Detecting flaws in composite materials – thermal model and simulation results

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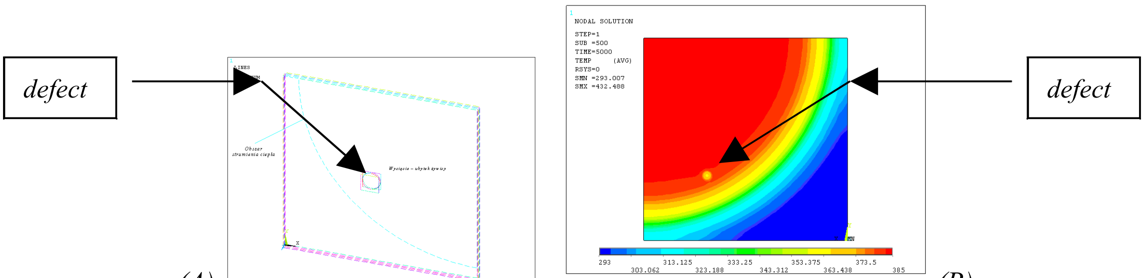
Composites are presently the most developing and particularly attractive special-purpose construction materials for ballistic applications, among others. They are the basic raw materials used in the production of composite ballistic shields, such as shrapnel and bullet-proof helmets, means of transport armour, bullet-proof shields, explosion protection, additional ballistic insets for shrapnel and bullet-proof vests, etc.

The term "composite" means a non-homogeneous material structure. Composites may be composed of metal and non-metal materials used in various combinations. By selecting the right components, you can obtain a composite material that has the required properties and therefore allows achieving benefits like lower weight, greater impact strength and better energy absorption.
The above properties are strongly impaired if a composite develops defects (in the technological process as well as subsequent use) such as ply separation, air bubbles and delamination, which are usually created as a result of impacts. The Authors propose a thermal model of a composite material with introduced defects, which allowed to perform a series of computer simulations to locate the inclusions and decrements in the composite.

The modelled material was a kevlar composite composed of over a dozen layers of kevlar fabric stiffened with formaldehyde resin. Because of the number of layers (more than a dozen), it was assumed in the simulations that the material is homogeneous. Defects that in reality result from random structural heterogeneity (e.g. air bubbles) were modelled as homogeneous areas with different technical parameters attributed. The aim of the simulations was to suggest methods of performing measurements. The modelling area was limited in the simulations to ¼ of the structure. Consequently, only a quarter of the infrared radiation source and the composite's corner was modelled (picture 1).



(A) *(B)*

Picture 1(A) Diagram of structure after limiting the area used for computer modelling.
(B) Temperature map on the back side. A cylindrical inclusion with a radius r_{wtr}=0.005 m and thickness d_{wtr}=0.0005 m is situated at a distance of l=0.00175 m from the lower surface; material: air. The map shows the temperatures for a given moment in time t=200 s. View from the side of the infrared camera.

An analysis of the temperature map led to the conclusion that it is best to input a constant signal with the same mean power value for a period long enough to achieve a steady state. We must emphasize, however, that this kind of situation would not allow to detect defects that have the same thermal conductivity and only differ in thermal capacity. Only dynamic states make it possible to detect the difference in thermal capacities.

We decided to use a sine wave input signal, therefore the most important observation was to determine the amplitude and phase at a frequency corresponding to the input signal frequency.
The phase and amplitude differences between the point in the middle of the inclusion (defect) and surrounding points were measured using the *CONTR* parameter. This parameter was defined as the absolute difference between the value in the defect's centre point (p_c) and those outside the defect (p_i where i = 1 to 4) referenced to the average absolute values of p_c and p_i.

$$\mathrm{CONTR} = \frac{1}{4}\int_{i=1}^{4} \frac{|p_c - p_i|}{0.5(|p_c| + |p_i|)}$$

The largest CONTR value means that at this frequency the phase shift between the inclusion's centre point and the surrounding points is the largest, which allows for a more precise detection of the given defect.