MILITARY APPLICATIONS OF INFRARED THERMOGRAPHY NONDESTRUCTIVE TESTING IN POLAND

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Abstract: Composite materials are often more practical in use for different military applications. These materials provide interesting results especially through their good strength properties, corrosion resistance and low specific weight. These materials have various structures. Any defect of these materials usually has a more complicated and other form than in metals and that is why methods and diagnostic techniques checked in metal constructions are often deceptive in constructions made from composite materials. The infrared thermography non-destructive testing methods prove to meet the expectations well in composite constructions. The main centre in Poland for research and development works on infrared thermography non-destructive methods is the Military Institute of Armament Technology (MIAT) where works are carried out for three groups of composite materials used in following areas: aviation, light ballistic protections and ammunition. Also some works on using the infrared thermography to detect the buried mines are conducted here. The paper contains a short review of current and planned research works on the above mentioned subjects in MIAT.

Introduction: Methods and techniques for nondestructive testing are designed for the detection of materials discrete defects and the estimation of material properties without causing changes of their performance. They are used in diagnostics and industry to assure high quality of components, final products, devices and constructions. Except numerous applications of nondestructive testing in civilian industry they have found a wide use in rocket industry, aircraft industry, arms industry and especially in military applications. Typical technical objects of nondestructive testing are among other things all types of materials connection (welded joints, glue connections, soldered joints etc.) and also constructions and elements made from composite materials.

Because requirements of users are growing so it is necessary to develop methods, techniques and equipment for nondestructive testing. This development is becoming faster. The equipment to nondestructive testing is more various. Growing requirements with relation to research methods and apparatus cause increasing demand on the staff involved on nondestructive testing to have higher level of knowledge. It relates both to the range of acquaintance of physical rules of research methods and apparatus handling as well as materials properties of testing objects.

One of nondestructive testing methods that has followed a quick development is the infrared thermography. This is caused by the new generation of quick thermal cameras, which make possible the research of quick processes of heat transfer, and by the development of data processing algorithms [1, 2].

In Poland in spite of relatively long traditions of works connected with nondestructive testing by infrared thermography method for military applications it is not developed so far to meet all the needs. This is connected among other things with unstable situation in military scientific – research establishments in last years. This results from the structural change occurring in the Polish army. At the moment the main center in Poland interested in the use of infrared thermography methods for military applications is the Military Institute of Armament Technology. Main directions of works on the infrared thermography carried out in the Institute are focusing at nondestructive testing of composite materials used in aviation, light ballistic protections and elements of rockets and ammunitions. There are also works carried out over the use of infrared thermography in such military applications as detection of buried mines, estimation of the mortar barrel temperature during firing or development of means to infrared camouflage of military equipment.

Results: In composite materials especially in aviation applications the detection of water and sogginess is very essential. Their occurrence is witnessed by the existence of micro-cracks through which water or steam can penetrate into the material at large differences of pressure and temperatures occurring in a short time. In paper [3] we introduced the use of several methods of infrared thermography to find out which of them is more effective for detection of sogginess in composite materials of honeycomb type. In comparative research we used four methods: optical lock - in thermography, reflection method, transmission method and active method with microwaves source. In all these methods we used thermal camera AGEMA 900 LW to record the results. To identify the areas in composite material which contain the water it was used a prepared suitable test-sample which was a 290x215 mm sized sandwich panel with two 0.7 mm thickness fiberdux face skins. Between covers a honeycomb core with height 12.8 mm with areoweb was placed. Covers with the core were joined by an epoxy resin. Different content of water (5.0 ml, 2.5 ml, 1.2 ml and below 1 ml) were introduced in the sample to four cells. The fig. 1 represents a lock - in amplitude image of this sample obtained at f = 0.0146 Hz and profile plots of cells containing water.

