Quality control of parts which were manufactured from polymeric composite materials with hybrid matrix with the application of method of infrared thermography

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Abstract. This article contains the description of different polymer composite materials (PCM) with different types of hybrid matrices. One of the components of PCM’s hybrid matrix is hardened as the other one stays in its viscoelastic condition. The following materials are chosen to serve as viscoelastic components of hybrid matrix: technical wax compound, anaerobic and organosilicone polymer materials. The use of viscoelastic materials allows the enhancement of PCM’s stress-strain properties. This article also contains: the destruction mechanism of polymer composite materials with different types of hybrid matrices; the quality control process of products made of polymer composite materials with different types of hybrid matrices; the localization method of hybrid matrix viscoelastic components by using infrared thermography during product molding process. The results of quality control are shown as thermograms.

1. Introduction
Today, in most of world’s industrial leading countries a lot of attention is paid to find a way to reduce the metal consumption of machinery production and other industrial branches. One of such ways is to replace metal parts to those made of polymer composition materials (PCM).

The use of PCM in production allows solving a number of problems, including not only reducing the product’s weight, but also achieving their desired properties, as well as the ability to provide the best resistance to external influences (for example, alternating loads (vibrations) that follow the operation of any mechanism) and (as a result) to premature destruction [1-2].

PCM based on fibrous fillers are materials with high level of energy dispersion. Such PCM have a significant internal friction, the action of which leads to fading of free vibration. For long-term resistance to fracture under alternating loads, polymer composite materials must have high deformation properties (in particular, elasticity) and durability.

The integration in matrices of PCM based on fibrous fillers of viscoelastic components that stay in its «fluid» condition after the product molding process allows making a construction material with a variable volume of elasticity module. This provides high stress-strain properties in load application points and, as a result, the resistance to alternating loads (similar to higher stress-strain properties of live wood compared to those of dry one) [3-5].

According to the analysis of hardening mechanisms of different polymer materials following compounds were chosen as hybrid matrix viscoelastic components: anaerobic polymer material...
2. The destruction mechanism of hybrid matrix polymer composite materials containing viscoelastic components

Viscoelastic components contained in fibrous fillers based PCM’s hybrid matrix represent the inner reduced durability interface. To implement on the interface the Cook-Gordon crack blunting mechanism (figure 1) [6-8] the durability of interface should be less than 1/5 of the overall material’s linkage strength. The amount of 1/5 is taken regarding that with any shape of crack and its way to spread, the ratio of the maximum parallel tension range to the maximum perpendicular (to the crack’s surface) tension range is constant and equal approximately 1/5 [6].

The functional concept of crack blunting mechanism on the interface is that when the crack A (figure 1, a) grows, on some distance from its top is located the peak of tension stresses acting in the parallel to the crack’s spread direction (figure 1, a). These stresses cause the transverse separation on the interface B (figure 1, b), forming an additional (secondary) crack – C (figure 1, c). Formed on the interface, secondary crack C acts as a «trap» for the crack A, and doesn’t let it to spread any further (figure 1, d).

So, more fracture energy is needed to destroy a PCM with a hybrid matrix that contains viscoelastic components, than for a PCM with a hybrid matrix that doesn’t contain any. This circumstance explains the higher stress-strain properties of PCMs with a hybrid matrix that contains viscoelastic components compared to those with a matrix that doesn’t contain any and have their interfaces durability range more than 1/5 of overall material’s linkage strength [3]. If the durability of interface B is more than 1/5, then the inner interface will not be destroyed, a crack will just cross it and the material behavior will not change.

Despite any expectations, weak inner faces don’t weaken the material itself, but even increase its durability, making it more viscous, like live wood or bone. However, it should be noticed that if the
linkage on the interface is too weak, then the material itself will be weak and not solid. Therefore, the effective combination of durability and viscosity depends of the right choice of linkage forces on the interface [9-10].

So, by creating viscoelastic components location zones in PCM’s hybrid matrix structure, having interface’s durability less than 1/5 of overall material’s linkage strength, the significant improvement of product’s stress-strain properties in load application areas can be achieved, resulting in durability enhancement.

3. The use of infrared thermography in the location of the viscoelastic components of a hybrid matrix in polymer composite materials

The production use of new construction materials requires the development of nondestructive quality control procedures.

One of the main quality control factors of molding process of PCM product with different types of reviewed hybrid matrices is the precision of location of viscoelastic components in material’s structure. It’s possible to carry out the viscoelastic components location control with different methods of nondestructive control methods, allowing the registration of material’s density changes. Among these are: infrared thermography, ultrasonic inspection, radiography and radioscopy, computer tomography [11-12].

Compared to other methods, the infrared thermography is less expensive and less laborious and at the same time the simplest and the safest method that allows to carry out large parts quality control. The active infrared thermography method involves the object’s excessive heating or freezing and the registration of thermal field and thermal diagnostic signals on its surface with an infrared camera. A thermal diagnostic signal is formed by differences between thermophysical properties of a defective and normal structures.

