# MODELLING THE STRUCTURAL BARRIER ABILITY OF WOVEN FABRICS

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## *Abstract*

*Woven fabrics with their full, systematically arranged and non-stochastic structure, are the subject of increasing interest as barriers to fluids, radiation, micro-particles, and micro-organisms. The structure of woven fabrics, which is characterised by inter-thread channels of predetermined shape and location, is especially important. Some procedures for designing channel shape and methods for sealing barrier woven fabrics are presented.*

## *Keywords:*

*barrier woven fabric, woven fabric structure, channels, tread configuration, density increase, structure tighten.*

## 1. Introduction

Woven fabrics belong to that group of textiles which do not have a stochastic structure, but whose structure design is repeated in every element of the fabric. This is why woven fabrics are often applied as effective barriers for controlled flow, penetration, and permeation through their structure by:

- liquids,
- thermal, optic, ionising, and electromagnetic radiation, and
- particles of dimensions from the micro- to the macro-scale.

From the structural point of view, the above-mentioned barrier functions of woven fabrics are determined by the shape and dimensions of the channels (which means the free spaces between threads) which penetrate the fabrics. On the other hand, the generally used identification of the open-work feature at most resolves itself into determination of the surface cover of the fabric by warp ($Z_o$), by weft ($Z_w$), or by both these arrangements simultaneously ($Z_{ow}$). The above-mentioned fabric covers are expressed by the following equations:

$$Z_o = g_o\, d_o,$$
$$Z_w = g_w\, d_w, \text{ and}$$
$$Z_{ow} = Z_o + Z_w - Z_o Z_w \times 10^{-2},$$

where:
$g_o$, $g_w$ – the warp and weft settings, and
$d_o$, $d_w$ – the nominal diameters of warp and weft threads.

In the past, mill gauzes were manufactured with thread settings of up to 1,000/1dm, and sometimes even more. Such settings resulted in 1,000,000 pores per 1 $dm^2$ of clearance dimensions below 0.05×0.05 mm.

At present, the much widespread functions of the barrier woven fabrics are not only realised as separation (sifting) of particles. This is why, in order for an effective modelling of the woven fabric structure to perform such responsible functions (as mentioned above), a need arises for simultaneous consideration of the following problems:

- the possibility and the means to tighten the thread structure (increase in thread density) aimed at programmable decreasing of the channel cross-sections; and

- the choice and identification of the chosen spaces between threads (the channels) considering their shape and location.

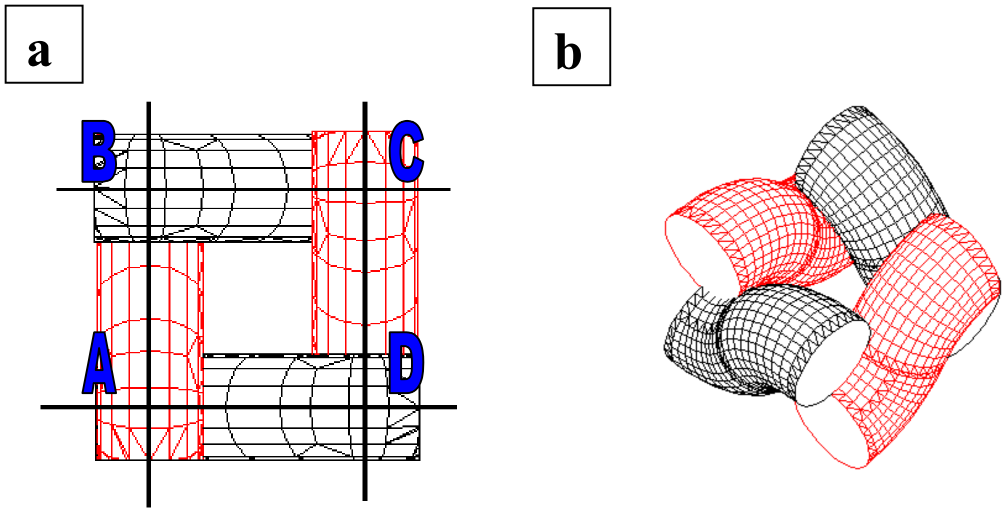


**Figure 1.** Model of a woven fabric of square structure (i.e. of equal warp & weft structure, which means of equal warp & weft sets, thread diameters, and material), double-system resistance surface, with non-deformable threads of circular cross-sections, and plain weave: a) perpendicular projection of one woven fabric element, b) view of a skew projection of this element.

