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Active IR-thermography as a method of fiber content evaluation in carbon/epoxy composites

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ABSTRACT

Purpose: The primary purpose of the present work was to find relationships between achieved results of the thermal non-destructive testing and the local fibre content in a carbon/epoxy composite materials. The paper also describes the methodology, a prototype testing station and results achieved during investigations.

Design/methodology/approach: The experiments have been performed using a prototype testing station designed and built specially for the purpose of the investigation. Each carbon fiber reinforced plastic (CFRP) composite was prepared with different fiber content. Thermal non-destructive testing (NDT) technique was employed to measure such parameters as threshold temperature rise, upper limit temperature and temperature growth rate on the specimen surface. The results achieved were then analysed and correlated with carbon fiber content.

Findings: The study has assessed the ability of IR-thermography to carry out a testing of fiber content in CFRP composite materials. The experimental results revealed relationship between fiber content and upper limit temperature and also between fiber content and temperature growth rate.

Research limitations/implications: In order to obtain reliable results, there are many factors to be considered such as void content in composite matrix, type and quality of composite surface and others. Further work is needed in this area.

Practical implications: The results obtained would be of considerable importance in the industrial applications to achieve a first estimate of fiber content in polymer composite materials.

Originality/value: A new approach to the problem of fibre content examination has been demonstrated by means of thermal non-destructive testing. The method developed should be of interest to the industrial quality control applications and has a great importance for the products with a high failure-free requirements.

Keywords: Non-destructive testing; Thermography; Fibre content; Carbon/epoxy composites

PROPERTIES

1. Introduction

Carbon fibre reinforced plastic (CFRP) composites are one of the most attractive materials for high performance applications in the modern aerospace and aircraft industry due to their high strength- and stiffness-to-weight ratios and many others advantages [1,2]. It is also known that the mechanical properties of fiber reinforced composites are very sensitive to the local fiber content variations. The effect of fiber content on the chosen

characteristics of composites can be found in the literature [3-5]. Local reinforcement variations arising during production process decide about out-of-control variations of strength and stiffness in a given component, which is of a great importance for the products with a high failure-free requirements. Previous research results [6-9] showed that the inhomogeneous distribution of glass fibers, which significantly affect the mechanical properties, is detectable by ultrasonic measurements. To improve manufacturing quality it is necessary to develop a new reliable non-destructive testing (NDT) methods which are suitable for the purpose of reinforcement content evaluation.

In a wide range of different NDT techniques, thermography was until recently considered as an emerging technology [10] and nowadays is widely used in characterization of composite materials [11]. It is also known that infrared (IR) thermography is able to detect defects and anomalies in many engineering materials [12-14]. In the case of polymer composite materials, it is applicable to the detection of cracks, impact damages and fatigue degradation [15]. Thermography also seems to be the promising method for the purpose of fiber content evaluation because the total thermal conductivity of composite material highly depends on the thermal conductivity of constituent materials and their relative volume fraction. So far, no information is available on application of thermography for the fiber content evaluation in polymer composite materials. The authors made such an attempt in the present investigation.

2. Experimental

2.1. Methodology

The thermal non-destructive testing (NDT) using a prototype testing station was conducted to measure the threshold temperature rise, upper limit temperature and temperature growth rate on the opposite side of the heated surface of carbon/epoxy composites. Each specimen was prepared with different carbon content within the range of 23 to 37wt.%. The results achieved were analysed and compared for each composite and correlated with carbon fiber content.

2.2. Materials and specimen preparation

The composite specimens were made of cross - ply plain weave [0/90] carbon fabric ("Sigratex", "SGL Carbon Group", Germany), epoxy resin („Epidian 53", "Organika-Sarzyna", Poland) and hardener ("Z-1", "Organika-Sarzyna", Poland). The selected details about constituent materials are shown in Table 1.

Carbon fiber reinforced epoxy composites were fabricated by hand lay-up with a variation of carbon content. The variation of fibre content was achieved using different number of carbon layers with the same total thickness of the specimens. To eliminate a rough front surface after hand lay-up and to achieve high accuracy of the thickness (6 mm ±0.2), the specimens were covered with flat PMMA plate and pressed with load during curing process. The epoxy resin was cold-cured under ambient conditions (~20 ºC) and after curing process was thermally hardened at 50 ºC for 24 hours. The next step was to cut the edges of the specimens to the final dimensions of 100 x 100 mm.

The composites prepared in such a way had 23, 30 and 37wt.% carbon content and 6 mm average thickness.

Table 1.
The properties of constituent materials

Parameter	Carbon fibre (* fabric)	Epoxy resin
Areal weight / Density	240 [g/cm^2]*	1.15 [g/cm^3]
Thermal conductivity coef.	~15.0 [W/mK]	~0.22 [W/mK]

2.3. IR-thermography measurements

The most important issue to be taken into account, when using active IR-thermography in the case of present purpose was to obtain the repeatability of the measurements. This reason caused the application of a prototype testing station (Fig. 1) which was designed and built specially to provide a uniform heating conditions such as stable specimen mounting, constant distance between heating source and specimen and also precise heating time for all measurements.

