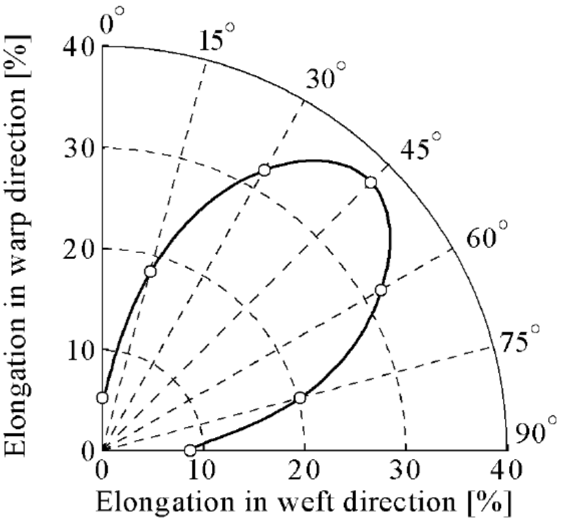

Figure 5- Anisotropy of breaking elongation [15]

Despite of cited investigations, it is seems that the current knowledge is not adequate to evaluate anisotropy of geometrical-mechanical behavior of woven fabric simultaneously in advance applications. Accordingly, this study has been planed to assess yarn deformation and configuration in structure of woven fabric when it is subjected to stress in arbitrary direction. Concurrently, the tensile force required for certain deformation is studied in this investigation.

3. Used methods (Použité metody)

3.1 Theoritical methods

On the basis of elliptical yarn cross-section and curves a geometry model was suggested for fabric structure before deformation (figure 6). This model was extended to evaluate fabric deformation in bias direction (figure 7).

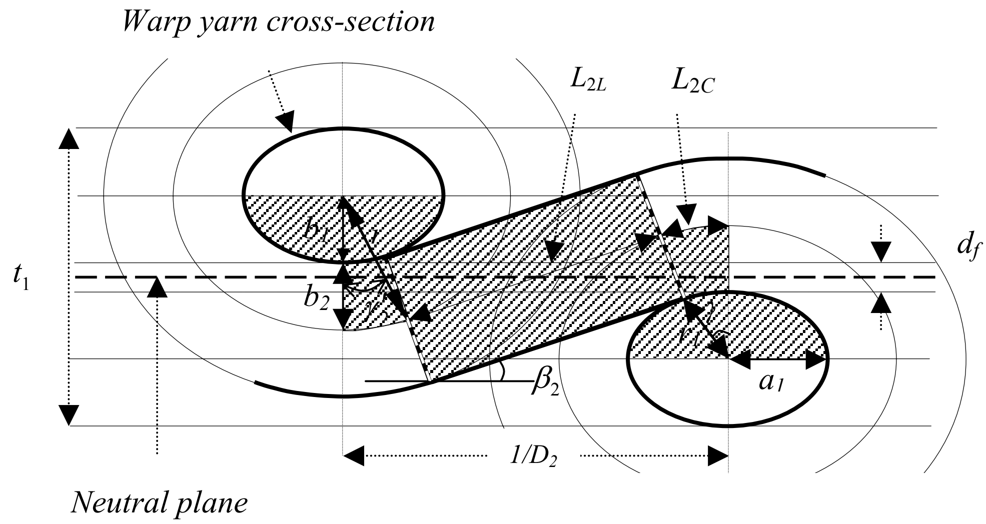

Figure 6- Warp cross-section

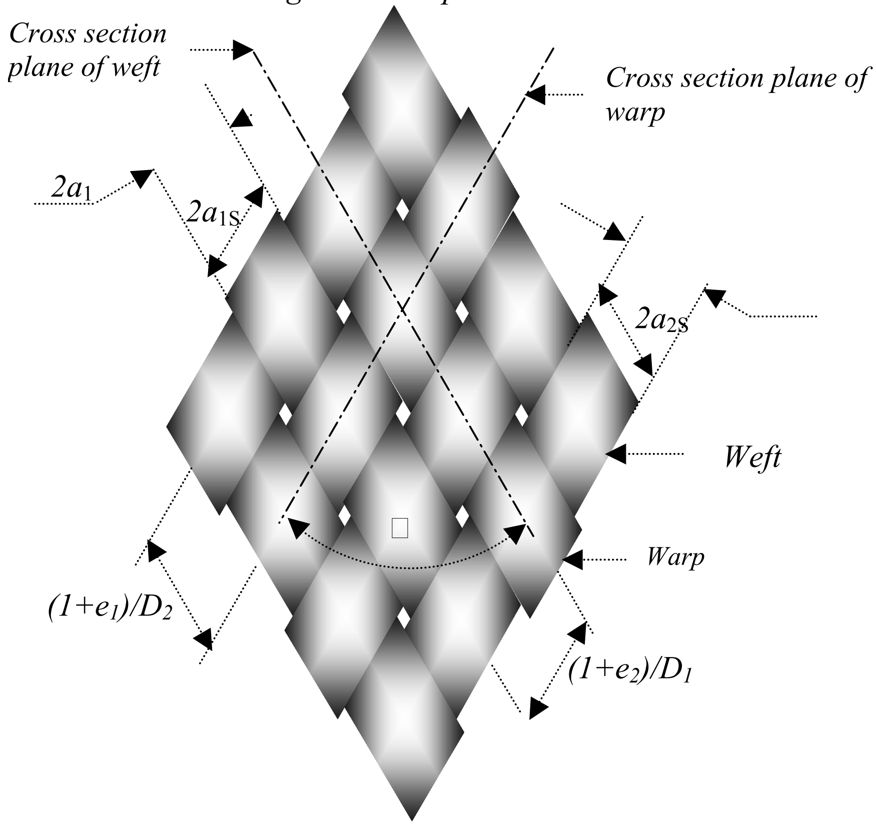

Figure 7- Schematic diagram of woven fabric under shear deformation

Afterward, on the source of yarn deformation another mechanical-geometrical model was put in forward. Yarns crimp interchange, yarns flattening and bending rigidity of yarns (figure 8) was contemplated in this model. According to observations, additional assumptions are considered in exterior deformation of a fabric in arbitrary direction (figure 9).