## 2. One-layer barrier woven fabrics

### 2.1. Weave selection

The weave selection can be carried out considering:

- the means for obtaining the greatest possible tightness (density) of the fabric by threads, i.e. increasing the medium-tightness of the barrier, and
- the formation of channels between the threads.

The values of maximum thread tightness, which depends first of all on the fabric's weave, are determined for ideal woven fabrics by warp and weft filling, ($E_o$ and $E_w$, respectively), whose values in this case are equal to 100%. The fillings $E_o$ and $E_w$ are determined by the following equations:

$$E_o = (d_oR_o + d_wp_w) / R_oA_o \times 100\%, \text{ and}$$
$$E_w = (d_wR_w + d_op_o) / R_wA_w \times 100\%,$$

where:
$R_o$, $R_w$ – warp repeat, weft repeat,
$P_o$, $p_w$ – number of inflections of one warp or weft thread within the range of warp or weft repeat,
$A_o$, $A_w$ –warp or weft thread sets.

The greatest tightness of a particular thread system can be achieved for weaves of a small number of inflexions in relation to the repeat of the other thread system. Such weaves are for example sateen, rep, and hopsack weaves (an exemplary hopsack weave is presented in Figure 2).
The smallest relative densification can be achieved for the woven fabric model shown in Figure 1, i.e. for the plain weave.

If $E_o = E_w = 100\%$, then:
- the fabric cover for the individual thread systems ($Z_o = Z_w$) equals 50%, and
- the total fabric cover of both thread systems ($Z_{ow}$) equals 75%; this means that the clearance is a quadrangle of a side whose length equals the nominal thread diameter, and the share of pores in the total fabric surface equals 25%.

The first step in channel formation should be the selection of one of only four channel forms [1, 2, 3, 4, 5]. In Figure 3, the four structural moduli of all the weaves used are presented; the 3D views illustrate the possible inter-thread spaces. The next step is the determination (for asymmetric moduli) of the moduli location in relation to the vertical axis.

