Chapter 1

Classical Thermoset Epoxy Composites for Structural Purposes: Designing, Preparation, Properties and Applications

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Abstract

Classical thermosetting epoxy composites for structural purpose, along with nanocomposites, are now widely used in various industries. An epoxy matrix is considered as a dominant polymer matrix in the design of such composites due to its study, high performance and wide commercial use. The optimization of processes and design and technological parameters of the equipment for their molding and processing of polymer composite materials (PCMs), as well as the creation of PCMs with a predetermined set of properties, remains an urgent task nowadays. An equally important problems are the production of defect-free and monolithic structures of such composites with increasing the productivity of their molding. Particular attention is paid to low-frequency ultrasonic as a basic method of physical modification of liquid epoxy media and intensification the processes of capillary impregnation and "wet" winding.

Keywords

Thermoset, Epoxy, Composite, Prepreg, Modeling, Design, Technology, Ultrasonic

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1. Introduction – Classical Thermosetting Composites of Structural Purpose on the Basis of Reinforced Fibers and Epoxy Matrix

Classical thermosetting composites of structural application on the basis of reinforced fibers and epoxy matrix are widely used in many spheres of modern industry. The latter include aviation, rocket and space industries, engineering, energy, communications, gas, chemical, shipbuilding, electrical engineering and a lot of other industries.

Such materials also find increasing application in the municipal economy, in particular, in technologies for connecting and repairing of polymeric pipelines. Today, there is a huge amount of polymer composite materials (PCM), which differ not only in compositions and properties, but also in production technology. However, the optimization of processes and design and technological parameters of the equipment for their molding and processing, as well as the creation of a PCM with a predetermined set of properties, remains an urgent task nowadays [1].

Manufacturing products from PCM is a relatively complex technological process, which is based on the use of certain physical and chemical patterns. Depending on the molding conditions of PCM, its physical and mechanical properties change. Therefore, the choice and justification of the regime parameters of molding, as well as the parameters of the forming equipment, are of fundamental importance.

Of particular importance is the development of the theoretical foundations of molding and processing of PCM in connection with the growth of PCM production – both thermoplastic and reactoplastic. This puts high demands on existing molding technologies and equipment that implements them [2].

We will understand the modification of PCM (both on the basis of thermoplastic and on the reactoplastic matrices), as it is customary for scientific and technical literature [1, 2], as directed regulation of their structure and properties. Such modification can be carried out by both chemical and physical (or physico-chemical) methods. In addition to purely chemical methods of modification (such as copolymerization, grafting, cross-linking, etc.), the polymer processing technology operates with physico-chemical methods.

Among the latter one can distinguish such methods as plasticization, filling, fusion of two or more polymers, treatment with high frequency currents, ultrasonic (US), laser and radiation [1, 2]. These methods can change the chemical structure of the polymer, its physical (supramolecular) structure, composition and phase structure of both the oligomer and the polymer binder (PB) on its basis. All this leads to a directed change in the properties of the final solidified polymer.

It should be noted that prediction and creation of a PCM with the necessary complex of properties is an extremely complex scientific and technical task for a number of reasons. First, there are still no enough clear theoretical concepts that allow to synthesize new PCM with specific properties, and also to predict the regime parameters of their formation. Especially it concerns modeling of technological processes of impregnation, "wet" winding, and also forecasting of constructive and technological parameters of forming equipment [3]. An effective direction of modeling and forecasting of parameters of the abovementioned objects is the use of adequate structural (structural-parametric) models of the media (objects) under consideration.

If we investigate the history of the creation of polymer systems, we can see that in most cases the theoretical ideas about the properties of polymers (in particular, their adhesion) appeared after the development of the corresponding (specific) materials [4]. These theories and concepts are certainly important, as they expand our understanding of the mechanism of emerging processes.

However, none of the existing theories is universal. Therefore, it seems advisable to talk only about the creation of a scientifically based system of representations, which covers a wide range of issues related to the physico-chemical modification in the molding of PCM [1 – 4].

