Tensile Test of Motorcycle Garment Leather

T. Bońkowski[1,*], R. Kottner[1], J. Krystek[1], L. Hubík[2], T. Görner[3], L. Hynčík[1]

[1] *European Centre of Excellence, NTIS - New Technologies for Information Society, Faculty of Applied Sciences, University of West Bohemia, Univerzitní 8, 306 14 Plzeň, Czech Republic*

[2] *PSi Hubík, s.r.o., Daimlerova 3, 301 00 Plzeň, Czech Republic*

[3] *Regional Technological Institute, Faculty of Mechanical Engineering, University of West Bohemia, Univerzitní 8, 306 14 Plzeň, Czech Republic*

[*] *tomasz@ntis.zcu.cz*

Abstract: This work describes tensile tests of random selected leather samples. Tests were performed according to ISO 3376 standard. Dimensions of cross sections were measured (mean thickness = 1.4 mm, mean width = 19.8 mm) and then samples were grouped with a view on texture (with and without perforation). The aim of the tests was to obtain average strength and distribution of stiffness in the tested group of samples. Additionally cyclic (3 cycles) tests were performed. Three sets of Ogden model parameters were identified to obtain material models for the leather having minimum, average and maximum stiffness.

Keywords: leather; tensile test; motorcycle garment; ISO 3376; cyclic test; Ogden model.

1 Introduction

To create a realistic tool for motorcycle driver injury assessment, it is necessary to take into account influence of all types of personal protective equipment (PPE). Natural leather is the main material which is used to produce motorcycle protective garments. Therefore, the investigation of leather mechanical properties which allow the creation of the numerical model of the garments was the subject of this work. Since leather is a heterogeneous and anisotropic material with nonlinear behavior [2, 3, 4, 5, 6, 7], providing data for the numerical model is a complex problem. Moreover, application randomness of leather (treatment of leather, angle of cutting in the relation to the direction of majority of collagen fibers, the location of cutting in the relation to the part of an animals body, etc.) in the garment manufacturing process does the task more complicated.

2 Methodology

The study was carried out in order to obtain average strength and fit a constitutive material model of leather samples cut from a motorcycle garment. Moreover, differences of ultimate strength between samples having different texture were examined. Seven steps can be distinguished in the research methodology :

- samples preparation according to ISO [1] standard,
- determination of the sample texture and condition,
- measurement of real dimensions of the samples,
- uniaxial tensile tests (ultimate strength, cyclic response),
- experimental results evaluation and selection of 3 representative characteristics,
- fitting hyperelastic constitutive material model,
- validation of material model in finite element method (FEM) environments (Abaqus, Virtual Performance Solution $\langle$ VPS $\rangle$ - former PamCrash).

3 Samples Preparation

Samples of the leather were randomly cut from a motorcycle garment using a press knife. Fig. 1 describes the geometry of tested samples. "Large" dimensions series of samples were selected according to ISO [1] standard.

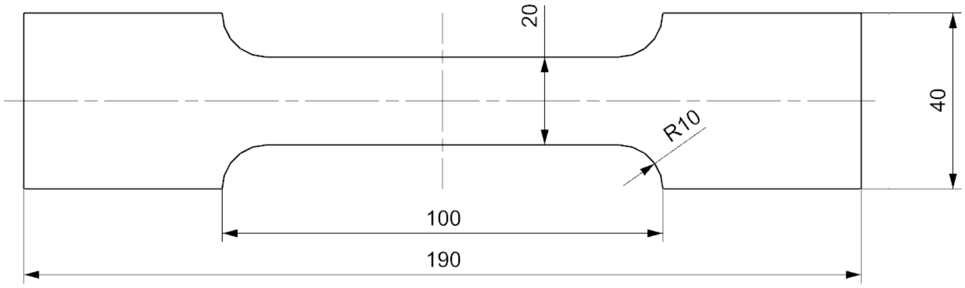
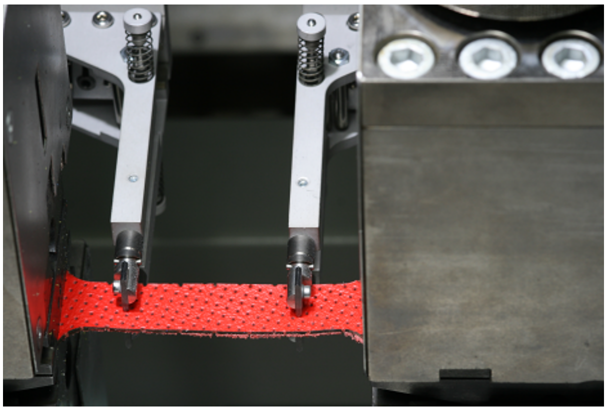