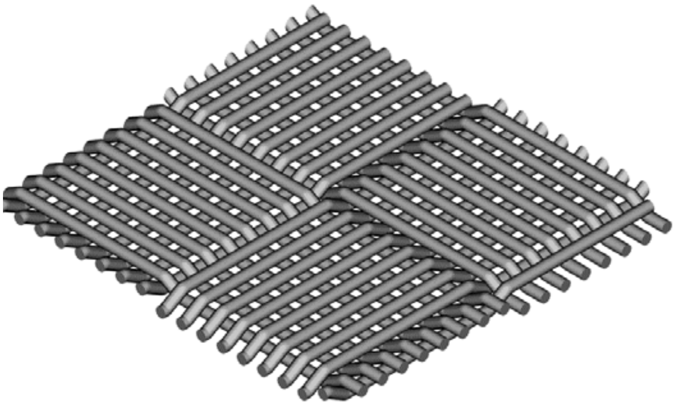

**Figure 2.** Hopsack weave with $R_o = R_w = 16$, $p_o = p_w = 2$, [8]

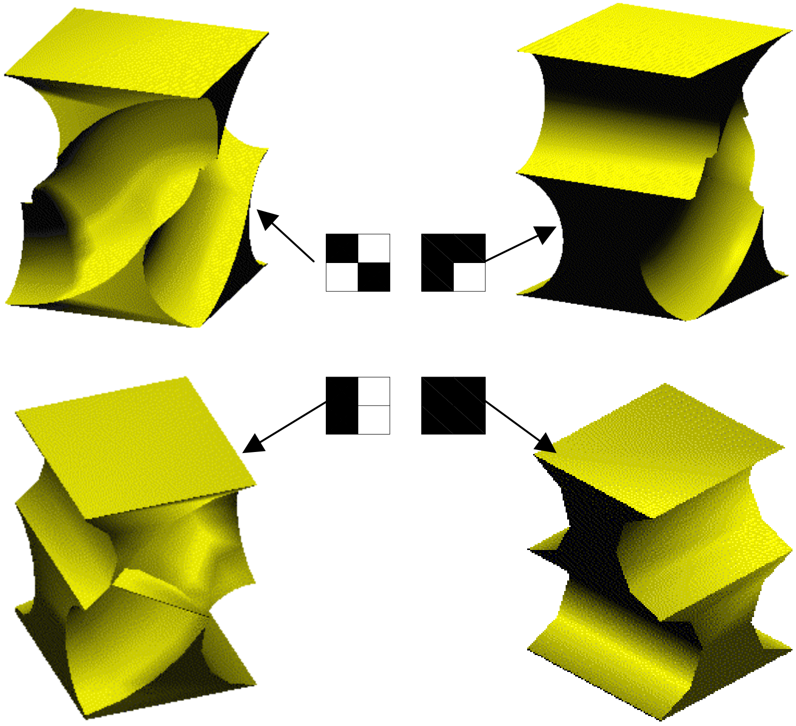

**Figure 3.** Structural moduli of the weaves

Each of the moduli presented in Figure 3 has its own specific geometrical characteristic which differ from the others. This results in fabrics (constructed from the particular moduli) with differentiated barrier features, i.e. of different conditions for transport, penetration, and permeation of a given medium. The whole fabric can either be determined by one kind of weave, or consist of a set of various kinds of moduli. The following modifications are possible:

- different locations in relation to the vertical axis, and
- changes in the structural phase.

## 2.2. Methods of increasing the medium-tightness

### *2.2.1. Phase changing of the woven fabric's structure*

The decrease in the dimensions of the clearances located between threads, which means exceeding the maximum cover limit of the woven fabric's structure with a double-system resistance surface (of the fabric with the square structure discussed above; see description of Figure 1) is possible after the phase change of the woven fabric structure. The decrease in the deflection of one thread system and a consequent increase in the deflection of the other system can lead to this condition. The thread system with increased deflection forms a single-system surface of the fabric. The limit of these procedures reaches a zero value for one of the deflections. Figure 4 presents a virtual structural model of the woven fabric from Figure 1 after changing the double-system resistance surface into a weft single-system resistance surface.

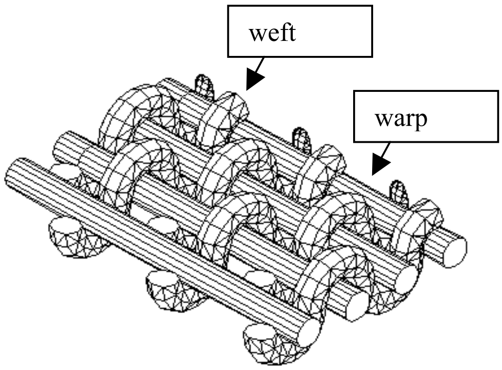


**Figure 4.** Model of the woven fabric presented in Figure 1 after changing the previously existing phase in a limiting structure phase with a weft single-system resistance surface.

The structure mentioned above makes it possible to tighten the threads which form the resistance surface even up to the cover value of 100% (see Figure 5), and at the same time to change the shape and dimensions of the channels.

