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DETECTION OF DEFECTS IN COMPOSITE HELMETS USING ULTRASONIC IR THERMOGRAPHY

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ABSTRACT

This paper presents the results of experimental research of composite helmets after fragment-proof tests by ultrasonic IR thermography method. Tests of composite helmet damage caused by shots with standard fragments were performed using ultrasonic IR thermography. During the ballistic tests, fragments of 1.1 g (without sabot according to STANAG 2920 ed. 2) were shot. The research on composite helmets was carried out using a generator (stimulator) of ultrasounds. During the stimulation the ultrasounds frequency was (22.5 ÷ 25) kHz. Changes in the temperature field on helmets surface were recorded by the FLIR SC 7600 camera in the sequence consisting of 250 images (thermograms) with a resolution of 512x640 pixels. The output power of the generator was 200 W (max. 2 kW). The time of generating the ultrasonic signal and the total recording time was 10 s.

Keywords: non-destructive testing, IR thermography, ultrasonic, composite helmets.

INTRODUCTION

Composite materials consisting of very durable fibers are increasingly used in ballistic shield constructions, including in vests and helmets. For non-destructive testing of composite materials, the method of active thermography is usually used (Swiderski, 2003). One of the main methods of active thermography research is vibrothermography - VT (Maldague, 2001). The definition of vibrothermography was developed to determine thermal testing procedures, which are designed to assess the hidden structural inhomogeneities of material, based on surface temperature fields, at cyclic mechanical loads. A similar procedure can be carried out with ultrasonic stimulation of the material. When excited by mechanical waves, internal friction of the defect walls occurs which is the source of a significant increase temperature. Ultrasound stimulation is commonly used (Favro, 2000), (Wang, 2014), (Maldague, 2001). The advantage of thermal stimulation from the so-called internal sources of heat (including ultrasounds) is the lack of optical interference and occurrence of temperature anomalies only in areas with defects as a result of friction of the cracks 'walls.

In personal ballistic shields, i.e. safety helmets (and protective vests), multilayered composite materials are used, which are woven materials (including aramid fibers) connected with plastic as a binder. Such materials are characterized by being lightweight, corrosion-resistant, easily moldable, which allows them to be adapted to the surface they are to protect. Defects that may occur in this kind of composite materials are, among others inaccuracies in gluing composite layers, delamination caused by impacts, fragments and shots with projectiles. Lightweight ballistic shields are made of materials whose thermophysical parameters differ significantly from the parameters that have potential defects that may occur in these materials.

Therefore, non-destructive testing with thermography methods can be effective in detecting defects.

EXPERIMENTAL TESTING

Tests of composite helmet damage caused by shots with standard fragments was performed using ultrasonic IR thermography. Figure 1 presents the diagram of the helmet test stand used for the thermographic tests containing an ultrasonic thermal stimulation.

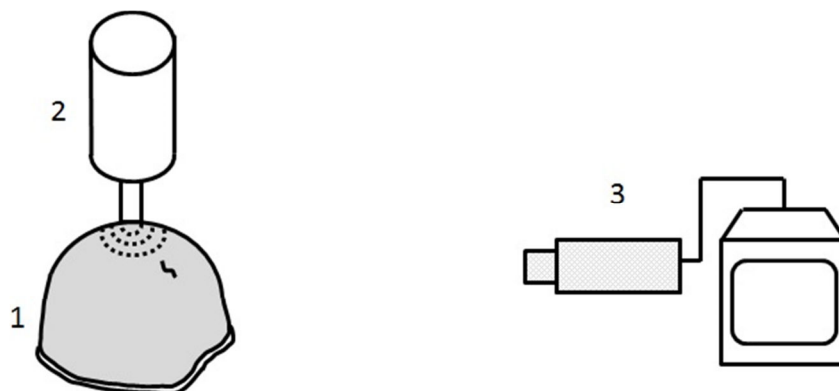


Fig. 1 - Diagram of the helmet test stand (1 - sample, 2 - ultrasonic transducer, 3 - IR camera).

During the ballistic tests, fragments of 1.1 g (without sabot according to STANAG 2920 ed. 2) were shot. Ballistic tests of helmets have been carried out in order to obtain damage to helmets (e.g. delaminations occurring between composite layers) resulting from impacts caused by fragments. After ballistic tests, the helmets were tested to detect damage. Helmet made of pre-impregnated aramid, after destructive testing (using FSP- Fragment Simulating Projectile) is presented in Figure 2.

