AIR PERMEABILITY AND PHYSICAL-MECHANICAL PROPERTIES OF FABRICS FOR PRODUCTION OF AIRBAGS IN AUTOMOBILES

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ABSTRACT: *This paper describes the analysis of raw material composition and structural parameters on the mechanical properties of fabric for the production of airbags. It is about polyamide and polyester fabrics. The breaking force and breaking elongation measurements were performed on a dynamometer, while air permeability measurements were performed on an air permeability device. Five different measurements were taken for each sample and the mean values were determined. All sample analyzes were conducted in a standard atmosphere and the samples were left for 24 h before testing. The mechanical characteristics of fabrics depend on their structural parameters, as well as on the technological conditions of fabric production in the weaving process. Fabric tearing is mainly the result of individual fibers tearing. In fabrics, individual fibers or threads are interwoven, so the application of an external load leads to a rearrangement of the fabric structure, which to a greater or lesser extent results in the stretching of fibers and threads along the axis, which results in anisotropy of mechanical properties. It is noticeable that higher breaking force values were observed for polyamide fabric compared to polyester fabric. Higher breaking force values were observed for the polyamide fabric. Higher air permeability is noticeable with polyester fabric*

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Keywords: *airbags, mechanical properties, fabric, air permability.*

PROPUSTILJIVOST VAZDUHA I FIZIČKO-MEHANIČKA SVOJSTVA TKANINA ZA PROIZVODNJU VAZDUŠNIH JASTUKA U AUTOMOBILIMA

APSTRAKT: *U radu je opisana analiza sirovinskog sastava i strukturnih parametara u odnosu na mehanička svojstva tkanine za izradu vazdušnih jastuka u automobilima. Reč je o poliamidnim i poliesterskim tkaninama. Merenja prekidne sile i prekidnog izduženja su obavljena su na dinamometru, a merenje propustljivost vazduha na uređaju za propustljivost vazduha. Za svaki uzorak obavljeno je pet različitih merenja i određene su* *srednje vrednosti. Sve analize uzoraka urađene su u standardnoj atmosferi i uzorci su ostavljeni 24 h pre ispitivanja. Mehanička svojstva tkanina zavise od strukturnih parametara, kao i tehnoloških uslovima proizvodnje tkanina u procesu tkanja. Kidanje tkanine je uglavnom rezultat kidanja pojedinačnih vlakana. U tkaninama su pojedinačna vlakna ili niti isprepletena, pa primenom spoljašnjeg opterećenja dolazi do menjanja strukture tkanine, što u većoj ili manjoj meri rezultira rastezanjem vlakana i niti duž osi, što rezultira anizotropijom tkanine mehaničkih svojstava. Primetne su veće vrednosti prekidne sile za poliamidnu tkaninu u poređenju sa poliesterskom tkaninom. Vrednosti prekidnog izduženja su veće vrednost za poliestersku tkaninu u poređenju sa poliamidnom tkaninom. Kod poliesterske tkanine uočene su veće vrednosti propustljivosti vazduha.*

Ključne reči: *vazdušni jastuci, mehanička svojstva, tkanina, propustljivost vazduha.*

1. INTRODUCTION

Polyamide is widely used because of their excellent properties such as the possibility of processing and low cost. Despite this widespread use, polyamide suffers various types of degradation that lead to major modifications of their mechanical properties during use [1-3].

Polyester fiber is, by definition, a fiber composed of linear macromolecules that have at least 85% by weight of diol ester and terephthalic acid in the chain. Regardless of the properties achieved during spinning, polyester fibers have a relatively high degree of crystallinity and therefore low absorption of water and moisture from the air [4].

Air bags are designed to act as an additional safety device in addition to the seat and seat belts. There is a significantly greater reduction in moderate to severe head injuries for people who use airbags and seat belts together than for people who use only seat belts, compared to drivers who do not use seat belts [5, 6].

Over the last two decades, the airbag has become an essential safety device in cars. The airbag is composed of a woven fabric that inflates quickly during a crash. It disperses the passenger's kinetic energy and thus reduces injuries and the escape of gas through the ventilation openings. Thus, the performance of the airbag is greatly influenced by the mechanical properties of the fabric [7].

Air permeability is a very important factor in the performance of a textile material. It is particularly considered for clothing, parachute sails, vacuum cleaners, airbag fabrics and industrial filter fabrics. Air permeability mainly depends on fabric mass and construction (thickness and porosity) [8].