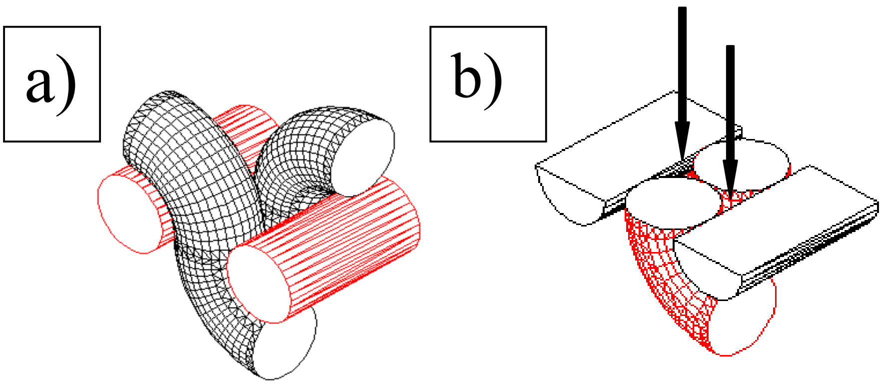


**Figure 5.** Virtual model of the woven fabric presented in Figure 1 after changing its phase in the limiting structure phase and increasing the weft thread set up to the limiting value $Z_w$ = 100%: a) view of the skew projection of a weave modulus, b) view of the same modulus but cut in the plane of half the diameter of the warp threads.

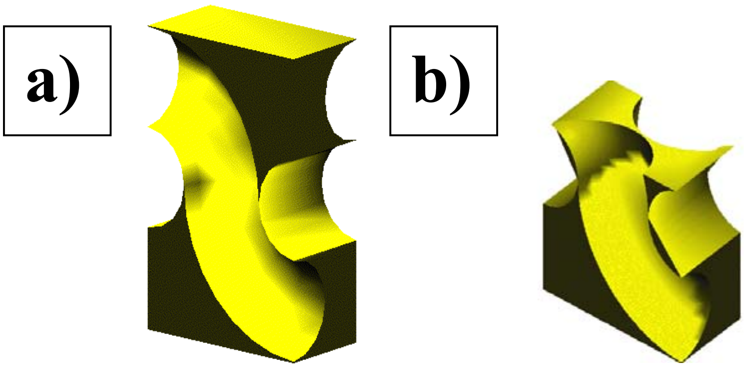


**Figure 6.** Views of an inter-thread channel of the virtual model of the woven fabric shown in Figure 5: a) total view related to Figure 5.a, b) partial view related to Figure 5.b.

#### *2.2.2. Influence of the thread diameter on the tighten-possibilities of woven fabrics*

In Figure 7a, a virtual model of a woven fabric manufactured from linear textile products with an ellipsoidal cross-section is presented. The perpendicular projection of this fabric, shown in Figure 7b, makes visible the channels which are located on both sides between the threads but of relatively very small dimensions. The fabric cover of both thread systems exceeds 90% ($Z_{ow}$>90%).

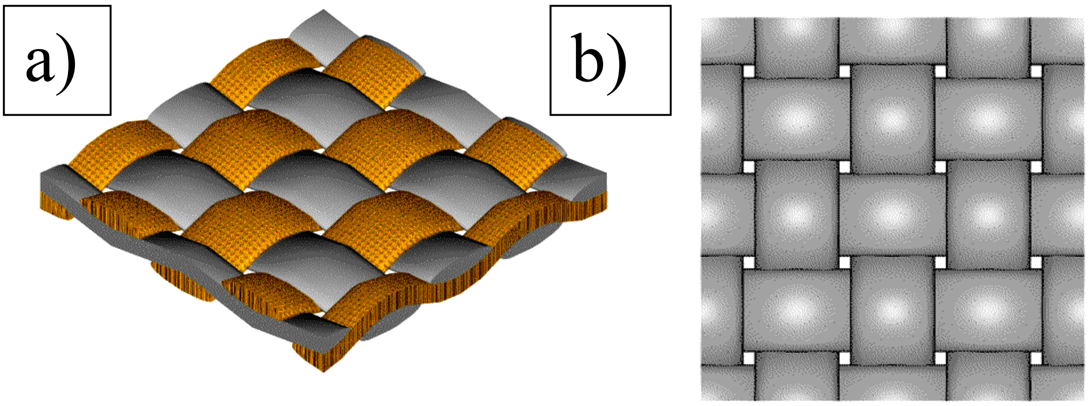


**Figure 7.** Virtual model of a square woven fabric with a double-system surface resistance: a) view of the skew projection, b) view of the perpendicular projection [6].

