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Static Identification Tests of Auxetic Fabrics

Piotr Szurgott, Marian Klasztorny, Tadeusz Niezgoda, Danuta Miedzińska, Andrzej Kiczko
Katedra Mechaniki i Informatyki Stosowanej, Wydział Mechaniczny, Wojskowa Akademia Techniczna
email: piotr.szurgott@wat.edu.pl, marian.klasztorny@wat.edu.pl, tadeusz.niezgoda@wat.edu.pl,
danuta.miedzinska@wat.edu.pl, andrzej.kiczko@wat.edu.pl

ABSTRACT: Static identification experimental research on four selected auxetic fabrics were conducted in terms of the tensile test in the auxetic fibres direction. A new methodology of such tests was developed, based on capstan brackets as well as on video-extensometer and extensometer technology. The identification tests were carried out at temperature of 20°C and 180°C due to planned using of an auxetic fabric as a protection curtain against a shock wave induced by gas explosion. An ultimate tension force per unit width of a fabric, effective Poisson's ratios in the fabric plane and in the transverse plane, and the absorbed energy were determined. An auxetic fabric with the best energy-absorption properties, recommended for explosion-proof applications, was identified on the basis of the comparative analysis.

KEYWORDS: auxetic fabric, material properties, tensile test, static identification, energy absorption

1. Introduction

An auxetic fabric, composed of auxetic yarns as a warp and ordinary fibres as a weft, is considered. The fabric is of a plain weave type. An auxetic fibre is wound in a double helix, and contains a thin high-stiffness, high-strength spiral wrap and a thick elastomeric core. Under tension in the yarn direction, the spiral wrap tends to straighten, which causes bending of the the core resulting in a negative effective Poisson's ratio. Hence, the elastomeric core absorbs energy by bending itself. Changes in the wrap angle during tension of the auxetic fibres result in a Young's modulus and Poisson's ratios depended on strain [1].

Components of an auxetic fabric are well-known materials with positive Poisson's ratios. A negative effective Poisson's ratio is caused by geometrical configuration of the components of significantly different mechanical properties.

The main advantages of auxetic materials are as follows [2]: increased shear stiffness, a double synclastic curvature in bending, increase in the fracture strength, increased resistance to dents, and increased damping.

2. Fabrics specification and experimental research methodology

Four types of auxetic fabrics commercially available in England are considered in the current study. Their components are listed in Table 1.

Experimental identification research concerns the tensile test in the auxetic fibres direction. The tests were carried out using an INSTRON 8862 testing machine. Capstan roller brackets LaborTech TH224080 type were used. This method of attachment is used to test seat-belts since it eliminates the tension-compression state at the ends of strip samples. A fabric strip is wound on two rolls of a 40 mm diameter and 80 mm length. Two wraps of the strip on the rolls were performed.

The displacement-controlled tests were conducted at 50 mm/min velocity of the crosshead. The signals were recorded with a frequency of 25 Hz until the capacity loss of the sample. The tests were carried out at temperature of 20°C (T_1) and 180°C (T_2). For the tests at elevated temperature, the environmental temperature was raised at a 1 K/min rate and then the sample was left for 5 minutes at 180°C in a thermal chamber. The following devices were used to perform the tests:

- a video-extensometer (a Phantom v12 high-speed camera) to measure the longitudinal and transverse strains, based on four 2×2 mm square markers painted on a fabric strip and the TEMA software used for the identification;
- an extensometer with platelets at the ends for the strain measurement in the thickness direction of the fabric;
- a thermal chamber assembled with an INSTRON 8862 testing machine.

The following principal directions of an auxetic fabric are assumed: 1 – auxetic yarns direction, 2 – warp direction, 3 – thickness direction. Dimensions of fabric samples are: L_0 = 700 mm, B = 80 mm, L = 200 mm, l = 100 mm, b = 60 mm. Fastening of a fabric sample using capstan roller brackets and location of test markers is illustrated in Fig. 1, where: E – extensometer, VE – video-extensometer, c – roller radius.

Table 1. Components and some properties of auxetic fabrics (AF) selected for experimental tests

Parameter		Auxetic fabric			
		AF1	AF2	AF3	AF4
warp fibres		DuPont Kevlar 29 (3000 den)	glass fibre with stainless steel wire inclusions	para-aramid Twaron Type 2200 (1100 dtex)	ballistic Nylon 6-6 HT (940 dtex)
auxetic yarns	spiral wrap	DuPont Kevlar 129	DuPont Kevlar (777 dtex)	Twaron Type 2200 (1100 dtex)	Honeywell Spectra 1000 (375 den)
	elastomeric core	0.6 mm diameter, elastomeric polyester monofilament (1000 den)			
weight		700 gsm	820 gsm	650 gsm	650 gsm
remarks		—	higher fire resistance	—	resistant to UV radiation

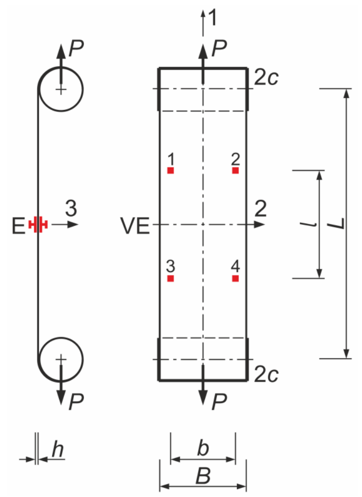

Fig. 1. Fastening of fabric sample using capstan roller brackets and location of test markers

