ANNOTATION

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Modified binders for composite materials

Relevance of the research topic. Epoxy binders and fibrous fillers form the basis of polymer composites. Their lightness and superior strength make them highly desirable in a wide range of industries. Epoxy resins can be easily modified, demonstrate minimal creep, and offer good processability.

Designing and producing polymeric binders, and then evaluating their properties, is a complex and interdependent undertaking. Success in this requires defining the target technological and operational characteristics of the new materials. The expanding raw material options have complicated the selection of initial components with optimal properties.

The abundance of components available on the market (hardeners, catalysts, diluents, modifiers, etc.) provides an almost infinite number of combinations for binder development. Therefore, when a binder is formulated, materials are selected based on the following parameters:

-Availability of components on the raw materials market, low cost, and reduced toxicity;

-Curing components should provide a low and easily controllable exothermicity of the curing process, optimal reactivity, and enhanced viability of the binders;

-The components used in the "resin part" (epoxy resins, diluents, modifiers, etc.) should contribute to creating a composition with an optimally low initial viscosity of the binder at the prepreg processing temperature, which will facilitate effective impregnation of the fibrous reinforcing filler;

-The selected components should enable the creation of a binder with the necessary technological characteristics that will support its processing using a low-cost, energy-efficient, autoclave-free technology;

-The applied components should ensure the possibility of obtaining an epoxy composition with enhanced thermomechanical properties.

Modification of epoxy binders used in polymer composite materials with ultra-low filler surface density (from 30 g/m^2), and the developed prepregs will enable the creation of lightweight composite materials for a wide range of products, not only for aviation and aerospace applications, but also for the production of elements for the sports industry (hockey sticks, fishing rods, golf clubs, etc.).

From the comparison of technical level indicators based on the main technological characteristic for ultrathin prepregs – "surface density from 30 g/m2" – it follows that the prepregs we are developing for carbon fiber reinforced plastics and hybrid materials with low filler density, according to their main technological characteristic, will meet world standards. Furthermore, the development of polymer composite materials based on them will allow for the improvement of the technical and operational characteristics of the composite products created, by reducing their weight and increasing their strength properties.

State of topic development

The invention relates to epoxy resin compositions for the production of hybrid reinforced structural polymeric composite materials with fibrous fillers and articles thereof, by prepreg technology. The invention has been patented (№ 2854311). The materials incorporated into the binder are non-toxic by virtue of the absence of halogen-containing species in the formulation. The impact of a range of modifiers has been examined. The binder is characterised by enhanced reactivity, enabling curing at a temperature of 130 °C. This results in epoxy specimens with a high degree of curing of the polymer matrix (α = 98.9–99.7 %), elevated thermal stability as reflected by a glass transition temperature Tg = 145–150 °C, superior strength properties (flexural strength of cured specimens $\sigma_и$ = 145–160 MPa), and improved fracture toughness (critical stress intensity factor K_{1c} = 1.910–2.100 $MPa{\cdot}m^{1/2}$).

The aim of this dissertation is to develop methods for synthesizing of a novel epoxy binder modified to provide enhanced processability, improved mechanical strength characteristics ($\sigma_и$ = 145–160 MPa), and superior fracture toughness (K_1c = 1.910–2.100 $MPa{\cdot}m^{1/2}$). The resulting binder is designed for the fabrication of prepregs for carbon-, glass-, organic-, and hybrid-fibre polymer composites, featuring an ultra-low areal density of the fibrous reinforcement (starting from 30 g/m^2).

The main objectives of the work are:

1. Modification of the epoxy resin using high-performance polysulfones and elastomers, followed by characterisation of the obtained properties.

2. Determination of the kinetic parameters of the curing process for modified binders.

3. Investigation of the influence of modifiers on the thermal stability of the modified binder.

4. Evaluating the impact of modifiers on the physico-mechanical performance of the modified binder.

5. Study the technology of fiber spreading.

6. Manufacturing of prepregs based on carbon, glass, and aramid fibres, with the application of fibre spreading technology.