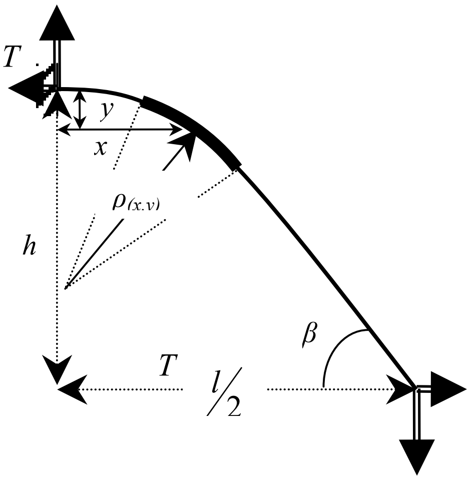

Figure 8- Curvature and cantilever bending at fixed point

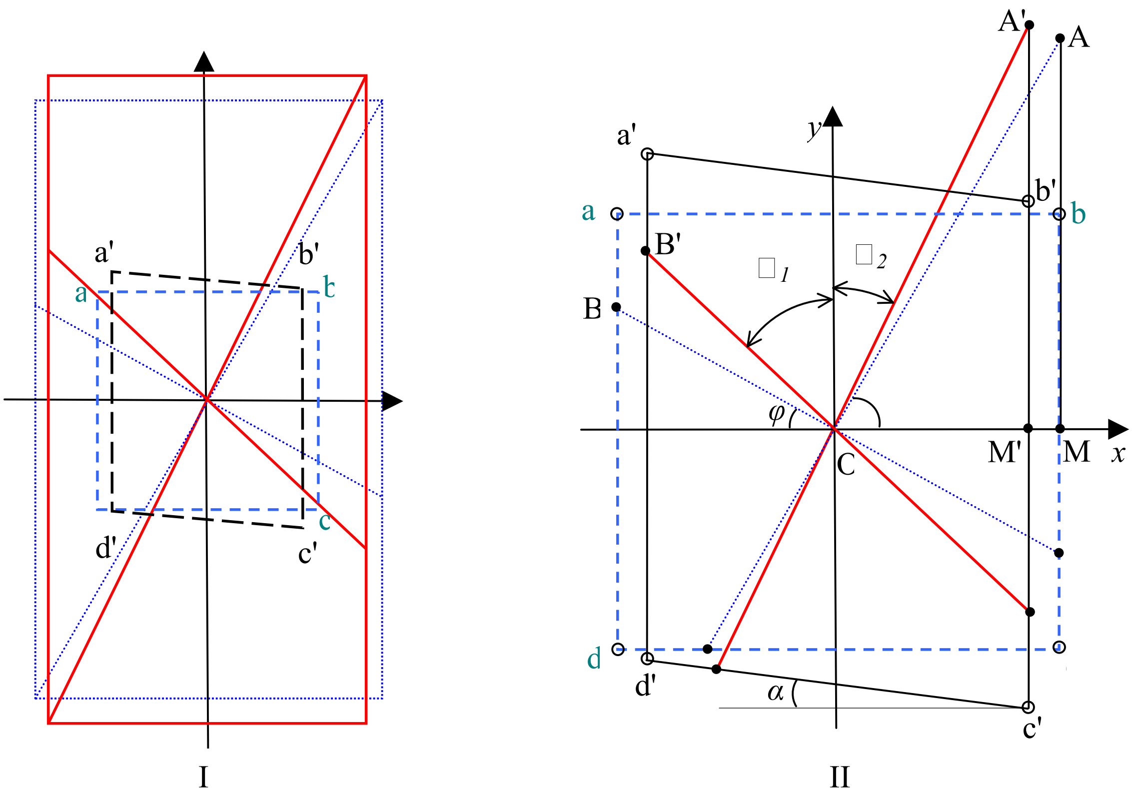

Figure 9- Imaginary square abcd on center and parallel with sample's edges. I: deformation of squares II: converting square to parallelogram in details

3.2 Emperical methods

The authority of developed models was investigated by imposing tensile stress on a series of fabrics in different directions. To evaluate exterior geometry of fabric during deformation an image processing method was explained and applied (figure 10). A method was developed and utilized to measuring flattening of yarn (figure 11). Furthermore, modified jaws were employed to reduce stress concentration on sample's corners (figure 12).

