

## **Nondestructive testing of composite armours by using IR thermographic method**

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### **Abstract:**

Composite armour is a preferred solution against military and paramilitary sources of present threats. Frequently, it has been aimed to reducing mass of battle vehicles thus providing a possibility of their quick air-transport which is an important tactical requirement of today. This also gives possibilities for quick transport of heavy armament during realization of military missions in distant parts of the world. With this in mind, the family of thick monolithic steel armours is being slowly replaced now by a generation of composite materials. Such composite armours should be resistant against mines, grenades, fragments and bullets. Except visible surface defects of armour, detecting invisible internal defects are also of great importance. In the Military Institute of Armament Technology, the active IR thermographic nondestructive testing method has been used to designate delamination areas in composite armours. The inspection results are presented in this paper.

### **1. Introduction**

As a result of the new NATO strategy and greater activity of international organizations the range of tasks realized by armed forces in crisis situations worldwide has significantly broadened. Military contingents from several countries frequently participate in international missions which have character of peaceful and stabilization operations. Peaceful operations, in which detachments of armed forces are involved, can be realized in various forms. They usually include operations for maintaining or extorting peace. The tasks assigned to soldiers of military contingents are similar to the traditional tasks of police forces executed on the terrain of their own countries, as well as to the special tasks, which result from counteractions against terrorism or criminality and contribute to the support of peaceful operations. Adequately equipped vehicles create a part of indispensable equipment of these detachments. Military vehicles used in operations of low intensity, such as maintenance of peace, may perform the following tasks:

- patrolling, escorting and recognition,
- protection of objects,
- blockades and control of roads,
- escorting convoys,
- evacuations of wounded,
- transportation and protection of lightly armed sub-units,
- support of infantry operations,
- fights by using light armament.

Several development scenarios at different situations are possible when executing assigned tasks in the face of various threats. Therefore, military vehicles designed to work in conflict zones should also meet some special requirements in order to provide the best possible additional protection of soldiers. The armours of these vehicles should be resistant against:

- common and rifle bullets,
- grenades,
- anti-personal mines,
- IED – improvised explosive devices,

as well as against exploding nearby:

- shells,
- mortar bombs,
- bombs,
- anti-tank mines.

Evaluation of efficiency of armored vehicles is justified by their wide use in various operations at the present time: in zones of terrorist attacks and diversion groups or also in mined areas. Therefore, a particular equipment is needed to verify protection grade of vehicles which are being presently used and modernized, as well as to develop novel protection means. The effectiveness of armored vehicles must be understood as the assurance of suitable safety level in respect to their crew.

There is a NATO document which could be presently regarded as a basis for imposing suitable requirements to the ballistic protection of vehicles. It is the NATO standardization agreement covering the standards for the "Protection Levels for Occupants of Logistic and Light Armored Vehicles" – STANAG 4569. In this document, the classes of protection are set on the basis of 90% probability of personal protection in vehicles subject to threats.

## 2. Ballistic Protections in Vehicles

Recently, NATO countries initiated an intensive investigation process to introduce modern composite materials into protection systems of armored vehicles and infantry fighting vehicles. The composites reinforced by fibres are used in structural elements of vehicle trunks. The programs of investigations CIFV (Composite Infantry Fighting Vehicle) and CAV (Composite Armored Vehicle) were fulfilled in the USA and the ACAVP (Advanced Composite Armoured Vehicle Platform) program - in the Great Britain. Vehicle trunks are made of composites reinforced with glass fibres and, in the case of ballistic protection, composite material may consist of ceramic, aramide and polythene plates (as it was in the case of the ACAVP project). As the result of conducted investigations, it was confirmed that composite materials reinforced with glass fibres are more resistant and efficient as ballistic protection against bullets and mines, as well as against explosive charges, to compare to steel constructions.

In the last decades, some novel materials were invented and existing materials were modified, mainly by introducing fibres in order to ensure high resistance, merely to mentionm carbon/glass/polymer fibres, as well as novel aramide and polythene fibres.

Aramide composite structures have been used in light armored military vehicles as:

- basic layers in ceramic-layered armours,
- anti-fragments liner which is fixed in a vehicle to protect crew against fragments of bullets, as well as armour pieces knocked out by bullets,
- module and continuous composite structures used in light armoured vehicles.

