2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

REINFORCEMENT OF COTTON 3-D NONWOVENS BY QUASI-YARNS

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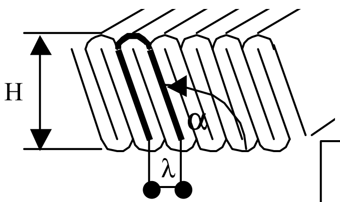
Abstract

A method of mechanical fixation of 3-D fiber fleece fabrics is described. Rotating elements twist the fiber ends on one surface or on both surfaces of the fleece and hereby create linear formations that were called "quasi-yarns." These are used to fasten suitable reinforcement networks to the fleece surfaces that give the products necessary properties such as tenacity, stiffness, or toughness. The principle of mechanical fixation and conditions for quasi-yarns formation are explained. Examples of developed products are presented. Application possibilities in cotton nonwovens production are mentioned. Results of measurement of noise insulation parameters of 3-D nonwoven samples made of cotton noils and fixed by quasi-yarns are presented.

Introduction

The industrial application of a web "wave" as the basic "construction" element of a 3-D nonwoven fabric inspired to look for a mechanical method of fixation of these web waves in products, to look for such a method that would not significantly change the web structure (as it happens e.g. in case of needle-punching).

For the 3-D textiles manufactured through vertical folding of a web (Krcma 1995) or, as the case may be, of other 2-D textile formations (e.g. punched textiles) into "waves" (Hanus 2000), the main characteristic fact is that the folded formation goes "through" the product – fleece - from its one side to the other one). The basic relations between the product parameters (Figure 1) and technology parameters (Figure 5) were derived (Hanus 2002).



$$H = \frac{v_1}{v_2}\frac{g_p}{\gamma}; \quad v_2 = \frac{v_1}{i}; \quad v_3 = \frac{\rho A v_1}{i}; \quad H = \sqrt{\frac{i^2 - 1}{4\rho^2}};$$

v_2 = output velocity of the conveyer 2 [m/s]; v_3 = velocity of the working roller 3 [m/s];
A = tooth pitch of the working roller 3 [m]; α = wave inclination angle;
H = product thickness [m]; g_p = area weight of the web [kg/m^2];
γ = density of the product [kg/m^3] ρ = wave number [number of waves per 1 m]
λ = length of the wave [m]

Figure 1.

The basic idea of the described method is to splice the waves of web into a cohesive whole just on their peaks (Hanus 1995). In case of such a method we can a priori suppose that it will be less energy demanding than e.g. the "heat fixation" and that neither the structure nor the shape of the product will be significantly changed. The idea to "splice mechanically just the wave peaks" is approximately 8 years old. In course of this time it has been also verified. To its purposeful development we come only now, in connection with the development of "corrugated" 3-D textile fabrics (Hanus 2002) and with the effort to find their specific applications in mattresses and insulating materials. Today, there are two following generally known methods of mechanical fixation of web surfaces that can be applied in case of fleece sorts manufactured of a web. There are:

- Splicing by means of fiber bundles which is executed on the MULTIKNIT machine supplied at the market by the German company Mayer (Albrecht 2000);
- Method developed at the Department of Nonwovens of the Technical University in Liberec which is based on twisting of fiber ends protruding from the web wave peaks into so-called quasi-yarns (Krcma 1995).

The second method is simpler and quicker than the first one. The machine (Figure 5) for implementation of this method includes no parts performing oscillatory motion. The appearance and properties of the products of course conform to the different fixation principles.

Theoretical Aspects

We found out that if a rotating cylinder- or cone-shaped body moves on the web surface by its base or by its surface line (Figure 2), it leaves behind a "track" in form of twisted fibers. The shape of this „track" is similar to the classical yarn and therefore we called it "quasi-yarn".
The model of the quasi-yarn structure can be compared to a "centipede". Its body represented by twisted fibers lies on the web surface, its legs reach to the web depth as sketched in Figure 3.