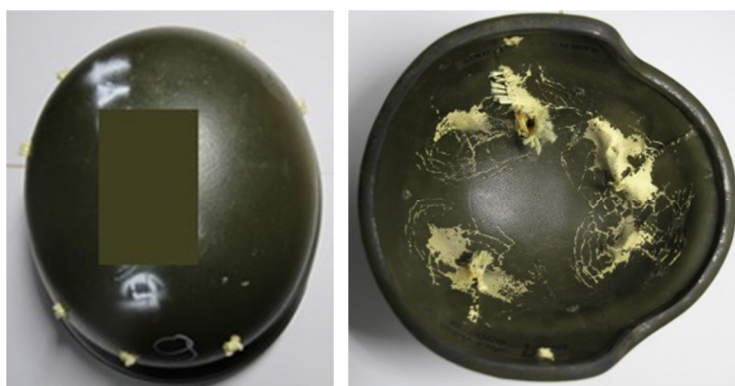


Fig. 2 - Composite helmet after ballistic tests (using a standard fragments)

The research on composite helmets was carried out at Military Institute of Armament Technology (MIAT) with the use of ultrasound generator (stimulator). During the stimulation the ultrasounds frequency was $(22.5 \div 25)$ kHz. Changes in the temperature field on helmets surface were recorded by the FLIR SC 7600 camera in the sequence consisting of 250 images (thermograms) with a resolution of 512x640 pixels. The output power of the generator was 200 W (max. 2 kW). The time of generating the ultrasonic signal and the total recording time was 10 s.

Figure 3 presents the experimental set-up used for the thermographic tests containing an ultrasonic thermal stimulation.

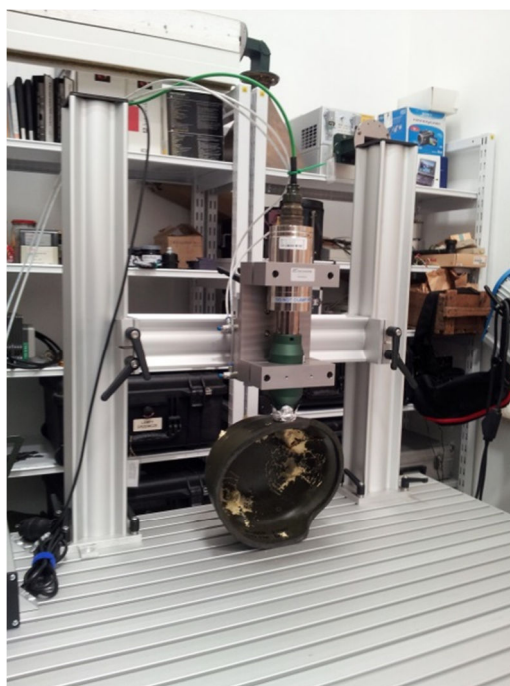


Fig. 3 - Experimental set-up for the test of composite helmets using ultrasound infrared thermography

RESULTS

Figure 4 presents an example phase image of the outer surface of the helmet (after ballistic tests) obtained during non-destructive tests using ultrasonic IR thermography. On the phase image, areas of destruction of the helmet material are visible as a result of shots with standard fragments.