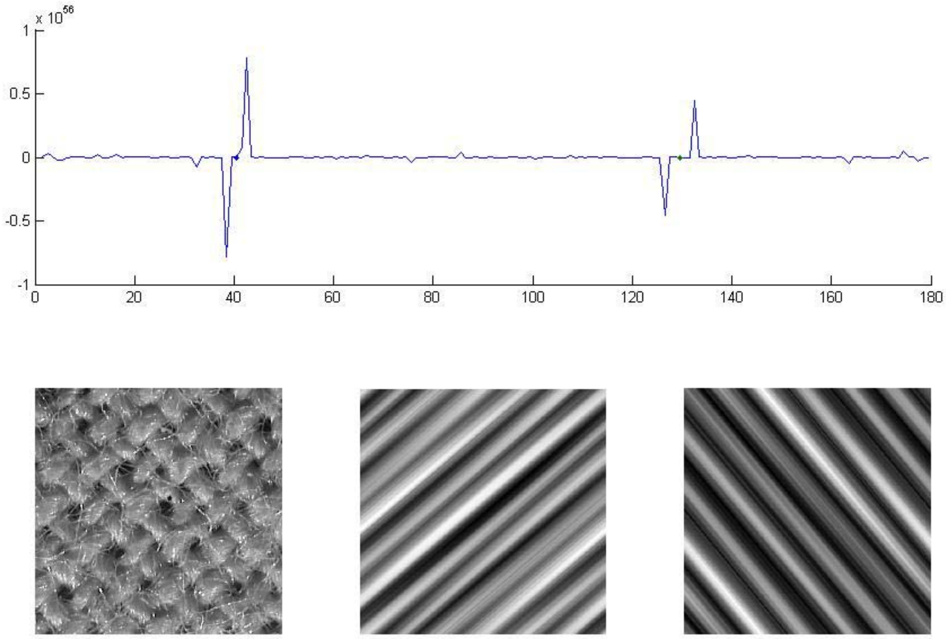

Figure 10- Yarn detecting from real fabric image

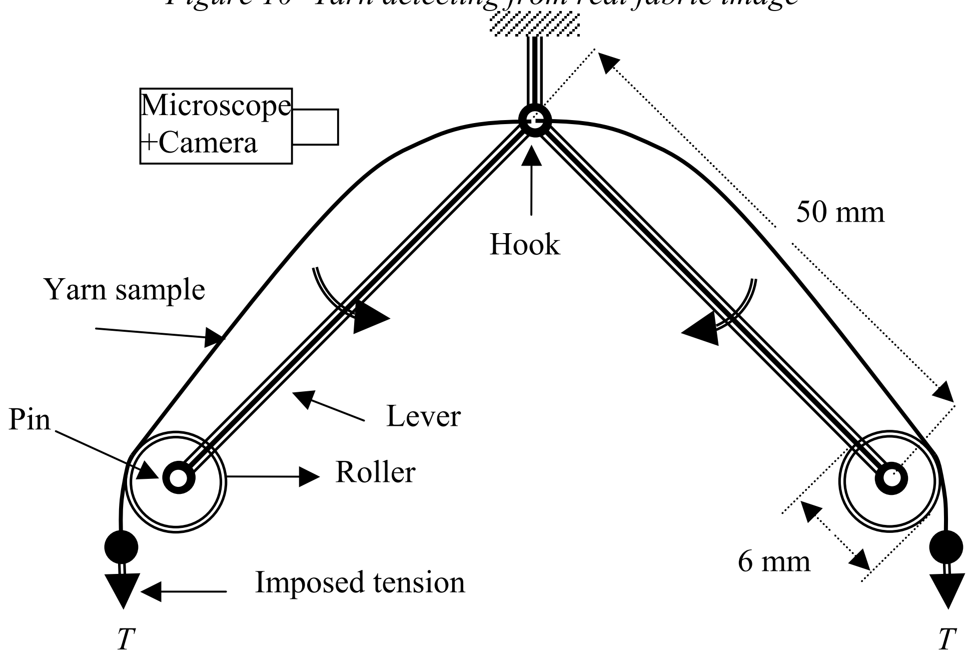

Figure 11- Yarn flattening measurement concept

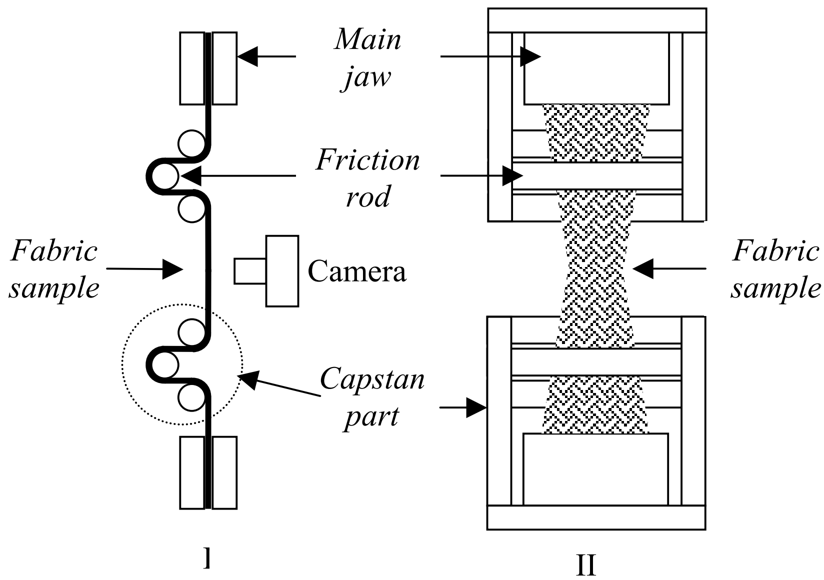

Figure 12- Modifying jaws to reduce concentrate stress at corners, I: Schematic cross-section of fabric path, II: Schematic modified jaws

4. Survey of results (Přehled dosažených výsledků)

4.1 Deformation in bias direction

The validity of proposed model to evaluate fabric geometry during deformation in bias direction was studied by experimental works. For instance, figure 13 shows the measured and predicted values of warp-weft yarns angle of a polypropylene fabric by explained methods. Figure 14 indicates these values for yarns sett of mentioned fabric.

