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# DETECTION OF DEFECTS OF MULTILAYER ARAMID COMPOSITES AFTER FRAGMENT-PROOF TEST BY ULTRASONIC IR THERMOGRAPHY

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***Abstract***

*Modern soft ballistic armour is composed of high-strength fibres often used as packages of loose fabrics or laminates. These fibres include carbon, glass fibres, polymer fibres including aramid fibres and polyethylene fibres. Soft armour is applied to provide ballistic protection typically against the impact of small arms projectiles and fragments. In order to determine the level of ballistic protection for ballistic armour, fragment-simulating projectiles (FSP) are used which simulate the properties of fragments created during the explosion of various types of grenades and projectiles. The above-mentioned composites can include a variety of defects such as manufacturing defects, moisture ingress, projectiles impact and other defects. Infrared thermography is a method, which can be used to non-destructive testing and detecting defects of this type of material. However, ultrasonic stimulation is one of method of thermal stimulation used for detection defects in composite. The article presents the results of experimental research of multilayer aramid composite after fragment-proof tests by ultrasonic IR thermography method.*

***Keywords:*** *ultrasonic IR thermography, composite material, aramid fabrics, ballistic protection*

## 1. Introduction

Multi-layered composite materials based on highly durable aramid, glass, graphite and carbon fibres are commonly used in military applications. Composite materials are increasingly applied in ballistic protection structures. Individual ballistic armour represents the final protective barrier of the soldier against fragments and projectiles. Ballistic armour is tested for fragment-proof. These tests involve shooting at a sample of ballistic shield with standard fragments used to determine the level of ballistic protection (STANAG 2920, [1]). To stimulate destruction ballistic shield from the explosion of hand grenades 5.56 mm fragments weighing 1.1 g are most often used. A ballistic protection level of $V_{50}$ is determined, which indicates the velocity of impact of the fragment, at which the probability of penetration of the ballistic shield is 50%. To stimulate the destruction of combat vehicles from the explosion of artillery projectile there are usually used 20 mm fragments of mass 54 g and the effect of firing for the specified fragment hit velocity is checked. During the impact, the fibres are stretched and broken to absorb the kinetic energy of the projectile.

In order to identify the areas of material weakness (damage zone) of the ballistic shield caused by shooting, non-destructive diagnostic method are required.

For diagnostics of composite materials, active thermographic testing methods are usually used [2, 3]. As part of the research on the damage of multilayer aramid composite, infrared thermography was used. During tests, ultrasonic stimulation was used.

## 2. Ultrasonic infrared thermography

One of the active methods of infrared thermography is vibrothermography. This is a method developed to detect hidden heterogeneity in a material structure based on surface temperature fields generated during mechanical cyclic loading (i.e. mechanical vibration). A similar technique can be used with sound and ultrasonic stimulation of the material. Stimulating the test sample with mechanical waves causes an increase in temperature. The rise in temperature is due to the fact that mechanical energy is converted to heat, which is the source of internal friction of defect walls and stress. Where the test sample is subjected to periodic mechanical loading, the defects will be areas of stress concentration.

The commonly used method is ultrasonic stimulation and the research method is ultrasonic infrared thermography [4, 5]. In this research method, the defects and inhomogeneous structures of the material can be seen as a thermal anomaly in the sample that can be recorded by the IR camera [6, 7].

## 3. Experimental testing

The experiments at Military Institute of Armament Technology (MIAT) was made using a FLIR SC 7600 IR imager (image format 640×512) in a sequence of 300 thermograms. Ultrasonic stimulation was performed with an ultrasound generator at the frequency of 25 kHz. Output power was 300 W (the maximum allowed power was 2 kW). The ultrasonic signal was generated by 1 sec. While the registration time was 3 s. Fig. 1 presents the set-up used for the thermographic tests containing an ultrasonic thermal stimulation.

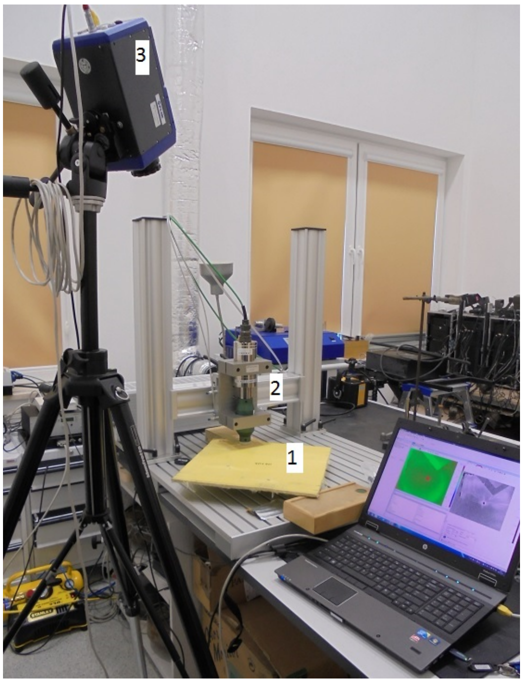


*Fig. 1. Experimental set-up (1 – sample, 2 – ultrasound generator, 3 – IR camera)*

