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Composite Material for the Manufacture of Plastic Sleepers

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Abstract: The composite materials intended for the manufacture of plastic sleepers were produced, which significantly differ from the materials widely used in railway transport of wooden and reinforced concrete sleepers. The coefficients of linear thermal expansion of the obtained materials are significantly lower. Polyvinyl chloride is used as a polymer binder, and the filler is a mixture of softwood flour with the mineral filler in the form of finely ground chalk. It was shown that by varying the content of the components of the composite, a change in its density is achieved by 19%, and the change in the value of the coefficient of linear thermal expansion depends on the temperature and relaxation of internal stresses in the samples, varying by 18.7 times – from $288.4 \cdot 10^{-6}$ to $15.4 \cdot 10^{-6}\,^{o}C^{-1}$.

Introduction

Sleepers are one of the main elements of the upper structure of the railway track, which ensures its stability during operation. According to the structural features and materials used, sleepers are divided into sub-rail elements of traditional structures made of wood, concrete and steel. These include wooden, reinforced concrete and steel sleepers, and plastic (composite) sleepers manufactured on the basis of a polymer matrix [1]. Compared to traditional designs, plastic sleepers have a number of advantages. The main advantage is the possibility of achieving a compromise of physical and mechanical characteristics between light and elastic wooden and heavy and rigid concrete sleepers.

Other advantages of plastic sleepers are the possibility of using solid waste as raw materials for their manufacture, reducing the environmental burden on the environment, high durability, the possibility of recycling such sleepers for the manufacture of similar structures, and a number of others [2]. Expanding the production of plastic sleepers largely solves the problem of recycling industrial waste and by-products produced by modern post-industrial society, which puts them among the most competitive and promising structures in the railway construction market.

At the same time, a serious obstacle to the use of plastic sleepers in railway transport is the high value of the thermal expansion coefficient (CLTE) for the polymer matrix, which is an order of magnitude higher than the same indicator for sleepers made of traditional materials, which is for wood $(5\text{-}6) \cdot 10^{-6}\,^{o}C^{-1}$, and for concrete and steel – $(10\text{-}12) \cdot 10^{-6}\,^{o}C^{-1}$. This prevents the provision of a stable width of the railway track at high temperature differences and, accordingly, the safe operation of the railway track on plastic sub-rail bases [3]. Therefore, the study of the thermal properties of filled plastics and the search for ways to reduce the value of CLTE of the plastic sleeper material is a priority scientific task that is of great practical importance for the railway industry in the practical implementation of such innovative sub-rail bases [4].

Let us consider the works in which the thermal properties of a number of polymer composites are studied. The thermal expansion of polymer composites filled with carbon nanotubes is described using the fractal approach [5]. It is found that an increase in the concentration of nanotubes in the composite leads to a decrease in the coefficient of thermal expansion. Comparative estimates of the physical and mechanical properties of some polymer composites, including those containing carbon nanotubes, are given.

It was found that CLTE of composites decreases when copper, aluminum powders and glass and carbon fiber segments are introduced into poly-2,6-dimethyl-1,4-phenylene oxide [6]. This phenomenon is caused by the formation of boundary layers of the matrix around the filler particles. The macromolecules in the boundary layers are laid parallel to the surface of the filler particles, which leads to a decrease in CLTE.

The thermal properties of wood-polymer composites are considered in [7-9]. It is shown that the introduction of mineral filler reduces the coefficient of thermal expansion.

Materials and Methods

Materials for sleepers were prepared on the basis of the production of wood-polymer composites (WPC) by Savewood. Manufacturing samples of material of sleepers was carried out on industrial extruders company Savewood. The extrusion temperature in different zones of the extruder varied from 145 to 200 ^{o}C. The extrusion velocity is 0.25-2 m/min. For the tests, five formulations of the composite material were made, the composition of which is shown in Table 1.

Table 1. Weight fractions of components in the samples

Composition number	Relative units by weight		
	Wood flour	Calcium carbonate	PVC
1	1.167	1.167	1
2	-	0.538	1
3	0.436	0.436	1
4	1.553	0.780	1
5	-	0.873	1

The concentration of all other components – modifiers, stabilizers, flame retardants and other additives – was the values inherent in the classic formulation of WPC materials produced by Savewood, which, in turn, are a trade secret.

CLTE measurement was carried out in accordance with the standard GOST 32618.2-2014 (ISO 11359-2:1999) plastics. Thermomechanical analysis (TMA). Part 2. Measurement of the coefficient of linear thermal expansion and the glass transition temperature.

