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Infrared thermography of 3D-woven fabrics subjected to service loading

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ABSTRACT: The paper introduces the use of an infrared thermographic technique to detect the manifestation of physical processes of damage in a three-dimensional woven polyester fabric subjected to the traffic of heavy vehicles. Thanks to the thermomechanical coupling occurring in the polyester fabric, this non-destructive, noncontact and in real time technique (NDT) highlights the heat generation caused by the energy dissipated by the material during the passage of a wheel. Experimental results show that the infrared thermographic technique provides a useful means to evaluate the mechanical performance of geosynthetic products under full-scale service loading.

1 INTRODUCTION

A three-dimensional woven polyester fabric has been recently proposed and used as an efficient and rapidly deployable mobility enhancement matting, which is able to sustain wheeled and tracked vehicle movements on weak native soils presenting a very low bearing capacity without prior preparation. This has eventually fulfilled the need for the future development of a means of quickly constructing an inexpensive aircraft parking, a taxiway system or a temporary roadway in area known to be difficult to access.

2 PROPOSED METHOD

Damage process and failure behavior of this three-dimensional woven polyester fabric under realistic service loading are therefore an important consideration in connection with design of this innovative product in order to meet the required specifications of customers. This paper aims to illustrate the use of infrared thermography (Luong 2000) as a nondestructive, noncontact and in real time technique to observe and detect the physical process of damage, subsequently leading to failure, under realistic service loading. It has been shown (Luong and Khay. 1998) that infrared thermographic analysis allows to estimate the evolution of dissipative behavior on a standardized specimen of woven and non woven geotextiles submitted to classical 1D-tension tests.

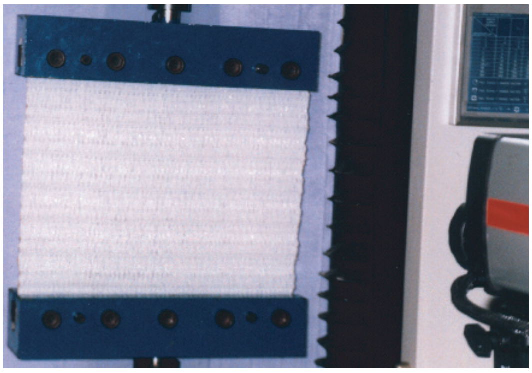

Figure 1. Standardized one-dimensional testing on 3D-woven polyester fabric.

3 LABORATORY TESTING

In laboratory, several standardized one-dimensional tension tests (Figure 1) demonstrated that the heat generation due to energy dissipated by the 3D-woven polyester fabric is a sensitive manifestation of damage occurrence. Obtained results of dissipation under increasing tension (Figure 2) readily permit the evaluation of a limit of acceptable damage beyond which the geosynthetic material is led to failure (Figure 3).

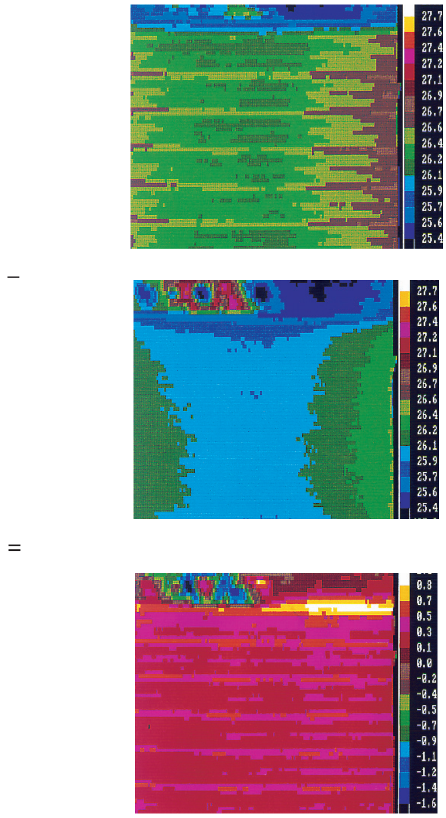

Figure 2. The intrinsic dissipation of the tested 3D-woven polyester fabric is obtained by subtraction of thermal images recorded at different tension levels.

