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Analysis of the Mechanical Properties of Woven and Nonwoven Fabrics as an Integral Part of Compound Fabrics

Abstract
In this paper the difference between the mechanical properties of woven and nonwoven fabrics is presented, and the important role of constructional parameters (particular the cover factor) of reinforcement fabric in the compound fabric is stressed. Some basic mechanical properties, such as tensile strength, elongation at break, work to rupture and the force by 1% of elongation were measured and analysed. The stress/strain diagrams show the differences in the behaviour under defined loads of different woven and nonwoven fabrics. The results show that the fabric with good mechanical properties is not always suitable as reinforcement, where the needle punching is used as a method of linking layers into compound fabric.

Key words: *technical textiles, compound fabrics, construction parameters, cover factor, reinforcement fabric, mechanical properties.*

Introduction

In comparison with apparel textiles, the main advantage of technical textiles is their purpose of use, which requires less but very specific project demands of them. The use of compound fabrics for technical applications is constantly increasing. One type of compound fabrics, which will be the focus of our discussion, consists of at least three layers, upper and lower nonwoven needled fabrics, and reinforcement layer(s) of woven or nonwoven fabric. For example, nonwoven-woven-nonwoven (NWN) compound fabric or nonwoven-malimo-nonwoven (NMN) compound fabric can be usedas conveyor belts in the automotive, chemical, mining and textile industries, as well as in many public institutions such as airports and hospitals. Nonwovens are widely used textile materials because of their low production costs, and so they have great growth potential. Needle-punch technology is one of the oldest bonding technologies, but the statistical data of worldwide nonwoven production processes prediction for 2020 shows that the use of needle-punch technology will continue to grow [1]. Woven technical textiles are designed to meet the requirements of their end use. Their strength, thickness, extensibility, porosity and durability can be varied. Higher strengths and greater stability can be obtained from woven fabrics than from any other fabric structure using interlaced yarns [2].

When engineering NWN or NMN compound fabrics, the following parameters should be taken into consideration:

- the nonwoven fabric ‘s constructional parameters,
- the woven fabric’s constructional parameters,
- the number of layers in the compound fabric structure,
- the methods and parameters of bonding and finishing.

Nonwovens are normally made from continuous filaments or from staple fibre webs or batts strengthened by bonding using various techniques such as adhesive bonding, mechanical interlocking by needling or fluid jet entanglement, thermal bonding and stitch bonding [3]. With the proper selection of fibres, technological process of web production, and methods of web bonding and finishing, the desired properties and applicability of nonwovens can be achieved. The mechanical properties of nonwovens depend on the constructional parameters of the web (the basic structure element of the web, the fibres’ composition and orientation, the method of web production), and the type of web bonding and finishing [4]. In the case of needle punch production, it has been stated that the tensile properties of needle punched fabrics are above all highly dependent upon the frictional properties of the constituent fibres, as well as the way in which the fibres are arranged [5, 6, 7].

Comparing the mechanical properties of nonwoven and woven fabrics, the mechanical properties of the latter are shown to be much better. The use of woven fabric in the compound fabric structure is therefore inevitable in order to achieve proper mechanical properties. Woven fabric as an integral part of compound fabric has a reinforcing role. Woven reinforcement exhibits good stability in the warp and weft direction, and offers the highest cover or yarn packing in relation to fabric thickness [2].

When engineering woven fabric as reinforcement in the compound fabric for specific end use (conveyor belts), the following project demands should be taken into consideration: high breaking strength, low elongation at break, high Young′s module level, high tensile force by 1% of elongation, and fabric thickness lower then 1 mm [8]. Woven fabric mechanical properties are the function of the mechanical properties of the fibres used, the mechanical properties of constituent yarns, the woven fabric geometry (yarn linear density, thread density, type of weave) and the technological parameters of spinning, weaving and finishing processes [9]. By studying the load-extension properties of woven fabrics, most researches focused on the basic weaves, rather then the fabric’s tightness [10].

