Exploring the effect of thermoplastic composition on light emission

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Abstract. Currently, reflective coloring agents are used for road markings. To obtain the best result from the use of the light-reflecting effect of the marking, we propose to use luminophore (light-emitting powder), by adding it to the thermoplastic composition heated at about 200 °C. It can ensure the best visibility in the dark, in the conditions of rain and snowfall. The effect of the use of this technology will be visible both in urban and rural areas, where it can surely be an excellent alternative in case of the absence of stationary lighting. This will give the driver a good view of the route, even with the lights off. By analyzing the available and relevant information and conducting the necessary research and experimentation, the main goal will be to obtain the best results and a rational proportion of components in the manufacture of experimental samples that provide the maximum light-emitting effect.

1. Introduction

The glow effect of the luminophore in the dark helps a driver to concentrate solely on the road when the opposite vehicle blinds with high lights. In addition, driving in the dark, especially over long distances, is associated with psycho-emotional stress, fatigue and drowsiness for the driver. At night, the human body should rest and recover, and the attention and reaction of the driver at night are noticeably different from the driving conditions in the daytime. Road markings, glowing in the dark, not only enhance the attention of drivers, but even make the trip exciting. The use of this technology on the structural elements of bridges or other road structures, especially in dangerous places on the road, will reduce the number of accidents. The lack of visibility of road markings is the most frequent disadvantage of the road leading to road accidents [1,12].

The principle of operation of the technology is quite simple: the surface, which absorbs and accumulates the energy of light from natural or artificial sources, begins to glow in the darkness. The maximum intensity of the glow could be observed for a few hours, followed by its gradual decrease. At night, luminous lines, writings and other symbols serve as an additional measure of the security system on difficult sections of motorways. Moreover, on sports fields and cycle tracks this light provides an opportunity for exciting competitions even at night. The new luminous direction in the field of road arrangement opens:
• huge earning opportunities for road companies;
• unique opportunities for real energy savings;
• real opportunities to ensure safe traffic on the roads;
• excellent opportunities to enjoy the beauty of the night trails.

Figure 1. Luminous markings on a highway.

The most "problematic" parameter is the specific coefficient of retroreflection. Insufficient values of this important characteristic of the road marking, which determines its visibility in the dark time with reflected light from the headlights of vehicles, are often recorded both on the new marking (during the acceptance control) and during operation. It is also necessary to note another disadvantage of the markings, directly related to this parameter - an uneven value of the elements spread on the area, first of all applied by hand markings [2].

2. History and origins
The word Luminophore comes from the Latin "lumen" - "light" and the Greek "phoros" - "bearing." Since ancient times, people know the glow of natural luminophores - some insects, minerals, rotting wood. Scientists were able to understand the nature of such a glow - luminescence - only relatively recently, with the development of atomic physics. After all, luminescence is explained by the phenomena occurring in the atom of matter: excitation of the atom and then its return to a stable energy state; during this transition light is emitted [3].

Excitation of an atom can cause ultraviolet and x-ray radiation, electric field, chemical reactions. Luminophores transform all these different types of energy into light. In some luminophores, the color of the glow is ultraviolet, in others - blue, green, yellow, red. By combining various luminophores, we can get a spectrum of daylight. These mixtures are usually used in fluorescent lamps.

Organic luminophores are used to create luminous colors, road signs. Luminophores are also used for the analysis of various substances, the manufacture of luminous devices, in the extraction of minerals, in biology.

Photoluminophores are a type of luminophores that have the properties of preserving the stored energy upon excitation, and its return, with the possession of its own afterglow of a certain duration after the cessation of excitation in the form of light radiation in the visible, ultraviolet or infrared region. A very wide list of compounds belongs to this class of luminophores. Scientists distinguish both natural photoluminophores and artificially synthesized [7].

3. Luminophore characteristic
Luminophore is a substance that is capable of converting the energy absorbed by it into light radiation [4]. All luminophores by their chemical nature are divided into inorganic (most of which belong to
crystallophosphorus) and organic. Self-luminescence of inorganic phosphors is caused in most cases by the presence of extraneous cations, which are contained in small amounts (up to approximately 0.001%) [5].

The most common types of luminophores on the market are photoluminophores and electroluminophores. They are a mixture of a very complex composition: strontium aluminate activated by europium, dysprosium, yttrium. Their chemical formula is: \((\text{SrAl}_2\text{O}_4):\text{Eu, Dy, Y}\).

Aluminate-based photoluminophores are inert to aqueous and solvent media, resistant to various irradiations and have an afterglow of up to 20 hours.

Luminophores are inherently non-toxic, fire and explosion safe, and have no dangerous radioactive radiation.

Photoluminophore is a non-hazardous substance, hazard class of the components is 4. Luminophore does not pollute the environment and has high stability of chemical reactions [5].

The comparative characteristics of zinc-based luminophores and aluminates of strontium luminophores of long afterglow are shown below. The DLO-7D brand and zinc phosphor were taken as the basis.

Glowing in the dark luminescent pigment (Luminophore), is characterized by its peculiarity, ability to absorb the energy of natural and artificial light sources and emit it in the form of a visible glow in the dark. DLO-7D brand pigment consists of very thin crystals, which basically have the molecule of strontium aluminate \(\text{SrAl}_2\text{O}_4:\text{Eu, Dy, Y}\), radically different from ordinary phosphorescent pigment, which is based on zinc sulfide or radioisotopes with their self-luminosity properties.