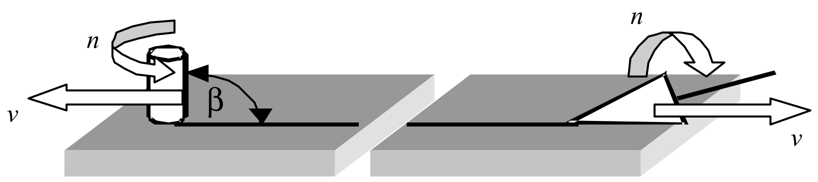


Figure 2.

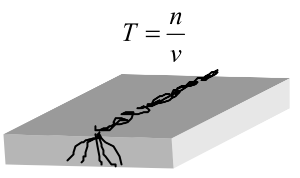


Figure 3.

Quasi-yarns can be laid out on the web surface for example parallel, theoretically though in optional spacing. The basic technological parameter of the quasi-yarn is "T"- the number of the twists per 1m but its measurement on the quasi-yarn is very difficult.

If are the fleece "pressed" to the rotating cone on both sides, it results into a quasi-yarn between them. This quasi-yarn will link both the semi-products up (Figure 4). This process is utilizable for „mechanical laminating" of 3-D textiles and enables to manufacture products of various thickness.

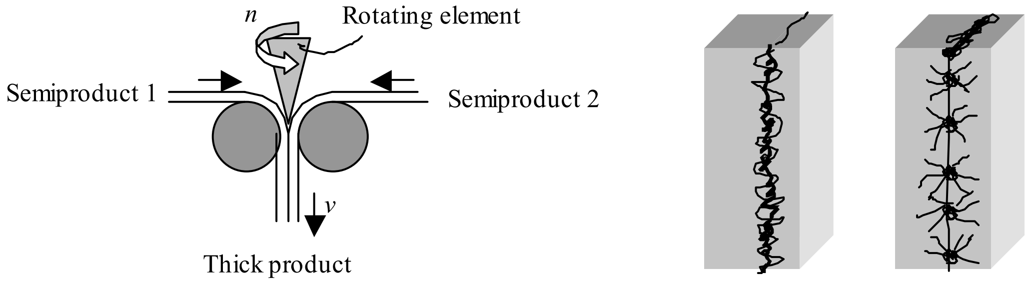


Figure 4.

Strength of Quasi-Yarns
The strength of different quasi-yarn sorts is influenced by many factors (Hanus 95), such as:

- Shape of the rotating element;
- β-angle between the surface line of the rotating element and the fleece;
- Diameter of the rotating element;
- Speed of the rotating element;
- Feed velocity of the fleece under the rotating element;
- Coefficient of friction between the surfaces of the rotating element and of the fleece;
- Number of fiber ends on the fleece surface;
- Resistance of fibers to twisting;
- Fleece structure;
- Contact pressure between the rotating element and the fleece;

However, the study of quasi-yarns strength in dependence on the mentioned parameters showed that quasi-yarns strength values in themselves are not sufficient enough to ensure the necessary strength of most product sorts (Hanus 1995). It also turned up that the mechanical fixation by quasi-yarns is a suitable method for "linking" of reinforcing networks to the fleece surface. These reinforcing networks then take over the functions initially expected of quasi-yarns (e.g. the handling strength) so that the product obtains a number of new properties such as shape ability, dimensional stability, flexural rigidity etc. The reinforcing networks represent a "technologically" necessary and "user" beneficial part of 3-D nonwoven textile products made of web sorts fixed by means of quasi-yarns.

Practical Aspects

The fixation of 3-D textile fabrics by quasi-yarns can be applied to all products fulfilling the requirement to "link both the fleece surfaces by fibers". The fibers have to go through the fleece, from its' one surface to the other. This condition can be fulfilled by both the systems of perpendicular web-laying as well as of aero-dynamical fleece forming.

Textile Fabric Manufacture

The production process of 3-D nonwovens is obvious from the Figure 5. The scheme of elements for realization of the mentioned process can be divided into two subsystems (A and B). The A-subsystem is the equipment for web forming. It can be a perpendicular web layer or a machine for aerodynamic web forming. The advantage of applying the rotation layer is the possibility of production of so-called corrugated textiles. An appropriate control of the v_2 and v_3 velocities enables to manufacture textile fabrics with articulated surface, e.g. according to the Figure 10. The B subsystem is equipment for production of quasi-yarns.

