Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Mechanical behavior of non-woven geotextiles studied by infrared thermography techniques

K. BUET GAUTIER, C. WAGNER KOCHER, J.-Y. DREAN, E.N.S.I.T.M., Mulhouse, France

ABSTRACT: The knowledge of non-woven mechanical behavior is essential to control their draping or their resistance in use. Because their bending stiffness is low, it demands a specific extensometry, without contact not to disturb the measurement. Then, an optical method, combined with picture analysis techniques, is used to measure the strains. Moreover, the thermal cartography of the non-woven surface is taken in, during the test, using infrared thermography. The aim is to establish a link between phenomena occurring at the scale of the fibrous tangle on the one hand and the macroscopic behavior of the geotextile on the other hand.

1 INTRODUCTION

Tensile behavior of non-woven is complex. Many authors had carried out experiments concerning uniaxial tensile tests in order to get one aspect of this behavior (Myles & Carswell 1986, Baudonnel et al. 1986, Zhao 1991, Villard & Giraud 1998, Adanur & Liao 1999 for example). Tension versus strain curves classically show an important non-linear zone and point out significant extensions that non-woven support before the failure.

Made of fibers, those textiles are probably the place of numerous phenomena occurring at the scale of the fibrous tangle : friction and movements between fibers, extension of the fibers… Those phenomena will be called mesoscopic because they occur at an intermediary scale between the one of the non-woven (macroscopic) and the one of the fiber alone (microscopic). The phenomena occurring without energy dissipation will be called elastic; others will be called dissipative.

In parallel, the analysis techniques of images obtained by infrared thermography are widely used to point out thermomechanical couplings existing in solid materials loaded over their yield point (Chrysochoos & Peyroux 1998, Luong 1998, Offermann et al. 1998). We are going to adapt this technique to study non-woven structures, in the aim to link their macroscopic behavior during an uniaxial tensile test to mesoscopic phenomena.

2 PRINCIPLE OF MEASUREMENT

2.1 *Tested materials*

In this work, two materials will be compared : a heatbonded and a needlepunched non-woven. In order to prevent structure effects that can modify the analysis, the non-woven had been chosen of likely the same mass per unit area: 185g/m² and 195g/m² respectively for the heatbonded and the needlepunched.

The fibers are produced by melting raw materials and then extrusion. They are laid continuously and in a random manner to make a fiber web nearly homogeneous and isotropic. Several layers of this fiber web are overlapped to obtain the right mass per unit area. Finally, bonded points are generated between the layers to link them, chemically, by heating or mechanically.

The mechanical method (needlepunched non-woven) consists in linking the different layers by interlacing the fibers of each layer. Because of the tension applied in the machine direction, generally two directions can be distinguished in a needlepunched non-woven : the machine direction and the cross direction.

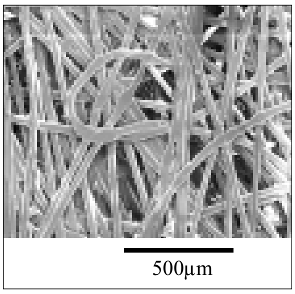


Figure 1. Heatbonded structure.

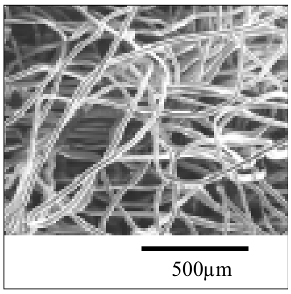


Figure 2. Needlepunched structure.

In the case of heatbonded non-woven, the web goes through two heated rolls of a calander where, locally, some fibers are melt to link the different layers. This leads to a more isotropic product.

Because of these two process, the mesoscopic structures of the non-woven are quite different (see Figure 1 and Figure 2).

2.2 *Specimen*

Several experimental studies on geotextiles (Cazzuffi & Venezia 1986, Rowe & Ho 1986, Wayne et al 1993) had shown that it is preferable to choose a specimen said "long" (i.e. ratio of height to gauge width equal to 2 or beyond) in order to obtain a good homogeneity of the strain field at the middle of the specimen. Moreover, to limit edge effects and to ensure a fracture in the middle part of the specimen, it is better to choose a dumbbell or a circular shape (Zhao 1991, Thorr 1997). Then, in this study a circular shape is chosen with a minimum width of 150mm and a tested length of 300mm (see Figure 3).

