Experimental Research and Modeling of the Air-Bag Fabric Material

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Abstract

The response of the typical airbag's material has been extensively studied under conditions of simple tensile tests and bias extension probes, from both experimental and numerical viewpoints. The work presented here is related to the measurements of the deformation characteristics of PA 6.6 textile fabric under conditions of simple and bias extension. Obtained results confirmed that the global behavior of the investigated material can be predicted with reasonable accuracy.

Keywords: airbag's material, modeling, experiments

1. Introduction

Airbags are one of the most important elements of vehicle's passive safety system. The main objective of these inflatable cushions is to passengers against the effects of collisions. Generally, a classical air bag system consists of a gas generator (inflator) and flexible container (cushion made of woven nylon-cotton or nylon impregnated rubber neoprene). Activation of the air bag is initiated by special sensors (mainly inertial) placed in various parts of the vehicle. The purpose of sensors is to identify the strength and direction of the impact and consequently the activation of the proper cushions. Airbag opens a few thousandths of a second after the start of the crash. The Passenger body accelerated by crash forces impacts the air bag and pushes the gas out of the cushion, which escapes through the simple hole or controllable valve.

During the collision the airbag's material is not only subjected to a complex stress state. Fabrics developed for the most critical use of all, preserving life during car accidents, should have besides high tensile strength also appropriate heat resistance and low air permeability.

In this paper the authors investigate the suitability of the fabric material's model, implemented in the LSDyna environment, and the strategy is proposed for determining the materials characteristics required to capture the real behavior of the textile structure. The behavior of the typical woven material has been studied
under conditions of uniaxial and bias extension tests, from both experimental and numerical points of view.

To gain acceptable results of an air-bag fabric material modeling, it is necessary to perform a wide range of experiments [Johnson, 1999]. Besides the standard uniaxial tension tests under various directions, it is also recommended to perform a bias extension and biaxial tests. Basing on the direct experimental data force in function of displacement characteristic are obtained. After that it is necessary to transform the data to appropriate stress and strain tensors.

In this work the research of simple extension and bias extension tests are presented. Data from experiments were transformed to II Piola-Kirchhoff stress tensor and Green-Lagrange strain tensor. Having prepared appropriate material's characteristics, the airbag woven material was modeled in LS-Dyna environment.

2. Tests

Generally two main experiments are conducted to gain the shear characteristics of the textile material. The most popular is the picture frame test [Mohammed et al. 2000, Potter, 2002]. In such a test the testing piece is clamped in a special swivel frame [McGuinness et al., 1999]. Directions of the investigated fibers are parallel to the arms of the rig. The frame is pinned at the four corners and consequently forces shear behaviour onto the specimen. Although such an experiment eliminates lot of problems related to the fiber slippage, but any misalignment between the fiber and the frame has a strong effect on the experimental data [McGuinness, Bradaigh, 1997].

The other, applied in the presented paper experiment is to use a simple tensile test of a strip of the textile cut on the bias to the test direction. For investigated material this equates to ±45. This measurement technique has been described in details in Wang et al. [Wang et al., 1998]

The work reported here was carried out on a PA 6.6. textile fabric. Such material was taken into consideration as this material was of prime interest to the next stage of the research - developing an innovatory shape of the airbag for the special applications.

Two various types of material samples were prepared. For the purpose of simple extension tests the oar-shaped specimens were provided. The testing pieces for bias-extension probes were in a rectangular shape with additionally reinforced ends. The schemes of the material samples are illustrated in Figs. 1 and 2.
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2.1 Simple extension test

Experimental research was carried out using universal MTS testing machine. The simple extension tests were performed on five experimental samples (Fig. 1). Since the samples were oar-shaped, it was not appropriate to calculate strains using simple yaws displacement measured by the testing machine. On the other hand, strain measurements made on the basis of classical extensometer could introduce some measuring inaccuracies of the real material's behavior, mainly because of the extensometer's weight, in comparison to investigated fabric's stiffness. Having in mind the previously mentioned problem the authors decided to collect the strain data using the non-contact 3D deformation measuring system ARAMIS (which is basing on the optical data acquisition system. The signals from the testing machine sensors were sent to the ARAMIS environment and as a result it was possible to plot the force charts, which were provided by the testing machine, in a function of engineering strain, calculated by the ARAMIS system. A typical characteristic acquired for a simple extension test is depicted in Fig. 3.
Fig. 3 Typical force vs. strain characteristic obtained for simple extension test

The strain measurements in this case were analogous to classic measurements performed by the extensometer – difference in distance between two selected points was defined. This type of survey gave the information of strains only in selected points, while the distribution of strain in the tested samples does not have to be uniform. ARAMIS system enabled strain measurements not only in a special point but in a whole sample what is an obvious advantage over classical tests performed using extensometer.

Fig. 4 Strain fields recorded by the ARAMIS system

In Fig. 4 the typical strain fields of investigated material calculated by ARAMIS system is illustrated.
2.2 Bias extension test

As it was previously mentioned the bias extension tests were performed to gain the shear characteristic of the material [Harrison, 2004]. Because the samples had a rectangular shape, and additionally stiffness in this direction is much lower than the testing machine's stiffness the authors decided to assume that the strains were calculated directly from the machine’s jaws displacement. In discussed tests three samples were investigated. Acquired results have been depicted in Fig. 6.

![Fig. 6. Force in function of jaws displacement measured during bias extension test](image)

3. Transformation of the experimental data in II Piola-Kirchhoff stress tensor and II Green–Lagrange strain tensor

In the next part of the paper only experiments related to simple extension tests will be investigated.