#### *2.2.3. Closing the free spaces between threads*

The general outline presented herein does not consist in tightening the structure of the basic thread systems, but is based on introducing additional linear textile products in the free spaces between the threads [8]. These additional products may perform further functions, thanks to appropriate selection of specific material; for example, they can be distinguished by individual sorption ability for a given medium.

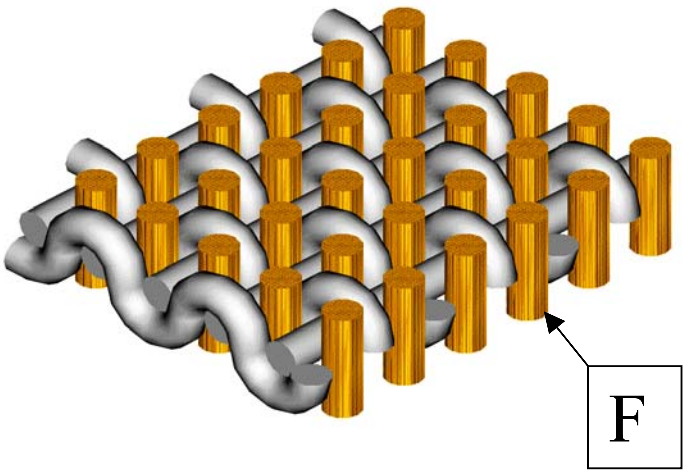


**Figure 8.** Virtual model of a woven fabric with an inter-thread channel filler (W).

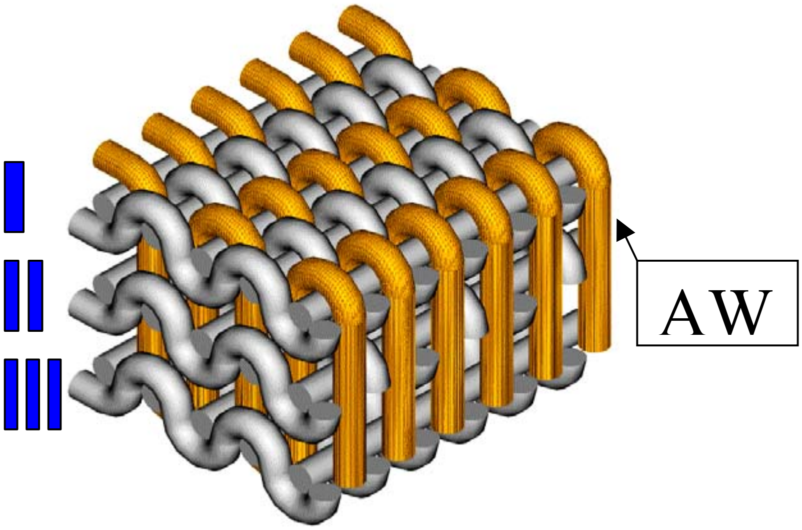


**Figure 9.** Virtual model of a ternary woven fabric with layers I, II, and III joined by an additional warp (OD).

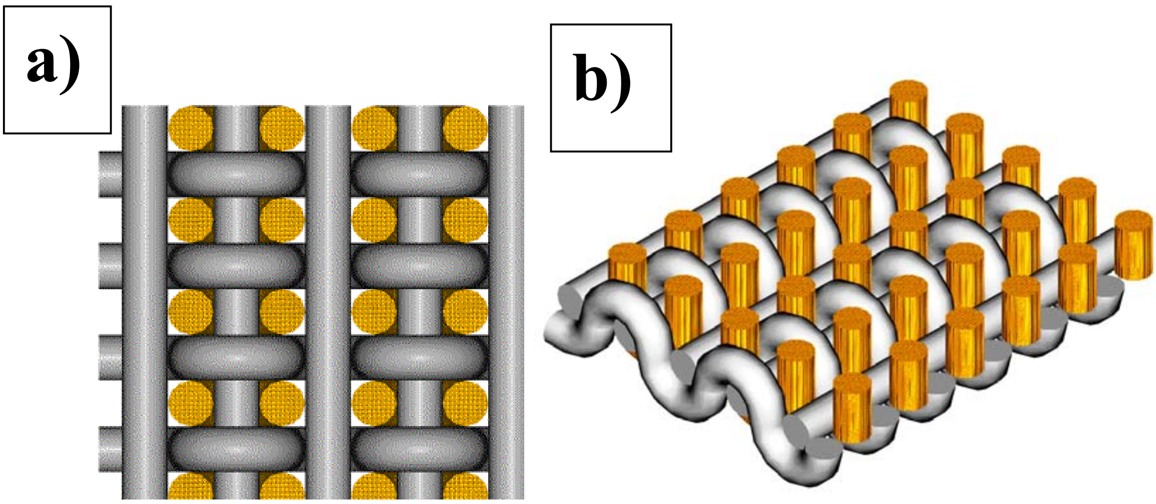


**Figure 10.** Views of virtual moduli of the layers: a) the middle (II), and b) the bottom (III) or the upper (I) layers.

A method for realising such a structure is to manufacture a ternary woven fabric in which the layers are joined by an additional warp system (Figure 9). After cutting the ternary woven fabric through the planes between the layers, we obtain three fabrics which fulfil the condition of free space reduction between the threads of the basic systems. The middle fabric is shown in Figure 10a, whereas the upper and the bottom fabrics, which both have the same structure, are presented in Figure 10b.