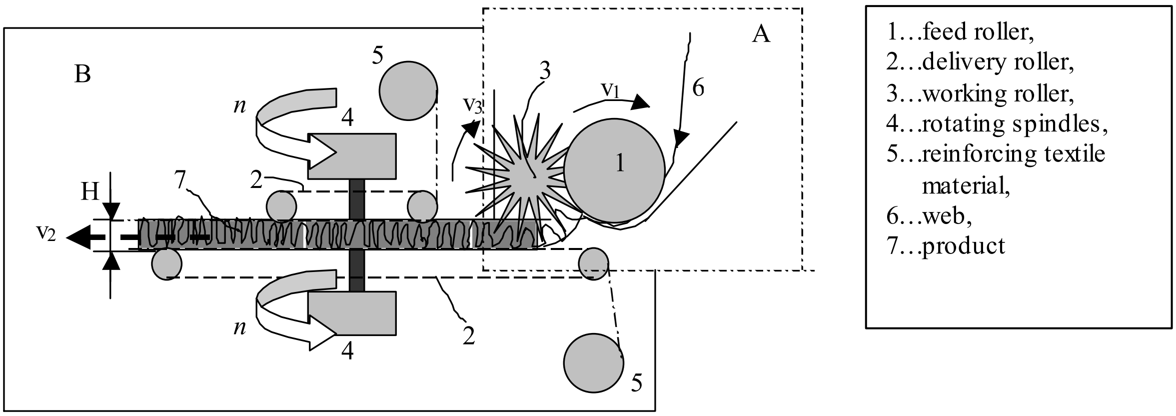


Figure 5.

The principle of 3-D nonwoven textiles production according to Figure 5 consists in the fact that a working disc (3) pushes the web waves between two band-conveyers (2). In the space between the bands of conveyer there are inserted rotating spindles (4) of cylindrical shape (Figure 2). The control of contact pressure between the element and the web can be made by changing of insertion depth of the elements rotating between the conveyer bands. The elements' revolutions are also adjustable and they control the twisting process efficiency. As mentioned above, quasi-yarns do not ensure the necessary product strength, and the required properties are obtained by using of various reinforcement network types (5). Such networks are driven to the front of the rotating spindles (4) between the conveyer and the fleece. The rotating spindles will "link" the reinforcement networks to the fleece surface as we can see in Figure 6.

Production of Laminated Textile Fabrics

For lamination of textile fabrics it is possible to use the system according to the scheme in Figure 4. A precondition for lamination is a "hair-like" product surface. From this hair, the quasi-yarns between the laminated products are "twisted". Figure 7 shows a quasi-yarn in a section of a textile fabric manufactured by laminating of two vertically laid 3-D textile products.

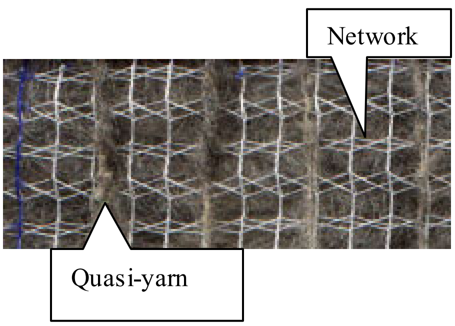


Figure 6.

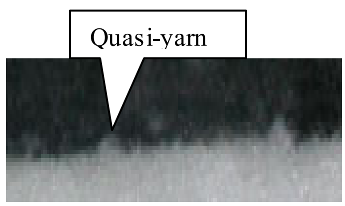


Figure 7.

Examples of Products

The described production process enables to produce "smooth" products, i.e. of constant thickness (Figure 8), or so-called corrugated products (Figure 10), i.e. e. of varying height or, as the case may be, of varying density. These Both variants can be realized with one or two reinforcing networks.