For the appropriate modeling of mechanical behavior of the textile fabric in LsDyna environment it was necessary to transform the direct experiment data into II Piola-Kirchhoff stress tensor and Green–Lagrange strain tensor. In this part of the work the transformation equations are presented.

From the definition, the II Piola-Kirchhoff stress tensor is described by

\[
\mathbf{T} = \mathbf{F}^{-1} \cdot \mathbf{T}_0
\]  

(1)

where: \( \mathbf{F} \) – deformation gradient,
\( \mathbf{T}_0 \) – I Piola-Kirchhoff stress tensor.
To determine the deformation gradient it is necessary to define the equations for the deformed body. In the further part of the paper the deformed body is described by a lower case, whereas undeformed body by capital letters. Fig. 7 depicts the configuration of deformed and undeformed bodies.

The configuration of deformed body can be calculated as:

\[ x_1 = \frac{h}{H} \cdot X_1 \]  
\[ x_2 = \frac{l}{L} \cdot X_2 \]

Basing on (2) and (3) the deformation gradient may be written in the form

\[ F_{ij} = \frac{\delta x_i}{\delta X_j} \]

\[
F = \begin{bmatrix}
\frac{h}{H} & 0 \\
0 & \frac{l}{L}
\end{bmatrix}
\]  

The I Piola-Kirchhoff stress tensor \( T_0 \) for the uniaxial tensile is given by

\[
T_0 = \begin{bmatrix}
0 & 0 \\
0 & \frac{f}{A_0}
\end{bmatrix}
\]
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\[
\mathbf{T} = \begin{bmatrix}
  \frac{H}{h} & 0 \\
  0 & L/l \\
\end{bmatrix}
\begin{bmatrix}
  0 & 0 \\
  0 & \frac{f}{A_0} \\
\end{bmatrix}
= \begin{bmatrix}
  0 & 0 \\
  0 & \frac{L}{l} \cdot \frac{f}{A_0} \\
\end{bmatrix}
\]

(8)

The component 22 of above tensor after gentle modification can be calculated from

\[
(\mathbf{T})_{22} = \frac{f(\varepsilon_{\text{eng}})}{A_0} \cdot \frac{1}{1 + \varepsilon_{\text{eng}}}
\]

(9)

where: \(\varepsilon_{\text{eng}}\) - engineering strain,
\(A_0\) - initial cross section of the investigated sample.

From the definition the II Green-Lagrange stress tensor is

\[
\mathbf{E} = \frac{1}{2} \cdot (\mathbf{C} - \mathbf{I})
\]

(10)

where: \(\mathbf{C} = \mathbf{F}^\mathsf{T} \cdot \mathbf{F}\), 
\(\mathbf{I}\) - identity matrix.

Substituting \(\mathbf{C}\) and \(\mathbf{I}\) for (10) the above equation will be equal

\[
\mathbf{E} = \frac{1}{2} \cdot \begin{bmatrix}
  \frac{h^2}{H^2} - 1 & 0 \\
  0 & \frac{l^2}{L^2} - 1 \\
\end{bmatrix}
\]

(11)

The element 22 of the tensor (1) can be written in the form:

\[
(\mathbf{E})_{22} = \frac{1}{2} \cdot (1 + \varepsilon_{\text{inz}})^2 - \frac{1}{2}
\]

\[
(\mathbf{E})_{22} = \frac{1}{2} \cdot (1 + \varepsilon_{\text{eng}})^2 - \frac{1}{2}
\]

(12)

Formulas (9) and (12) enabled a transformation of the direct experimental data acquired from the uniaxial tests (engineering stress and strain) into II Piola-Kirchhoff stress tensor and II Green-Lagrange strain tensor. In Fig. 8 the differences between stress-strain curves described in a different way are depicted.
4. Modeling

To model the real mechanical response of considered fabric material in the LS-Dyna environment the material model MAT_FABRIC (#34) was used [Hirth et al., 2007]. This material model has been developed for many years starting from the simple linear constitutive law and ending on the latest implementation with a nonlinear biaxial loading and unloading curves. The newest model of the material allows to simulate the porosity of the structure where the gas flows out [Schlenger, 2010].

Fig. 8 Characteristics of the investigated material in various configurations

Fig. 9. Verification of numerical and experimental data

In order to ensure that the investigated air-bag's material model works correctly the comparison between simulation and experimental research was done.
Based on geometrical dimensions of the tested samples FE models were prepared. The material data obtained in experiments were implemented to FE model. Additionally, it was necessary to define the main orthotropic direction of the material. When FE model was completed the analysis were performed using explicit Ls-Dyna code. As a result it was possible to verify the experimental and numerical results.

The comparison of the numerical model's response and direct experimental data is depicted in Fig. 9.

5. Conclusions

In this paper the authors focused on the experimental research and numerical modeling of the typical textile material suitable for the air-bags.

To perform numerical tests in LS-Dyna environment, nonlinear materials characteristics have to be provided. Such characteristics are obtained on the basis of experimental tests. The range of the paper was restricted to simple uniaxial tensile tests. For the considered case, it was shown how to transform the experimentally determined engineering stress-engineering strain characteristics into required II Piola-Kirchhoff stress tensor vs. II Green-Lagrange strain tensor. Such characteristics enabled calibrating a numerical model implemented in LS-Dyna software. Each of numerical simulations that were carried out in this paper were correlated with experiment. Obtained results confirmed the correctness of the proposed approach. Observed in Fig. 9 differences between the real and simulated responses of the material in a simple uniaxial test are negligible. The calibrated material model can be used in the design process for air-bags for industry.

In the further work it would be desirable to perform bi-axial tension tests and attempt to model the material's behavior with reverse engineering method, using specialized tools for optimization, like Ls-OPT [Dubois D., Forsberg J., 2013] to identify the material mode.

References