Figure 2 shows a sample from a multi-layer ballistic protective shield made of high tenacity fibres and resin. The test sample of this composite had a thickness of about 10 mm and lateral dimensions of 410×410 and was after the destructive (fragment, FSP) tests.

The sample was shot with a standard fragment of 1.1 g. The V50 ballistic protection level was determined during the test. The tests of the sample damages (complete penetration, partial penetration) resulting from fragments shooting was performed by ultrasonic infrared thermography.

Figures 3 and 4 show examples of thermograms of non-destructive testing using ultrasonic IR thermography. A good image of the places hit by fragments is visible, which are located on the left side of the sample (Fig. 3).

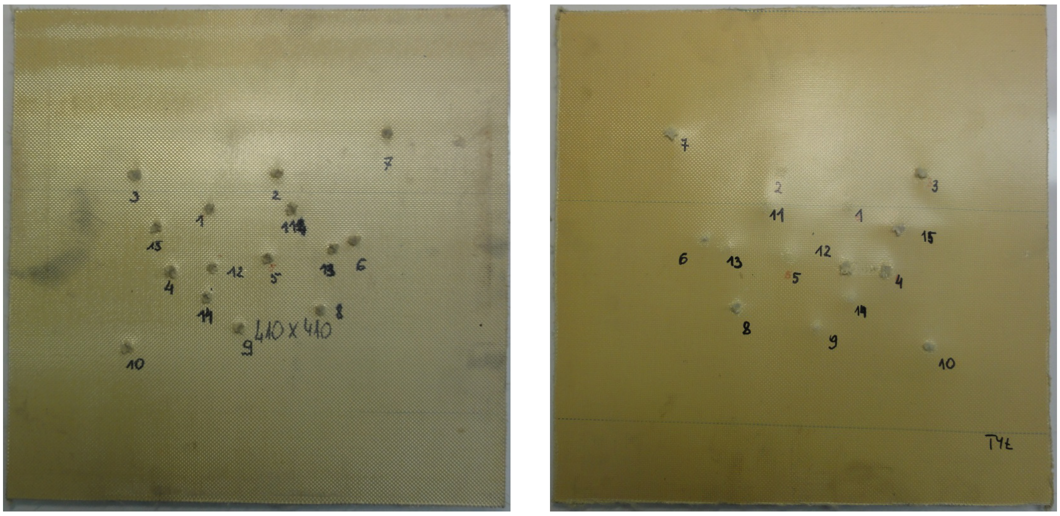


*Fig. 2. Photographs of the sample of ballistic shield after destructive (fragment) testing. On the left: front of the sample, on the right back of the sample*

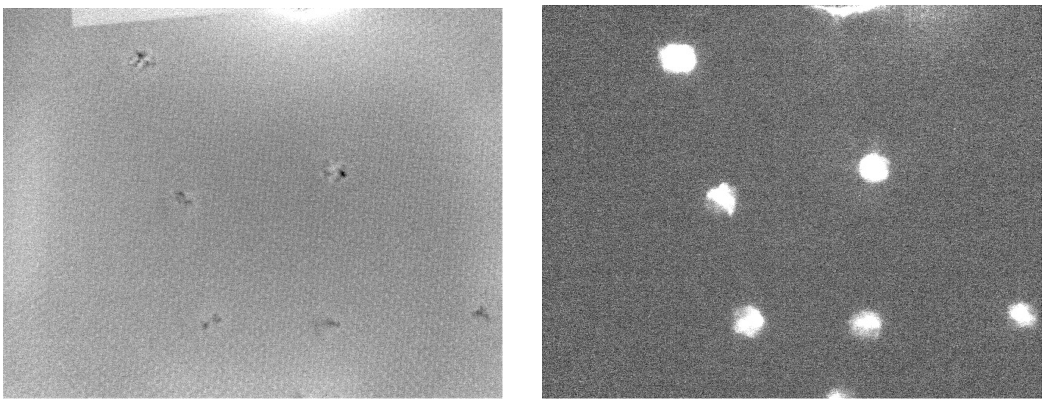

*Fig. 3. Thermogram by ultrasonic IR thermography of the front surface (impact side) of part of the sample after destructive (fragment ballistic) testing – on the left: amplitude image, on the right: phase image*