In the case of Malimo fabric, which can also be used as a reinforcement instead of as a woven fabric, the mechanical properties depend on the mechanical properties of longitudinal, transversal and stitching yarns, as well as on the type of stitching.

The mechanical properties of a compound fabric are not simply the arithmetical sum of the properties of a separate layer in a compound fabric. When engineering needle-punched NWN or NMN compound fabric, not only woven or nonwoven fabric geometry parameters must be taken into account. Another very important parameter is the number of reinforcement layers of fabric in the compound textile structure. The number of layers in the compound fabric depends above all on the mechanical properties of the reinforcement fabric. By using woven fabric with excellent mechanical properties, such as high breaking strength, low elongation at break, and a high Young′s module level, the number of layers in the compound fabric can be reduced. When needle punching, on the other hand, the reinforcement fabrics can be damaged to such an extent that their tensile properties rapidly become impaired, and the tensile properties of compound fabrics also become unsuitable [8].

This paper reports the main difference between the mechanical properties of woven and nonwoven fabrics. The difference between the mechanical properties of the different fabric constructions being used as reinforcement in the compound NWN or NMN fabric structure is also emphasised. The aim of the presented research was to establish which fabric is most suitable as reinforcement in compound fabric, according to their constructional parameters as well as their mechanical properties.

Experimental

Materials and Methods

Our experiment was focused on compound fabrics that consisted of at least three fabric layers. The upper and lower layers were nonwoven fabrics (NF5) – fibrous webs, made by conventional pneumatic system and bonded on the pre-needle machine. As the reinforcement layer, three types of multifilament woven fabrics (WF1, WF2, WF3) and one nonwoven Malimo fabric (MF4), with differing constructional parameters, were involved in this research (Figure 1). The constructional parameters of the fabrics used are listed in Table 1. The weaves of woven specimens were as follows (description following standard ISO 9354): plain (10-01 01-01-00), basket (10-02 02-02-00) and 4-end broken twill (21-01 03-01-02 03 02 01).

We used the dynamometer to measure the following mechanical properties of the fabric specimens: breaking strength, elongation at break, stress by 1% elongation, and work of rupture. All the fabrics' mechanical properties were measured according to standard ISO 5081.

Table 1. The constructional parameters of fabrics as an integral part of compound fabric.

Ref. sample	Raw material	Warp - weft linear density, tex	Warp - weft density, threads cm^{-1}	Weave	Fabric mass, g m^{-2}	Fabric thickness, mm	Cover factor
WF1	PES	111-111	6-2	plain	104	0.262	0.26
WF2	PES	228-232	11-10	basket	482	0.752	0.79
WF3	PES	110-044	20-11	4–end broken twill	324	0.758	0.66
MF4	PES	110-110	11-10	tricot stitch	298	0.541	0.61
NF5	PES	-	-	-	280	2.021	-