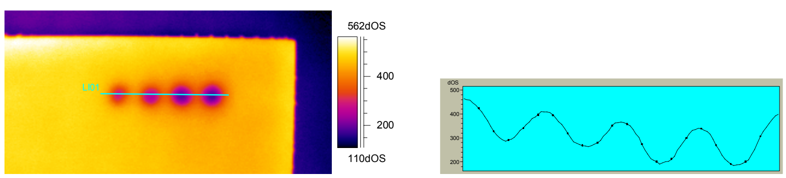

Fig. 1 : Lock-in amplitude image and profile plots of cells containing water, f = 0,039Hz

On this amplitude image (Fig. 1) is well visible which cell contains more water and which less. In these experiments the lock - in thermography method proved to be the best one as even for minimum-quantity of water below 1 ml it was possible to qualify precisely in which cell it was found. This difference is confirmed by the graph of the profile (Fig. 1) obtained along the line through the centers of cells containing water and is also confirmed at the test of the second sample which was a piece of a propeller also of a honeycomb construction and 250x300-mm area and 38 mm thickness. An aluminum sheet of 0.5-mm thickness covered the core made from aluminum foil. This cover was bonded by resin to the core. 5 ml of water was introduced into the test-sample. Fig. 2 shows lock-in phase image (f = 0.0146 Hz). There is very clearly visible area with water. In composite materials of honeycomb defects of cell sides or separation of cover from core can appear typically. Such type of defect detected with the lock-in infrared thermography method is represented in paper [4]. There is a sample from a plane element with honeycomb core made from the aluminum foil and coated with aluminum sheet of 0.5-mm thickness.

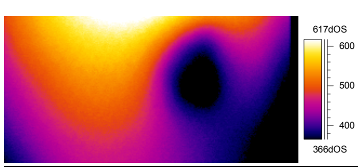

Fig. 2 : Lock-in phase image of propeller f=0,0146Hz

The core with covers was joined by a resin. Fig. 3 represents phase image of this sample obtained at f = 0.03 Hz with a visible light spot for the separation of several vicinal cells from the cover. Other types of composite materials, which were the subject of the nondestructive testing in MIAT, are the light ballistic protections. The fiber reinforced polymer composites is the basic of light armour structures. The multi-layer structures are mainly made of the following materials:

- aramid fabrics the ace and fabrics with different constructions and the area-hyperbolic density ,
- prepregs the handicap moulding the ace aramid fabrics coated by the special resins,
- high performance poliethylene fibers the ace fabrics, modulus structures and composite plates,
- ceramic plates made on Al_2O_3, SiC, B_4C [5].

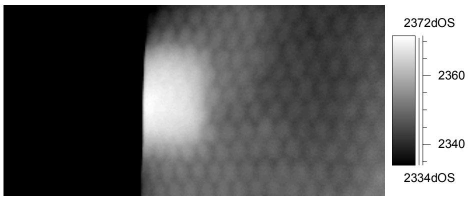

Fig.3. Phase image (f = 0.03 Hz) composite with defect in form of separation of several cells from cover.

These materials exist in different combinations and versions of constructions depending on their application. The ballistic polymer composites reinforced fibers are applied in e.g.: helmet shells, antiballistic panels the bullet - proof vests or in ceramic armours the ace the back plates. Defects of light ballistic protections can appear as result of impact. Other types of defects are the results of production process or a long-term use. Papers [5, 6, 7, 8] include some results obtained at researching of different type of light ballistic protections when subjected to different kind of loads causing internal damage of composite. Fig. 4 [5] represents the results of research obtained at estimation of delamination area after execution of a ballistic protection testing on light armour. The test sample was made from multi-layered composite aramids. The thermography testing used a lock - in method. Fig. 4 a) represents a selected fragment of sample from the front side with ballistic impact. On Fig. 4 b) a phase image at f = 0.0146 Hz and excitation power 900 W is represented. On this phase image an area of delamination around the ballistic impact (gray color) is visible. Fig. 4 c) represents the phase of the image from Fig. 4 b) in form a of three-dimensional graph. Other type of the defect is represented on Fig. 5 [4] where the sample of armour reinforced by aramid fabrics had thickness about 4 mm and consisted of three layers of aramid fabrics coated resin PVB creating stiff plate was tested. Fig. 5 presents experimental results obtained at investigation of this sample. In the top right corner of the phase image at frequency 0.06 Hz a defect is visible in the form of delamination (light line). The sample was investigated by the lock - in thermography method. The sample was heated with 1000 [W/m^2] lamp maximum value heat pulse density applied on the surface of sample.