Some advantages and differences of luminophore pigments:
- The luminescence period in the dark is 50 times longer than that of a conventional pigment based on ZnS.
- Activation by waves of different lengths (200-450 nm), but the best result is obtained with activation energies above 350 nm [6].
  - It does not pollute the environment and has high chemical stability.
  - Absence of hazardous and radioactive substances.
  - The initial brightness of the afterglow is at least 10 times longer than that of radioluminescent and photoluminescent pigments.
- Increased luminescence and afterglow with increased activation time.
- Excellent weather and light resistance of the pigment.

The DLO-7D luminophore (Figure 2) continues to accumulate and preserve light energy, not reaching the saturation point, much longer than the classic phosphorescent pigment.

![Figure 2. Luminophore DLO-7D.](image-url)
4. Afterglow characteristics
Brightness, afterglow and color diffusion.
When activated, the most effective energy saturation can be obtained when the unprotected pigment is exposed to the directional ultraviolet ray (UV) of the sun, a halogen lamp, a gas discharge lamp, and other light sources rich in ultraviolet light.
On the other hand, ordinary fluorescent lamps are rich in ultraviolet light, and then quick activation is possible if we add pigment next to them. The brightness of the afterglow is also proportional to the intensity of the ultraviolet contained in the activating light and the activation time.
The upper curve shows the characteristics of the afterglow of the strontium aluminate luminophore SrAl$_2$O$_4$:Eu, Dy in comparison with the pigment based on zinc sulfide.
The measurements were taken from shielding silky surfaces that were activated by a 200-lux light source for 4 minutes.
As can be seen from the graph (Figure 3), SrAl$_2$O$_4$:Eu, Dy is 10 times brighter and has approximately 10 times longer afterglow than the pigment based on Zn: Cu sulfide.

![Figure 3. Afterglow Efficiency.](image)
The activation time and brightness of the afterglow of SrAl$_2$O$_4$:Eu, Dy continues to accumulate and preserve light energy (without reaching the saturation point) much longer than the classical phosphorescent pigment. The graph (Figure 3) shows the results when both types of pigments were activated using D65, a standard source of daylight intensity of 200 Lux.

5. Retroreflective materials
The most important property of the marking is its good visibility in bright light, and in dark nights, and in heavy rain, and in cloudy weather, and in the light of the sun, and in the light of headlights. Due to this property, it is possible to reduce the number of road traffic accidents at night by 30%.

Thermoplastics designed for road marking on asphalt pavements are made by dry mixing of the following components: binders, fillers, pigments, processing aids [13].

Good visibility is achieved by using retroreflective materials in road markings, for example, reflective glass beads [14]. They are not used independently as marking material, but only in combination with it, to increase the visibility of marking, especially at night, rainy and cloudy weather.
Their reflective property is based on the ability of glass beads, which are located on the surface of the marking material, to refract the light coming from the headlights of the car and reflect it at a different angle so that it gets into the eyes of the driver.

There are three methods of application:

1. The introduction of the marking material in the amount of 10 - 20%;
2. Sprinkling onto freshly applied markings in an amount of 200 - 300 g / m²;
3. A combination of these two methods at the same time.

To guide the light of the headlights, refracted by the bead and reflected from its inner surface, into the driver’s eyes to the greatest extent, the bead must be half the height above the marking surface, and its surface should be free from marking material. In this case, it is also fairly well retained by the marking material. But if the bead protrudes from the marking layer by more than a half, it could easily be hit by the wheel of a car. If the bead is immersed in a layer of marking material more than a half, the amount of reflected light will decrease [13,14].

6. Research results
The purpose of the study was to study the effect of luminophore on thermoplastics, i.e. in obtaining a rational ratio of substances that provide the maximum retroreflective effect in conditions of complete absence of light.

To determine the rational ratio of luminophore to thermoplastic, we drew up an experimental plan.

During the study, we calculated various ratios of substances:

| Luminophore, g | Thermoplastic, g |
|---------------|-----------------|
| 20            | 200             |
| 40            | 200             |
| 60            | 200             |
| 80            | 200             |
| 100           | 200             |
| 120           | 200             |
| 140           | 200             |

The results of the dependence of the illumination time on the radiation level of the samples in the ratios 20/200, 40/200, 60/200, 80/200, 100/200, 120/200, 140/200 are shown in Figure 4.

![Figure 4](image-url)
As a result of the study and processing of the obtained indicators, we determined that the characteristics of the experimental samples with a high luminophore content practically did not differ. They also have increased brightness compared to other experimental samples, but the duration of the glow decreases faster.

Thus, samples with 60 grams and 80 grams of luminophore will be rational in terms of component ratio and efficiency.

7. Conclusion
As a result of research on the properties of thermoplastics, we determined the most effective indicators of the luminophore glow in thermoplastics.

We determined and processed the luminosity indices for a certain period of time, luminosity indices during the complete decay of prepared thermoplastic samples with different ratios of thermoplastic and luminescent powder.

The application of the above technology has many advantages compared with the technology of conventional thermoplastics:
1. Creating a favorable aesthetic appearance in the conditions of the city, rural areas, etc.
2. Ensuring safe traffic on roads in the absence of light or in the presence of sections of roads with low light.
3. The absence of negative effects on the environment and human health.
4. Low material costs compared to conventional thermoplastics.
5. The application of this technology is possible with a road marking machine, which will improve the performance of the equipment and increase its efficiency and road safety.

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