## 3. Multilayer woven fabric barriers

### 3.1. A piled-up single-thread system

On the boundary of single- and multilayer woven fabrics, we find structures with only one thread system piled up. In Figure 11, a virtual model is presented of a woven fabric with warp threads displaced in two layers, the upper and the bottom, with deflections equal to zero, but interlaced with wefts placed in one layer. The medium-tightness is secured by the warp threads, which in a real product are pressed together. This task can be accomplished by thickness differentiation of the warp and weft threads.

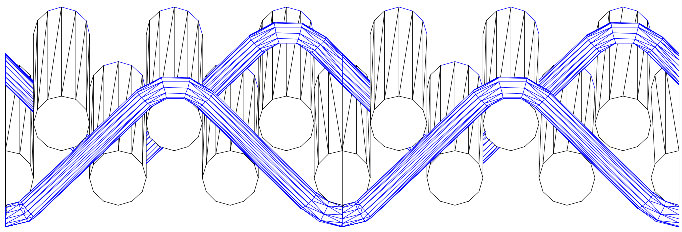

**Figure 11.** Virtual model of a woven fabric with a single warp thread system piled up

### 3.2. A simple piling up of a double-thread systems

Barriers of such a structure are manufactured by piling up two or more (Figure 12) independent woven fabrics. Even if their structure is identical (Figure 12b), a random distribution of the mutual positions of the inter-thread channels in two adjacent layers can be observed. In such a case, many advantages connected with the non-stochastic structure of the woven fabric can be lost.

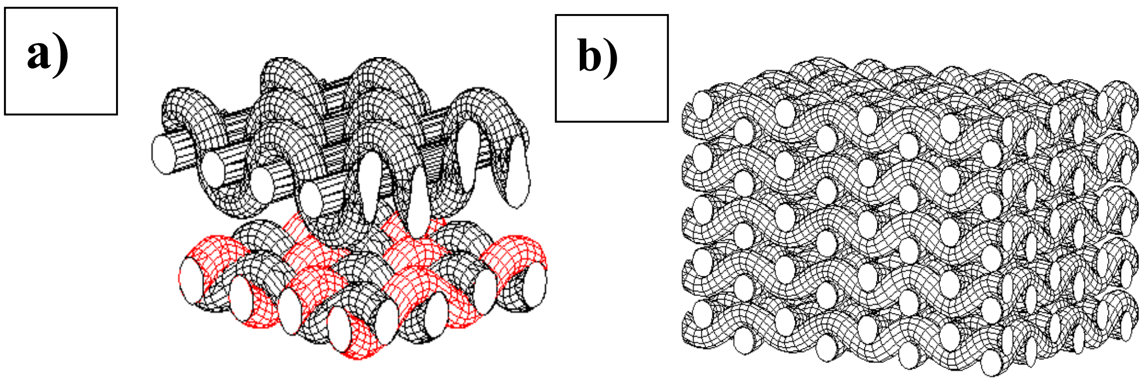


**Figure 12.** A simple piling-up of two woven fabric systems – a woven fabric barrier: a) a double-layer barrier from woven fabrics with different weave moduli, b) a five-layer barrier from structural identical woven fabrics.