The air permeability of a fabric is a measure of the passage of air through the fabric itself. Air permeability is important for technical textiles, the standard measure of air permeability is the speed of air passing through the sample depending on its surface and pressure drop [9].

The aim of this paper is to compare the most important properties of raw polyester and polyamide fabric for the production of airbags. It is about analyzing the different properties of these two fabrics in controlled laboratory conditions. Fabrics used to make airbags must have high density, good wear resistance, high level of durability.

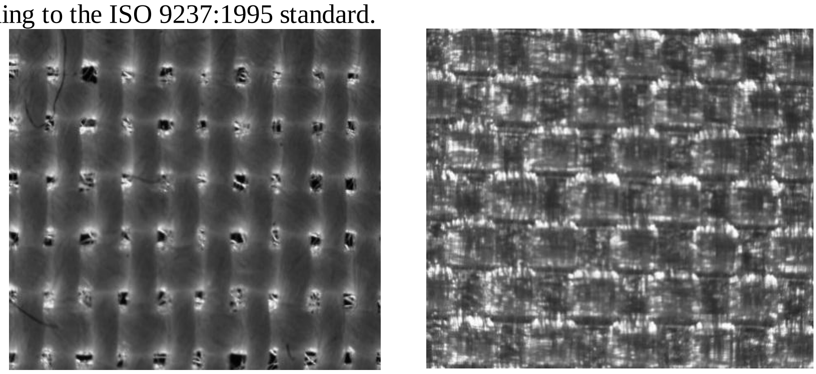
2. MATERIALS AND METHODS

In the experimental part, two types of fabric were used: 100% raw polyester fabric (PES) and 100% raw polyamide fabric (PA). The fabrics were kindly obtained from a textile factory (Autostop Interiors, Leskovac). The basic characteristics of raw polyester and polyamide fabrics are given in table 1.

Table 1: Basic characteristics of raw polyester and polyamide fabric

Properties		PES fabric	PA fabric
Longitudinal mass of yarn, tex	warp	66	56
	weft	70	46
Wire density, cm^{-1}	warp	19	18
	weft	15	18
Surface mass, $g \cdot m^{-2}$		233	217
Interlacement		Linen	Linen

Figure 1 shows a microscopic image of samples of (a) raw PES fabric and (b) raw PA fabric. The thickness of the PES fabric sample was 0.35 mm, and that of the PA fabric was 0.40 mm. A stereomicroscope (Leica M50 stereomicroscope, Germany) was used to record the samples (figure 1). Fabric samples were 10 × 10 cm in size. The surface of the test tube was 5 cm^2. This samples used to measure the air permeability.
The fabric samples used to measure the breaking force were 25 mm × 200 mm in size. The width of the test tubes was reduced from 50 mm to 25 mm due to the range of the dynamometer which is 5 kN. The speed of movement was 300 mm/min. Breaking force measurements were performed on a dynamometer (Tinius Olsen H5KS, Horsham, USA) according to the ISO 9237:1995 standard.



(a) (b)

Figure 1: Microscopic image of a raw sample of (a) polyester and (b) polyamide fabric

The methods for checking the properties of importance are as follows:

● Air permeability measurements, device Air permeability tester - SDL M021S according to standard EN ISO 9237:1995. The pressure at which the samples were tested was varied: 200 Pa, 400 Pa, 600 Pa, 800 Pa, 1000 Pa and 1200.

● Weaving is calculated according to the equation [10]:

$$u = \frac{l-L}{l} \cdot 100\ (\%) \tag{1}$$

where: l is the length of the straightened thread (mm), L is the length of the test tube section (mm).

● The linear filling of the fabric, filling by warp and weft, (l_o) and (l_p), are determined according to the following equations [11]:

$$L = l_o + l_p \tag{2}$$

$$l_o = \frac{d_o \cdot g_o}{10} \tag{3}$$

$$l_p = \frac{d_P \cdot g_P}{10} \tag{4}$$

where: d_o – conditional warp diameter (mm), d_p – conditional weft diameter (mm), g_o – warp density (cm^{-1}), g_p – weft density (cm^{-1}).

● Fabric void (C) is calculated using the following equations [12]:

$$C_o = 1 - I_o \tag{5}$$

$$C_p = 1 - I_p \tag{6}$$

$$C = C_o + C_p \tag{7}$$

● The surface coverage of the fabric (IA), is calculated using the equation [13]:

$$I_A = I_o + I_p - I_o \cdot I_p \tag{8}$$

where: I_o - surface filling of warp, I_p - surface filling of weft.