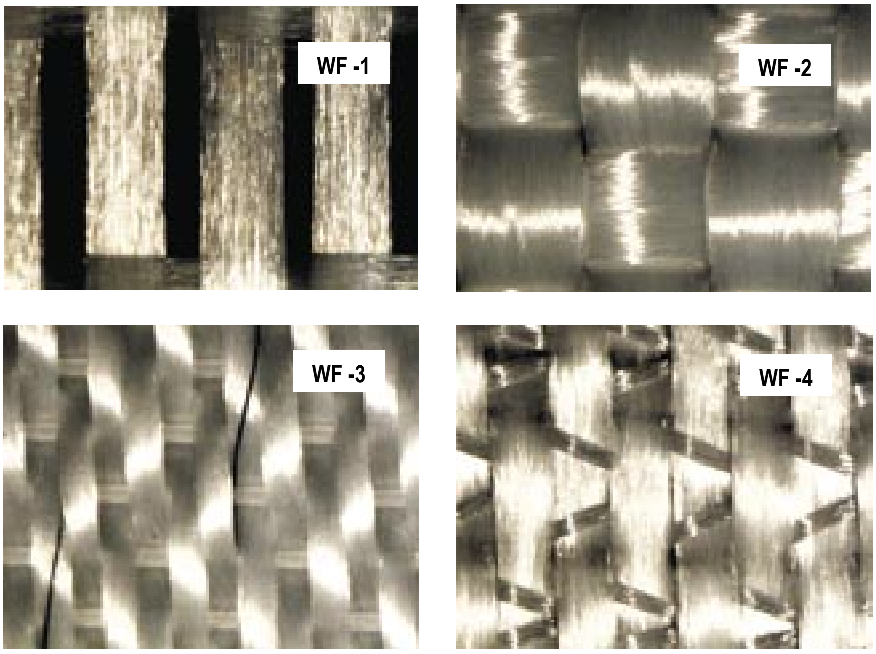

Figure 1. Photomicrographs of reinforcement fabrics at magnification ×20.

Results and Disscusion

The results of measured mechanical properties of tested fabrics are listed in the figures below (Figures 2-5), while

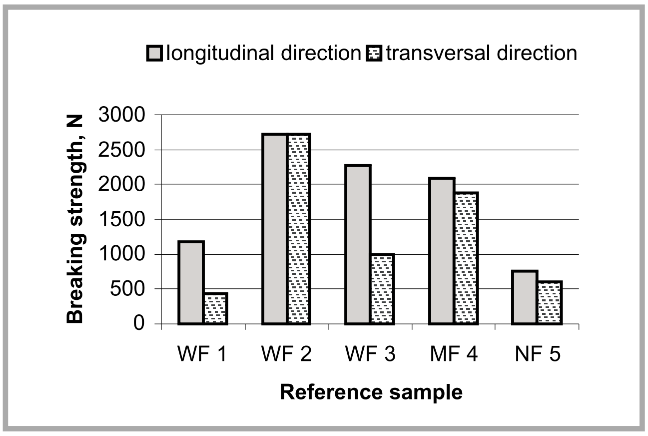

Figure 2. Breaking strength of samples.

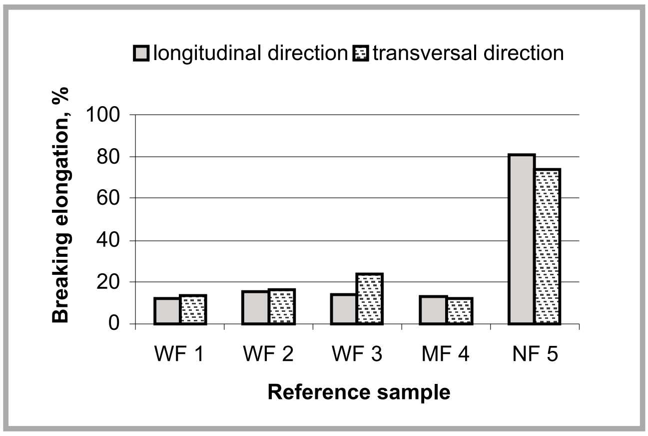

Figure 3. Breaking elongation of samples.