Products of Constant Thickness

Among such products we count e.g. thermal insulation fabrics made of 100% wool fibers (blends of various types of lower quality wool sorts) and PL reinforcing networks added to both surfaces. According to their heat conductivity, textile insulation fabrics of wool fibers can be included in the insulation group of heat conductivity $\lambda = 0{,}040\ Wm^{-1}\ K^{-1}$. Measurements proved the lowest heat conductivity with a wool product of density 20 $kg.m^{-3}$ (thickness 50 mm). The above mentioned production process enables to bring to the market new products not only of good insulating properties but also "environment friendly".

Other example of a "smooth" product is a "blanket" (inner layer of the blanket; its outer layer is a cover), manufactured in two versions, i.e. with one or two reinforcing networks, of thickness ca 15mm, specific area weight 200 g/m^2 and 400 g/m^2. Models of these products having constant thickness are showed on the Figure 8.

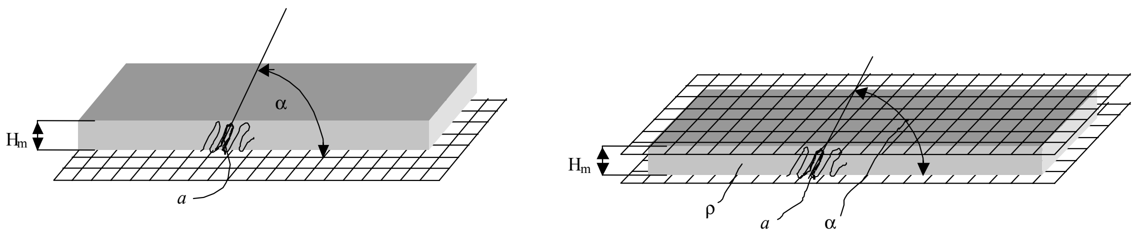


Figure 8.

Further example is a mattress (Hanus 2001) of 125 mm thickness, consisting of five "sub-mattresses" (a, b, c, d, e), each of 25 mm thickness made according to Figure 9. The sub-mattress is product type according to Figure 8, two networks. Individual sub-mattresses are mutually linked on the device arranged according to Figure 6 by quasi-yarns. By means of mutual laminating of sub-mattresses it is possible to get a mattress of thickness to 200 mm. An example of contact pressure value measurements between the mattress and the patient body taken on a model of antidecubite textile mattress after 60 minutes of loading is shown in Figure 9. The red points are places where contact pressure between body and mattress exceeded 32 mm of Hg.

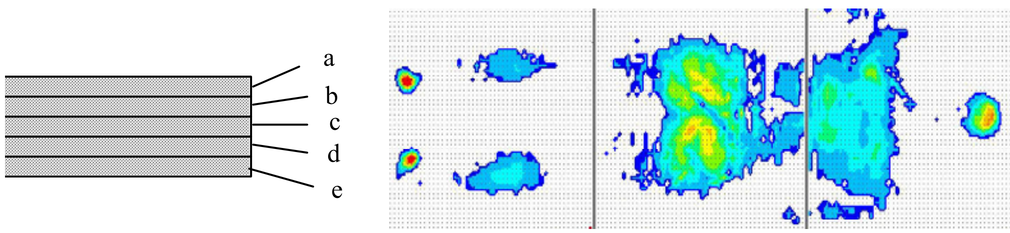


Figure 9.

Cotton 3-D Nonwovens

Cotton fleeces had reinforced by quasi-yarns and network was tested in the last experiment. Parameters of technology and specific product properties were studied.

The previous works interested in cotton nonwovens states:

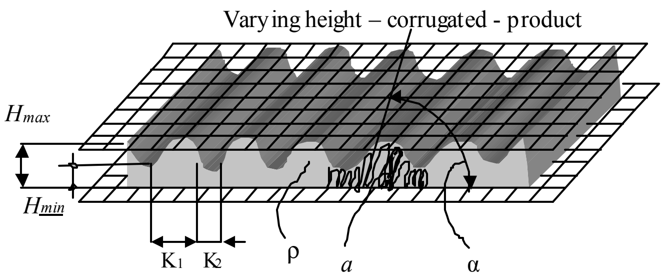
- Cotton nonwoven products compression resistance decreases with the increasing cotton ratio in a blend with synthetic fibers (Parikh 2002);
- Cotton fibers prove a good thermal insulating power even in a wet condition (Parikh 1999);
- Cotton by virtue of its unique structure offers comfort, exceptional absorbency, efficient wicking, electrostatic charge resistance, good process ability, resilience and softness (Cristine Sun).