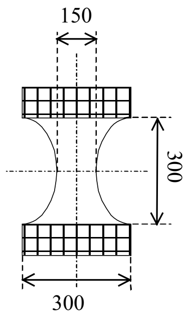


Figure 3. Shape of the samples

2.3 *General device for the measurement*

Uniaxial tensile tests are performed on an universal tester. Because of the great extension of the non-woven structures, displacement rate of the frame crosshead is 10mm/min. This value is in the range commonly used to test geotextiles (Baudonnel et al 1984, Myles et al 1986). Moreover, a preliminary study has shown the little influence of this parameter on non-woven behavior, in the range of 1mm/min to 100mm/min.

Not only the load is measured. A numerical camera takes pictures of the surface of the specimen, at regular intervals, time t=0s being defined by a pretension of 10N. Those pictures are used to build the strain field (see § 2.4). At the same time, an infrared camera takes in the thermal cartography of the specimen surface (see § 2.5).

2.4 *Strain field*

Considering the softness of this kind of structure, a classical extensometry is not well adapted : it is better to use techniques without contact that do not disturb the measurement. The strain field at the middle of the sample is then calculate via optical measurements. A grid is firstly drawn on the non-woven (see Figure 4). Pictures of this grid is taken each 30 or 60 seconds to see its distortion during the test. Data are then treated and analyzed with a picture analysis software.

Displacements of the points are calculated as the difference of their coordinates between current state and initial state, and the strains are determined in the field of large distortions.

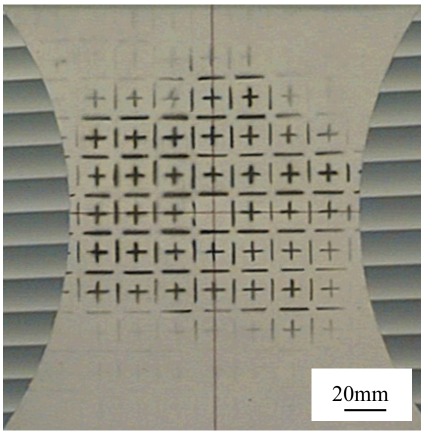


Figure 4. Grid on the surface of a specimen (initial state)

2.5 *Infrared thermography*

The infrared thermography allows to produce thermal cartography of a surface from the invisible radiant energy emitted by a solid. This method is without contact and so does not disturb the phenomena. The higher the temperature of the specimen is, the higher the emitted energy is. The measured energy differences correspond to temperature differences because of :

$$W = a.T^4.\varepsilon \tag{1}$$

where W=radiant energy ; a=constant; T=absolute temperature ; ε=emissivity of the material.

The amount of radiant energy depends on thermal effects that are generated by the thermomechanical coupling and developed under load.

From those thermodynamics quantities that describe thermodynamic process and from the fundamental equations of the mechanics, the equation of the thermomechanics is (Lemaître & Chaboche 1988) :

$$\rho.C_v.\dot{T} = \underbrace{K.\nabla^2.T}_{\text{thermal diffusion}} + \underbrace{\left(\beta : D : \dot{E}^e\right)T}_{\text{thermo-elasticity}} + \underbrace{S : \dot{E}^I}_{\text{intrinsic dissipation}} + \underbrace{\rho.r}_{\text{heat well}} \tag{2}$$

where ρ=density ; C_v=specific heat ; K=thermal conductivity ; β=tensor of thermal expansions ; T=absolute temperature ; D=tensor of elastic behavior ; E^e= tensor of elastic strains ; S=tensor of stress ; E^I= tensor of anelastic strains ; r=source of heat per unit mass.

Notice that E, tensor of strains, is :

$$E = E^e = E^I + \beta(T - T_R) \tag{3}$$

where T_R=reference temperature.

The equation of the thermoelasticity shows that the temperature variations results from four very different phenomena that need to be well dissociated by special test conditions or by specific picture treatment methods. Luong (Luong 1998) showed that it is the main difficulty during the result analysis.