Thermomechanical curves were measured using the TMA Q400 (TAInstruments) instrument (Fig. 1) under conditions of punch penetration into a cylindrical sample at a temperature increase of 5 deg/min. The diameter of the punch was 2.5 mm, the load on the punch was 100 g.

Fig. 1. Thermomechanical analyzer Q400

Results and Discussions

Table 2 shows the results of measurements of the average density values of samples of plastic sleepers and the spread of the measured indicators, characterized by the coefficient of variation. As follows from the data given in Table 2, characterized by high uniformity of the measurement results – the coefficient of variation does not exceed 1.9%, the material density of the studied compositions varies in the range from 1.370 (composition 5) to 1.627 g/cm^3 (composition 1) or by 19%. The resulting density of the material of plastic sleepers occupies an intermediate position between the density of the material of wooden (0.50 g/cm^3) and reinforced concrete (2.5 g/cm^3) sleepers, which allows you to reach a compromise between the operation of rolling stock on the railway track in the "soft" (on wooden sleepers) or "hard" (on reinforced concrete sleepers) mode. On the other hand, for the material of plastic sleepers, it is possible to vary their weight (in the range of 19%), achieving greater stability of the railway. paths to emissions from the action of temperature stresses in the rails due to the use of heavier plastic sleepers with a higher material density.

Table 2. Density of plastic sleeper material compositions

Composition number	Average sample density $\overline{\rho}$ (g/cm^3)	Coefficient of density variation υ_ρ (%)
1	1.627	1.7
2	1.489	1.1
3	1.417	1.9
4	1.441	1.1
5	1.370	1.4

Another important indicator of the material properties of plastic sleepers is CLTE, the values of which for the prepared materials are shown in Table 3 and in Figures 2-6. As is known, the coefficient of thermal expansion is not a constant value, but a variable depends on the temperature range in which it is measured – as the temperature increases, the value of CLTE of the material, as a rule, increases. Taking into account the fluctuations in the value of CLTE when the ambient temperature changes is important for ensuring the safe operation of railway transport, as it ensures the stability of the geometric parameters of the railway track and especially its width. Therefore, the values of CLTE were measured in the temperature range from -50 to 109 ºC, in which included the scope of operation temperature of railway sleepers.

Table 3 shows CLTE values for the prepared materials at different temperatures, which are in the middle of each temperature range.

Table 3. CLTE values at different temperatures

Test temperature (ºC) /CLTE value (10^6 ºC $^{-1}$), sample compositions				
1	2	3	4	5
-40/46.3 -20/50.4 0/46.0 20/53.7 40/23.9 109/108.4	-30/35.4 -10/31.3 10/25.6 30/52.6 50/89.0 70/288.4 90/302.3	-50/20.5 -30/31.1 -10/32.0 10/47.7 80/68.9	-40/30.5 -20/42.9 0/49.9 20/52.5 80/111.0	-40/47.8 -20/40.4 0/15.4 20/26.2