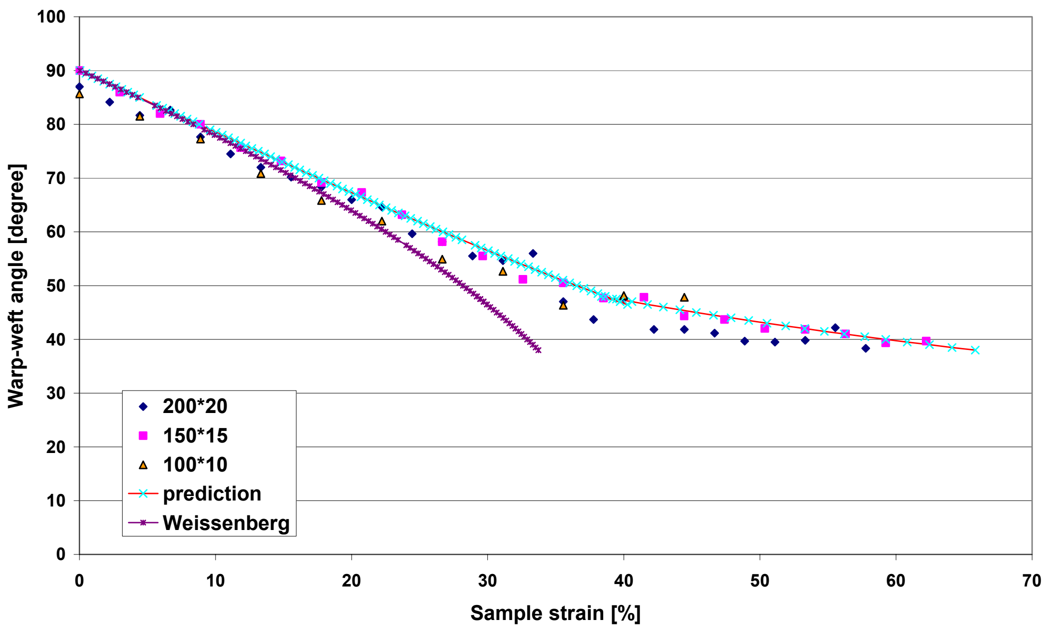

Figure 13- Measured and predicted values of warp-weft angle for fabric (P30) during bias deformation

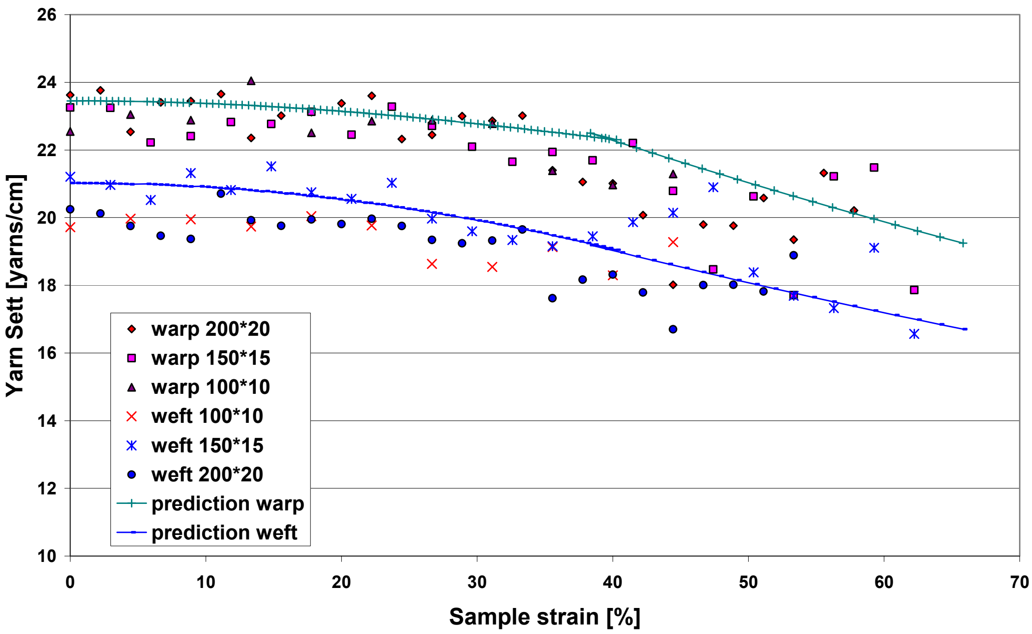

Figure 14- Yarns sett comparison between measured and predicted values (fabric P30)

4.2 Deformation in arbitrary direction

Figures 15 and 16 reveal the real images from a cotton fabric before deformation aligned in 15° and 60° directions. Figures 17 and 18 demonstrate the exterior deformation of these samples respectively. A micro mechanical model is suggested to evaluate fabric geometry during deformation in arbitrary direction. Simultaneously, this model presents a tensile force-strain of fabric in arbitrary direction. The measured and predicted yarns sett values in principal direction and 15°, 45° and 75° directions are summarized in figures 19-22. Figures 23-25 represent the warp-weft yarns angle during deformation in 15°, 45° and 75° directions. Despite of complex behavior of fabric in deformation, it is seems that this model is responsible for evaluate fabric geometry during deformation in arbitrary direction.

Eventually, estimated tensile force- strain curve of this fabric in different direction is reviewed in figure 26. The authority of this proposed model to evaluate tensile force- tensile curve also can be observed in this figure.