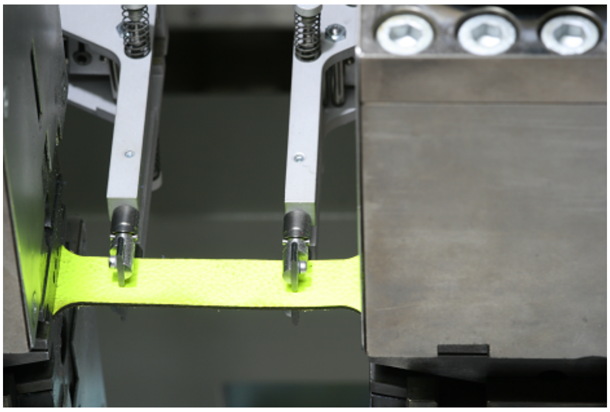
Fig. 1: Sample shape and dimensions [mm].

4 Sample Texture Determination

In addition to the protective function of motorcycle garments, different types of leather textures are used to provide thermal comfort. Specimens were grouped with a view on the texture (with and without perforation - Fig. 2).



(a) Perforated sample.



(b) Non perforated sample.

Fig. 2: Differences in samples texture.

5 Real Dimensions Measurement

The sample cross-section area is essential to obtain stress-strain relationship from force-displacement characteristics. Real dimensions (Tab. 1) of each sample (thickness, width) were measured using vernier calipers at three positions on the grain side and three on the flesh side.

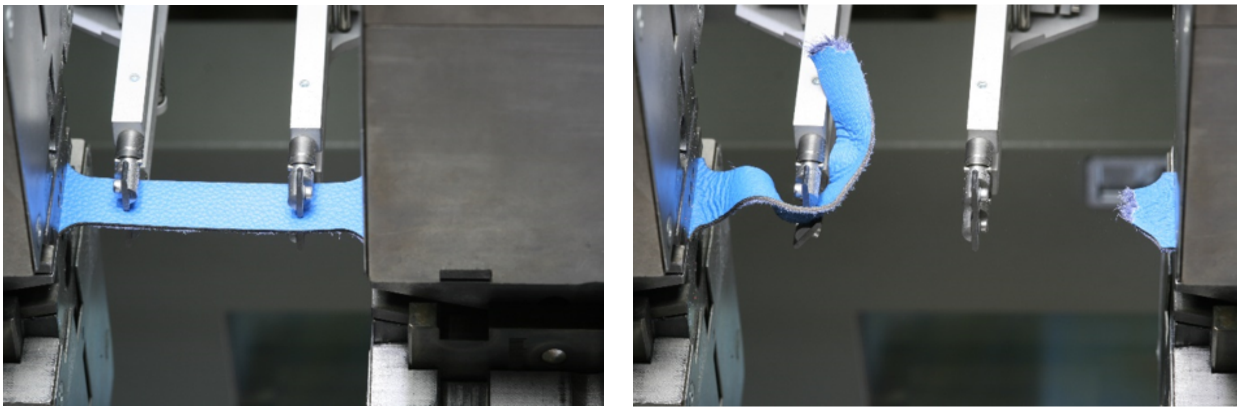
Tab. 1: Average dimensions of samples cross-section.

	mean thickness[mm]	mean width[mm]	mean area[mm^2]
non perforated samples	1.42	19.76	28.07
perforated samples	1.36	19.82	26.91

6 Uniaxial Tensile Test

6.1 Ultimate Strength Test

18 samples were selected for the ultimate strength test (Fig. 3). The test was performed with speed of 100 mm/min, temperature was equal to 23 °C, relative humidity was 50%. Preload of 1N was applied to each sample before the test.



(a) Sample before elongation (b) Sample after failure

Fig. 3: Ultimate strength test.