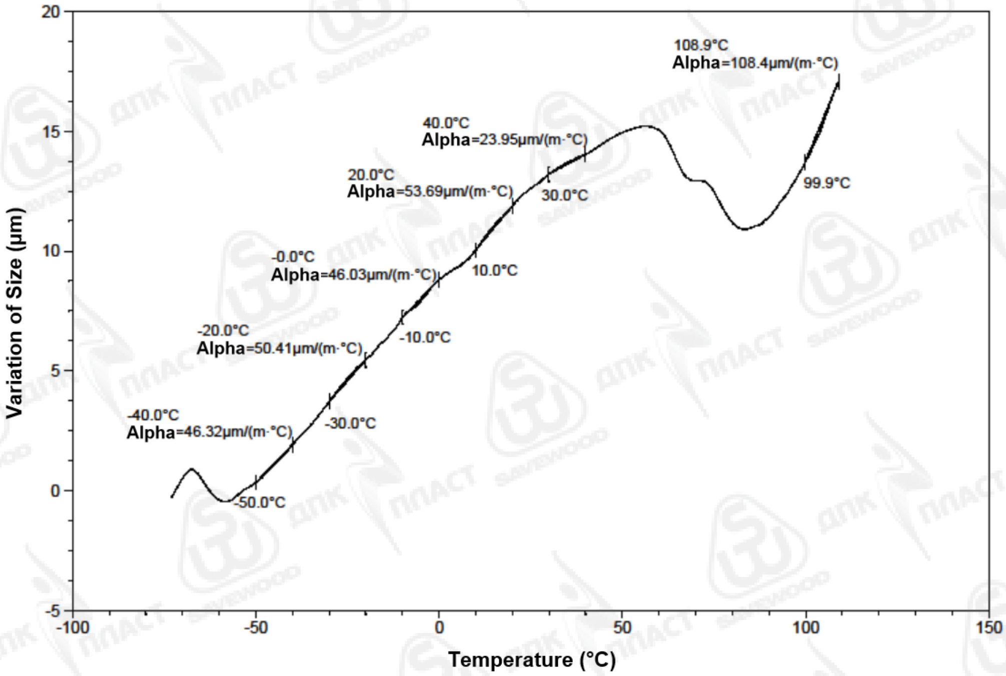

Fig. 2. Temperature dependence of the change in the size of sample 1 (3.4315×6.0000 mm)

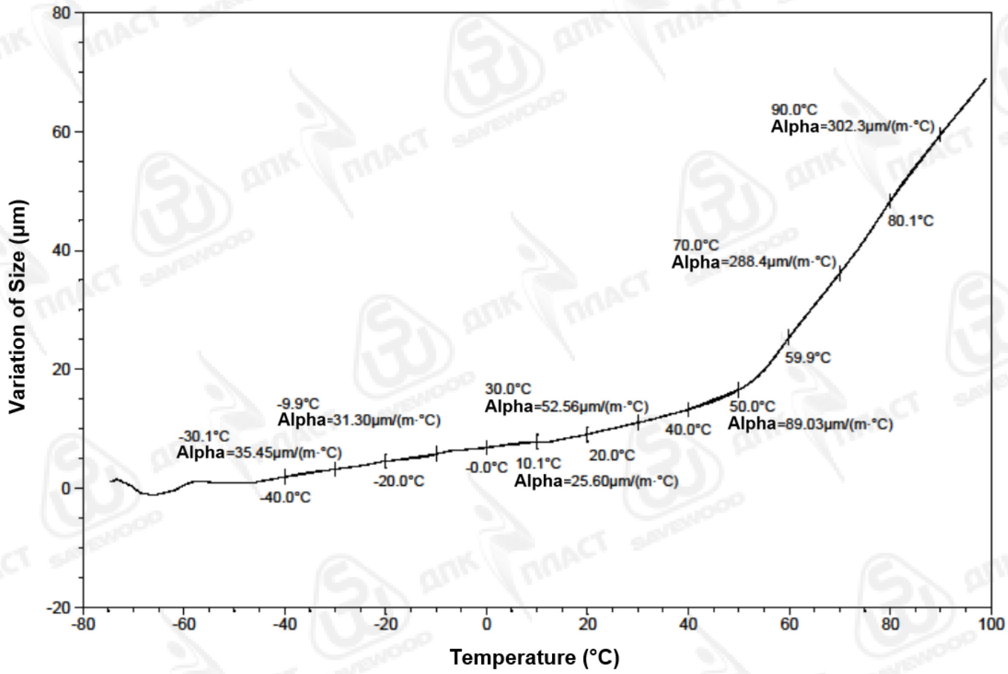

Fig. 3. Temperature dependence of the change in the size of sample 2 (3.7171×6.0000 mm)