3 RESULTS AND ANALYSIS

Considering the complexity of the structure and the phenomena involved in the distortion, the reorientation and the inter-fiber sliding, the non-woven behavior is far from the one describe in the theory of continuous elastic materials.

3.1 *Displacement fields*

On figure 5, displacements fields, calculated as described in §2.4, are presented. The empty circle is the initial position of the point (spaced of 20mm along x and y axis), little black circles are the positions at various moments of the calculation and big black circle is the final position of the points of the grid.

The differences between heatbonded and needlepunched have to be noticed. Indeed, as it has been already said, the needlepunched geotextile is quite anisotropic and has two preferential directions which are machine direction (the fibers are mainly oriented along this axis) and cross direction. Then, during a tensile test along the machine direction, filaments are not changing much their orientation and move mainly along the tensile direction. In addition, during a tensile test in the cross direction, large movements are occurring in order to modify the orientation of the fibers and make them be parallel to the tensile direction. An important shrinkage of the specimen is then noticed. Those movements are allowed because of the mechanical bonding process that does not lock much the structure.

On the contrary, the behavior of the heatbonded non-woven seems to be quite isotropic. There are two reasons for this. Firstly, the mean of production does not tend to give a preferential orientation as much obvious as for needlepunched textile. Secondly, the local melt of the fibers locks relative movements of one fiber compared to the others. So, the displacement fields are quite the same, the load being in one direction or in the other.