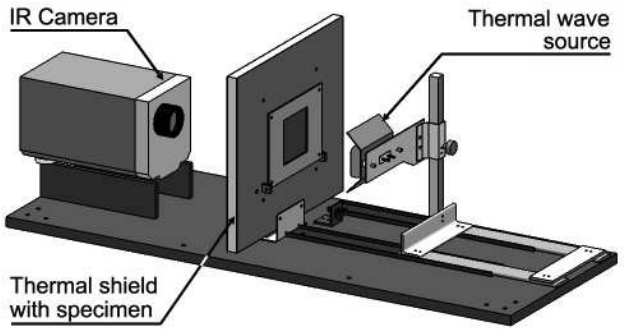

Fig. 1. View of the thermography testing station

It has been found in the literature [10] that good results can be obtained for slow thermal response materials, such as CFRP, using modest power illumination sources operating in the long-puls mode [10]. Due to the low conductivity of considered composites a long-pulse active thermography approach was selected. The heating time of 30 seconds and distance between thermal wave source and specimen (60 mm) was determined experimentally using a neat resin specimen when the temperature difference between heated specimen surface and neighbourhood (~20 ºC) was satisfactory for the investigations. The temperature variations on the opposite side of the heated specimen surface was measured and recorded using IR camera ("Inframetrics 760", USA) connected with PC system. The schematic view of the experimental configuration is shown in Fig. 2.

To provide a high accuracy and repeatability of all measurements a prototype testing station (Fig. 1) was used. Each specimen was mounted vertically (parallel to the wave source) in a hole of the thermal shield. As a thermal wave source a 300 W ceramic infrared radiator ("Elstein", Germany) with surface dimensions of 125 x 62 mm and wavelength range of 2÷10 μm was used.

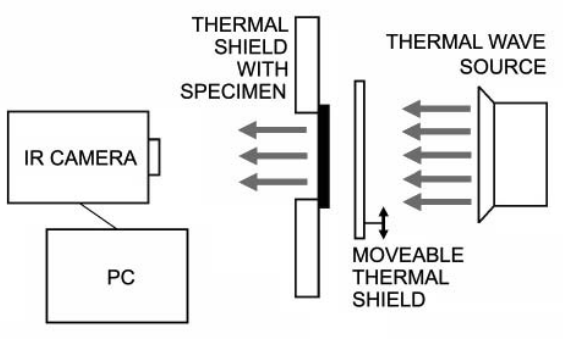

Fig. 2. Scheme of the thermal non-destructive testing with equipment

3. Results and discussion

More than 50 thermal images were captured from the completed experiments but only a selection of them are presented due to the restriction on space. All three specimens were investigated by means of active IR-thermography testing and the results were analysed and compared.

Figure 3 shows the line profile plot of the temperature increase with time for carbon/epoxy specimen (30wt.% carbon content) for which the thermal images have been demonstrated in Fig. 4. For all considered specimens the slope of straight line (Fig. 3.) as well as the highest achieved temperature on the opposite side of the heated surface had different values.

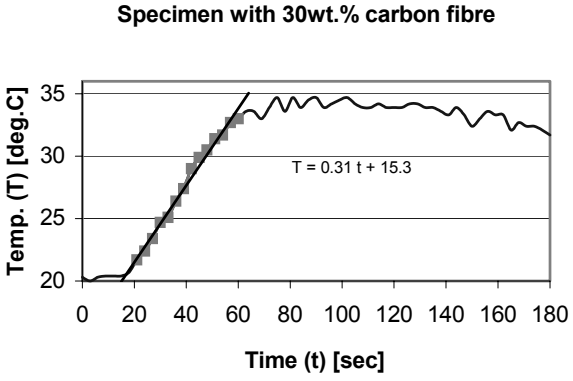

Fig. 3. Temperature variations vs time for carbon/epoxy specimen with 30wt.% carbon fibre

Figures 4a, 4b and 4c show the thermal images of the selected 30wt.% carbon specimen captured between 30 and 180 seconds after heating termination. Figure 5 shows relationship between the highest achieved temperature and fiber content for all three specimens. The results from Fig. 5. shows that the highest temperature, measured on the opposite side to the heated surface of the specimen, increases proportional with the carbon content.