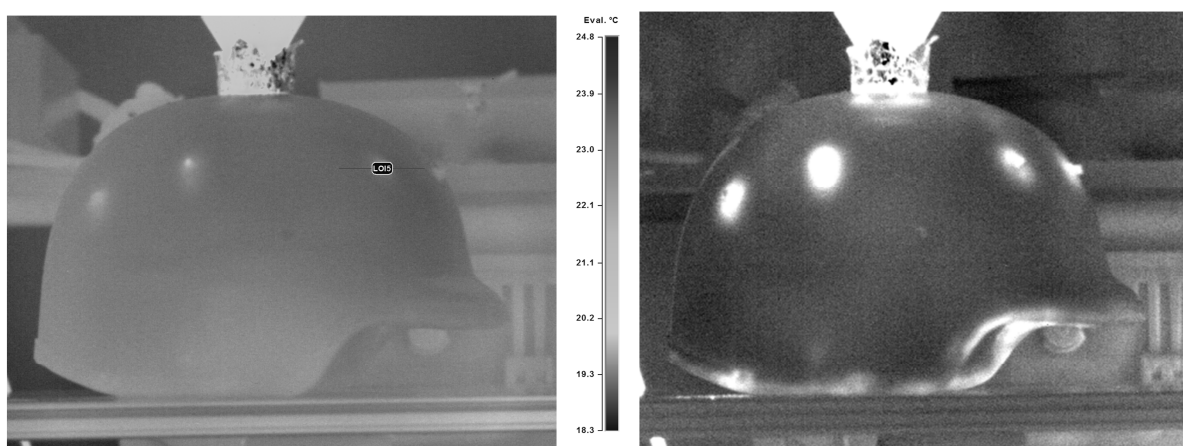


Fig. 4 - Helmet tests results after ballistic tests - thermogram of the outer surface of the helmet after ballistic test (on the left), ultrasonic thermography lock-in phase image (on the right)

Figure 5 shows the temperature graph on the outer surface of the helmet along the damage caused by the fragment (Figure 4 - thermogram) during 5 s and 10 s.

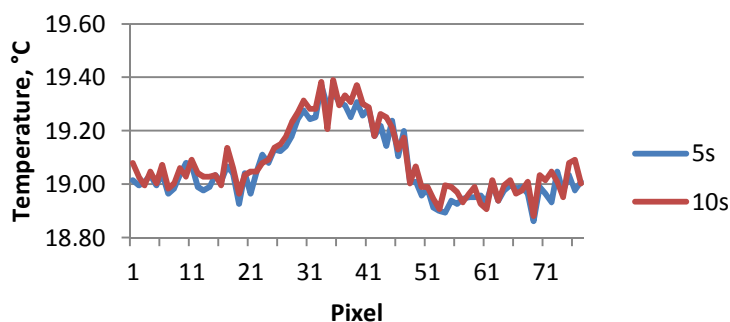


Fig. 5 - Temperature graphs on the outer surface of the helmet along the damage caused by the shot with a standard fragment in 5 s and 10 s.

In turn, figure 6 presents an example phase image of the inner surface of the helmet (after ballistic tests) obtained during non-destructive tests using ultrasonic IR thermography.

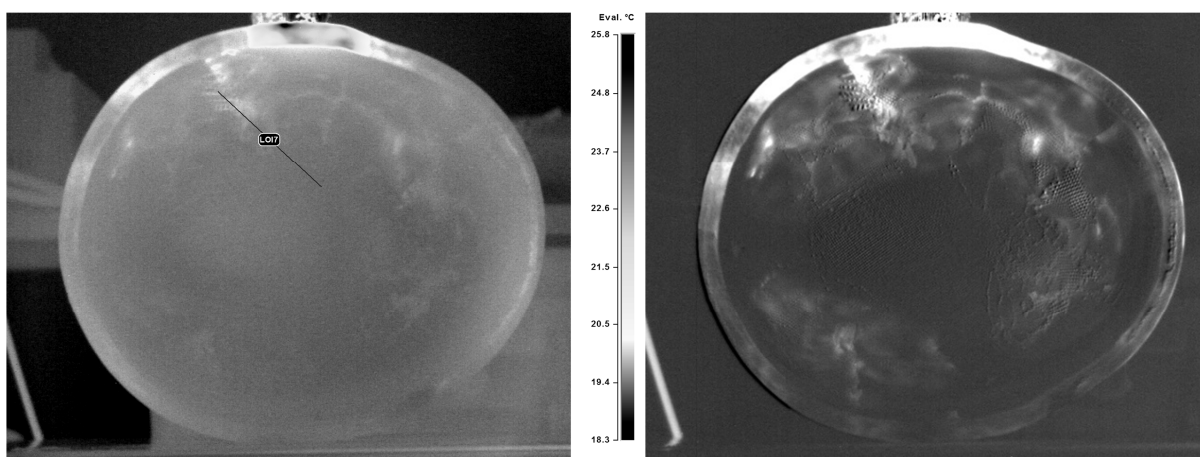


Fig. 6 - Helmet tests results after ballistic tests - thermogram of the inner surface of the helmet after ballistic test (on the left), phase image with visible areas of helmet damage made by ultrasonic thermography lock-in method (on the right)

Figure 7 shows the temperature graph on the inner surface of the helmet along the damage caused by the fragment (Figure 6 - thermogram) during 5 s and 10 s.