● The volumetric mass of the fabric (γ) is calculated as [13]:

$$\gamma = \frac{M \cdot 10^{-4}}{h}\ (g \cdot cm^{-3}) \tag{9}$$

where: h - thickness of the test tube (cm), M - surface mass of the fabric (g·m^{-2}).

● The porosity of the fabric (P) is determined according to the equation [14]:

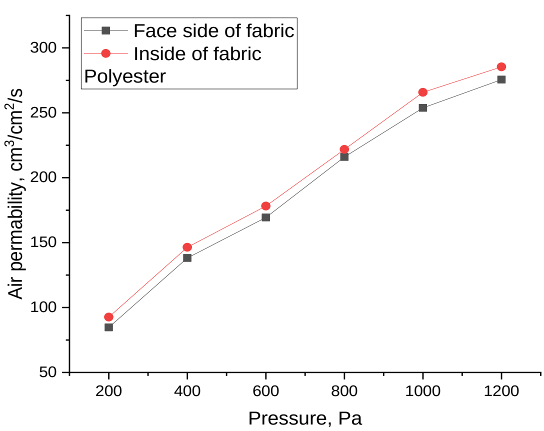
$$P = \left(1 - \frac{\rho_{fabric}}{\rho_{fiber}}\right) \cdot 100\ (\%) \tag{10}$$

$$\rho_{fabric} = \frac{m}{d \cdot 1000} \tag{11}$$

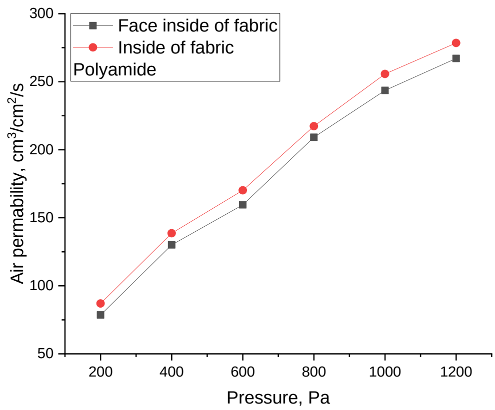
where: m – sample mass, d – sample thickness, ρ_{fiber} – fiber density, ρ_{fabric} – fabric density. Based on all the experiments that were carried out in the laboratory and aimed at checking the different properties of raw polyester and polyamide fabric, the OriginPro software was used to process the data and display the results.

3. RESULTS AND DISCUSSION

In designing of airbag fabric, precise control of air permeability is crucial. After deployment, controlled deflation through vents, seams and fabric pores protects vehicle occupants to minimize injury. Therefore, it is important to fully understand the mechanics of fabric permeability in product development and process optimization. Synthetic fabrics such as polyester and polyamide and their mixtures are most often used for the production of airbags to improve certain properties for better performance fabrics and thus can be economical to produce compared to commercial fabrics for the production of airbags [15].
Figure 2 shows the diagram of air permeability on the face and back of raw polyester and polyamide fabric at different pressures. In the case of polyester fabric, it was observed that the lowest air permeability is on the face of the fabric, i.e. 84.68 $cm^3/cm^2/s$ at the lowest pressure of 200 Pa, and the highest value 275.6 $cm^3/cm^2/s$ at the highest pressure of 1200 Pa, while on the innermost fabric the permeability at the lowest pressure was 92.62 $cm^3/cm^2/s$, and at the highest pressure 285.4 $cm^3/cm^2/s$. It was observed that the air permeability is higher on the reverse than on the face of the fabric.
Polyamide fabric showed the lowest value of air permeability on the face of the fabric 78.56 $cm^3/cm^2/s$ at a pressure of 200 Pa, and the highest value 267 $cm^3/cm^2/s$ at a pressure of 1200 Pa. Higher air permeability values are noticeable on the reverse side of the fabric, i.e. 86.99 $cm^3/cm^2/s$ at a pressure of 200 Pa and 278.5 $cm^3/cm^2/s$ at the highest used pressure i.e. 1200 Pa.
The results show that there is a small difference in the air permeability of the examined fabrics determined from the face and back of the material. It can be seen that with both analyzed fabrics, higher values of air permeability were obtained on the reverse than on the face of the fabric. Air permeability increases with increasing pressure.
Polyester fabric has a higher air permeability compared to polyamide fabric due to its higher porosity and lower fabric thickness. It is necessary to adjust the values of fabric thickness and porosity, because thickness improves thermal insulation, and porosity conditions air permeability.