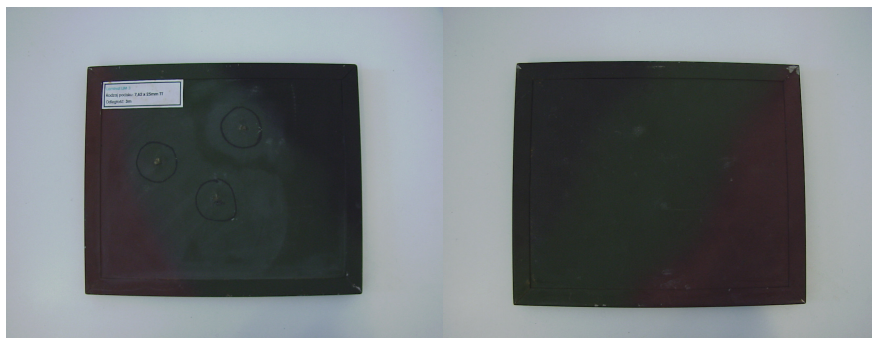
Using an aramide laminate in junction with various materials, e.g. ceramics, results in reduction of armour surface weight in regard to steel keeping the same level of protection against bullets. A composite laminate used as the basic layer in ceramics is especially effective in armours subject to fragments of shells. Thanks to considerable mechanical resistance of aramide composites, they can absorb a relatively large kinetic energy to provide good resistance against bullets and fragments. However, this may cause deformations of the laminate, as well as delaminations and tearing off fibres thus reducing protective ability of this armour section. Considering quality and protection ability of armour, the extent of internal damage should be kept in mind except the direct ability to stop bullets and fragments. The Military Institute of Armament Technology in cooperation with Military Institute of Armour & Automotive Technology carried out a project on using active IR thermographic nondestructive testing method in order to evaluate destruction zones in a light ballistic armour which appear as a result of impact of bullets and fragments.

## 3. Samples

Three samples of light ballistic armour were prepared for testing:

- Sample 1 – two-layered composite consisted of ceramic corundum layer by thickness 8 mm and lateral size 50 cm glued to aramide fabric by thickness 15 mm (Fig.1),
- Sample 2 – laminate from an aramide fabrics by thickness 15 mm (Fig.2),
- Sample 3 – polyester-glass laminate by thickness 12 mm (Fig.3).

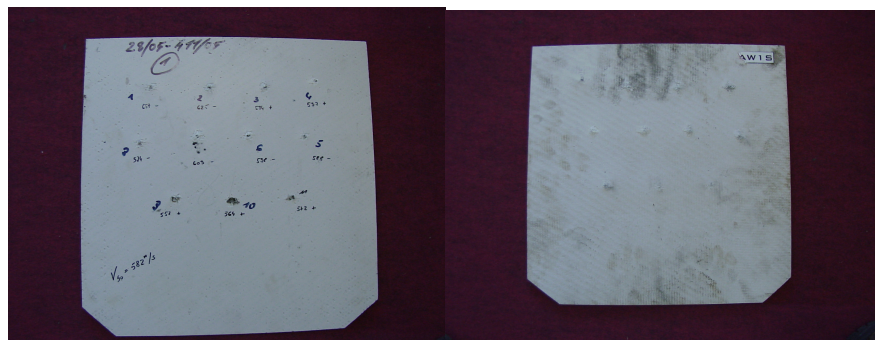
The samples were subjected to testing procedures for resistance against perforation by bullets and fragments. The  $V_{50}$  testing method for ballistic protection of light armours was used. In this method the  $V_{50}$  velocity of a round or standard fragment is defined (according to STANAG 2920) as the velocity at which armour is penetrated at the probability 50% [4]. The distribution of points hit by bullets or fragments on the surface of armour is fairly important. In fact, only correct distribution of these points guaranties objective assessment of a tested material. After hitting by a bullet, an area of damage in a composite armours depends on an armour type and design being quite different by shape and size. Such areas are different for varying constructions of composites depending on a reinforcing material. Knowledge of damage characteristics allows better positioning hitting points in order to avoid overlapping of damaged areas.