Apart from density changes the infrared thermography method allows to detect such PCM defects as: layer separation; fiber linkage interruption; fiber’s coaxial alignment corruption; fractures; excessive pores; thickness changes; caverns; impurities and moisture presence. However, this method has limited application near highly flammable matters, as well as parts made of thin multi-layer materials and with low emissivity surfaces. Besides, unbalanced heating of controlled object can lead to false control results, as well as thermal limits exceeding can lead to irreversible destruction of composite material’s matrix of filler. Therefore the choice of any nondestructive control method should be a result of an integrated analysis both properties of controlled objects, those of their surfaces, and the quality control conditions [11-12].

3.1. Preparing the samples and carrying out researches

To carry out the quality control of PCMs with different types of hybrid matrices containing viscoelastic components by infrared thermography method, three types of BT400 basalt fabric-based 400x600 mm PCM samples were made:

1. PCM with hybrid matrix, including an anaerobic polymer material as a viscoelastic component (Loctite 638);
2. PCM with hybrid matrix, including a bicomponent organosilicone polymer material as a viscoelastic component (Uniseal-9628);
3. PCM with hybrid matrix, including a technical wax compound as a viscoelastic component.

These samples were made with prepreg technology, using epoxide Epolam 2017 as a bonding adhesive. Viscoelastic matrix components were applied between the third and the second layers of basalt fabric, along the samples. The drying of samples was done with Trommelberg IR3C Standard set, which provided the heating to +80°C accurate within ±2°C.

While carrying out the infrared thermography to locate the viscoelastic components of prepared PCMs hybrid matrices, the samples were heated using a heat gun. This way of heating was chosen to apply the excessive temperature to a spot on a sample’s surface. The prepared basalt fiber based
plastic polymer samples with different types of hybrid matrices were heated up to overall temperature of 33°C.

The registration of thermal field distribution on surfaces of PCM samples with different types of hybrid matrices containing viscoelastic components was carried out with Testo 875-li thermal camera.

3.2. Research results analysis

The results of implementing the active infrared thermography of prepared basalt fabric based polymer plastic samples with different types of viscoelastic components containing hybrid matrices had shown that there’s a correspondence between a diagnostic signal intensity and viscoelastic material. It is supposed by the authors of this article, that the result of the active infrared thermography is strongly influenced not only by viscoelastic component’s density, but also by such property of liquid polymers as limiting wetting angle.

Therefore, the organosilicone polymer material limiting wetting angle, unlike the one of technical wax compound, is much less than 90° so, when it (Uniseal-9628) is used as a viscoelastic component, the temperature gap between the areas with viscoelastic components and without them is just 0,1-0,3°C. This property does not provide enough precision for PCM’s hybrid matrix viscoelastic components location control with infrared thermography method. Anaerobic polymer material (Loctite 638) has the limiting wetting angle close to 0° and during the molding process spreads into interlaminar space, so the active infrared thermography couldn’t locate this viscoelastic component.

The best diagnostic signal was acquired by the active infrared thermography quality control of the sample which had the technical wax compound as a viscoelastic component of hybrid matrix (figure 2, d). The software processing of acquired thermogram (figure 2, a) had provided the sample’s excessive temperature bargraph (figure 2, b).

![Figure 2](image)

**Figure 2.** The location of hybrid matrix viscoelastic components in PCM: a – the location process thermogram of hybrid matrix viscoelastic components in heated PCM, b – the bargraph of sample’s excessive temperature distribution on hybrid matrix PCM surface, c – viscoelastic components location thermogram in PCM’s hybrid matrix being cooled, d – a photograph of viscoelastic components (technical wax compound) being inserted as a part of PCM’s molding process.

The technical wax compound has lower thermal diffusivity than the main material of composite, that’s why its heating and following cooling are slower, than ones of the other viscoelastic materials.
This property allows to locate hybrid matrix viscoelastic components with active infrared thermography (figure 2, a, c).

Throughout the heating process the average temperature which defines the best thermal signal of viscoelastic components (technical wax compound) of PCM is about 32,6°C with average PCM temperature about 33,5°C. While cooling, the average temperature of viscoelastic components (technical wax compound) of PCM is about 31,9°C with average PCM temperature being about 31,4°C. So, these amounts allow the highly precise location of viscoelastic components (technical wax compound) in PCM with active thermography method.

4. Conclusions
Therefore, we can figure out that the quality of PCM infrared thermography with different types of hybrid matrices mostly depends of viscoelastic components properties, such as density and limiting wetting angle. The lower the density and limiting wetting angle of viscoelastic components – the lower the quality of active thermography location of these. The lower the limiting wetting angle of viscoelastic components, the better it’s absorbed by PCM’s reinforcing material and the weaker its thermal diagnostic signal.

So, to locate the viscoelastic components of PCM’s hybrid matrix with low density and limiting wetting angle close to 0°, it’s necessary to use alternative methods of nondestructive control, for example industrial computer tomography or ultrasonic testing.

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