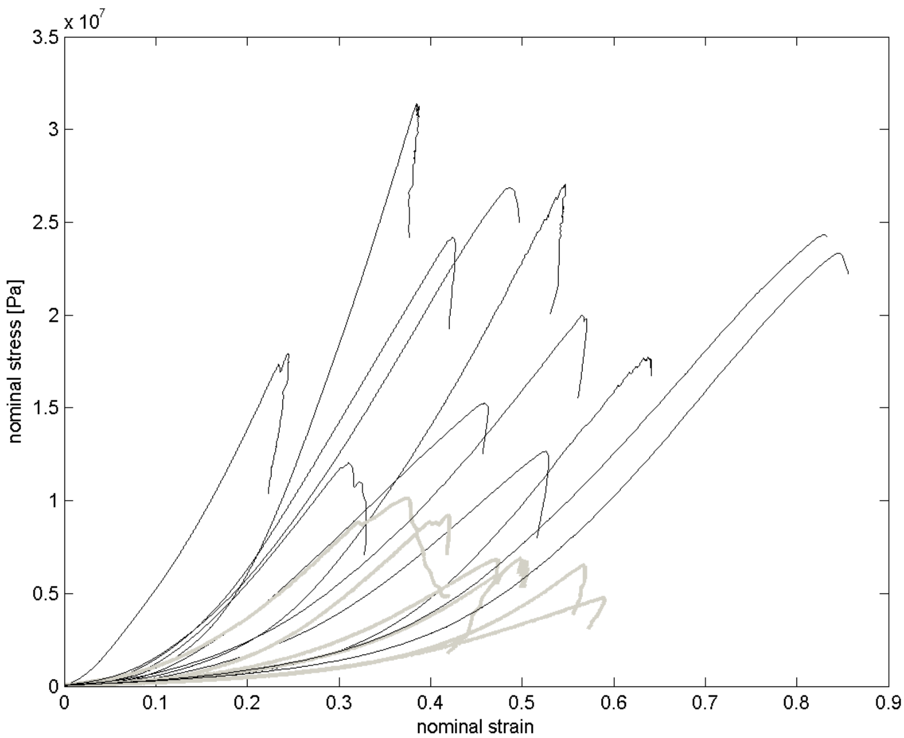


Fig. 4: Stress-strain curves (gray - perforated, black - non perforated).

Performed tests (Fig. 4) shown that leathers used to produce motorcycle protective garments have significantly inconsistent mechanical properties. Failure occurred in wide range of strains (0.23–0.86) and stresses (5–32 MPa). Non perforated samples had average ultimate strength approximately 21 MPa, average ultimate strength in case of perforated specimens was 3 times lower.

6.2 Cyclic Loading Test

Additional set of samples was tested using cyclic loading (3 cycles). Value of nominal strain 0.18 was prescribed as a upper limit for the cyclic loading. After reaching the upper limit of strain, testing machine was maintaining strain for 1 minute. Then a sample was unloaded with speed of 100 mm/min (Fig. 5).

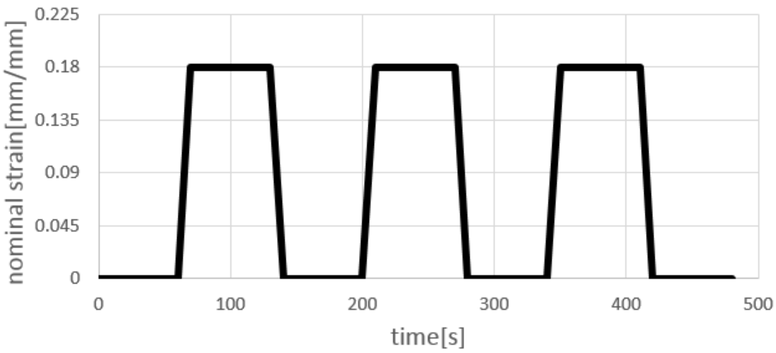
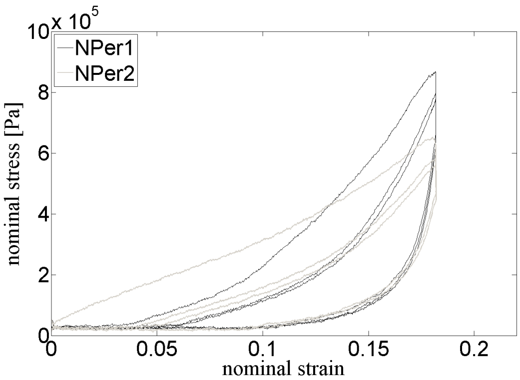
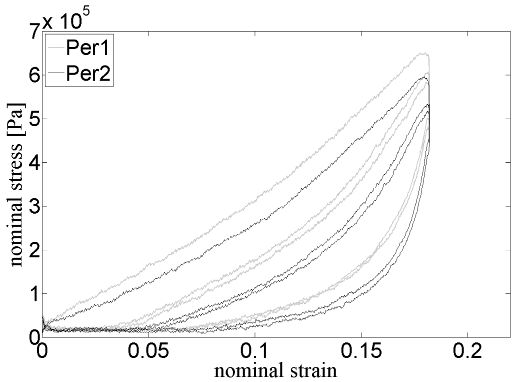