a)



b)

Figure 2: Air permeability of a) face side, b) face inside of polyester and polyamide fabric at different pressures

Table 2 shows the structural parameters of polyamide and polyester fabric. Based on the porosity values of both fabrics, 46% for polyamide and 67% for polyester fabric, it is generally considered that when a fluid (liquid or gas) flows through the material, the pressure drop is due to viscous and inertial forces. Inertial forces can be neglected unlike viscous forces. Therefore, the structural and geometric properties of the textile material that determine the resistance to the movement of the air flow define its ability to pass air.
Air permeability through the fabric is one of the more important characteristics of the clothing fabric because it directly affects the feeling of comfort of the user of the textile product. The ability of the fabric to retain and pass air affects the thermal insulation properties of the clothing, because the air present in the clothing significantly increases the thermal properties of the clothing item. The warm feeling of the product is primarily due to the thermal insulation caused by the presence of air in between fibers in yarn and fabric. To increase air permeability in the finishing process, treatments can be applied that change the thickness, porosity and surface structure of the fabric. Processing can also lead to greater porosity of the fabric.
In this sense, in addition to the overall porosity of the textile material, air permeability is directly conditioned by the number, shape and size - cross-sectional area and length - of macropores. With the decrease in the size of the macropores in the material, the resistance to air flow increases, which reduces its air permeability.
The results of the research showed that the same coating has similar values of surface filling and therefore air permeability, i.e. it was found that the type of interweaving has an effect

on the air permeability of the fabric. Different types of interlacing patterns showed higher or lower permeability.

Table 2: Structural properties for used fabrics

Type of fabric	Volume mass fabric, $g \cdot m^{-3}$	Linear coverage of fabric	Incompleteness of fabric	Surface coverage of the fabric	Porosity of fabric, %
PES	0.05	1.15	0.84	0.52	67
PA	0.06	1.04	0.96	0.77	46

Knowing the mechanical, surface and physical properties of fabrics is important for the entire process of making fabrics, because the designer chooses the appropriate fabric based on the knowledge of the properties. Table 3 shows the results of breaking force and breaking elongation of the warp and weft of polyamide fabric for airbags. The average value of the breaking force is 1435 N. The breaking elongation is 61.75%. The quality of the material is linked to these parameters and they represent a plastic example. The appearance of damage directly affects the mechanical and physical properties of fabrics.
Fabric tearing is mainly the result of individual fibers tearing. In fabrics, individual fibers or threads are interwoven with each other, so by applying an external load, the structure of the fabric is rearranged, which results to a greater or lesser extent in the stretching of fibers and threads along the longer axis, which results in anisotropy of mechanical properties. The tensile stress itself is resisted by the weft or warp threads when they match. The directions of their axes with the direction of the acting loading as well as of standing in the structure under the influence of forces whose directions do not coincide with the directions of the weft or warp.

Table 3: Results for breaking force of polyamide and polyester fabric

Number of samples	**Breaking force of polyamide fabric (N)**		**Breaking force of polyester fabric (N)**	
	Warp	**Weft**	**Warp**	**Weft**
1.	1385	1355	1135	556
2.	1485	1375	1195	926
3.	1505	1385	1165	883
4.	1405	1305	1195	946
5.	1395	1295	1185	874
X_{sr}, N	**1435**	**1343**	**1175**	**837**
SD, N	**49.79**	**36.61**	**22.83**	**143**
CV, %	**0.04**	**0.30**	**0.02**	**0.19**

Table 4 shows breaking force and breaking elongation in warp and weft direction of polyester fabric for airbags. The average value of the breaking force is 837 N. The breaking elongation is 66.09%. Although the work of tear is determined by the specific breaking force and the breaking elongation of the fabric, it seems that the breaking elongation, at least within the experimental material, is the determining factor of the breaking work. Thus, the highest breaking work was recorded in the polyamide fabric characterized by a significantly higher breaking elongation compared to the polyester fabric.