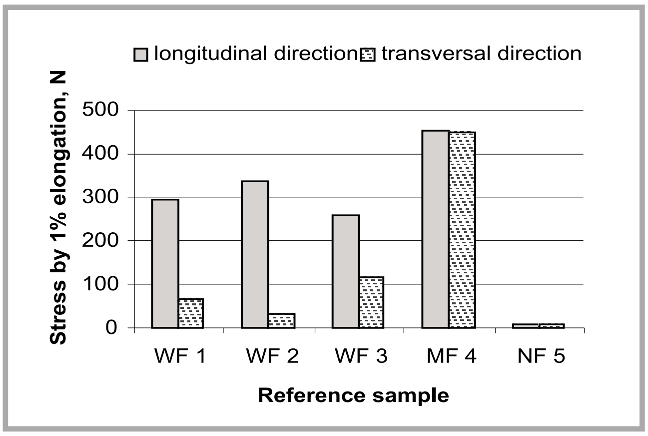

Figure 4. *Stress by 1% elonfation of samples.*

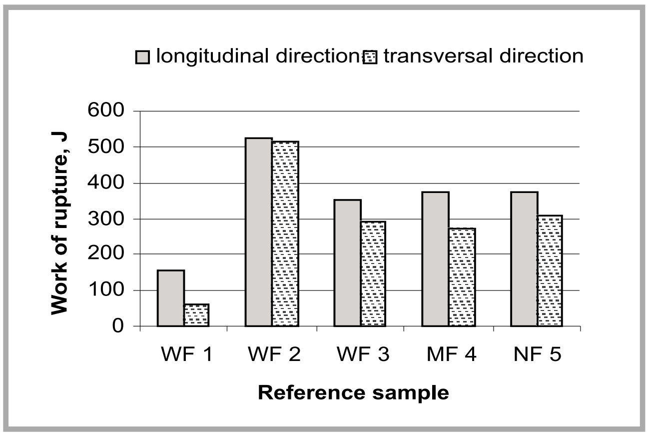

Figure 5. *Work of rupture of samples.*

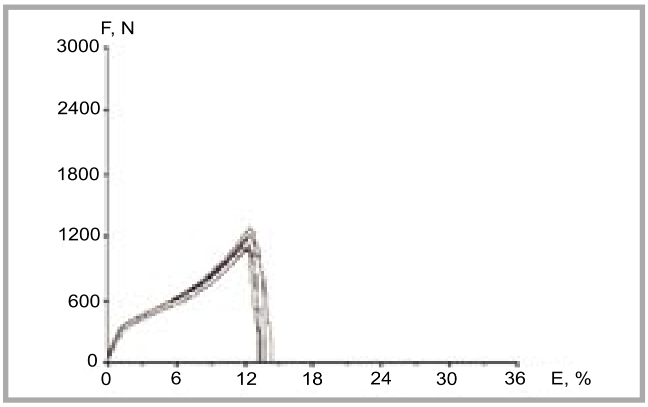

Figure 6. *Stress-strain curves of WF1.*

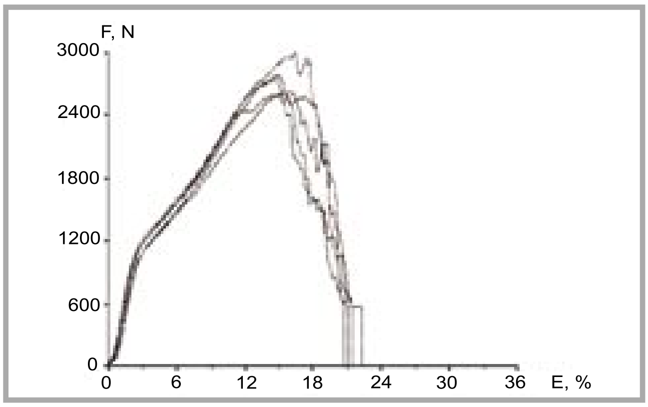

Figure 7. *Stress-strain curves of WF2.*

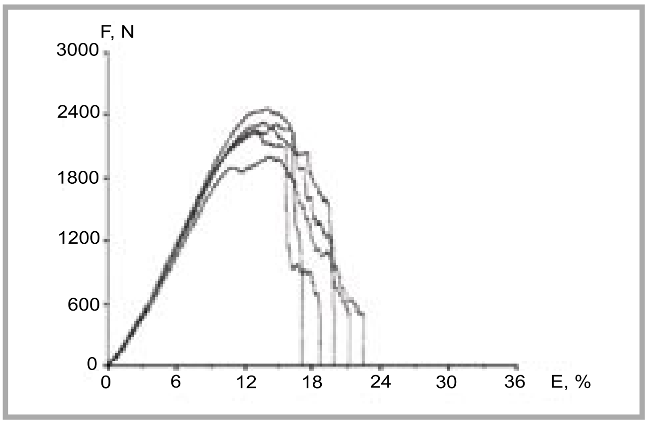

Figure 8. *Stress-strain curves of WF3.*

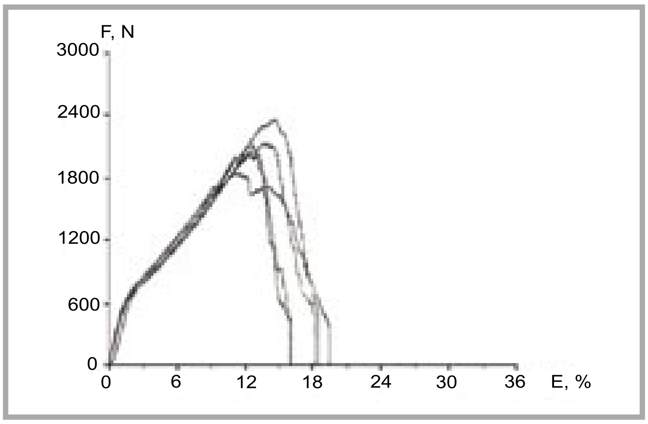

Figure 9. *Stress-strain curves of WF4.*

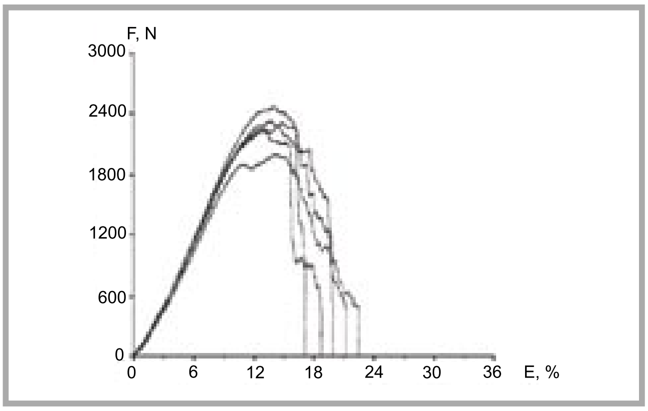

Figure 10. *Stress-strain curves of NF5.*

the stress-strain curves (five specimens of each fabric) are shown only for the longitudinal direction of fabric samples, while this direction is more important for end-use. (Figure 6-10).

By analysing the behaviour under stress of the different woven fabrics, the non-woven Malimo fabric and the conventional nonwoven fabric (fibrous web), the following conclusions can be drawn:

- In the case of the woven and Malimo

fabrics, a higher Young's module occurs, which means that the higher stress is needed to extend the fabrics regarding the conventional nonwoven fabric. For the last-mentioned fabric, the lower stress extends the fabric to a much greater range. There is almost no resistance to the force in the area of elasticity, which is the result of the low strength of the web, so plastic deformation already occurs in the area of low tension.

