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Assessment of the Relationship between Air Permeability of Woven Fabrics and Its Mechanical Properties

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Abstract
Every piece of woven fabric is an integration of warp yarns and weft yarn through intersection, the extent of which is largely dependent on the friction between fibers and yarns together with fiber entanglement. The distance between two parallel adjacent yarns determines the porosity of the fabric structure .Air permeability is an important property of the fabric. Mechanical properties are the treatment of a fabric according to the force applied. These properties have a large effect on the performance and behaviour of woven fabrics. In this paper the relation between these properties is investigated. As the experimental results show, there is an inverse relation between woven air permeability and mechanical properties, which is logarithmic, meaning that variation in the fabric air permeability changes the mechanical properties inversely, signifying a less amount thereof.

◼ Introduction

Every piece of woven fabric is an integration of warp yarns and weft yarns through intersection, the extent of which is largely dependent on the friction between fibers and yarns together with fiber entanglement. The distance between two parallel adjacent yarns determines the porosity of a fabric structure [1]. Porosity is the way in which air flow can pass through, giving the fabric its permeability property.

Air permeability is an important property of fabric as it has a decisive influence on the utilisation of fabric for some technical (filters, parachutes, and sails) and clothing applications [2]. The main structural parameters, which have an influence on fabric air permeability, are the fabric density, warp and weft linear densities, and the weave [3, 4]. Fabric air permeability is defined as "the rate of air flowing through a material under a differential pressure between the two fabric surfaces" [5, 6].

Mechanical properties are the result of the treatment of fabric according to the force applied. As previous researches show, fabric mechanical properties are related to each other [7, 8]. When a bending force is applied to a fabric, a shearing force occurs between its yarns and fibers, or when a tensile load is applied to the fabric, yarns begin to slip at the crossing over point, where the weft and warp yarns are in contact with each other. There are many related works which have been done on the mechanical properties and air permeability of woven fabrics separately [9, 10, 11], but no work has been found regarding the relation between woven air permeabil-

ity and its mechanical properties. This study will help to understand the effect of fabric mechanical properties and air permeability on user satisfaction and cloth comfort. Fabric comfort depends on the ability of the fabric to pass the air, heat and humidity of the body outside the cloth. On the other hand the formability and ability of clothing to cover the body in such a way that has a pretty pattern depends on its mechanical properties. Hence we can conclude that the relation between fabric air permeability and its mechanical properties should be considered [12, 13].

In this research we study the relation between the air permeability and mechanical properties of woven fabrics. For this purpose we used fabrics with different weave parameters. First we put the samples into different groups to find the most effective parameter in the relation between properties. The samples were in 3 groups of single fabrics: in the first group the weft setting changed; in the second the weave structure changed, and in the third group the weft count changed.

◼ Experimental

Viscose/polyester yarns were used for the warp and weft. We selected 3 kinds of samples. The first type were fabric samples with different weave structures, including a plain weave, a 2/2 twill weave, a 2/6 twill weave, a crape weave, a rib weave, warp rib weave, a basket weave, and a dice weave. All the samples were single fabrics in which only the textile structure changes. These weave designs are shown in ***Table 1***. Plain weave, 2/2 twill weave, and dice weave are three fundamental textile weaves with the following characteristics: plain weave has

Table 1. *Various designs of textile weaves.*

Textile weave	Complete repeat	Textile weave	Complete repeat
Plain weave		Warp rib	
2/2 twill weave		Basket weave	
2/6 twill weave		Dice weave	
Rib		Crape weave	

Table 2. *17 samples of woven fabric.*

Sample Index	Warp setting	Weft setting	Textile weave	Weft count(Tex)	Warp count(Tex)
1	24/cm	12/cm	Plain	30/1	20/2
2	24/cm	14/cm	Plain	30/1	20/2
3	24/cm	18/cm	Plain	30/1	20/2
4	24/cm	22/cm	Plain	30/1	20/2
5	24/cm	22/cm	Crape	30/1	20/2
6	24/cm	22/cm	Warp rib	30/1	20/2
7	24/cm	22/cm	Rib	30/1	20/2
8	24/cm	22/cm	2/2 twill	30/1	20/2
9	24/cm	22/cm	Basket	30/1	20/2
10	24/cm	22/cm	2/6 twill	30/1	20/2
11	24/cm	22/cm	Dice	30/1	20/2
12	24/cm	12/cm	Plain	30/2	20/2
13	24/cm	10/cm	Plain	30/2	20/2
14	24/cm	8/cm	Plain	30/2	20/2
15	24/cm	10/cm	2/2 twill	60/1	20/2
16	24/cm	10/cm	2/6 twill	60/1	20/2
17	24/cm	10/cm	Crape	60/1	20/2

considerable interlacing of warp and weft yarns; 2/2 twill weave displays ridges on the fabric surface, and dice weave has a lot of floating yarns. The other woven fabrics used were derivatives of these three weaves. In other words crape weave is a derivative of plain weave, and 2/6 twill weave is a derivative of twill weave. Therefore, these textiles include a mixture of the features of the three basic weaves.