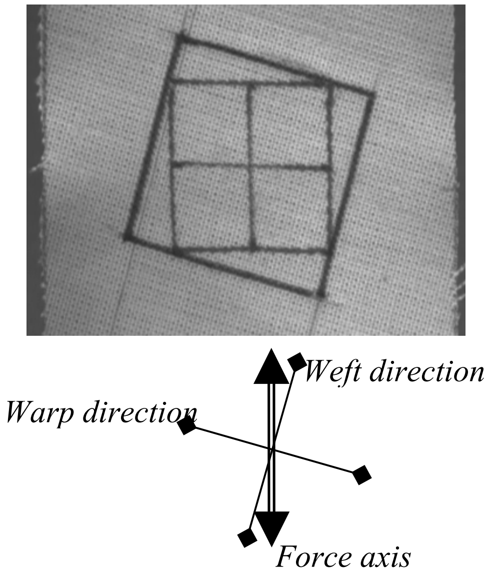

Figure 15- Inner and outer squares in center of sample φ=15°

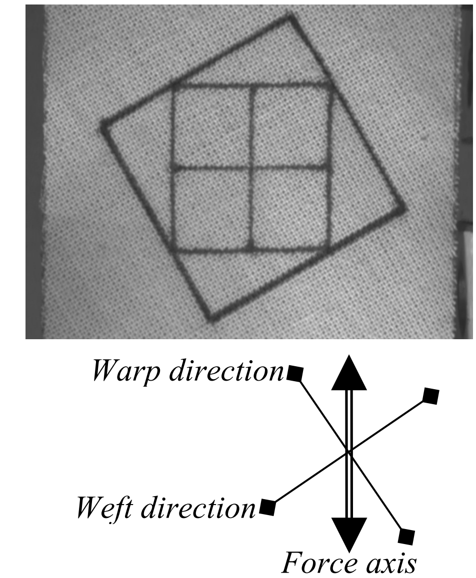

Figure 16- Inner and outer Squares in center of sample φ=60°

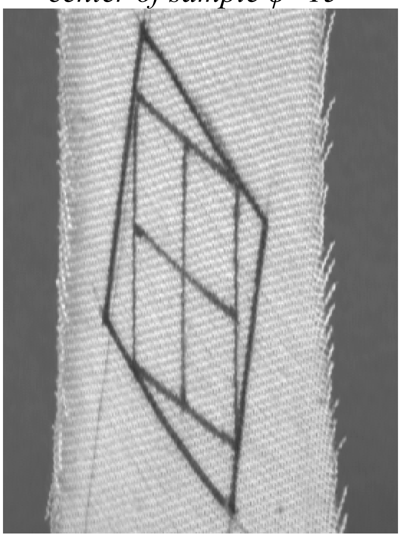

Figure 17- Inner and outer squares in center of sample φ=15° after deformation and near to rupture point

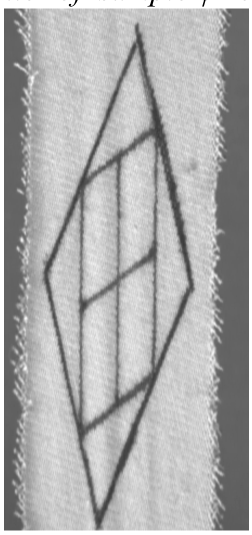

Figure 18- Inner and outer Squares in center of sample φ=60° after deformation and near to rupture point

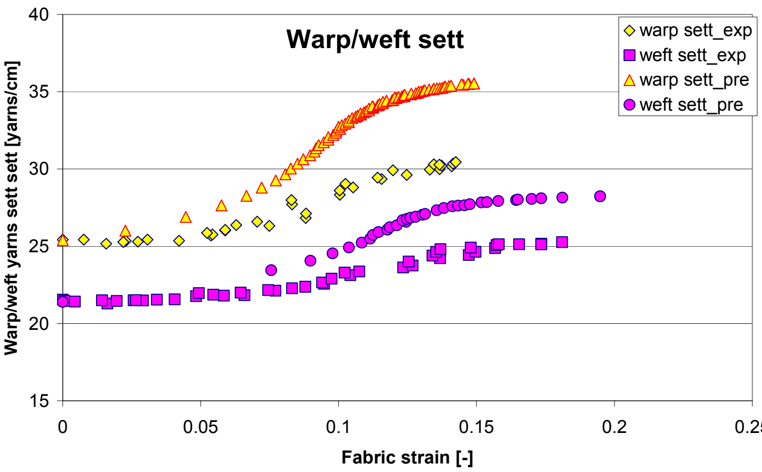

Figure 19- Comparison between predicted and measured values: Change in warp and weft yarns sett when the fabric is subjected to tensile stress in weft and warp

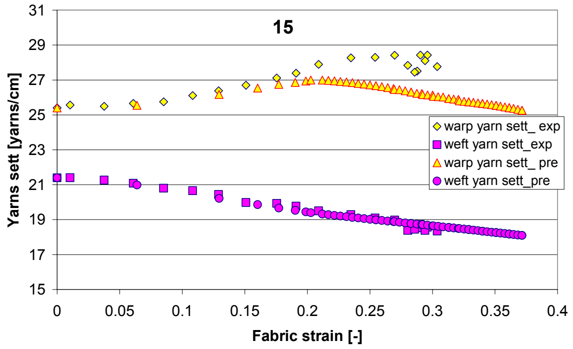

Figure 20- Comparison between predicted and measured values: Change in yarns sett for force angle φ=15 °