- After the yield point, the behaviour of the stress–strain curve of the woven and Malimo fabrics differentiate in comparison with the conventional nonwoven fabric. The slope of the stress-strain curve of the woven fabrics (and Malimo fabric) decreases against the slope of the initial segment, while the slope of the stress-strain curve of the conventional nonwoven fabric increases.
- All the values of measured mechanical properties are much better for any type of woven fabric, and also for the Malimo fabric, than in the case of a conventional nonwoven fabric. That justifies the use of woven or Malimo fabric as reinforcement in the compound fabric.

By comparing the results of the mechanical properties and behaviour under stress of the tested fabrics in order to decide which fabric would be most appropriate as reinforcement in the compound fabric, regarding the project's demands, the following conclusions can be drawn:

- Observing the fabric mechanical properties (in longitudinal direction), the following ranking of fabric suitability in decreasing order can be made:
  - Breaking strength:
    WF2 – WF3 – MF4 – WF1,
  - Breaking elongation:
    WF1 – MF4 – WF 3 – WF2.

  The measured values of elongation at break for all the tested specimens are in approximately the same class, between 12-15%.
  - Stress by 1% of elongation:
    MF4 – WF2 – WF1 – WF3.
  - Work of rupture:
    WF2 – MF4 – WF3 – WF1.