The second group consisted of fabric samples with different weft settings, including 8/cm, 10/cm, 12/cm, 14/cm, 18/cm and 22/cm. All the samples were single fabrics in which only the textile weft setting changes, and they have the same weave structure (plain weave).In third group, there were fabric samples with different weft counts, including 30/1, 30/2 and 60/1. These weave features are shown in **Table 2**.

Measuring mechanical properties

The air Permeability was measured by shierly apparatus under high sensitivity conditions. Basic mechanical properties such as the tensile property, and the bending and shearing rigidity were measured by the FAST system under high sensitivity conditions, the temperature being 20 – 0.5°C, and the relative humidity – 65% – 5.

Results and discussion

As mentioned above, we first considered the relation between properties for whole samples to define the relation type, and next by grouping the samples according to weave parameter, we established the most effective parameters for each relation. The results of measuring the fabric mechanical properties are shown in **Figures 1** to **3** (see page 70). In order to find the correlation between the tensile property, shear rigidity, bending rigidity and the air permeability, we considered the R square of each relation and used the ANOVA Table to see whether the relation obtained was acceptable or not.

The relation between the air permeability and strength of the fabric is shown in **Figure 1**. As we can see, by increasing the air permeability of the fabric, its strength was reduced. The distance between yarns increased, and the number of yarns which endured the load force decreased; hence, the sample strength was reduced. The correlation coefficient between the fabric air permeability and the tensile property is 0/76, which shows a negative relation between the sample's permeability and strength.

The relation between the fabric shear and bending rigidity is similar to that for the strength, meaning that by increasing the fabric air permeability, the shear and bending rigidity are reduced. However, the correlation coefficient between them is different. In the case of shear rigidity, the correlation coefficient is 0/69, and for the relation between the air permeability and bending rigidity we obtained 0/48. Thus we can observe that because of the complicated behaviour of the fabric bending property, there was not a high correlation. We can declare that when the fabric permeability increases, the compactness of yarn, their contact with each other and, hence, their crossing-over decreases. Therefore we need a lower force for bending and shear movement in the fabrics.

In order to see whether each of the relations is acceptable , we used the ANOVA Table. In each case we defined the fabric air permeability as a dependent variable and the tensile property, shear rigidity and bending rigidity as independent variables. **Table 3** shows the p-value of each relation obtained. We can declare that all the relations between the fabric air permeability and mechanical properties attained are acceptable.

In the next step we tried to establish the most effective structural parameter for the relations mentioned above. For this purpose we put the fabrics into 3 groups. Next we studied the correlation coefficients and p-values of the relations in order to find the highest correlation coefficient acceptable for us. The basis of the grouping were the weave parameters: the weft setting, weave structure and weft count.
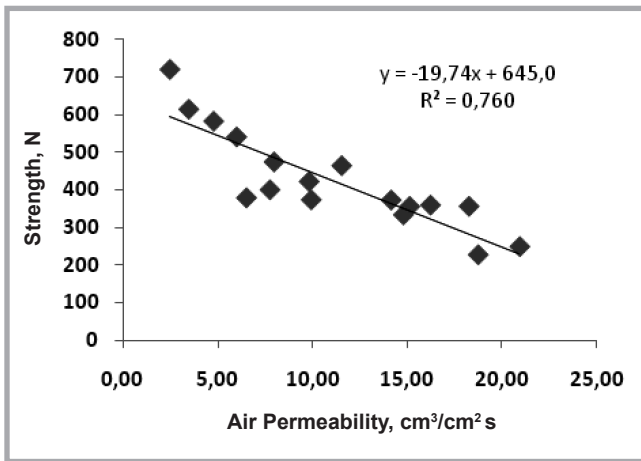
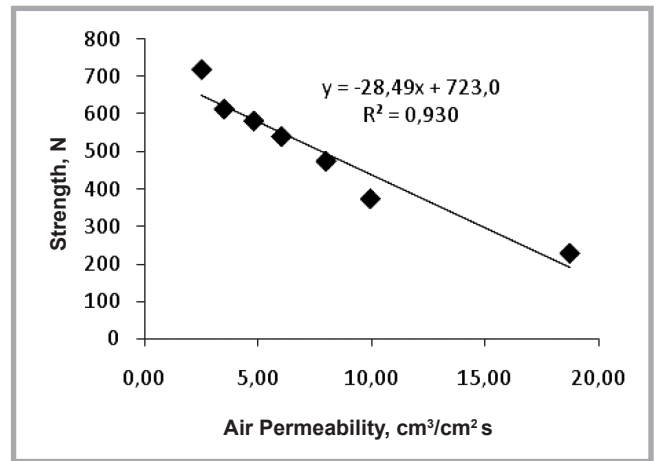**Figure 1.** *Relationship between the air permeability and strength of samples.*

