Layered composite for a geopolygon mire

A P Kondratov, G N Zhuravleva and Y M Syltanova
Moscow Polytechnic University, 38 Bolshaya Semyonovskaya str., Moscow 107023, Russia
a.p.kondratov@mospolytech.ru

Abstract. We have investigated flexible composite materials of test objects (mires) intended for setting the aviation optical equipment for remote sensing of the Earth. The brightness fields and control images of the mire contrasting elements are obtained by the method of ink-jet printing on banner fabric. We have proposed a new layered structure of the material for the operating contrast control. We have established quantitative patterns of changes in the optical characteristics of test objects when using an outer layer made of a transparent polymer film, which makes it possible to vary the characteristics of test objects for adjusting thermal imaging devices and aviation optical equipment using low-cost polygraphic methods.

1. Introduction
One of the most important interdisciplinary areas of modern applied physics and materials science is the development of systems for multivariable integrated control of thermal imaging devices and the creation of test objects for setting the onboard aircraft equipment [1–3]. Full-scale tests of such systems are always associated with significant financial costs and interdepartmental organisational arrangements. As a result, the shortages of design solutions and errors in the choice of materials for test objects are revealed at the final stage of testing.

The object of this paper is to develop the structure of a layered composite with minimal material costs and the ability to vary the contrast of the radiation temperature of the geopolygon mire elements.

A test object know, a passive geopolygon mire for setting and determining the parameters of onboard aircraft equipment in the infrared range [4, 5], contains rectangular strips of thin aluminum tubes with a light-return surface, the strips have recesses in the form of corner reflectors adjoining each other with the edges of recesses [6].

Aluminum tubes with a knurled surface provide noise immunity of the test object from side illumination and control the radiation temperature of IR-mire strips.

The disadvantage of the learned passive geopolygon infrared mire is the use of significant amount of non-ferrous metal, a high probability of mechanical damage (deformation) of thin tubes, the impossibility of prompt installation and dismantling if it is necessary to change the direction of laying the stripes depending on the direction of aircraft movement.

In recent years, test objects made of polymer and composite materials that are easily and quickly erected on the earth's surface have been created and patented [7], these materials are obtained by high-performance methods of processing thermoplastic polymers into films, fabrics, and nonwoven fibrous materials. A layer of aluminum or paint (using printing equipment) is applied to flexible polymer fabrics.
Monochrome images of a certain optical density are printed in order to obtain the specified contrast values for the radiation temperature or the reflection coefficient of electromagnetic radiation. So, for example, a mire for setting and determining the parameters of optoelectronic systems [8–10] contains several dashed images of various sizes applied to the surface of a flexible material of contrasting color at different angles to the intended direction of flight. The device consists of a main rectangular fragment made of a fabric-reinforced polymer material of dark color, with width multiple of three meters with light images of groups of rectangular dashes applied to it, located at angles of 0°, 45°, 90° and 135° to the side of the fragment, and rectangular auxiliary unified fragments of the side background. The dashed elements of the test object are made of a nonwoven polymeric material with an identical spectral reflection coefficient of electromagnetic radiation to the background areas and containing regularly repeating recesses located at an equal distance from each other.

2. Subjects and methods
Material: banner fabric S-PRW334240B made in the Republic of Korea from a mesh of polyester threads coated with PVC plastisol.

The water-base ink was applied to a transparent film of polyethylene terephthalate (lavsan) made by Emtec using a Canon Pixma MG2540S ink-jet printer.

The optical density and reflection coefficient of D65 built-in light source at an observation angle of 2 degrees were determined using an X-Rite Pantone e-Xact spectrophotometer with GretagMacbeth KeyWizard V2.5 software. Banner fabric without a layer of paint was used as a white balance standard. We carried out 10 identical measurements over the entire area of the presented sample and calculated the mean value of the changeable values, the mean root square deviation of the optical density and the reflection coefficient which are shown in the diagram (Figure 3).

3. Results and discussion
Figure 1 shows a cross-section of a non-woven fibrous fabrics which is used for the production of the lower layer of the test object by the method of hot calendering of the fabric made of thermoplastic fibers, the regularly spaced prismatic recesses are formed on the lower layer forming the background of the mire. The fabric surface is covered with a mirror layer of aluminum, which provides an effective reflection of light and heat radiation. The shape, size of the recesses and the frequency of their location provide uniform radiation scattering. To obtain contrasting images, the stripes of polymer material painted in light colors are applied to the background fabric. To vary the contrast of the elements of the test object in [2], it was proposed to perforate the outer layer so that the integral flux of radiation reflected from the stripes would make up a certain fraction of the radiation flux reflected from the background or exceed it by a certain amount.