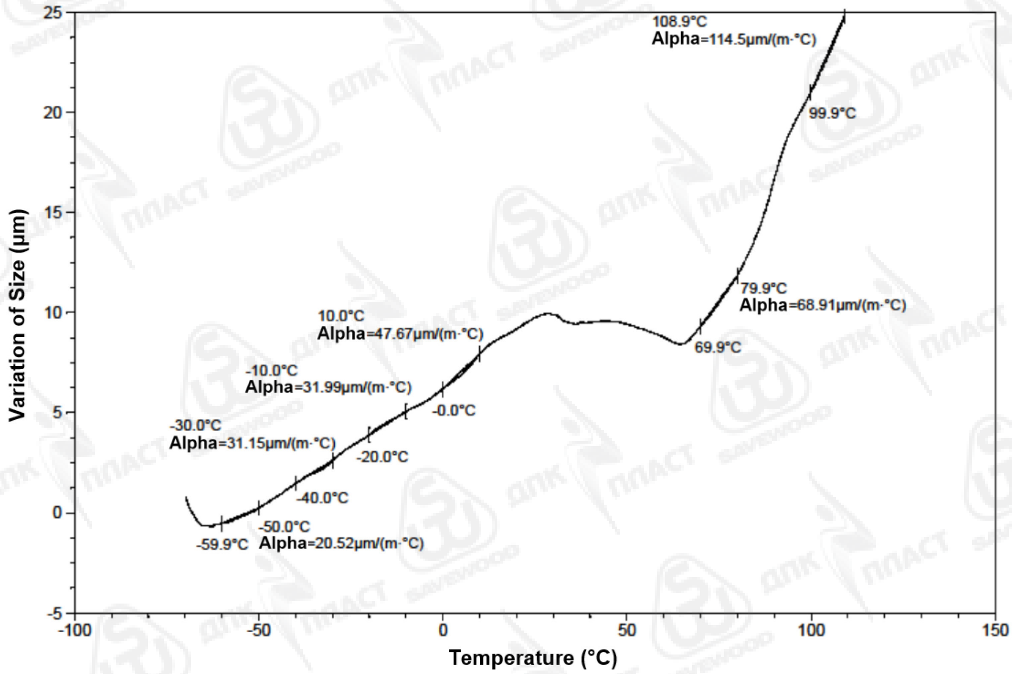

Fig. 4. Temperature dependence of the change in the size of sample 3 (3.6821×6.0000 mm)

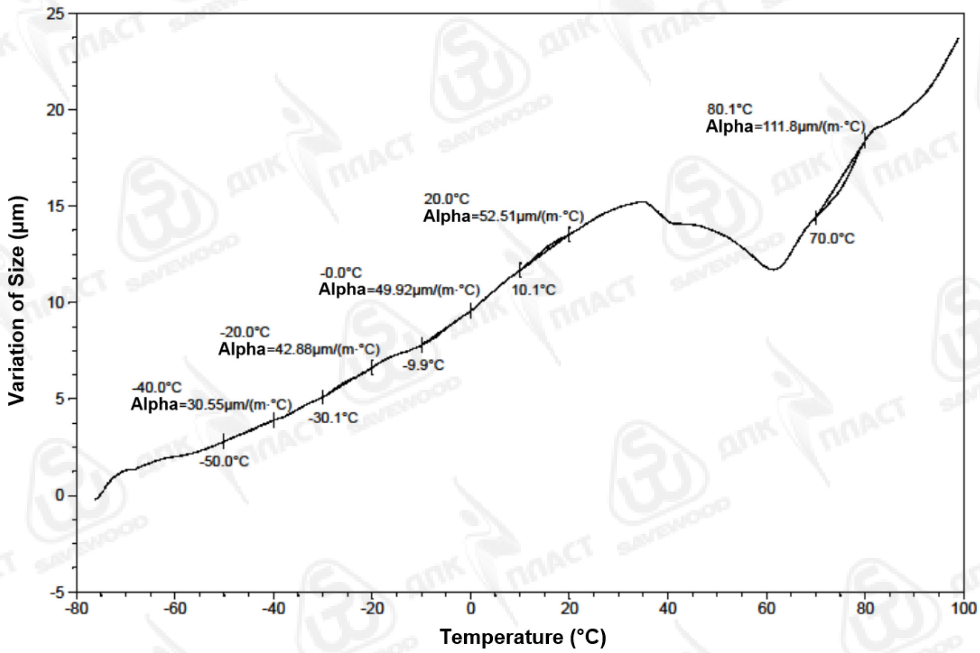

Fig. 5. Temperature dependence of the change in the size of sample 4 (3.5590×6.0000 mm)