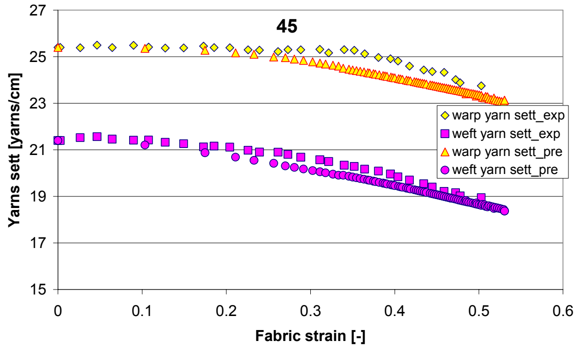

Figure 21- Comparison between predicted and measured values: Change in yarns sett for force angle φ=45 °

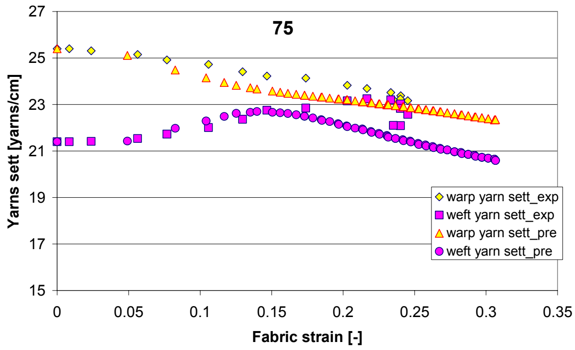

Figure 22- Comparison between predicted and measured values: Change in yarns sett for force angle φ=75 °

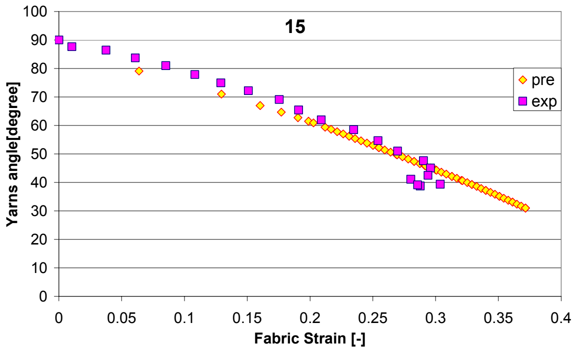

Figure 23- Comparison between predicted and measured values: Warp-weft yarns angle for force angle φ=15 °

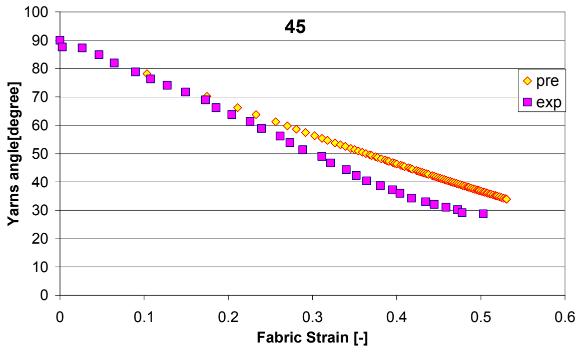

Figure 24- Comparison between predicted and measured values: Warp-weft yarns angle for force angle φ=45 °

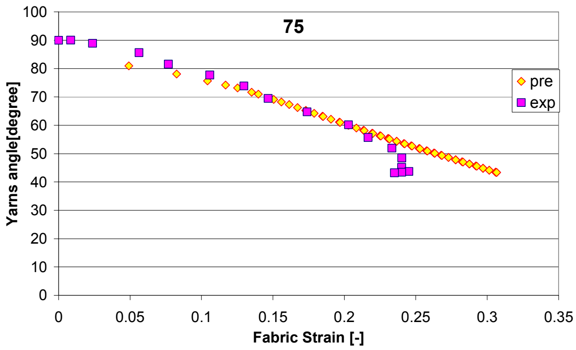

Figure 25- Comparison between predicted and measured values: Warp-weft yarns angle for force angle φ=75 °

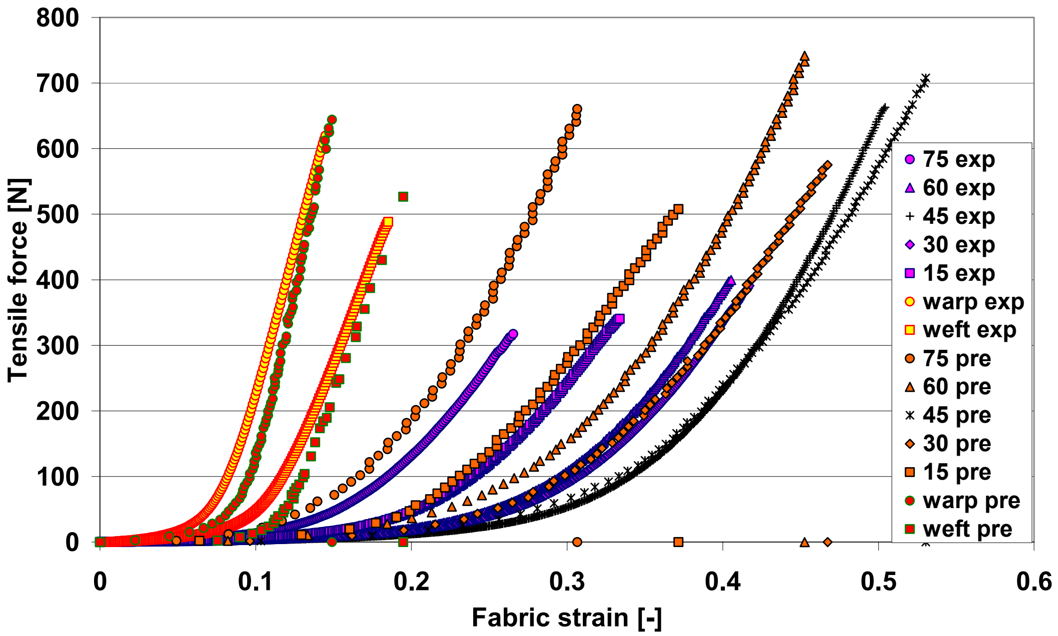

Figure 26- Comparison between predicted and measured values: tensile-strain curves of samples in different directions