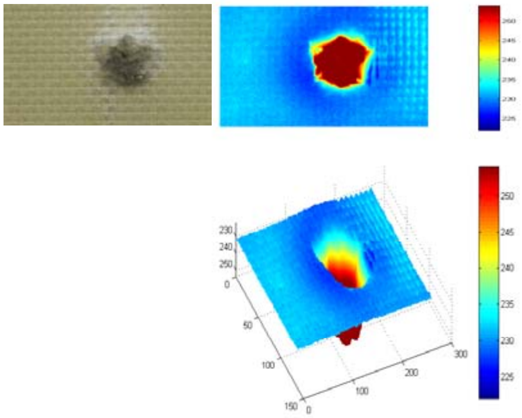

Fig. 4. Sample with ballistic impact

The detection of buried mines by infrared thermography is an interesting work carried out in MIAT. Research works made in MIAT were described in many papers [9-17]. The project concerning the detection of mines consists of a series of theoretical and experimental works with the aim to learn about the specificity of thermal signature changes for buried mines and other subsurface disturbances in function of time, type of ground and its undergrowth, in different wetness and weather conditions. The program of works was oriented on: producing of prediction methods for the best times to do research with thermal method and examining of a possibility for adaptation of the dynamic thermography method based on the analysis of changes of radiant ground surface properties in domain of time. To success with these aims the following three groups of research were created: in the form of mathematical- physical modeling and numeric simulation; in the form of verifying such modeling by a controlled experiment with an artificial extortion; in the form of thermal images acquisition and other relevant data recording on local test-field with real mines and environment conditions. Fig. 6 represents a comparison of computer simulation results with the laboratory- experiment of detection of a mine buried in the sand. Fig. 7 shows the thermal map of contrast calibrated on the mine buried in 2.5-cm depth. This result is obtained on the real test-field.

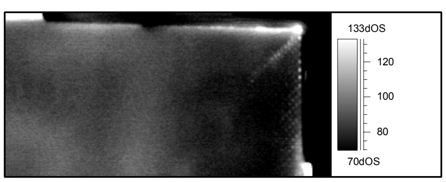

Fig.5. Phase image (f = 0.06 Hz) representing defect of thin delamination located in the middle of composite and running obliquely from right corner to down plate.

Paper [18] represents a method for estimation of temperature distribution over the internal surface of a barrel during firing of an exemplary 60-mm mortar. Estimations of temperature distribution were executed on the basis of barrel external surface temperature measurements made by the thermal camera. During the firing a bore is affected by high pressure and temperature propellant gases which in the case of the 60-mm mortar are reach respectively 150 MPa and over 3000 °C. A growth of pressure and temperature in the barrel have a short duration but at a series firing of rounds the growth of bore temperature can be considerable. A projectile is led in bore by means of lugs on its body and protrusions on the stabilizer fins. The projectile moving along the barrel at high temperature makes it more susceptible to a mechanical wear. The information concerning a growth of the bore temperature is very essential both at a mortar development phase and in weapon qualification tests for service life. I n the paper both the measuring method and some experimental results are introduced. The thermal camera (AGEMA 900 SW) was placed in a distance of 10 m from a mortar. The mortar barrel was positioned to fire at the angle of 60°. Fig. 8 shows a thermogram of the mortar before firing. Ammunition with a full charge was used for the firing to obtain the maximum pressure in the barrel. The maximum practical number of consecutive discharges in a combat use for this kind of the mortar is about 30 rounds in one session. In the experimental tests a series of 40 shots was fired. A thermogram of the mortar after firing this series of 40 projectiles is shown in Fig. 9. A comparison of the maximum temperature of external mortar barrel surface with an estimated maximum temperature of the internal bore is shown in Fig. 10. It can be noticed that the maximum temperature of bore surface after firing the series of 40 shots did not exceed 700°C which was the limit temperature.