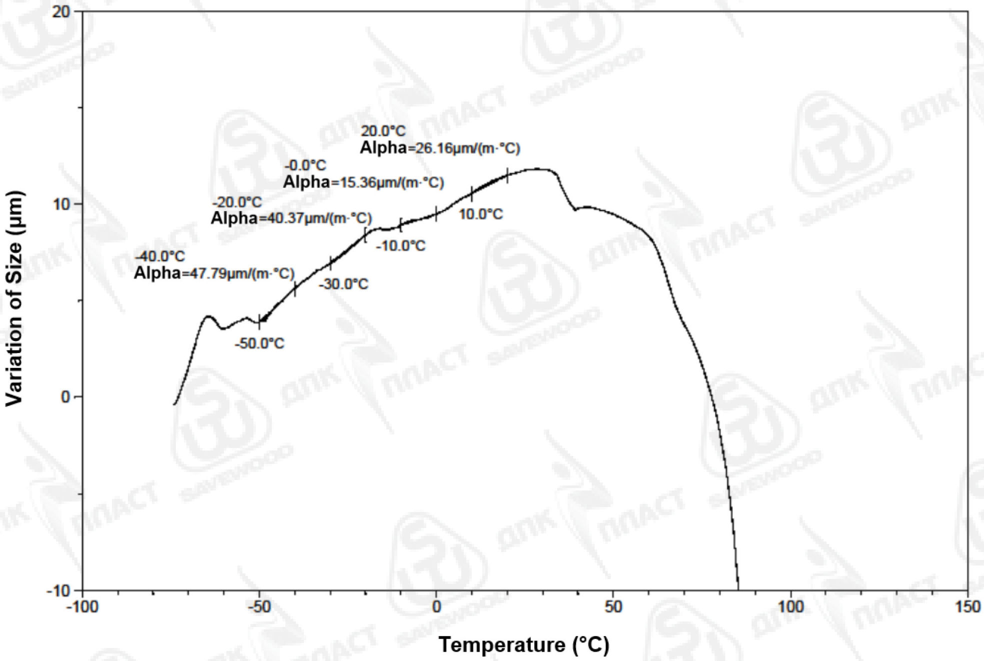

Fig. 6. Temperature dependence of the change in the size of sample 5 (3.6327×6.0000 mm)

As follows from Table 3, at temperatures from -30 to -50ºC, the highest value of CLTE is observed in composition 5 (α_5 = 47.8·10^{-6} ºC $^{-1}$), and the lowest – in composition 3 (α_3 = 20.5·10^{-6} ºC $^{-1}$), differing by 2.33 times. With an increase in temperature and its change in the range from -10 to -20^{0}C, there is a slight increase in the absolute value of CLTE with the highest value for composition 1 (α_1 = 50.4·10^{-6} ºC $^{-1}$) and the lowest for composition 3 (α_3 = 20.5·10^{-6} ºC $^{-1}$), while the difference in the values of CLTE for the studied compositions decreases and does not exceed 1.62 times. In the range of positive temperatures from 0 to +40ºC, CLTE values increase and are the highest for composition 1(α_1 = 53.7·10^{-6} ºC $^{-1}$), and the lowest for composition 5 (α_5=26.2·10^{-6} ºC^{-1}), differing by 2.05 times. In the area of high operating temperatures of the railway track exceeding +50ºC, CLTE value can reach 302.3·10^{-6} ºC $^{-1}$ (at a temperature of 90ºC, composition 2) with the lowest value of 68.9·10^{-6} ºC $^{-1}$ (at the temperature of 80ºC, composition 3).

As you can see, when the temperature changes, the value of CLTE can change significantly and, in addition, this indicator behaves unstable during the heating process. From the data presented in Figures 2-6 for samples 1, 2, 4 and 5, when the temperature increases from -70 to 40°C, the size of the samples increases due to their thermal expansion. Then, as the temperature increases, the size stabilizes or decreases. This indicates that there are internal stresses in the formed samples, which relax when heated. The relaxation rate increases with increasing temperature to 70-80ºC, which is the glass transition temperature of polyvinyl chloride. For sample 3, no negative size changes are observed, i.e., internal stresses are absent or insignificant. Thus, composition 3 shows, on the one hand, the lowest values of CLTE value, and, on the other, shows its stable change over a wide temperature range and, in this respect, such a composition is more preferable for the manufacture of plastic sleepers.

The temperature dependences of changes in the size of samples 1, 2, 3, 4 and 5 are shown in figures 2-6. For samples 1, 3, 4 and 5, when heated from -70 to 40°C, the sample sizes increase due to thermal expansion. Then, as the temperature increases, the size stabilizes or decreases. This indicates that there are internal stresses in the formed samples, which relax when heated. The relaxation rate increases with increasing temperature to 70-80ºC, which is the glass transition temperature of polyvinyl chloride. For sample 2, no negative size changes are observed, i.e., there are no internal stresses in it.

Conclusion

To produce the composite material of plastic sleepers, a composition consisting of a polymer binder in the form of polyvinyl chloride filled with a mixture of softwood flour with finely ground chalk is proposed. It is shown that, depending on the ratio of the composite components, its density can vary in the range from 1.370 to 1.627 g/cm^3, and the coefficient of linear thermal expansion depends on the temperature and relaxation of internal stresses in the samples. At the same time, among the conditions for ensuring the greatest safety of railway operation in the temperature range from -50 to +80ºC, according to the average density and the lowest value of the thermal expansion coefficient of the composite for the manufacture of plastic sleepers, composition 3 can be recommended, in which by weight 0.436 parts of calcium carbonate and 0.436 parts of wood flour account for 1 part of polyvinyl chloride.

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