5. Evaluation of results and of new knowledge (Zhodnocení výsledků a nových poznatků)

5.1 Geometry of fabric during bias deformation

Very simple geometrical model has been constructed with numbers of assumptions. This model had been utilized to evaluate geometry of a set non-deformed cotton fabrics. The comparison between tentative and estimated data indicates that this model is responsible in internal fabric geometry before deformation. Then this model is expanded to assess geometry of deformed fabric in bias direction by considering some more assumptions. To evaluate deformed fabric, the outcomes of this model had been compared with experimental work. It is found that suggested model reveal geometry of fabric as well as. Notwithstanding the capacities of this model to evaluate fabric geometry before and after deformation in bias direction, this geometrical model does not satisfy whole targets of our study. Consequently, a micro-mechanical model has been established.

5.2 Micro-mechanical model for evaluating fabric in arbitrary direction

When a woven fabric is subjected to stress in arbitrary direction then a complex behavior for the fabric can be anticipated. Relative rotation between yarns, crimp interchange in warp and weft yarns, yarns flattening, yarns extension etc. are the well known reactions of fabric's yarns when the fabric is suffering stress in arbitrary direction. For this purpose, deflection curve of a yarn under planar and normal forces has been determined by considering yarn bending stiffness and some assumptions. It has been demonstrated that the established model is successful to appraise tensile properties of fabric by comparing the empirical and theoretical data.

5.3 Developed methods

To investigate external geometry of woven fabric, the 2D FFT technique is modified and used effectively in this study. It is demonstrated that this technique can be employed to detect yarns shear angle and change yarns density during deformation. Moreover to evaluate flattening of tensioned yarn when it is subjected to normal force a simple method is suggested in this study. The exponential behavior in deformation of yarn cross-section under formal force is observed by applying this method. On the basis of a new concept, the jaws can equipped with capstan parts to apply tension on the sample gradually. The observations indicate that this method is more effective than the other solution to measuring tensile properties of woven fabric in arbitrary direction.

6. Works of author related to theses topics (Práce autora se vztahem ke studované problematice)

1- Conference Presentations:

- Tensile Properties of Plain Weave Fabric in Arbitrary Direction, Mehdi Kamali Dolatabadi, Radko Kovar, Monika Vysanska, 15th International conference STRUTEX, Liberec, Czech Republic, 2008.
- Contribution to Formulate Bending Rigidity of Tensioned Yarn, Mehdi Kamali Dolatabadi, Radko Kovar, TEXCOMP9 International Conference on Textile Composite, Delaware USA 2008.
- A Micromechanical and Geometrical Model of Tensile - Deformation Behavior of Plain Weave Fabric in Principal Direction, Mehdi Kamali Dolatabadi, Radko Kovar, The Fiber Society Fall Conference, Boucherville, Canada, 2008.
- Yarns tension distribution and rupture mechanism in narrow strip of plain weave fabric under bias stress. M. Kamali Dolatabadi, R. Kovar, Fall International conference and technical meeting of The Fiber Society, University of California at Davis, USA, 2007.
- Verifying a New Model for Geometry of Plain Weave Fabric. M. Kamali Dolatabadi, R. Kovar, J. Drasarova,14th International conference STRUTEX, Liberec, Czech Republic, 2007.
- On the relationship between plain weave fabric geometry and bias extension deformation. Part I: Initial state, 3D model of plain weave fabric before deformation, M. Kamali

Dolatabadi, R. Kovar, 6th International Textile Science conference (TEXSCI), Liberec, Czech Republic, 2007.

- On the relationship between plain weave fabric geometry and bias extension deformation. Part II: Shear state, 3D model of plain weave fabric under deformation. M. Kamali Dolatabadi, R. Kovar, 6th International Textile Science conference (TEXSCI), Liberec, Czech Republic, 2007.
- Angular deformation of warp-weft yarns in cut bias plain weave fabric under uniaxial load. M. Kamali Dolatabadi, R. Kovar, A. Linka, 13th International conference STRUTEX, Liberec, Czech Republic, 2006.

2- Patent and Publications in Journals:

- Modifying of jaws to reduce tension concentration at corners of fabric, Radko Kovar, Mehdi Kamali Dolatabadi, Pending Patent.
- Geometry of plain weave fabric under shear deformation Part I: measurement of exterior deformation, M. Kamali Dolatabadi, R. Kovar, A. Linka. *Journal of The Textile institute*. Under press, available at Forthcoming Articles 28 Jul. 2008.
- Geometry of plain weave fabric under shear deformation Part II: 3D model of plain weave fabric before deformation, M. Kamali Dolatabadi, R. Kovar. *Journal of The Textile institute*. Under press, available at Forthcoming Articles 28 Aug. 2008.
- Geometry of plain weave fabric under shear deformation Part III: 3D model of plain weave fabric under shear deformation, M. Kamali Dolatabadi, R. Kovar. *Journal of The Textile institute*. Under press, accepted for Publication 27 Nov. 2007.