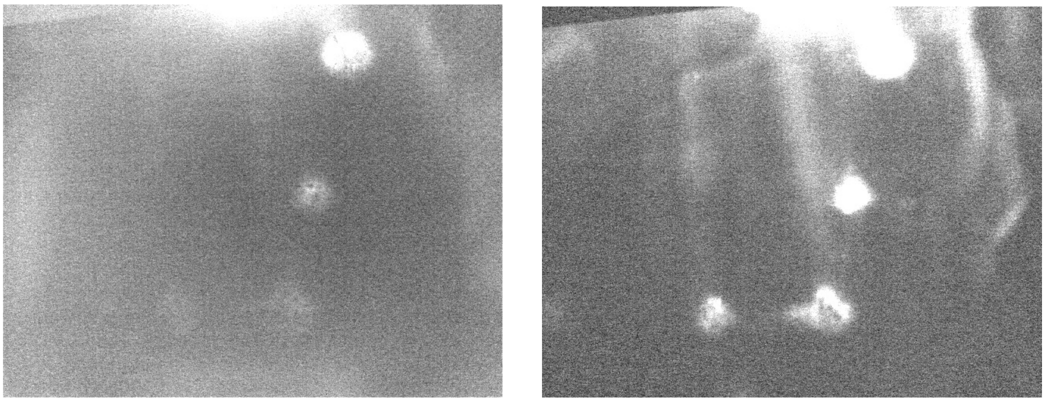

*Fig. 4. Thermogram by ultrasonic IR thermography of the back surface of part of the sample after destructive (fragment ballistic) testing – on the left: amplitude image, on the right: phase image*

Figures 5 and 6 show changes of the temperature field on the defect which is located in the upper left corner of the thermogram (impact side, Fig. 3) registered thermal imaging camera in time 0 s, 1 s, 2 s and 3 s. In this case, the sample of soft ballistic shield was completely penetrated by the fragment.

In turn, Figure 7 shows changes of the temperature field on the defect mentioned above, on the backside of the sample (Fig. 4) registered in time 0 s, 1 s, 2 s and 3 s.

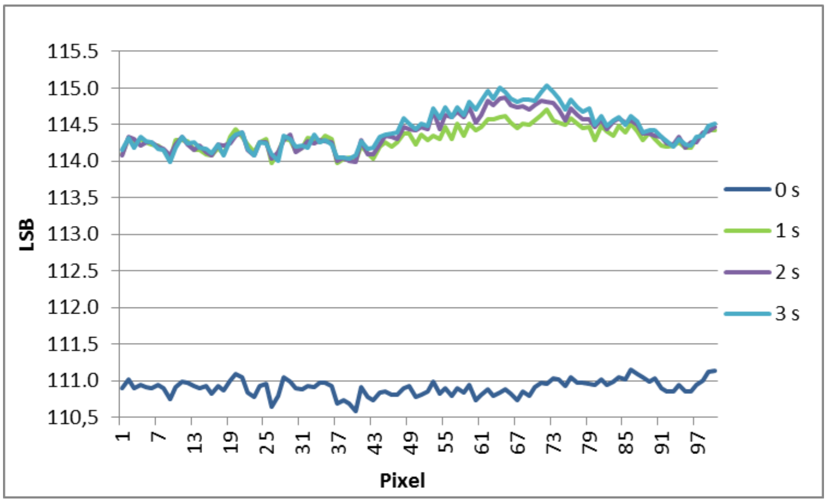


*Fig. 5. Surface temperature profile across defect (located in the upper left corner of the thermogram – impact side, Fig. 3) in time 0 s, 1 s, 2 s and 3 s*

