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ACTIVATION OF FILLER PARTICLES IN HYBRID COMPOSITE POLYMER MATERIALS UNDER SOLAR CURING

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Abstract: This paper examines the chemical reaction occurring between a polymer matrix and a substrate under the combined action of solar energy and ambient room temperature. Industrial kaolin grades of varying grade and locally sourced mineral graphite were used as fillers, and their mechanical activation was studied in relation to interstructural plasticization and the resulting performance of hybrid composite polymer materials (HCPM). The optimal filler content was established on the basis of processed experimental data [1].

Keywords: solar energy, hybrid composite polymer materials (HCPM), heterocomposite, adhesion strength, microhardness, impact toughness, dispersed filler, kaolin, graphite

Methods: Local mineral graphite and several grades of industrial kaolin from the Angren district of Tashkent region were selected as fillers for the composite materials under study.

Results: The experiments demonstrate the considerable potential of the activation–solar processing method for producing multifunctional composite polymer materials and coatings, and show how mechanical activation of the fillers affects the resulting structure. It was found that as filler content increased to 60 parts by mass for cast materials, the density of the material rose, though at different rates depending on filler type.

Introduction. Renewable energy sources are among the most promising and environmentally clean options available, owing to solar radiation and the scale of resources involved. The principal climate-forming factor is the significant flux of solar radiation, which in summer reaches 800–1000 MJ/m² per month [2,3]. This creates favourable conditions for the development of solar energy in the Republic of Uzbekistan. Solar energy is transmitted mainly through visible light and, to a lesser extent, infrared radiation. When light interacts with matter, part of the incident radiation is absorbed and converts to heat. On heating, the degrees of freedom of the elements of the polymer macromolecule increase and the polymer passes into a highly elastic state, becoming tacky. Direct exposure to sunlight has also been shown to improve the physico-mechanical properties of HCPM [4]. This is explained by the fact that during direct solar processing of a polymer coating — that is, during the chemical cross-linking reaction — the polymer mass, the curing (hardening) agent, and the substrate are all heated together. A reduction in the viscosity of the composition increases the mobility of the polymer's macromolecular chains and improves the orientation of the functional groups of the interacting components [5-6].

Mechanical activation of filler particles has traditionally focused primarily on particle size reduction. However, given that simultaneous activation by two different, differently directed forces influences structure formation in hybrid composite materials and improves their physico-mechanical and operational properties, this study also took into account the type of bonds formed

by the particles after mechanical activation. Natural minerals consist mainly of ionically bonded oxides, and the forces and trajectories involved in the formation of positively and negatively charged particles during mechanical activation were modelled. In this process, the activation of the particle surface is of greater significance than the particles' geometric dimensions.

The breakdown of macromolecular chains, or the destruction of neighbouring substituent groups, is referred to as polymer degradation. Degradation processes fall into two broad classes — physical and chemical. Processes caused by heat, natural sunlight, high-energy radiation, and mechanical action are classified as physical degradation, and are further subdivided into thermal, photochemical, radiation-induced, and mechanochemical degradation. Processes occurring under the action of chemical agents (acids, alkalis, water, oxygen) are classified as chemical ageing. Under real operating conditions, polymer ageing is most often caused by the combined action of several factors, particularly heat and air exposure during processing and use, which makes suppressing thermal and thermo-oxidative degradation especially important [7]. At present it remains difficult to apply heterocomposite materials to the working surfaces of machines that already use established modification methods such as ultrasound, radiation, or electromagnetic treatment. This motivated the present study of heterocomposite materials and coatings based on locally available raw materials.

Industrial kaolin enriched at “Angren-Kaolin” LLC (Angren district, Tashkent region) — grades AKF-78, AKS-30 and AKT-10 — together with locally sourced mineral graphite (C) powder, are widely used across various branches of the economy of Uzbekistan. These four filler types were selected for the present study.

Materials and Methods. Local mineral graphite and industrial kaolin of the grades AKF-78, AKS-30 and AKT-10, produced by “Angren-Kaolin” LLC in the Angren district of Tashkent region, were used as fillers for the epoxy-based nanocomposite coatings [18]. Their designations and principal applications are summarised in Table 1.