Table 4: Results for breaking elongation of polyester and polyamide fabric

Number of samples	Breaking elongation of polyamide fabric (mm)		Breaking elongation of polyester fabric (mm)	
	Warp	Weft	Warp	Weft
1.	62.19	42.86	41.18	70
2.	62.70	42.78	41.69	69.80
3.	64.59	44.38	42.69	62.99
4.	58.88	42.27	43.09	64.49
5.	60.39	41.98	42.08	63.19
X_{sr}, mm	**61.75**	**42.86**	**42.15**	**66.09**
SD, mm	**1.96**	**0.82**	**0.68**	**3.15**
CV, %	**0.35**	**0.02**	**0.18**	**0.05**

In figure 3, the diagram shows the dependence of breaking elongation in relation to the breaking force in the warp and weft direction for polyamide fabric. From the results shown in figure 3, there is a noticeable difference between the breaking force determined on the samples in the longitudinal and transverse directions. The reason for this behavior is probably due to the different orientation of the fibers in the analyzed samples. The diagram in figure 3 shows that the breaking force and breaking elongation have higher values in the warp direction than in the weft direction.

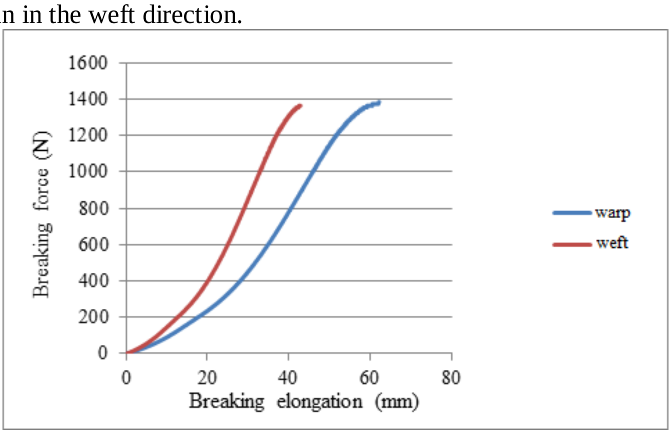


Figure 3: Dependence of breaking elongation in relation to breaking force for polyamide fabric in warp and weft direction

Figure 4 shows the dependence of elongation at break in relation to the breaking force in the warp and weft direction for polyester woven fabric. A difference was observed between the breaking force and the breaking elongation determined on the samples in the longitudinal and transverse directions. The reason for this behavior is probably due to the different orientation of the fibers in the analyzed samples. It is noticeable that breaking force and breaking elongation have higher values in the direction of the warp than in the direction of the weft.

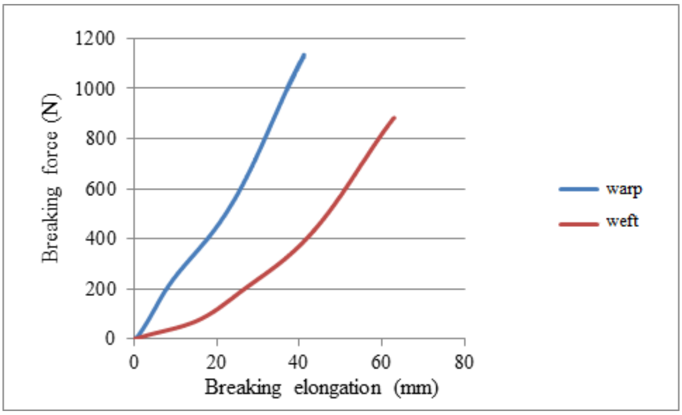


Figure 4: Dependence of breaking elongation in relation to breaking force for polyester fabric in warp and weft direction

4. CONCLUSION

With polyester fabric, it is noticeable that air permeability increases with increasing pressure. A higher air permeability is visible on the reverse than on the face of the fabric. By analyzing the permeability of the polyamide fabric, it was observed that the air permeability, just like that of the polyester fabric, increases with increasing pressure. By comparing the permeability of polyamide and polyester fabric on the face, it is noticeable that the polyester fabric has a higher permeability. The air permeability of polyester compared to polyamide fabric on the reverse side of the fabric showed that the polyester fabric has a higher permeability. Polyester fabric has less filling and a greater number of pores on the surface of the fabric, thus less air permeability.
The mechanical characteristics of fabrics depend on their structural and constructive solutions, as well as on the technological conditions of fabric production in the weaving process. Therefore, the most important role is played by the composition of the raw materials, the structural and physical-mechanical characteristics of the applied fabrics, the density of the warp and weft wires, the weaving of the wires, as well as the applied interweaving of the fabric. In addition, by knowing the connection of characteristics at the break boundaries, it is possible to simulate the behavior of fabrics during exploitation, which is a condition for the proper design of fabrics depending on their future purpose.

It is noticeable that higher breaking force values were observed for polyamide fabric compared to polyester fabric. Elongation at break has a higher value for polyester fabric compared to polyamide fabric. Higher breaking force values were observed for polyamide fabric.

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