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Resumé
Anizotropie tahových vlastností tkaniny v plátnové vazbě

Průmyslové využívání vlákenných struktur je v současné době na vzestupu. U textilních plošných výrobků se to týká především tkanin v plátnové vazbě, u které jsou sousední nitě provázány různě (osnovní vazné body sousedí jen s útkovými a naopak) a v porovnání s jinými textilními strukturami je tak provázanost extrémně veliká. Chceme-li získat pro koncového uživatele tkaninu se speciálními vlastnostmi, je potřeba zkoumat i její deformační chování v jiných nežli hlavních směrech, tj. ve směrech osnovních a útkových nití. Z tohoto důvodu se přiložená studie věnuje anizotropii deformačních vlastností tkaniny.

V rámci výzkumu anizotropie tahových deformačních vlastností tkaniny byl navržen model geometrie tkaniny před a po šikmé deformaci. Poté byl na základě posouzení deformace nitě úspěšně vyvinut další model, který hodnotí tahové deformační vlastnosti tkaniny v libovolném směru i mechanicky. Uvedený model počítá, kromě jiného, i s převodem amplitudy vazné vlny mezi osnovními a útkovými nitěmi, se zploštěním nití a s jejich ohybovou tuhostí. Nakonec je platnost modelu testována na skupině tkanin za pomoci měření tahových deformačních vlastností a vnější geometrie vzorků při zatěžování v různých směrech. Pro uvedené účely byla použita 2D FFT (Fast Fourier Transform) a modifikovaná metoda měření pevnosti a tažnosti tkaniny podle EN ISO 13934-1 s čelistmi upravenými tak, aby redukcí napětí vzorků v rozích upnutých do čelistí mohly být naměřeny věrohodnější výsledky (PV 2008-726). V některých případech byla modifikovanou metodou naměřena i více než trojnásobně větší pevnost nežli při použití standardního normovaného testu (viz příloha F disertační práce).

Bylo zjištěno, že první model se hodí pro hodnocení geometrie tkaniny před deformací a po deformaci v šikmých směrech. Experimenty rovněž prokázaly, že druhý model je vhodný pro predikci tahové deformační křivky při zatěžování vzorku tkaniny v určitém směru. Na grafu 26 jsou uvedeny typické modelové deformační křivky, získané za pomoci uvedeného modelu, a zároveň experimentálně změřené křivky pro bavlněnou tkaninu zatěžovanou v různých směrech. Rovněž bylo konstatováno, že geometrické parametry deformované tkaniny odpovídají parametrům, modelovým.

Zusammenfassung
Anisotropie bei Zugdehnungseigenschaften von Leinwandbindung

Heutzutage nehmen Anwendungen für Faser-Zusammenfügungen in der Industrie mehr und mehr zu. Im Rahmen von textilen Strukturen wird das Leinwandbindung-Gewebe verstärkt eingesetzt wegen individueller Garn-Anordnung und höchster Garn-Verflechtung.im Vergleich mit anderen Textilstrukturen. Um die individuellen Eigenschaften der Fasergewebe-Endnutzeranwendung zu erreichen ist es von großer Wichtigkeit, das Verhalten von Fasergewebe zur Achse zu verstehen. Daher wird die Richtungsabhängigkeit (Anisotropie) bei Zugdehnungseigenschaften von Fasergewebe in dieser Studie untersucht.

Um die Schwierigkeit der Richtungsabhängikeit bei Zugdehnungseigenschaften von Gewebe darzustellen, wurde ein Modell entwickelt, um die Gewebs-Geometrie vor und nach Deformation der Ausrichtung zu beurteilen. Anschließend wurde auf der Basis der Faser-Deformation ein mikro-mechanisches und geometrisches Modell erfolgreich eingeführt, um die Zugdehnungseigenschaften von Fasern in beliebiger Richtung zu ermitteln.

Der Garn-Einarbeitungs-Austausch, die Garn-Abflachung sowie die Biegeelastizität von Garnen wurden in diesem Modell eingehend betrachtet. Anschließend wurde die Direktion beider Modelle an einer Reihe von echten Geweben untersucht indem die Dehnbeanspruchung durch Zugdehnung sowie die äußere Geometrie von Geweben während der Deformation in verschiedenen Richtungen gemessen wurde. Zu diesem Zweck wurde die 2D FFT („Fast Fourier Transform“) als Bildverarbeitungsmethode angewendet und modifizierte Einspannbacken wurden eingesetzt, um den Belastungs-Schwerpunkt an den Ecken der Materialprobe zu reduzieren. Als Ergebnis stellt sich heraus, dass das erste Modell geeignet ist, um Gewebs-Geometrie vor und während der Deformation der Ausrichtung zu bewerten. Zudem wurde herausgestellt, dass das zweite Modell dafür verantwortlich ist, die Zugkraft-Belastung und die Gewebs-Geometrie vorherzusagen wenn ein Teil des Gewebes der Dehnung in einer bestimmten Richtung ausgesetzt ist.

Der Graph No. 26 stellt die typischen Ergebnisse von zweiten Modell und empirischen Messungen von Zugdehnungs- Kurven von einem Baumwoll-Gewebe dar, dass der Dehnung in verschiedene Richtungen ausgesetzt ist. Weiterhin wurde gezeigt, dass die geschätzte Gewebsgeometrie von diesem Modell mit experimentellen Werten vergleichbar ist.

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