3. Results of experimental tests and their analysis

Figure 2 shows graph of a force intensity S_1 as a function of an elongation Δl at room temperature. Based on these graphs, the following quantities were determined: the maximum tensile force in the 1-direction per unit length of the fabric in the 2-direction (force intensity, $S_{1\max}$), energy absorbed E_{a1} at tension of section l in the 1-direction, per unit length of the fabric in the 2-direction, up to capacity point $S_{1\max}$. Fig. 3 presents graph of effective transverse Poisson's ratio $\nu_{13}(\varepsilon_1)$ determined as contraction in the 3-direction at stretching in the 1-direction.

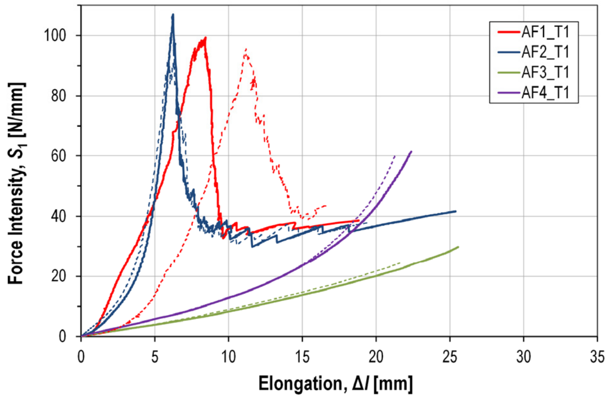

Fig. 2. Influence of fabric type on $S_1(\Delta l)$ graph. Tests at room temperature: sample 1 – solid line, sample 2 – dashed line

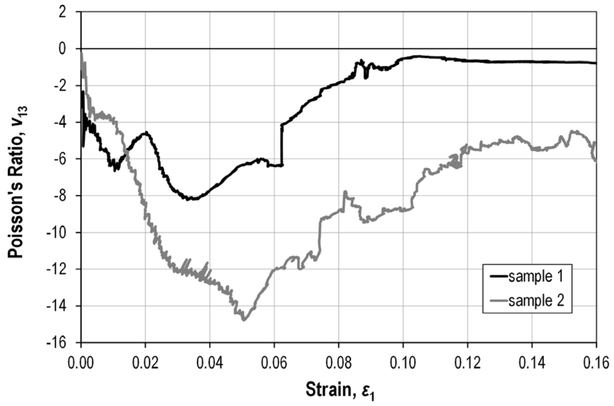

Fig. 3. Graph of effective Poisson's ratio $\nu_{13}(\varepsilon_1)$ for AF1 auxetic fabric. Tests at room temperature

Table 2 lists the following output quantities of the tested fabrics: ultimate tensile force per unit width of the fabric sample, $S_{1\max}$, variation ranges of effective Poisson's ratios, absorbed energy E_{a1}.

Table 2. Results of tensile test of AF1–AF4 auxetic fabrics

Fabric / Temp.		$S_{1\max}$ [N/mm]	range $\nu_{12}(\varepsilon_1)$	range $\nu_{13}(\varepsilon_1)$	E_{a1} [J/m]
AF1	T_1	97.5	(+0.15; +1.53)	(–11.5; –0.58)	334
	T_2	74.8	(+0.07; +1.79)	(–6.77; –0.57)	170
AF2	T_1	100.0	(–3.20; +0.72)	(–11.4; –1.90)	156
	T_2	79.6	(–0.11; +0.57)	(–6.76; –0.03)	182
AF3	T_1	27.2	(–0.24; +0.83)	(–5.01; +1.30)	273
	T_2	14.8	(–5.83; +0.22)	(–0.03; +5.58)	164
AF4	T_1	60.8	(–0.35; +0.52)	(–4.02; +0.69)	410
	T_2	6.5	(–0.42; +0.24)	(–0.02; +1.25)	109

4. Conclusions

Experimental static identification tests conducted within the current study concern four auxetic fabrics. Tensile tests in the auxetic fibres direction have been performed. The methodology of such tests, based on capstan brackets and video-extensometer and extensometer technology, has proven effective in determining the ultimate tension force per unit width of a fabric, the effective Poisson's ratios in the fabric plane and in the transverse plane, and the energy absorbed by a fabric.

It was reported that an effect of the negative Poisson's ratio is greatly disturbed in an orthogonal woven fabric with an auxetic weft. The tense string effect induced blocking the negative in-plane Poisson's ratio effect. On the other hand, the negative transverse Poisson's ratio effect was not blocked.

The fundamental characteristic obtained as a result of the stretching tests is a graph of the tension force intensity versus elongation of the measuring section, $S_1(\Delta l)$.

The AF1 fabric has been rated as the best for explosion-proof applications due to the following advantages: a high load capacity (force intensity), extremum negative values of Poisson's ratio $\nu_{13}(\varepsilon_1)$, maximum energy absorption, and high resistance to temperatures up to 180°C.

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