Fig. 5: Prescribed loading in cyclic test.

Temperature was equal to 21 °C and relative humidity was 46.5% during this test. Fig. 6 describes the behavior of specimens (representatives for each group) during the cyclic loading. It is obvious that plastic strain of 5.4% remained in the samples.



(a) Samples without perforation



(b) Samples with perforation

Fig. 6: Cyclic test response of representative samples.

7 Experimental Results Evaluation

In order to identify material model parameters, three (B2, Y3, Y4) experimental stress-strain characteristics were selected as representatives (Fig. 7). Each of the selected samples represented different stiffness:

- B2 sample - represented leather with highest stiffness,
- Y3 sample - represented leather with average stiffness,
- Y4 sample - represented leather with lowest stiffness.

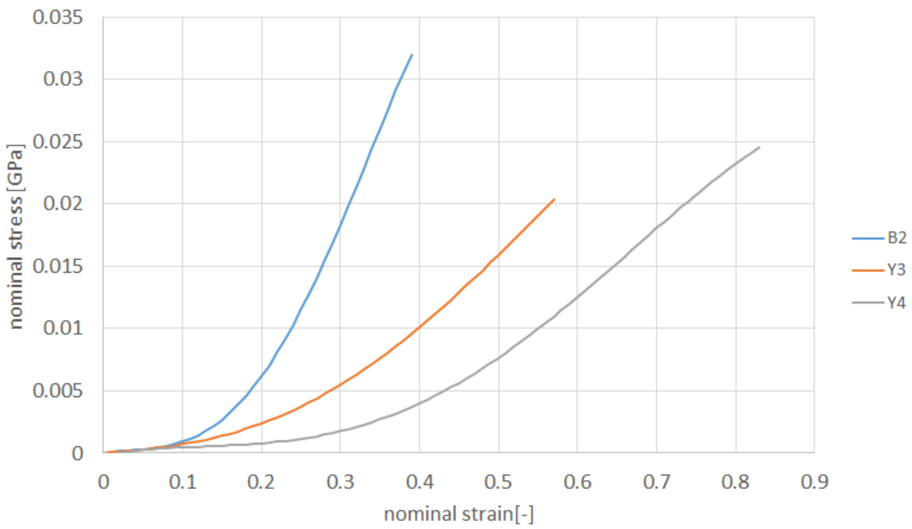


Fig. 7: Stress-strain curves of samples used to material model identification.

8 Hyperelastic Constitutive Model Fitting

The aim of these simulation was to fit a hyperelastic constitutive material model. With respect to the reference [2, 3, 5, 6], the Ogden hyperelastic material model was selected. The Hyperelastic constitutive material model using the Ogden formulation is based on the strain energy functional [8]:

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_{i=1}^{N} \frac{\mu_{i,o}}{\alpha_i} \left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) \tag{1}$$

where $\lambda_1, \lambda_2, \lambda_3$ are principal stretches, μ_i is Ogden parameter, α_i is Ogden exponent and N is model order. To determine the Ogden parameters from the tests, the material was assumed to be incompressible. The formulation with order N=1 was used.

In order to fit the model parameters to the experimental data, the linear least-square optimization method was used. The optimization was carried out under the build-in preprocessor of VPS (former PamCrash). The least square method minimizes the error in stress described by Eq. 2 [9]:

$$E = \frac{1}{2} \sum_{i=1}^{ND} \left(P_i^{test} - P_i^{derived}\right)^2 \tag{2}$$

where P_i^{test} is the measured nominal stress, $P_i^{derived}$ is the stress obtained from the strain energy functional W and ND is the number of experimental data points.