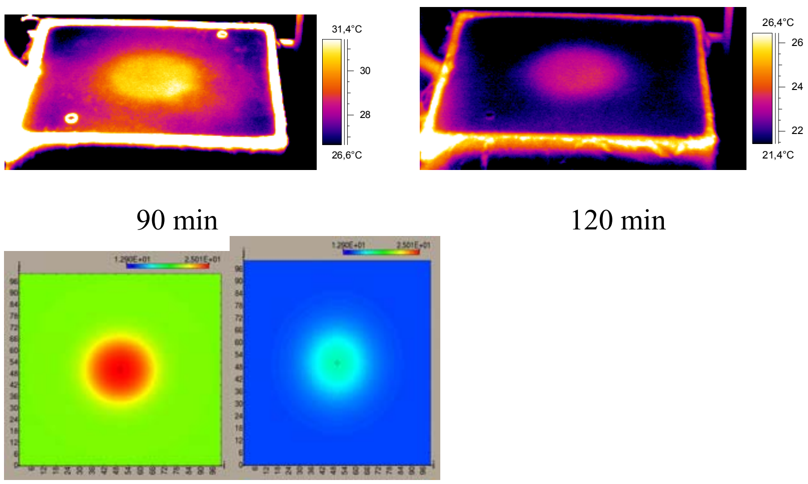

Fig. 6. Collects example of IR thermograms of plastic mine at various time of heating/cooling process made in laboratory to verify and to tune the numerical model.

The camouflage of military equipment in the infrared band is very essential from tactical point of view. For the sake of relatively not high costs the smoke ammunition is generally used as a sequestrant. The used fumigants should have properties for masking both in the visible band as and in the short wavelength (3-5 μm) band and the long wavelength (8-12 μm) band. Additionally a lifetime of such smokescreen should be greater than tens second. The effects of smoke ammunition consist of producing of aerosol (smoke or fog) in the air with a suitable concentration and dispersal reducing transmission of light to decrease the visibility what causes a camouflage result. However aerosols are very impermanent systems as the consequence of small parts sedimentation and movements of the air. In one of MIAT laboratory was developed a special burning pyrotechnic material containing a red phosphorus [19] exploiting the fact that blazing charge about mass 40 g produces an area about 1 m diameter which is characterized with intensive luminance what causes complete cover up of observed thermal target in short and long infrared band. The using of described effect in camouflage technique can be realized through producing in definite place of many fire-places of burning phosphorus or of other substances which are the sources of efficient disturbances of real target by comparatively long time. Fig. 11 show results of such camouflage described in paper [20].

Discussion: Works [3-8] carried out in MIAT on detection of defects in composite materials used in military applications focus in the importance of testing conditions selection what has the essential importance whether a defect or the damage of material will be detected or not. Testing conditions include the selection of a proper testing method for the given composite material and selection of its parameters. At the tests carried out in MIAT the first stage is to do a computer simulation to make possible an estimation of what defects of material can be detected by infrared thermography and what parameters of thermal extortion and which methods can be applied. In selection of suitable heating parameters of testing sample of composite material, such which would make possible the detection of subsurface detects, we use in our institute ThermoCalc – 3D™ computer program worked out by V. Vavilov [21]. This program makes possible the investigation of transient phenomena of heat conduction in the object – sample system. Our investigations also indicate that the large importance has an experience of a researcher over the earlier investigation of samples of composite material with purposely introduced test-defects.

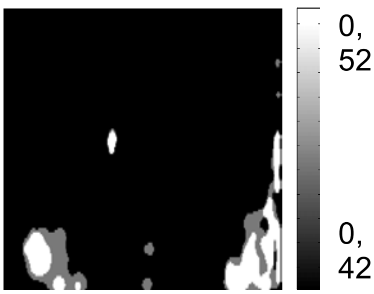

Fig.7. Map of thermal contrasts during 3 June 98 and scaled for mine at 2.5 cm depth (placed at left bottom corner)