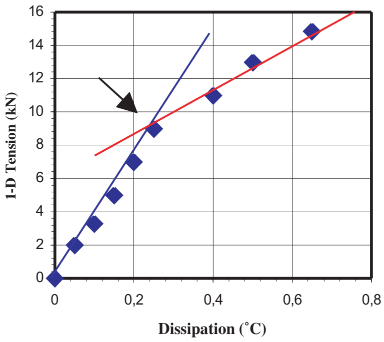

Figure 3. This diagram (Dissipation / Tension) provides a simple definition of a limit of acceptable damage (indicated by an arrow) beyond which the material is led to failure.

4 FULL SCALE TESTING

For the 3D-woven polyester fabric investigated in the present paper, traditional standardized 1-D tensile tests are not suitable to propose an aid for the determination of the lifetime under realistic service loading. Thus there is a need for evaluating the mechanical performance of the geosynthetic product under field conditions.

An innovative full scale field testing program was undertaken in order to investigate the mechanical performance of geosynthetic fabrics subjected to specific service loadings generated by vehicular traffic usage. Several specimens of three-dimensional woven polyester materials were submitted to the passage of motor vehicles characterized by different axle loads. This experimental research emphasizes the application of infrared thermography in field conditions to detect the occurrence of damage for real lifetime tests.

The experimental set-up consists in driving four vehicles of empty weights between 1 and 9 tons on a 2 m^2 specimen of geosynthetic simply lying on soil (Figure 4).

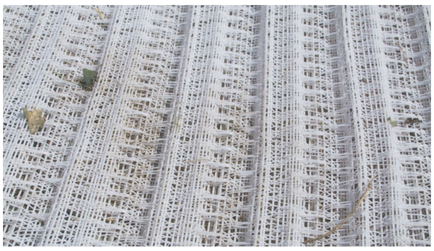

Figure 4. 3D-woven polyester mat lying on soil.

Figure 5. Heavy wheeled vehicle used as moving loading system on 3D-woven polyester mats.

Vehicles (Figure 5) are described in Table 1 and moved at constant speed of 15 km/h. The soil is not characterized from a mechanical point of view and results on the mixture of grass, gravel, ground and meteorological conditions. Field tests were conducted out during summer with high sun.

Table 1. Characteristics of the loading vehicles and mean values of temperature changes obtained by subtraction of thermal images before and after the passage of the right front wheel.

Vehicle	Empty weight (tons)	ΔT °C
# 1 (Renault Laguna car)	1,3	0.2
# 2 (Iveco truck)	2,11	2.5
# 3 (Mercedes 1217 truck)	6,02	4.5
# 4 (Mercedes 1823 truck)	8,64	5.5

An infrared thermographic camera scanned the geosynthetic material during the passage of the right front wheel of the loading vehicle. The infrared detector converts the detected radiated energy into a detailed real-time thermal picture in a video system. The quantity of energy emitted as infrared radiation is a function of the temperature and emissivity of the specimen. Differences of radiated energy correspond to changes of temperature. Hence, the infrared thermographic camera is used to visualize the evolution of the surface temperature field on the geosynthetic product. A specific computer aid thermography software allows the data reduction of obtained thermal images using calibration and correction procedures to take into account reflected radiation from the object's surrounding and experimental conditions. Video treatment attempted to quantify the temperature change due to the passage of the wheel to emphasize the heat dissipation which is a manifestation of damage process into the material during the realistic service loading.