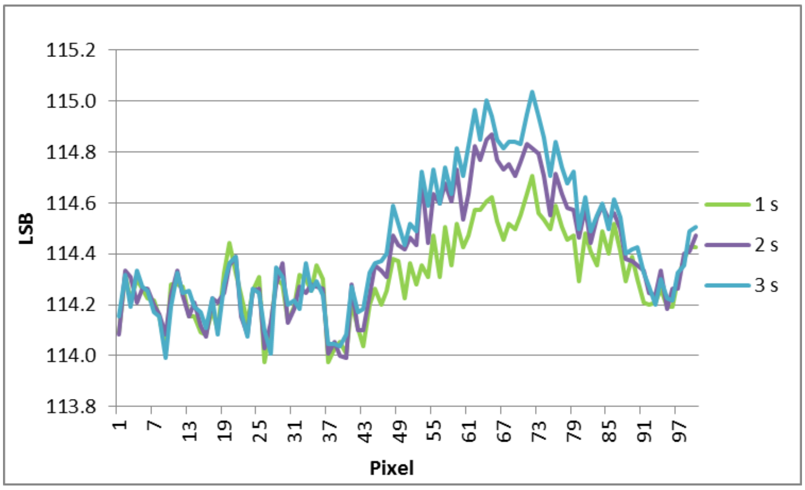


*Fig. 6. Surface temperature profile across defect (located in the upper left corner of the thermogram – impact side, Fig. 3) in time 1 s , 2 s and 3 s*

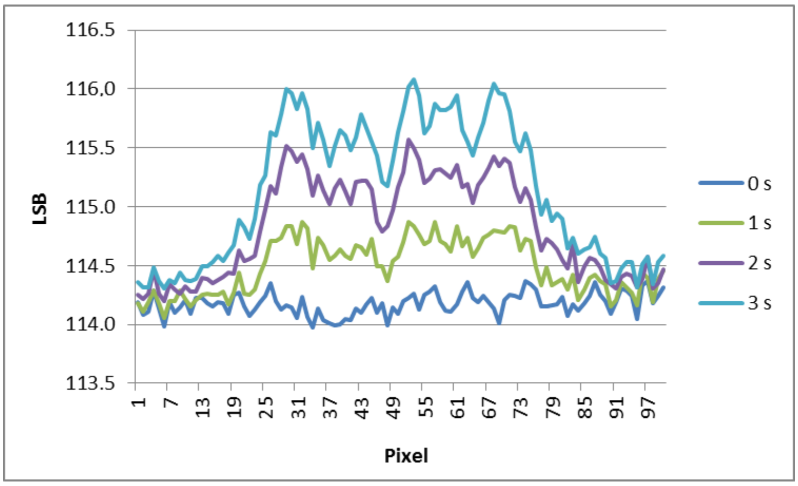


*Fig. 7. Surface temperature profile across defect (located in the upper right corner of the thermogram – opposite side, Fig. 4) in time 1 s, 2 s and 3 s*

After ultrasonic testing, the sample was x-rayed. The internal damage area of the sample and fragments stuck in the back layers of the sample are visible in X-ray images (Fig. 8).

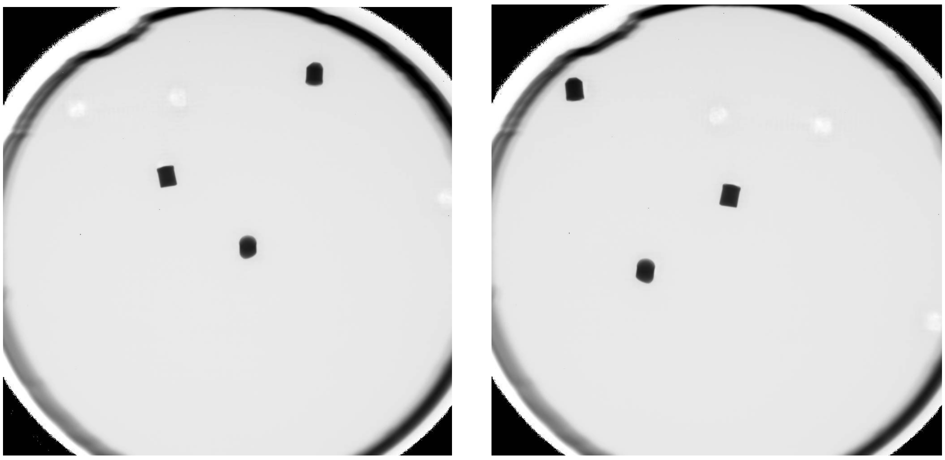

*Fig. 8. X-ray images of a part of a ballistic shield sample after destructive (fragment) testing. On the left: front of the sample, on the right: back of the sample*

## 4. Conclusions

Based on the research performed and the analysis of the results obtained, it can be concluded that ultrasonic IR thermography can be an effective method of detecting areas of damage in multi-layered aramid composites.

During the tests, it was found that the area of subsurface damage of the material from the opposite side (back) is larger than the damage area from the impact side of the fragment.

X-ray pictures can supplement the knowledge of the damage areas of the internal structures of composites, obtained using the ultrasound method.

Knowledge of the damage area of the material that occur inside the ballistic shield can be used in the development of new ballistic shield for modifying the samples' construction (weight reduction, use of other materials, other structure) while maintaining the required ballistic resistance.

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