It should be noted that the implementation of the Ogden hyperelastic model is different in commercial software (VPS and Abaqus). The Basic description of strain energy functional (Eq. 1 [8]) assumes parameter μ_i in slightly different way than commercial implementations. The VPS solver describes the strain energy functional by the equation [9]:

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_{A=1}^{3} \sum_{i=1}^{N} 2\frac{\mu_{i,p}}{\alpha_i} \left(\bar{\lambda_A}^{\alpha_i} - 1\right) \tag{3}$$

where A are principal directions and $\mu_{i,p}$ is the Ogden parameter in the VPS implementation. On the other hand the Abaqus is using the Ogden model in the following formulation [10]:

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_{i=1}^{N} \frac{2\mu_{i,a}}{\alpha_i^2} \left(\bar{\lambda_1}^{\alpha_i} + \bar{\lambda_2}^{\alpha_i} + \bar{\lambda_3}^{\alpha_i} - 3\right) \tag{4}$$

where $\mu_{i,a}$ is the Ogden parameter in the Abaqus implementation. To harmonize results of the parameters optimization, a correlation table has been developed (Tab. 2).

Tab. 2: Correlation of Ogden model parameter between different implementation.

	Ogden	VPS(PamCrash)	Abaqus
Ogden		$\mu_o = 2\mu_p$	$\mu_o = 2\frac{\mu_a}{\alpha}$
VPS (PamCrash)	$\mu_p = 0.5\mu_o$		$\mu_p = \frac{\mu_a}{\alpha}$
Abaqus	$\mu_a = 0.5\alpha\mu_o$	$\mu_a = \alpha\mu_p$	

9 Model Validation - FEM Simulation

In order to validate the material model, the simulations were performed in FEM the commercial software. Fig. 8 presents comparison between the numerical simulations (solid lines) and experimental data (dashed lines) for the three selected representatives samples. Material models sufficiently reflects the behavior of samples.

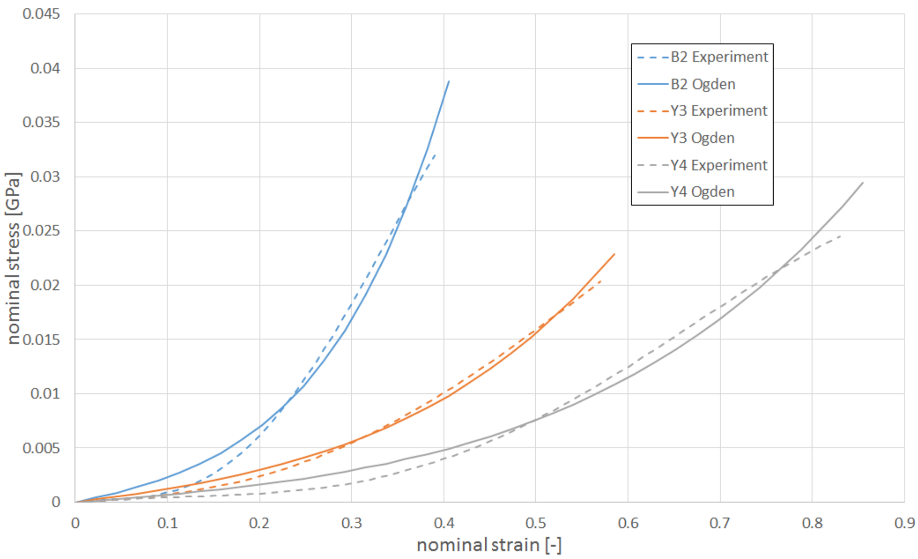


Fig. 8: Comparison between model and experiment.

Tab. 3: Identified Ogden parameters.

		B2	Y3	Y4
μ	VPS [GPa]	5.1360E-04	4.7720E-04	2.9530E-04
	Abaqus [GPa]	6.0040E-03	3.7747E-03	2.1640E-03
	Ogden [GPa]	1.0272E-03	9.5440E-04	5.9060E-04
α	VPS [-]			
	Abaqus [-]	1.1690E+01	7.9100E+00	7.3280E+00
	Ogden [-]			

10 Conclusion

The Average ultimate tensile strength of non perforated leather was approximately 21 MPa. Perforated samples had the average ultimate strength 3 times lower than non perforated. 5.4% of plastic strain remains in the leather samples during cycling loading with maximum strain on 0.18. The Cross-solver correlation table for the Ogden model has been developed. Ogden model parameters of the three samples were identified (Tab. 3). The model was validated using numerical simulations of performed tests.

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