Therefore we can expect that the favorable properties of cotton will be utilized in nonwovens made for blankets, specific dressings, agriculture textiles products and insulation products.

Considering the results of the previous works where thermal and compression properties of vertically laid nonwovens containing cotton were studied, we focused on acoustic properties of nonwoven products containing cotton noils. Three samples containing cotton noils marked Cq, Iq+t, Pq were manufactured. "Cq" sample consisted of 70% cotton noils, 30% PET 2,5 dtex/50 mm and a PET reinforcing network on both product sides, density of the sample 35kg/m^3. "Iq+t" sample contained 70% cotton noils, 30% PET bonding fibers 4 dtex/51mm type SKYRON and PET reinforcing network on both sides, density of the sample 39kg/m^3. Quasi-yarns and thermo-process were used for fixing of that sample. The sample "Pq" was made the same way like the sample "Cq" but from 100% PET fibers 2,5dtex/50mm only. Its density was 30kg/m^3. Thickness of all samples was 30mm. The results of the measurement made on the two-microphone impedance measurement tube, type 4206 made by Brüel and Kjaer are on the Figure 12. The sound absorption coefficient was measured. The best result shows sample "Cq" in spite of the fact that its density is not highest. Density difference between samples Cq and Iq+t (4kg/m^3) and density difference between samples Iq+t and Pq (5kg/m^3) are similar but the differences among the sound absorption coefficient curves of these samples are very different. We can deduce from these differences that 3-D cotton nonwovens are good material for sound insulation (thanks to higher cotton density 1,52). Differences between sound absorption coefficient curves indicate that "more free contact" among fibers is useful for sound insulation products. It indicates that described fixation by quasi-yarns is advisable for production of the textile sound insulations.

Corrugated Products

Using the possibility to control the amplitude as well as the ρ wave number in course of the production, we are able to manufacture products of articulated, e.g. of "corrugated" (Figure 10) or of toothy (Figure 11) surface.



$$\rho = \frac{v_3}{Av_2};$$

v_3 and v_2 are changed according to sine.

Figure 10.

By means of mutual laminating of "corrugated" textiles on device shown in Figure 6, it is possible to obtain "hollow" products or products of structured surface, for instance according to the scheme in Figure 11.

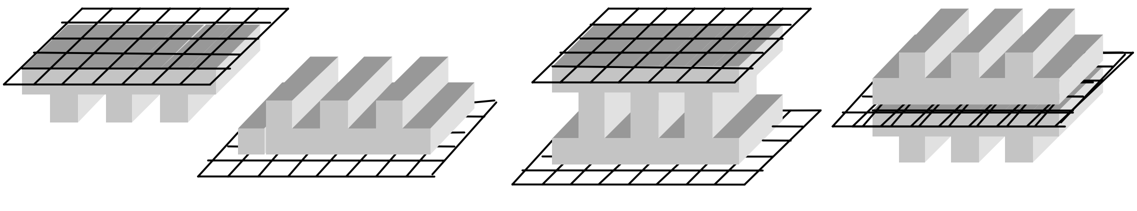


Figure 11.

Such product types are supposed to bring:

- Lower contact pressure in case of application in mattresses;
- Cut down of raw material consumption in case of technical applications;
- An unusual look in case of non-technical applications.

Properties of Products Fixed by the "Thermal" Method and by "Quasi-Yarns"

The factual properties of textiles of the described structure depend of the properties of the used raw materials. We use wool for example in thermo insulations where above all the heat conductivity is observed. For mattresses, where the contact pressure between the pad and the loading body is observed, we take PET fibers. It is justified to suppose that the differences in properties of products with different fleece fixation will result above all from different types of contacts between the fibers and of different layout of these contacts in the textile fabric section. By thermal fixation we obtain so-called "staying" contacts among the fibers. Their layout in the textile fabric section is (in most cases) uniform. By "mechanical fixation" we obtain so-called "loose" contacts, the strength of which depends above all on the frictional forces between the "contact making" fibers, consequently factually on the frictional forces in the quasi-yarn and its immediate neighborhood. We can than expect that this quality difference of contacts between fibers will result e.g. in different compression resistance and different results of the creep as well as of the relaxation experiments. It will also reflect in the permanent deformation value after a long-lasting stress.