Secondly, since the polymer forms the basis of the composition, the choice of a particular polymer is the first and decisive step in the development of efficient construction-oriented PCM. Third, PCM includes, in addition to polymer, fillers, including fiber fillers (FF), stabilizers, plasticizers, thickeners, thixotropic additives and other components. Each of these additives in the polymer system performs certain functions.

When creating a specific PCM, it is necessary to understand clearly how these components (that is, chemical modification) will affect the properties of the final PCM. Equally important is the use of various methods of physical modification. Such directions of physical modification include, for example, hardening using US, treatment with high-frequency currents, and others.

At the same time, the use of mechanical oscillations of the US range, or US vibrations (USV), is one of the most promising means of physical impact on liquid or solid components.

Such an effect is widely used in chemical technology to intensify a number of technological processes, in particular, the formation of reinforced plastics. For practical use, the inexpensive, high-strength, usually hard-cured epoxy polymers (EP) obtained on the basis of epoxy oligomers (EO) are of greatest interest as the reactoplastic polymer compositions.

They are widely used as epoxy binders (EB) for the manufacture, in particular, of fibrous PCM for structural purposes [5].

EP are characterized by a unique combination of a set of operational properties. Among the latter – high strength characteristics, good adhesion to various materials, high resistance to corrosive media etc.

Epoxy PCM far exceeds traditional compositions that contain mineral binders, as well as materials based on other synthetic resins (polyester, furan, carbamide, etc.). Thus, for example, the tensile strength of EP may reach 150 MPa, compression strength – 400 MPa, bending strength – 220 MPa, and the elasticity modulus – 5000 MPa [6]. Currently in the CIS countries more than 30 grades of injection molding and impregnating epoxy resins (ER) and epoxy binders (EB) are produced [7].

Epoxy-dian resins are the most widely used, and as a result their production in the total production volume is more than 90%. At the same time, more than one hundred grades of hardeners for ER have been developed. Also, there are developments in the field of creating new types of EP and their hardeners.

At the same time, it should be noted that the necessary condition for the optimal technological solutions being developed is to ensure high performance properties of molded PCM at the lowest energy costs of molding.

Thus, the aforementioned brief analysis of the different aspects of molding of classical thermoset PCM structural application on the basis of reinforcing fibers and an epoxy matrix brings out the actual directions of study. The following directions can be identified:

- analysis of aspects of physico-chemical modification of EP, including dispersed and continuous FF;

- substantiation of the effectiveness of physical modification in the form of US action for liquid epoxy matrices;
- investigation of the influence of US treatment regimes on the properties of EP;
- parametrization of devices and technologies for US treatment of liquid polymer systems;
- modeling of the structure of oriented and woven fibrous materials as the base stage of modeling the technology of capillary impregnation and "wet" winding;
- modeling of the technology of US production of PCM;
- analysis of the effective application of US in the production of thermoplastics and thermosets.

The above aspects are briefly studied in this chapter.

Conclusions

Despite the creation of new types of PCM (nanocomposites, intelligent PCM), classical thermoset composites of structural design based on reinforced fibers and epoxy matrix take an important place in the creation of a wide range of products and structures. The use of physical modification in the form of bulk US, along with chemical modification, opens up new possibilities for the directed regulation of the structure and properties of EC. This is due to a number of positive factors from effective US treatment.

In particular, the result of US treatment is an increase in the deformation-strength and adhesion characteristics of PCM. In addition, such an impact allows, to reduce the level of residual stresses, increase the durability, and also significantly reduce the total hardening time of PCM. The experimentally found optimal parameters for US modification of liquid EC (frequency, amplitude, intensity, temperature, static pressure) are used in determining the design and technological parameters of the corresponding shaping US equipment (such as volumetric sonification, impregnation, dosing and activation equipment based on US cavitation).

As for nanotechnology, the use of US is the most effective method, which facilitates the disaggregation (disintegration) of CNTs in organic solvents and liquid polymer media, and also improves the performance characteristics of NM PCM. Also, the use of US is effective in muff-adhesive and bandage technologies connecting PEPL during their repair. At the same time, an increase in the performance characteristics of repair connections is achieved by establishing an effective composition of EC and EAC, as well as optimizing the operating parameters of their US modification.

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