Figure 4. *Relationship between the air permeability and strength of samples with different weft settings.*
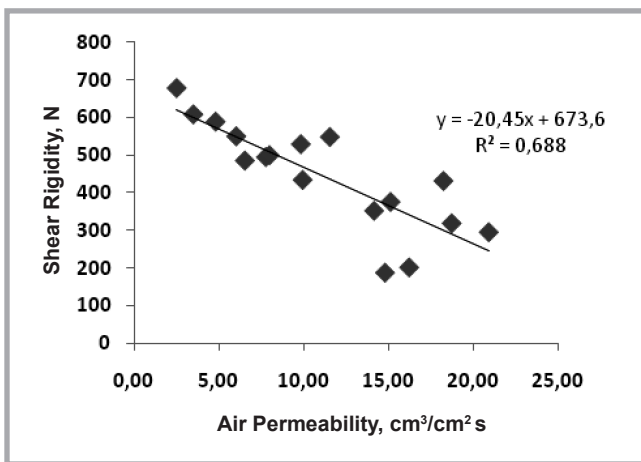

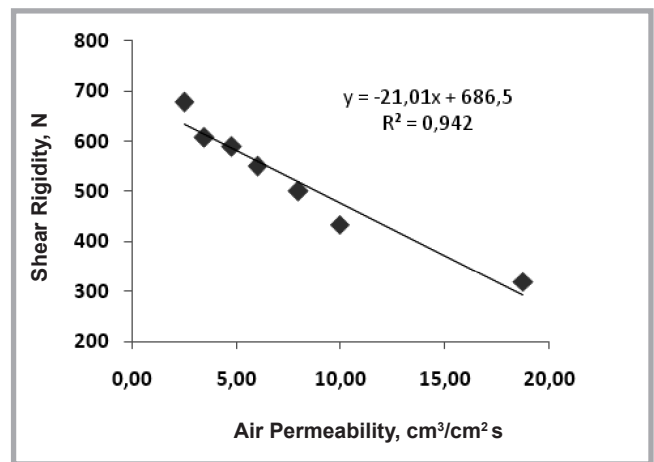**Figure 2.** *Relationship between the air permeability and the shear rigidity of samples.*

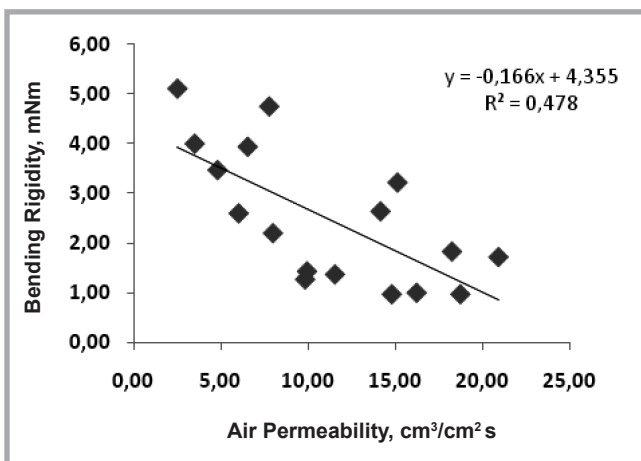**Figure 5.** *Relationship between the air permeability and shear rigidity of samples with different weft settings.*

Figure 3. *Relationship between the air permeability and bending rigidity of samples.*
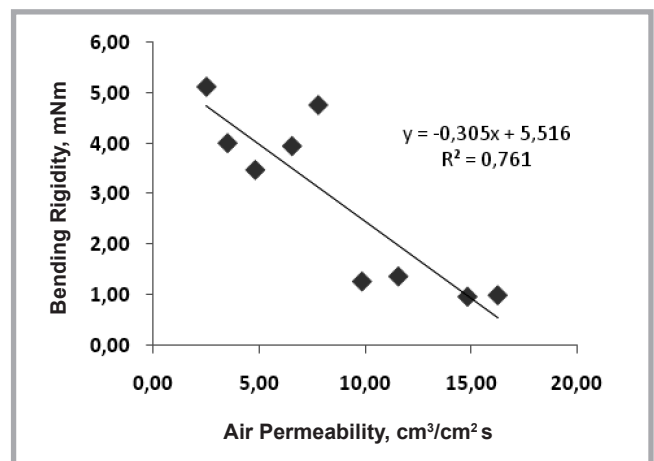