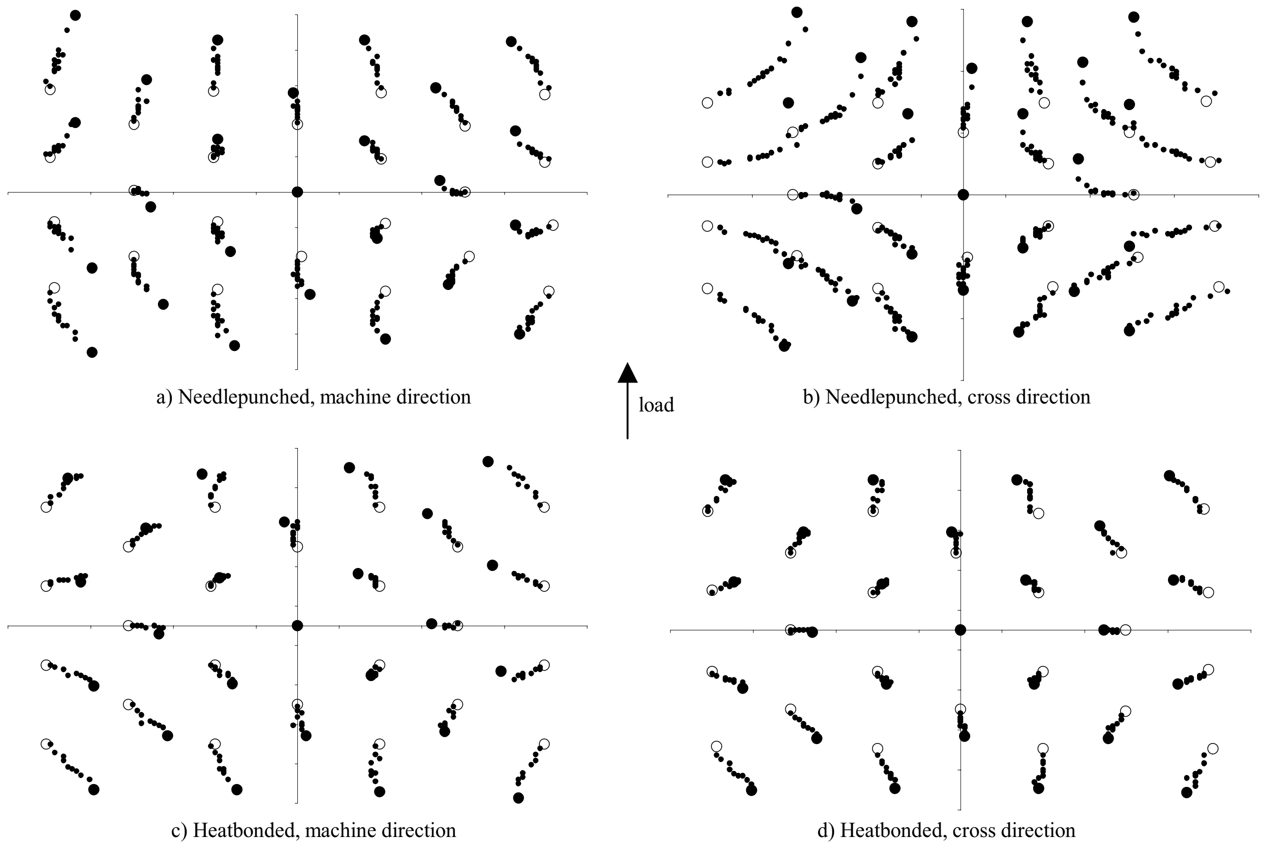
3.2 *Strain fields*

The analysis of the strain fields (see Figure 6) confirms the previous observations. It could be noticed that for the needlepunched geotextile, longitudinal (i.e. in the tensile direction) and transverse strains are similar during a test along the cross direction. Meanwhile, when the test is performed along the machine direction, a great asymmetry is noticed between the strain fields. Indeed, transverse strain is near zero while longitudinal strain is important : lateral shrinkage is very low.

On the contrary, longitudinal and transverse strain of an heatbonded are very similar whatever the load direction.

3.3 *Temperature in the middle of the sample*

On figure 7, the behavior curves are presented. They represent the load per unit true width of the specimen versus strain, along the two directions : longitudinal is called (1) and transverse (2).