Figure 1. Macrostructure of mire elements made of metallized non-woven fibrous fabric with recesses. 1 — polypropylene fibers, 2 — aluminum layer; 3 — the distance between the recesses; 4, 5 — frontal dimensions of the recesses.
We propose to use translucent prints on a polymer film to create a certain optical density of dashes and regulate the contrast of the target, instead of perforations of dashed elements, the film should be applied to a background canvas with a certain optical density or radiation temperature.

Printing on polymer film according to the "roll to roll" technological scheme is a high-performance printing process and can be used to make an easily removable outer layer of the mire [5]. Prompt replacement of the outer layer of a transparent film with geometric shapes applied to it allows to change the contrast of the mire elements.

Figure 2 shows a frontal view of the dashed element of the mire — a film, printed by alternating circles or squares, the total area of which is 20 ÷ 40%.

![Figure 2](image)

(a) (b) (c)

**Figure 2.** View of dashed elements of the mire with a proportion of the printed surface: (a) — 20%; (b) — 30%; (c) — 40%.

The prints were used to estimate the optical characteristics (optical density and light reflectance) of the samples. When determining the optical density of the printed film, a layer of banner fabric of white, gray or black color was placed under the film. The results of these measurements and calculations are shown in the table.

To calculate the total proportion of the area of prints the following formula is used:

\[ \alpha = \frac{\rho_f (k + 1) - \rho_{mp}}{(\rho_{mp} - \rho_f)} \]

where \( k \) is the contrast of the printed stripes in terms of the radiation temperature or the reflection coefficient of electromagnetic radiation; \( \rho_f \) — integral reflection coefficient of the radiation flux from the background fabric; \( \rho_{mp} \) — integral coefficient of electromagnetic radiation reflection from the printed strip of the mire.

The contrast of the dashed mire is determined by the ratio:

\[ K_M = \frac{(\rho_{mp} - \rho_f)}{\rho_f} \]

where \( \rho_f \) is the reflection coefficient of the background (banner fabric).

![Figure 3](image)

**Figure 3.** Dependence of the stripes contrast on the proportion of the filled (printed) film surface for white banner fabric: 1 — no air gap; 2 — air gap \( h = 0.14 \) mm; 3 — air gap \( h = 0.37 \) mm.

In the laboratory version, the optical density of the printed film and the reflection coefficient were estimated. Contrast was calculated based on the measurement results. We evaluated the possibility of the influence of the air gap between the white banner fabric (background) and the printed film (strip) on the optical characteristics of the material (Table 1).
Table 1. Optical characteristics of white banner fabric.

| Material | For printed film surface, % | Gap  | Optical density | Reflection coefficient | Contrast |
|----------|-----------------------------|------|-----------------|------------------------|----------|
| White banner fabric | 0.06 | 0.871 | 0.10 | 0.794 | 0.088 |
| | 0 | h = 0.14 mm | 0.12 | 0.759 | 0.129 |
| | | h = 0.37 mm | 0.17 | 0.676 | 0.224 |
| | | 0.15 | 0.708 | 0.187 |
| White banner fabric + film | 0 | h = 0.14 mm | 0.16 | 0.692 | 0.206 |
| | | h = 0.37 mm | 0.23 | 0.589 | 0.324 |
| | | 0.20 | 0.631 | 0.276 |
| | 20 | h = 0.14 mm | 0.23 | 0.589 | 0.324 |
| | | h = 0.37 mm | 0.32 | 0.479 | 0.450 |
| | | 0.28 | 0.525 | 0.397 |
| | 30 | h = 0.14 mm | 0.35 | 0.447 | 0.487 |
| | | h = 0.37 mm | 0.40 | 0.398 | 0.543 |

4. Conclusion
When the air gap size in a multilayer package made of polymeric materials is increased, the optical characteristics for all three colors of the banner film are increased, too, as well as the proportion of the printed surface is increased in all cases. So, as the air gap increases, the surface becomes darker.

The application of a multilayer package of polymer materials with interlayer printing provides an increase in the level of physical and mechanical properties of the product, thereby extending the operating time, but reduces the possibility of adjusting the optoelectronic equipment of aircraft.

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