Figure 6. *Relationship between the air permeability and bending rigidity of samples with different weft counts.*

In **Figure 4** we can see the relation between the air permeability and strength for the samples in which their weft setting was changed. As we can observe, the correlation coefficient in this case becomes 0/93, which is higher than that for all the samples. Hence we can see the effect of the weft setting on the relation between permeability and strength . As regards the correlation coefficient for the other samples, whose weave structure and weft count changed, we can declare that their coefficients are inversely proportional to those of the samples whose weft setting variable decreased. Thus the effect of the weft setting in the relation between air permeability and strength becomes clear. Details of the relation

Table 3. *Details of the ANOVA test for each relation.*

Air Permeability				
Quantity	Whole samples	Weft setting variable	Weave structure variable	Weft count variable
Strength	0/76 Sig=0/000005	0/93 Sig=0/00044	0/71 Sig=0/001	0/66 Sig=0/008
Shear Rigidity	0/69 Sig=0/000038	0/94 Sig=0/0003	0/64 Sig=0/002	0/79 Sig=0/001
Bending Rigidity	0/48 Sig=0/002	0/75 Sig=0/011	0/54 Sig=0/007	0/76 Sig=0/002

between the correlation coefficients and p-values are shown in **Table 1**.

As shown in **Table 3**, all the relations obtained for the air permeability and mechanical properties are acceptable in all cases and groups at a 5% significance level.

A similar analysis was made on the relation between the fabric air permeability, shear rigidity and bending rigidity for all the samples and next for the sub groups introduced. The results of this analysis are shown in **Table 3**. As we can see, in the case of samples with different weft settings, the correlation coefficient between the fabric air permeability and shear rigidity is 0/94, increasing in proportion to whole samples, for which the correlation coefficient is 0/69. Other correlation coefficients for the relation between air permeability and shear rigidity in the case of the weave structure and weft count variables are 0/64 and 0/79, which are less than that of the weft setting variable. The relation between the air permeability and shear rigidity of the fabric samples in which only the weft setting was changed is shown in **Figure 5**.

As regards the relation between air permeability and bending rigidity, the correlation coefficient of samples with different weft count variables is 0/76, which is higher than that of the other relations between the air permeability and bending rigidity of samples with different weft settings and weave structures, which are 0/75 and 0/54, respectively. The relation between the air permeability and bending rigidity of samples with different weft counts is shown in **Figure 6.**

As mentioned above, by grouping the samples according to weave parameter, we have a better picture of the effect of each weave parameter on the relation between the fabric air permeability, tensile property, and shear and bending rigidity.

The treatment of the bending rigidity of all the samples and different groups is complicated, hence we cannot achieve a very high correlation coefficient as with other properties.

Conclusions

The air permeability of a fabric is one of the very important properties of technical fabrics. The air permeability depends on the shape and value of the pores and inter thread channels, which are dependent on the structural parameters of the fabric. Mechanical properties are the result of the treatment of the fabric according to the force applied. When designing cloth, the parameters determining the comfort of the cloth and user satisfaction are dependent on the fabric air permeability and mechanical properties of the cloth.

In order to define the relationship between the woven mechanical properties and air Permeability of woven fabrics, we considered the weft setting, weave structure and weft count parameters. We studied the relation between the air permeability as well as the tensile, shear and bending properties of all the samples. Next we grouped the samples according to weave parameter in order to find the most effective parameters for each relation. From this experimental research the following conclusions could be drawn.

1. The results show that for woven fabrics the air permeability and mechanical properties have an inverse relation. Thus, by increasing the permeability, the fabric's tensile, shear and bending properties decrease.

2. Amongst the parameters that have an effect on properties, the yarn setting has the most influence on the relation between the air permeability of the fabric and its tensile and shear proper-

ties, whereas yarn count has the largest effect on the air permeability and bending properties of the fabric.

We should mention that the relation between the air permeability and bending rigidity of woven fabrics is not so clear because woven bending treatment is so complicated. However, from the experimental data we obtained we can see the inverse relation to some extent.

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