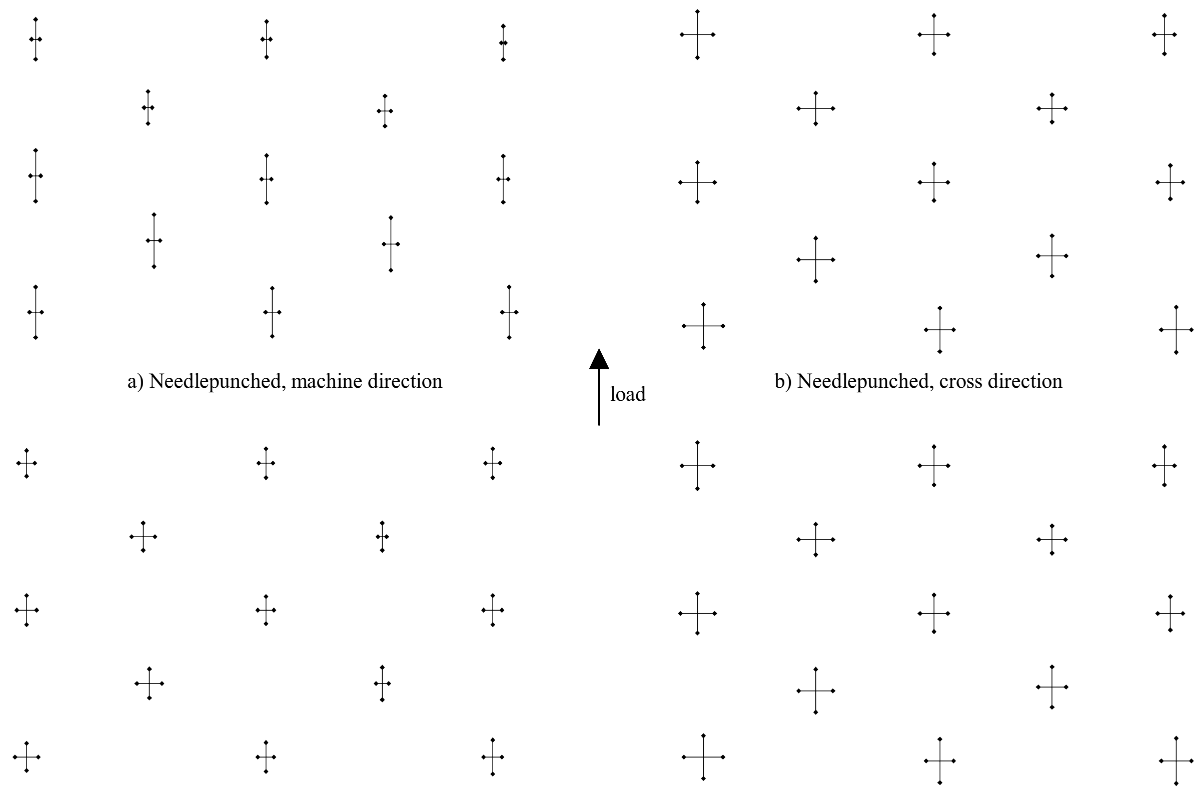
a) Needlepunched, machine direction

b) Needlepunched, cross direction

c) Heatbonded, machine direction

d) Heatbonded, cross direction

Figure 5. Fields of displacements (mm). Initial position ○ - Final position ●



a) Needlepunched, machine direction

b) Needlepunched, cross direction

c) Heatbonded, machine direction

d) Heatbonded, cross direction

Figure 6: Strain fields 1min before the fracture.

On the same graph, the variations of the temperature versus longitudinal strain during the test are given.

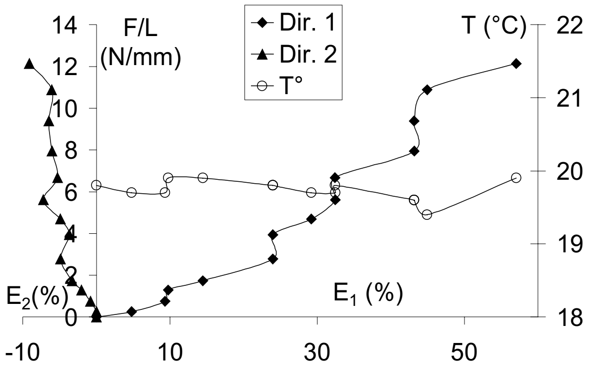
Measured in the middle of the specimen, the temperature is quite constant concerning the needlepunched geotextile, and rise slowly and continuously concerning the heatbonded. When the fracture is starting, local heatings become important (a few degrees); it occurs on the edge of the sample and progresses to the middle of the specimen. So, in the middle, the temperature only increases when the fracture has started. But this is a very fast phenomenon and it is not easy to measure the temperature and the strains in the very last moments of the test. It is why there is no point corresponding to this on the figure 7.

The mechanisms involved in the behavior just before the fracture are different in the case of a needlepunched or heatbonded geotextile. The fact that the temperature does not vary much in a needlpunched seems to demonstrate that the mesoscopic phenomena involved are not dissipative, so are reversible. Then, the frictions and the rearrangements of fibers occur without significant loss of energy, at least in the case of tensile effort in the machine direction. In the cross direction, at large extensions, there is a rise in the temperature linked to more important transformations necessary to line up the filaments.

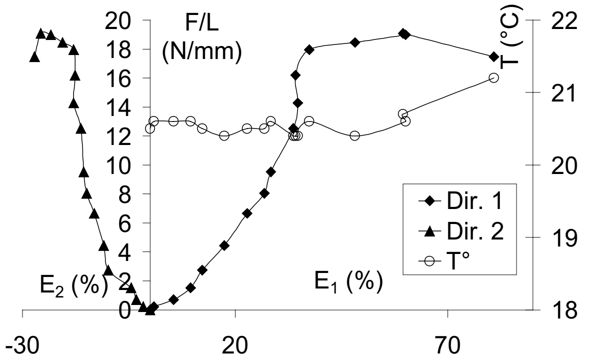
Concerning the heatbonded non-woven, locally, some of the melted points that link together the layers of fibers may broke. Those phenomena produce a certain quantity of energy that leads to a rise in the temperature.