*Fig.1. Sample 1*



**Fig.2. Sample 2**



**Fig.3. Sample 3**

#### **4. Nondestructive testing**

##### **Testing methods**

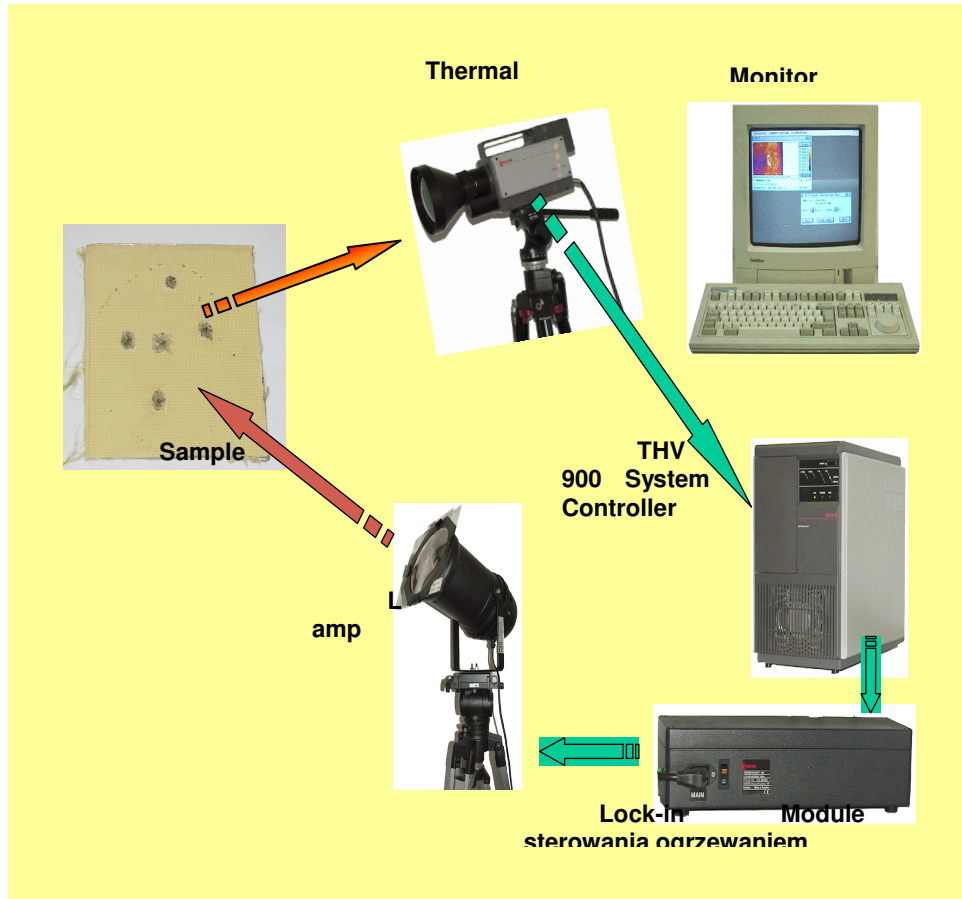
Lock-in infrared thermography and step heating methods have been used to inspect the samples after having tested their resistance against bullets and fragments.

The well-known lock-in technique uses the concept of harmonic thermal waves. Such waves propagate from the sample surface in-depth. When thermal waves come across areas with sharply changed thermal properties, they get reflected. Reflected waves reach back the surface and interfere with the surface waves being subject to a particular phase shift. As a result, surface defect patterns appear.

The set-up for experimental testing by lock - in infrared method is presented in Fig.4. Thermal waves are generated by an electrical lamp of about 1 kW power. The heat source is calibrated by means of the Lock - in Module, which ensures harmonic thermal waves of a chosen frequency [1, 2, 3].

In our experiments, thermal wave images have been produced by a THV 900 System Controller which collects image sequences and calculates both amplitude and phase images. It is believed that these images are relatively insensitive to the secondary radiation from the surface of tested object. In their turn, images of phase are not affected by emissivity variations and uneven heating phenomena.

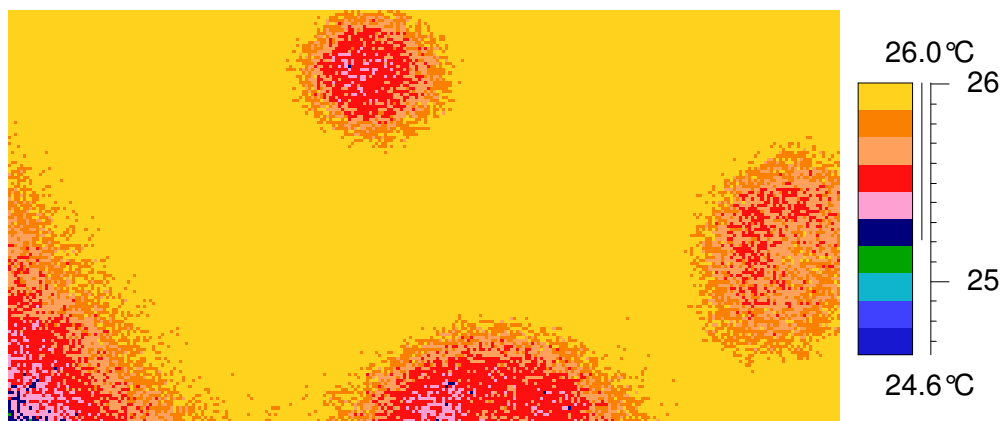
Step heating technique finds many NDT applications, one of them is evaluation of composite structures. In this case, a long heat pulse is used to stimulate samples with a relatively low power density (an electrical lamp has been used) in order not to overheat the samples. Inspection has been carried out in the transmission procedure which is supposed to be more sensitive toward hidden defects than a reflection procedure.