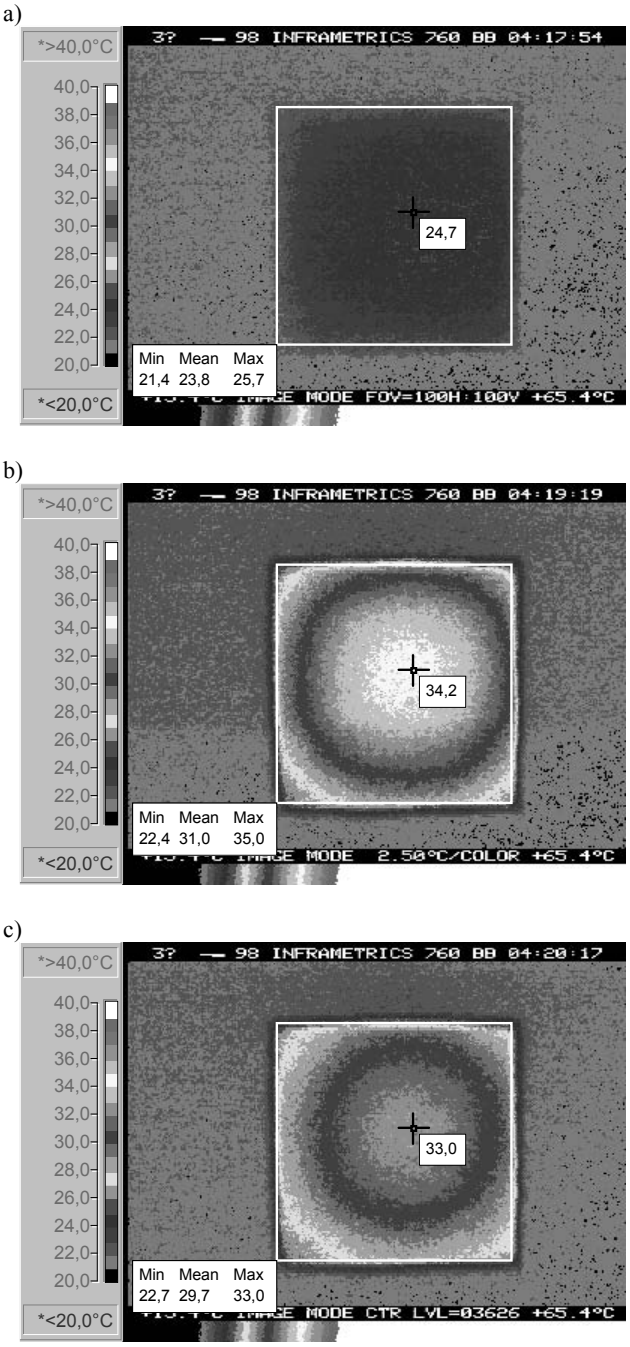

Fig. 4. Thermal images of 30wt.% carbon fiber specimen captured on the opposite side of the heated surface after: a) 30, b) 120 and c) 180 seconds of the heating termination

The similar situation can be seen in Fig. 6 where temperature growth rate increases with an increase of fiber content.

The results achieved during experiments together with the considered parameters provide a good starting point for any theoretical investigations.

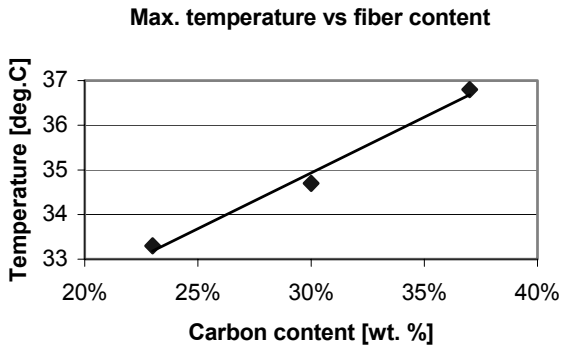

Fig. 5. Relationship between maximal temperature and fiber content for the three investigated specimens

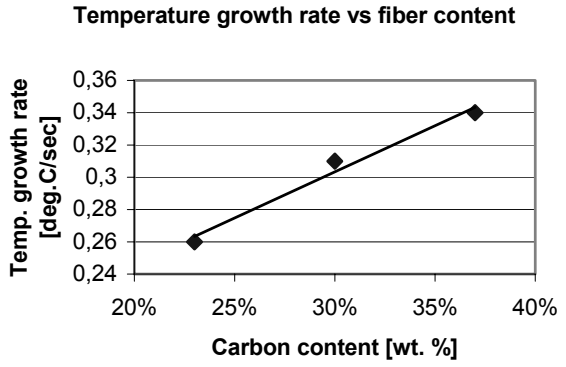

Fig. 6. Temperature growth rate vs fiber content for the three investigated specimens

4. Conclusions

In the present study, active IR-thermography was applied to evaluate the carbon fiber content in a specially prepared CFRP composite materials. The investigation has assessed the ability of thermography with a long pulse technique to carry out such a testing. The experimental results have shown relationship between fiber content and upper limit temperature and also between fiber content and temperature growth rate. Therefore, it is concluded that IR-thermography can be used in the evaluation of fiber content in polymer composites, producing interpretable results.

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