4 CONCLUSION

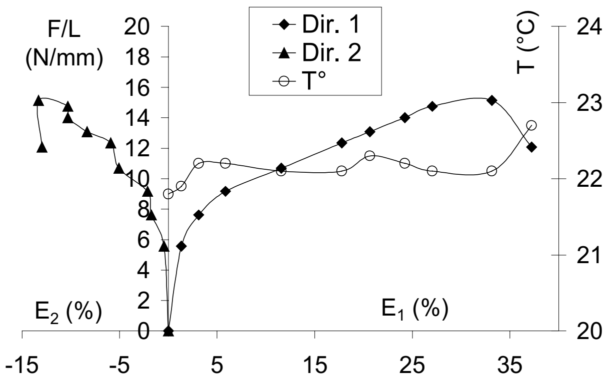
Those first tests have demonstrated the feasibility of the method that have to be improved. Particularly, more recent devices and acquisition systems would allow to obtain a temperature field to be related to the strain fields. The link between the mesoscopic structure, the macroscopic behavior and the thermomechanical mechanisms, however, have been highlighted. This study is in progress in order to supplement the first conclusions.



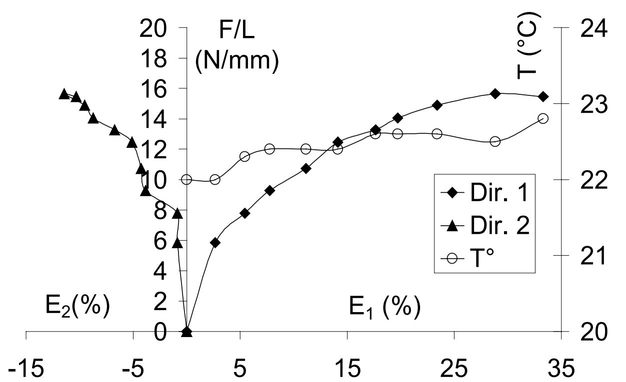
a) Needlepunched, machine direction



b) Needlepunched, cross direction



c) Heatbonded, machine direction



d) Heatbonded, cross direction

Figure 7: Load versus strain curves and fluctuations in temperature.

REFERENCES

Adanur, S. and Liao, T. 1999. Fiber arrangement characteristics and their effects on non-woven tensile behavior. *Textile Research Journal* 69 (11): 816-824

Baudonnel, J., Giroud, JP. & Gourc, JP. 1984. Experimental and theoretical study of behavior of non-woven geotextiles. *Second International Conference on Geotextiles, Las Vegas:* 823-828.

Cazzuffi, D. & Venezia, S. 1986. The mechanical properties of geotextiles: Italian standard and interlaboratory test comparison. *Third International Conference on Geotextiles, Vienna:* 695-700

Chrysochoos, A. & Peyroux, R. 1998 Analyse expérimentale et modélisation numérique des couplages thermomécaniques dans les matériaux solides. *Rev. Gén. Therm* 37: 582-606

Lemaître, J. & Chaboche, J.-L. 1988. *Mécanique des matériaux solides*, 2ième édition. Paris: Dunod

Luong, M.P. 1998. Thermographie infrarouge appliquée à la mécanique des solides. *Mécanique et géotextiles*: 115-129. Paris: Ecole Polytech.

Myles, B. & Carswell, I.G. 1986. Tensile testing of geotextiles. *Third International Conference on Geotextiles*. *Vienna*: 713-718

Offermann, S., Bissieux, C. & Beaudoin, JL. 1998. Statistical treatment to infrared thermoelastic analysis of applied and residual mechanical stresses. *Rev. Gén. Therm*. 37: 718-724

Rowe, R.K. & Ho, S.K. Determination of geotextile stress-strain characteristics using a wide strip test. *Third International Conference on Geotextiles*. *Vienna*: 885-890

Thorr, F. 1997. Contribution à l'étude de l'évolution de la structure de non-tissés sous sollicitation uniaxiale. *Thèse de l'Université de Haute Alsace*

Villard, P. & Giraud, H. 1998. Three dimensional modeling of the behavior of geotextiles sheets as membranes. *Textile Research Journal* 68 (11): 797-806

Wayne, M.H., Montalvo, J.R. & Boatwright, M. 1993. Relationship between wide-width strip tensile and modified strip tensile tests when testing nonwoven geotextiles. *Geosynthetics'93. Vancouver:* 571-577

Zhao, Y. 1991. Visualisation du champ de déformation de surfaces textiles. Mise au point et utilisation d'un logiciel d'analyse d'image. *Thèse Ecole Centrale de Paris*.