*Fig.4. Experimental set-up for performing lock-in infrared inspection*

**Results**

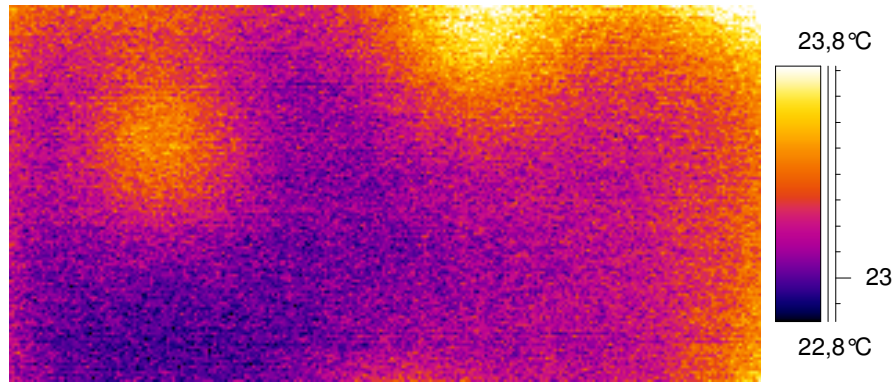
All samples were tested by applying the above-mentioned techniques (thermal wave and step heating). Figures 5÷7 show some examples of experimental results. Thermogram of Sample 1 shown in Fig.5 was received in the transmission mode. The sample was stimulated on the surface hit by bullets and the IR camera was placed on the opposite side, thus recording rear-surface transient temperature distributions. Defective areas within the internal structure of this ballistic protection sample are clearly seen in the thermogram.



*Fig.5. Sample 1 thermogram.*

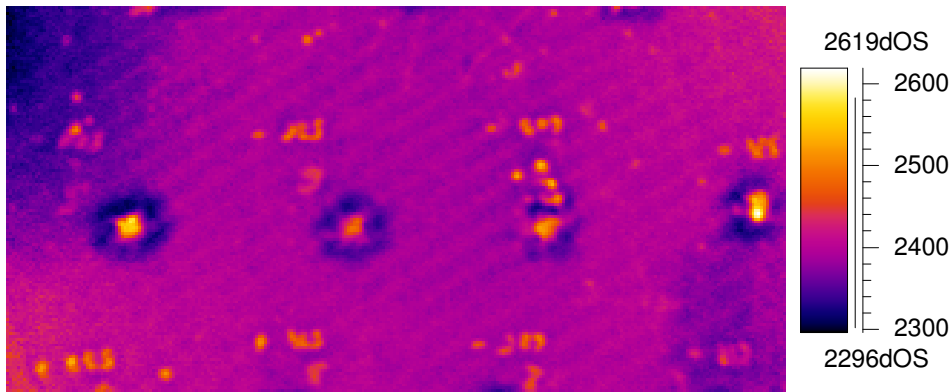
Thermogram of Sample 2 shown in Fig.6 was obtained with step heating in the transmission mode. Similarly to Fig.5 temperature distributions were recorded on the undamaged surface of the sample. Note that the image of Fig.6 was a result of advanced data treatment intended for enhancing signal-to-noise ratio.





**Fig.6. Sample 2 thermogram.**

Fig. 7 shows the phase image of Sample 3 obtained by applying the infrared thermographic lock-in method (at 0,04 Hz) to the sample surface affected by fragments. Again, the damaged parts of the ballistic protection internal structure are well visible around the sites hit with fragments.



**Fig.7. Sample 3 phase image.**

**5. Conclusions**

Nondestructive testing by using IR thermographic techniques has proven to be efficient in evaluating areas of internal damage in ballistic protection composite samples subjected to both hitting and perforating by bullets and/or fragments.

The lock-in IR procedure has seemed to be more effective in the inspection of ballistic protection made of polyester-glass laminates (Sample 3), and the step heating technique combined with the transmission inspection procedure has been more appropriate in the case of Samples 1 and 2.

It is believed that limits of the two above-mentioned techniques are related to ballistic protection thickness and a type of materials used in manufacturing composites.

**6. Acknowledgements**

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