### 3.3. A complex piling-up of a double-thread systems

Better control of the mutual dislocation of the inter-thread channels in adjacent layers secures solutions which are characterised by the interlaced joining of two adjacent layers by the particular threads. It is these solutions only, and no others, which ensure the possibility of layer selection according to the assumed efficiency of air flow, radiation and micro-organism penetration, or other features arising from the different weave moduli (Figure 3) or structural phases (Figure 4).

Double woven fabrics may play an important part in barrier ability formation. The simplest examples are layers joined by stitching from back to face (Figure 13) Thanks to such a solution, the mutual positions of the upper and bottom layer channels can be determined and then stabilised.

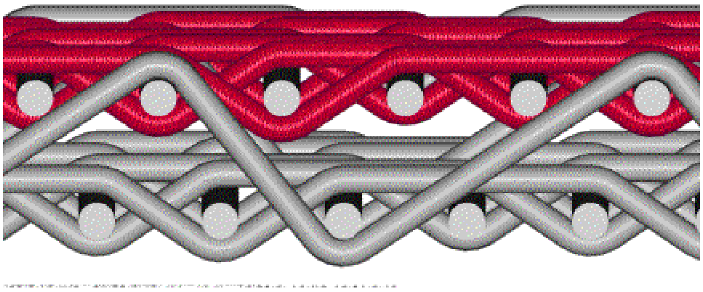

**Figure 13.** Double-woven fabric with layers joined by stitching from back to face with controlled channel dislocation in the layers.

Joining the woven fabrics by the method of layer exchange is a further step in barrier ability formation, which at the same time indicates how considerable are the possibilities offered by such a structure (Figure 14). First of all, the upper and the bottom layers may be used as subsequent filters, and the presence of closed lateral channels allows us to use them additionally, for example by filling them with a selected sorbent.

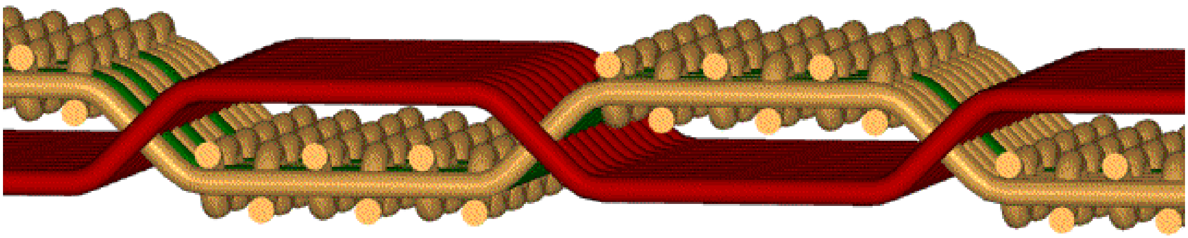

**Figure 14.** Virtual model of a double-layer woven fabric joined by the layer exchange method [7]

## 4. Final remarks

The ability to use woven fabrics (products with a precisely determined and stable structure) as barriers in a great range of applications outside the textile branch is enormous, upon consideration that the requirements of the putative user, which often very high, will be fulfilled. In this paper, the problems examined were confined only to those aspects of structure which often play a crucial part in the formation of the product's barrier ability, together with raw material and chemical processing.

Undoubtedly, the manufacturer of woven fabrics with predetermined structure must solve many difficult problems. One of the most pressing of these problems is the ability to form a structure of required phase from any kind of linear textile product.

This means that designers who deal with the woven fabrics' features must not forget to consider the basic problem of advanced identification of the selected product structure.

The framework of this paper allowed for only a simplified presentation of problems of the structural barrier ability of woven fabrics.

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