Classical coupling thermomechanical equations show that the detected temperature change results from different dissipative phenomena due to the microscopic behavior. At the macroscopic scale, damage parameters are considered as internal variables in phenomenological constitutive models such as a thermo-visco-plasticity model. The infrared scanning technique gives a measure of the macroscopic observation of the temperature evolution and then detects a manifestation of damage. To determine a model of the mechanical behavior of the material, the main difficulty lies in interpreting the thermal images to correctly discriminate the quite different phenomena. Such a theoretical study on constitutive model of the woven polyester material is beyond this experimental work.

Nevertheless, the present geosynthetic product is a dense fiber 3D-assembly for which the fiber deformation mechanism including friction between fibers and plasticity seems to be the major mechanical process involving the irreversible behavior and then energy dissipation. Due to the test conditions, the present analysis is focused on the apparition of the heat generation resulting from the applied moving load on the material.

Assuming the same soil interaction effect before and after the passage of the wheel, the comparison of thermal pictures allow to give a measure of the heat generation emitted by the material as a function of the different loads. The three-dimensional woven polyester fabric is loaded by a dynamic force which depends on many parameters such as, the applied pressure, the effective speed of the wheel or the contact nature between the wheel and the material.

In real use of geosynthetic products, the approximate weight of vehicles is given and other parameters such as the type or air pressure recommendations of pneumatic tyres are not clear. The specifications of customers are to determine the correspondence between geosynthetic products grades and given classes of vehicles referred to their empty weights. The infrared scanning allows the simple observation for that real condition of use.

5 EXPERIMENTAL RESULTS

Our infrared thermographic processing relies on the data exploitation on an analogical video band whose quality depends on electrical quality and signal processing.

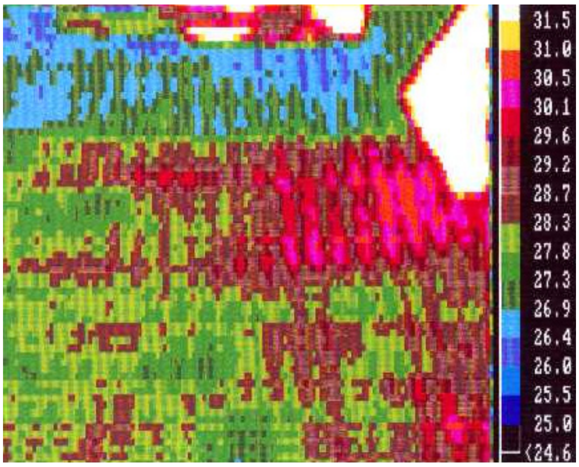

Figure 6. Thermal image of the polyester mat before the passage of the right front wheel.

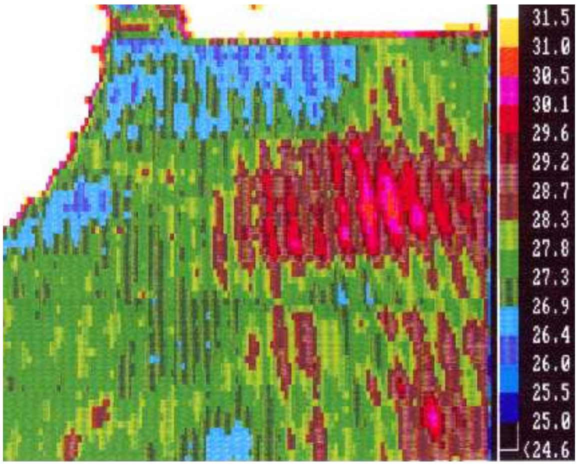

Figure 7. Thermal image of the polyester mat after the passage of the right front wheel.

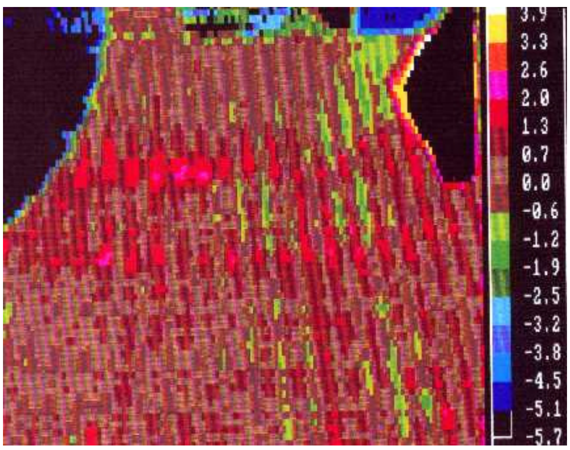

Figure 8. Heavy wheeled vehicle used as moving loading system on woven polyester mats.