AKF-78 (whiteness 78%) — used for the production of printing and writing paper from unbleached cellulose with a wood-pulp content. AKS-30 (Al_2O_3 content 30 ± 2%) — used in the production of ceramics, porcelain and earthenware. AKT-10 (Al_2O_3 content 10 ± 2%) — used as a filler for household chemical cleaning agents, resin-technical products, plastics and lacquer-paint products. AKO denotes off-grade waste kaolin from “Angren-Kaolin” LLC. Graphite (C) is a mineral consisting of carbon; it is a soft, oily, black-to-grey substance that leaves a visible mark on paper (hence its use in pencil manufacture), can be produced artificially by processing coke at very high temperature, and is highly heat-resistant.

At “Angren-Kaolin” LLC, 48% of the processed raw material output is converted into kaolin products: AKF-78 accounts for 25.7% of output and is intended for paper and lacquer-paint production; AKS-30 accounts for 42.9% and is used in the ceramics industry and for electrical-insulation materials; AKT-10 accounts for 31.4% and is used as raw material for glass production and other unfinished applications. AKS-30 is the company's principal kaolin brand.

Nanocomposite epoxy coatings were prepared with filler contents of 10, 20, 30, 40, 50 and 60 parts by mass, and their microhardness (H, MPa) was measured after a processing time of 30 hours for each of the five filler types [9-10].

Results and Discussion. The influence of filler type and content on the microhardness of the nanocomposite epoxy coatings is summarized in Table 2.

Table 1.

Effect of filler type and content (parts by mass) on the microhardness (H, MPa) of nanocomposite epoxy coatings (processing time 30 hours)

Filler type	10	20	30	40	50	60
AKF-78	161	161	143	132	112	–
AKS-30	172	162	152	138	125	–
AKT-10	164	172	178	175	161	144
AKO (waste)	148	158	161	154	139	138
Graphite (C)	150	159	174	177	140	145

As Table 2 shows, nanocomposite coatings filled with the AKT-10 grade exhibit the best overall performance characteristics, whereas coatings filled with AKF-78 show the weakest performance. Analysis of the results also shows that, although the fillers share broadly similar natural properties, their dispersity affects coating performance differently. It should be noted that at low filler content (10–20 parts by mass) coating performance is highest for the more finely dispersed (nano-scale) fillers such as AKF-78, whereas at higher, more economically favourable filler content (30–50 parts by mass) an increase in the proportion of nano-scale particles is instead accompanied by some deterioration of coating properties [11].

This can be explained in terms of processing behaviour: poorer wetting of the filler particles is observed with increasing nano-scale filler content, accompanied by a sharp rise in the viscosity of the composition. At a filler content of 60 parts by mass and above, coating quality deteriorates markedly. The results also show that, for cast materials, a filler content of 60 parts by mass is not yet the upper limit; as filler content increases further, the density of the material continues to rise, though at different rates depending on filler type and dispersity.

Direct exposure to natural sunlight is known to improve the properties of the composites studied. The improvement in physico-mechanical properties is explained by the heating of the polymer mass and the substrate, together with the curing agent, during direct solar processing of the coating — that is, during the chemical cross-linking reaction. A reduction in the viscosity of the composition increases the mobility of the polymer's macromolecular chains and improves the orientation of the functional groups of the interacting components. Under real service conditions, environmental factors such as temperature, humidity and solar radiation act together with mechanical wear to affect the technical condition of structural materials; in the case of HCPM, these factors promote physico-chemical processes within the material that alter its performance, in particular its strength characteristics [12].

Structural stabilisation and improved resistance to polymer degradation and ageing are achieved through a range of technological and operational measures. A relatively widespread approach to preventing degradation under light and radiation is the introduction of chemical agents

capable of absorbing ultraviolet and other radiation without themselves undergoing photolysis or self-alteration; such agents include fillers, stabilisers and related additives.

Conclusion. The lower the content of nano-scale filler particles (AKF-78, AKS-30, AKT-10, graphite (C)) in the composition, the less intensively the density of the material increases. This indicates the formation of micropores within the composite, resulting from poorer structure formation caused by the large specific surface area of the filler. Overall, the results confirm the considerable potential of the activation–solar processing method for producing multifunctional hybrid composite polymer materials and coatings from locally available mineral raw materials — industrial kaolin and mineral graphite from the Angren district of Tashkent region — and demonstrate how mechanical activation of the filler particles affects the resulting composite structure.

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