The mechanically fixed products are factually “softer” than the “thermo-fixed” ones. An example of products of approximately the same parameters (approximately the same height and density), differing just by their fixation methods shows that this difference is significant in practical terms. Figure 9 shows the compression deformation curves of these products.
From this example we can also deduce how the compression resistance of a quasi-yarn fixed product can be increased by subsequent thermo-fixation.

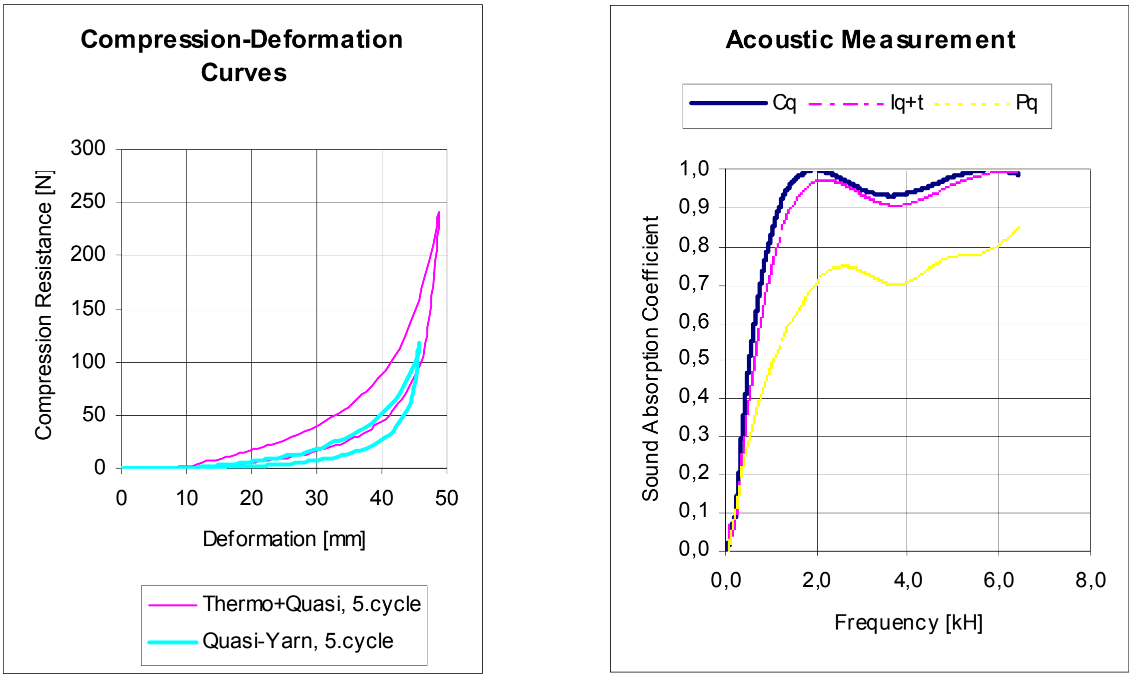


Figure 12.

Conclusion

The paper presents:

- The method of web fixation in 3-D nonwoven textile fabrics production by quasi-yarns;
- The method of lamination of 3-D nonwoven textile fabrics by quasi-yarns.

The quasi-yarn fixation is characteristic above all by:

- A low power consumption;
- It does not demand a large floor area;
- It requires neither specific fiber blends nor specific chemical agents;
- As opposed to the case of needle-punching, for example, this process neither:
- Reduces the thickness, nor
- Increases the density, nor
- Changes the fiber orientation in the product
- It ensures product variability;
- The development of the method continues.

The products fixed using quasi-yarns and networks are softer than the thermo-bonded products.

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