  Considering all the fabric properties together, the most suitable layer reinforcement fabric should be WF2 and MF4, and then WF1 and WF3. MF4 has the highest value of stress by 1% elongation, good breaking strength and the lowest breaking elongation.
- By deciding which fabric to use as reinforcement in the compound fabric, besides the mechanical properties the constructional parameters of fabrics should also be taken into account, as they have an influence on bonding. When producing NWN or NMN compound fabrics, great attention is given to the methods and conditions of linking the needle punching, among others. By the method of linking separate layers into one, the macropores in the reinforcement layer should be big enoughfor the needles to run easily through the fabric and not cause much damage. Previous research shows that the cover factor should not exceed 60% [8]. The low cover factor reduces the damage caused to the reinforcement fabric by needles and preserves the mechanical properties of the reinforcement fabric. According to the cover factor value of the fabrics tested, WF2 and WF3 are not appropriate for reinforcement in the compound fabric, and the value of NF4 is near the limit. The decision which fabric to use as reinforcement in the compound fabric thus remains between WF1 and WF4. WF1 has a better cover factor but lower breaking strength in comparison to MF4, but we should use more than one layer of WF1 as reinforcement in the compound fabric, considering that the thickness of reinforcement layer is not exceeded.
- According to all the information established above, WF1 would be the most appropriate fabric to be used as reinforcement in the compound fabric structure, if used in more than one layer (2 or 3).

Conclusion

It is well-known that the mechanical properties of a compound fabric are not simply the arithmetical sum of the properties of a separate layer in a compound fabric. By engineering the mechanical properties of the compound fabric, the effect of the constructional parameter of each layer should be carefully examined, as well as the number of layers in the compound structure, method of linking (parameters of needle punching), and finishing.

This paper shows the differences in the behaviour under stress and the mechanical properties of different fabric constructions (different types of woven fabrics and nonwoven Malimo fabric) that can be used as reinforcement in a NWN or NMN compound fabric for specific end use.

The results clearly show that the fabric with excellent mechanical properties is not necessarily suitable as reinforcement in the compound fabric. In the case of needle punching as a linking method, the cover factor has a great effect. As we have established, it is sometimes better to use more than one layer of woven fabric with lower mechanical properties, but with appropriate constructional parameters, so that the possibility of damage in the linking/needle punching phase is reduced. In this way the mechanical properties of individual layers are preserved, and the desired mechanical properties of the compound fabric are achieved.

References

1. Buchanan, D.R., "ITMA '99: A Review", Textile Progress, 2000, Vol. 30, No. 1/2, pp. 51-67.
2. Horroks, A.R., Anand, S.C.: "Handbook of Technical Textiles", Woodhead Publishing Limited in association with The Textile Institute, Cambridge, 2000, pp.62, 271.
3. Denton, M.J., Daniels, P.N., "Textile Terms and Definitions", The Textile Institute, Manchester, 2002, pp. 234.
4. Krčma, R., "Manual of Nonwovens", Textile Trade Press, Manchester, 1971, pp. 35-65.
5. Alvey, P.J., "The Production and Properties of Nonwoven Fabrics", Textile Progress, 1973, Vo.l5, No.3, pp. 43.
6. Pourdeyhimi, P., Ramanathan, R., Measuring Fiber Orientation in Nonwovens, Part I: Simulation, Textile Research Journal, 1996, Vol. 66, No. 11, pp. 713-722.
7. Liao, T., Adanur, S., Drean, J.Y., Predicting the Mechanical Properties of Nonwoven Geotextiles with the Finite Element Method, Textile Research Journal, 1997, Vol. 67, No. 10, pp. 753-760.
8. Filipović, P., Diploma work, University of Maribor, Faculty of Mechanical Engineering, 2001.
9. Dobnik-Dubrovski, P.,Žiberna-Šujica, M., The Connection between Woven Fabric Construction Parameters and Air Permeability, Fibres & Textiles in Eastern Europe, 1995, Vol.3, No.4, pp. 37-41.
10. Sun, F., Seyam, A.M., Gupta, B.S., A generalized Model for Predicting Load-Extension Properties of Woven Fabrics, Textile Research Journal, 1997, Vol. 67, No. 12, pp. 866-874.

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