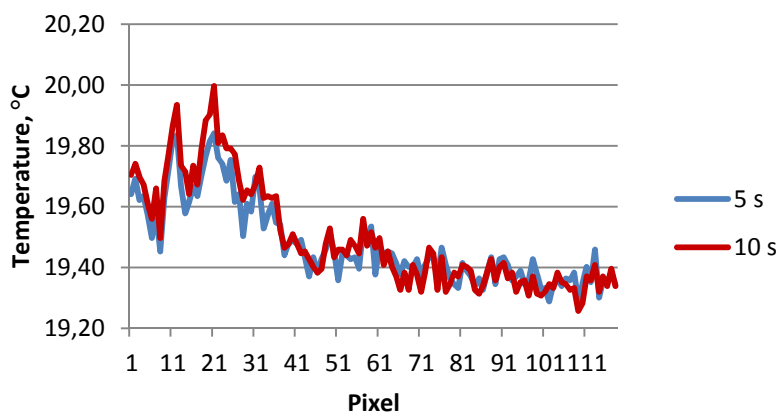


Fig. 7 - Temperature graphs on the inner surface of the helmet along the damage caused by the shot with a standard fragment in 5 s and 10 s.

Helmets were additionally subjected to non-destructive tests using an X-ray diagnostic system. The tests were carried out to check the possibility of detecting defects of composite helmets using the X-ray method. Exographs of selected fragments of composite helmet, on which defects were revealed, are shown in Figure 8. In the figure there are visible places of fragments hits (white traces), damage areas and fragments that have been stuck in the back layers of the helmet.

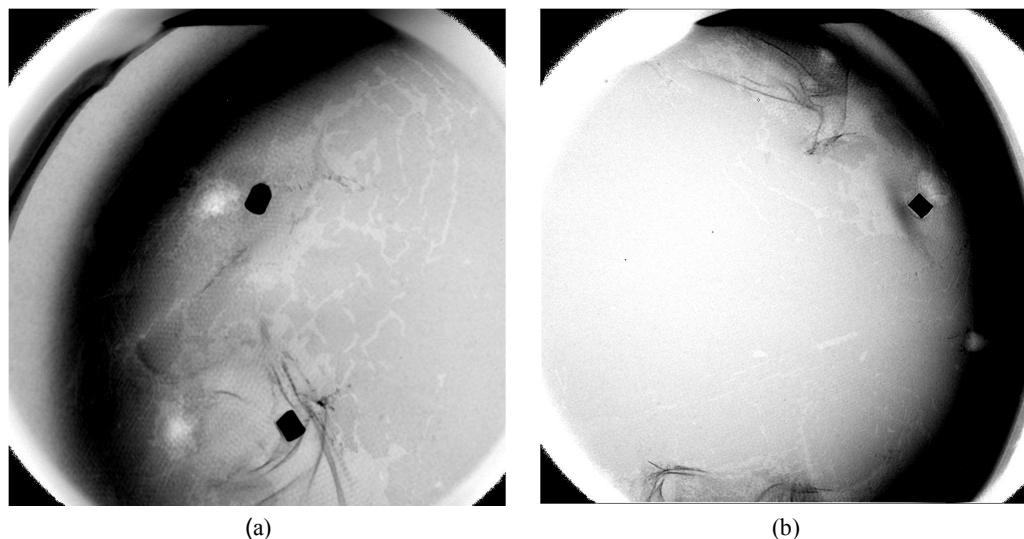


Fig. 8 - Exographs of fragment of the composite helmet after ballistic test. View from the inside of the helmet on: (a) front, (b) back

CONCLUSIONS

The paper presents the use of ultrasonic IR thermography to detect damage of composite helmets caused by shots from fragments.

For the purpose of comparison, X-ray tests were carried out using an X-ray diagnostic system.

Both the exographs and thermograms revealed damage to composite helmets. Exographs revealed the appearance of internal damage, which arose as a result of shots with standard fragments (i.e. damage areas of the internal structure and fragments that stuck in the back layers of the helmet).

An important aspect of non-destructive testing is properly trained and prepared staff. The staff should have knowledge about the construction of helmets, what is aimed at correctly analyze and evaluate helmets based on received thermograms and exographs.

In order to check the effectiveness of the ultrasonic IR thermography method used, further research will be based on finding better test parameters values (i.e. frequencies) and on performing tests on a larger sample of helmets in use.

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