For instance, Figures 6 and 7 present the obtained thermal images before and after the passage of the right front wheel for the truck # 4. White zones correspond to saturated radiated zones while a false color scale is used to magnify the quantification of temperature scale on the surface of the 3D-woven polyester specimen.

In each figure, the moving loading wheel is recognizable by its geometrical form and by its saturated radiation. The main surface of interest is the surface where the wheel runs and thus, thermal calibration is applied on that location. Even under sunshine conditions it is possible to compare these two pictures while the structure of the vehicle gives the same shadow just before and just after the wheel. Moreover, one can observe identical saturated zones in the two pictures for which the thermal quantitative analysis has no signification. The two temperature surface fields are quite similar and seem to be identical in the location under interest. The straight comparison of these two pictures can be not highlighted the heat generation due to the passage of the wheel.

The subtraction function between thermal images is a useful video signal processing to evaluate heat changes in degrees Celsius between two events. In addition this difference of thermal pictures before and after the passage of the wheel allows localizing the heat dissipation on the geosynthetic product and hence, completes the infrared observation by spatial information. Figure 8 presents the difference between thermal images presented in Figure 6 and 7. No temperature difference means that only reversible behavior exists or that too small dissipation energy cannot be detected. On the contrary, a significant heat generation is observed using the function difference of images where the wheel ran. The resulting heat change lies between one and two degrees in that zone.

Thanks to the thermomechanical coupling occurring in the woven synthetic, that heat increase represents the dissipated energy due to the passage of the wheel and is a manifestation of the irreversible mechanical deformation of the material. Such a dissipative behavior can lead to failure if loading is repeated and then is directly related to the lifetime of the woven geosynthetic. The infrared thermography detection allows observing the existence of progressive damaging process under load beyond which geosynthetic product is structurally destroyed.

All difference analysis of the thermal images show a heat elevation of the material localized on the passage of the wheel. The tests show that the heaviest vehicle provides the highest temperature elevation. For the four vehicles, Table 1 gives the observed mean temperature increase in the unsaturated running zone. These results are obtained for one only passage of each vehicle. In that configuration, the car do not provide a significant thermal response of the material while trucks clearly initiated a damage process. Empty weight can be considered as the main load parameter at this stage.

6 CONCLUDING REMARKS

The present experimental work has demonstrated that the infrared thermographic analysis offers the possibility to observe the manifestation of damage of the three-dimensional woven polyester fabrics subjected to the service loading generated by the traffic of heavy vehicles.

This technique is proposed as an efficient real time and non-destructive field-testing providing the determination of lifetime characteristics. It applies for geosynthetic products working under real-use conditions with a non-contact experimental set-up. The treatment of the thermal pictures provides a measure of the observed heat generation caused by the passage of a wheel of vehicles. Thus, it can be used as an indicator to follow progressive damaging process during the applied service loads and then to follow the evolution of the dissipative behavior of the material.

Thanks to the thermomechanical behavior of the tested material, the infrared observation of the low accumulation of damage attempts to obtain a limit beyond which the material leads subsequently to failure. According to previous results obtained in laboratory, a drastic change in the thermomechanical behavior can be waited for a given vehicle to determine a maximum number of passages for which the geosynthetic product can be used. Such a limit would depend on the soil interaction for a same vehicle. Consequently, further experimental procedure has to be planed to answer to the customers' requirements by choosing, for instance, referenced soils and vehicles.

7 ACKNOWLEDGEMENT

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