7. Manufacturing of composite materials featuring a reinforcing filler areal weight of 30 g/m^2 and above, filled with carbon, glass, and aramid fibres.

Scientific Novelty

Polymer composite materials with enhanced strength and fracture toughness, based on the developed epoxy binder, exhibit good compatibility with glass, carbon, and aramid fibre surfaces.

Owing to the employed method of producing interlayer hybrid composites and the use of prepregs based on spread carbon fibre reinforcement, these materials show a low scatter in strength values. This results in a reduction of the coefficient of variation of physico-mechanical properties (specifically, the interlaminar shear strength of polymer composite specimens) by approximately 1.8 times compared to that of specimens based on conventional binders. The coefficient of variation for the hybrid composite based on a conventional binder was 14.1, whereas for the hybrid composite based on the developed binder it ranged from 7.1 to 7.9.

The proposed epoxy binder and the materials derived from it will contribute to reducing the environmental burden on the biosphere. They will enable the production of articles with enhanced thermomechanical and impact strength properties, as well as the fabrication of hybrid composite materials with low scatter in their strength characteristics. This will ensure safety, reduce the risk of catastrophic failure and in-service breakdown of composite structures, thereby improving their reliability and extending their service life.

Theoretical and Practical Significance

The practical significance of the results lies in the expansion of the assortment of epoxy binders, prepregs based on them, and hybrid composite products. The developed prepreg, which contains the novel epoxy binder and a fibrous filler, has the following formulation (in wt.%): epoxy binder – 30.0–50.0, fibrous filler – 50.0–70.0. The formulation of the novel epoxy binder is characterised by reduced toxicity and an optimum ratio of ingredients. These features enhance the curing reactivity and lower the forming temperature, leading to cured materials with superior fracture toughness, thermomechanical and strength performance. Moreover, the binder enables the production of hybrid composites by stacking the prepregs in layers, yielding polymer composite materials with a notably low scatter in their mechanical properties, as reflected by the reduced coefficient of variation.

The specific effects of different polysulfones on the structure, composition, and properties of the epoxy binder have been elucidated.

The theoretical and practical significance of the work is also determined by the production of new prepregs containing various fillers:

- contains flattened carbon fibre filler;
- contains glass fibre reinforcement;
- contains aramid fibre reinforcement;
- contains combinations of prepregs based on glass fibre and flattened carbon fibre
- contains combinations of prepregs based on aramid fibre and flattened carbon fibre

Methodology and experimental techniques. The experimental work involved the use of state-of-the-art instrumental methods for polymer material testing and analysis.

Main propositions advanced for defence

1. Rheokinetic patterns of the curing process of epoxy binders modified with polysulfones and core-shell rubber particles;

2. Study of the correlation between the concentration and types of modifiers and the mechanical and service properties;

3. Comparison of methods for studying the conversion and curing kinetics of modified binders;

4. Experimental test results for composite materials fabricated with the synthesised binder;

Reliability and validation The experimental methods used in this work are justified and reliable. The main results and conclusions of the dissertation have been presented at a number of international forums, including the 29th All-Russian Conference of Young Chemists (Moscow, 2026), the 33rd International Lomonosov Conference (Moscow, 2026), the 21st International Conference "New Polymer Composite Materials. Mikitaev Readings" (Nalchik, 2025), the International Congress of Young Scientists in Chemistry and Chemical Technology (MKHT-2025, Moscow, 2025), and the 9th All-Russian Conference "Polymer Composite Materials and Next-Generation Production Technologies" (Moscow, 2025).

Publications. The dissertation results have led to 2 publications in peer-reviewed journals covered by Web of Science and Scopus. The main outcomes were also reported at all-Russian and international scientific gatherings, as reflected in 5 conference and symposium proceedings. Additionally, 1 Russian patent has been awarded.

Volume and structure of the dissertation. The dissertation is structured as follows: Introduction; Literature Review; Materials and Methods; Results and Discussion; Conclusions; References. The total volume is 116 typewritten pages, including 44 figures, 48 tables, and a bibliography comprising 138 sources.

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