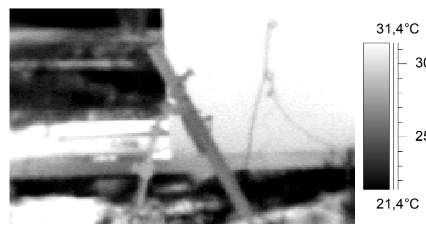

Fig. 8. Thermogram of the mortar before firing

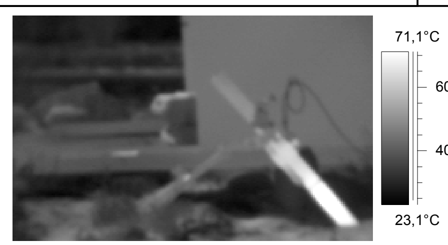

Fig. 9. Thermogram of the mortar after firing

Our works show that in most tests the most effective proved to be the lock - in infrared thermography method. The method's greatest advantage is that one can use different kinds of thermal extortion both external as and internal.

Fig. 10. Maximum temperature changes on the external barrel surface and bore surface during firing

In our works [9-17] were executed wide theoretical recognition and verification of usefulness of technical methods so-called dynamic thermography of thermal transient states to detection of buried mines. We used in this aim the specialized software and databases acquired from the field and laboratory experiments. Obtained thermal contrasts confirmed usefulness of detection methods of difference in of

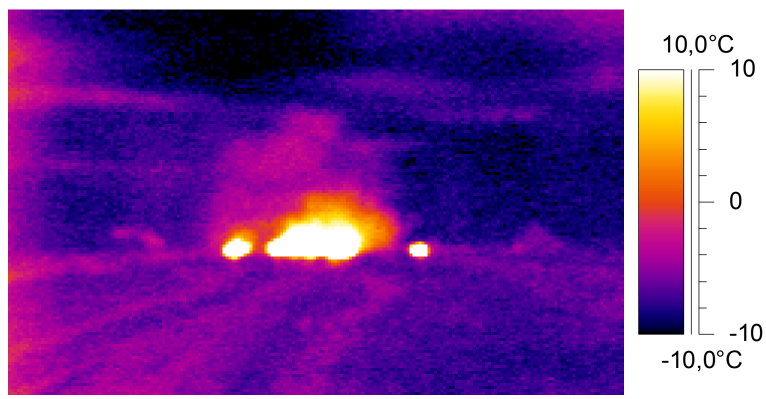

Fig. 11. Camouflage effect in infrared

thermal soil diffusivity without mine and with mine in the well-known location. In field at natural extortion conditions the thermal detection of mine signatures is strongly limited by a high level of disturbances due to differences of radiation temperature of the environment. The carried out investigations proved the influence of two factors i.e. inhomogeneities of surface cover of the soil and inhomogeneities of density and contents of water in subsurface layers of the soil.

The method represented in paper [18] for the estimation of a mortar bore temperature is sufficiently precise both for the designers and users of weapons. A great advantage of this method is non-invasive character and possibility of temperature registration from the distance. It has also the universal character because it can be used to different types of weapons and caliber everywhere a barrel is visible and one can register its image by thermal camera.

The analysis made in paper [20] over the ability of camouflage in infrared by different smoke mixtures showed that decisive influence on camouflage effect in infrared has a thermal image of the resultant cloud of smoke. The type of small solid parts forming phase of aerosol dispersing and absorbing the radiation seems to be of a secondary importance. For the space limited pyrotechnic charge containing burning phosphorus its vaporization into the air occurs and the steams of phosphorus with temperature of several hundred degrees react with oxygen and as result of exothermic reaction comes into being an area of heightened temperature to generate strong thermal signal in short and long bands.

Conclusions: In the presented paper the use of thermography techniques to military applications testifies that large possibilities exist in these specific applications. Relatively small number of publications about military applications of thermography techniques results first of all from the reason that not all of this information can be made publicly available. Also for this reason in the papers there is no introduced investigation results about elements of ammunition and rockets with the use of infrared.
In the paper the main directions of works executed in MIAT were introduced. Regarding the fast development and use of more complicated composite materials in military applications the future works in MIAT over the exploitation of infrared thermography will be directed mostly on nondestructive testing of these materials.

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