Chapter 25

ULTRASONIC TREATMENT IN THE PRODUCTION OF CLASSICAL COMPOSITES AND CARBON NANOCOMPOSITES

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Abstract

Low-frequency ultrasonic treatment in the production of classical composites and carbon nanocomposites is one of the dominant methods used in the preparation of such kinds of composites. For example, ultrasonic is a basic method of physical modification of liquid epoxy media, as well as to a method that intensifies the processes of sonification of liquid epoxy media, capillary impregnation, "wet" winding and dosed application. This method also promotes the production of defect-free and monolithic structures of such reinforced composites. The influence of ultrasonic treatment regimes on the technological and operational properties of epoxy polymers is investigated, as well as the strengthening of reinforced composites based on them. Technical means of ultrasonic cavitation treatment for classical epoxy binders and polymer composite materials based on them are investigated. Ultrasonic dispersing of nanoparticles in solutions and liquid polymeric media is studied. Aspects of preparation of nanosuspensions for the production of polymeric nanocomposites with ultrasonic treatment as also the production of nanomodified epoxy compositions and prepregs based on them are described. Ultrasonic treatment in the production of graphene and graphene aerogels is analyzed. Epoxy composites based on graphene aerogels with exceptional operational properties are studied.

Keywords: Thermoset, Epoxy, Composite, Classical, Nanomodified, Carbon, Graphene, Aerogel, Technology, Ultrasonic, Treatment

1. Introduction – Prerequisites for the Application of Ultrasonic Treatment in the Producing of Classical Composites and Carbon Nanocomposites

At present, in addition to the widespread use of classical polymer composite materials (PCMs) based on well-studied epoxy matrices [1], innovative world technologies for the creation of a new generation of PCMs are intensively developing. These studies reach the nanoscale molecular level of research into the components that make up PCMs [2]. In connection with this, one of the promising directions in modern science is the production of composites based on polymers filled with carbon nanomaterials, such as carbon nanotubes (CNTs), fibrils, graphene, graphene aerogels (GA), nanoplates, nanofibers, etc. [3].

It is therefore not surprising that many economically developed countries, as well as developing countries, in the next 20 years, associate the further economic growth of their countries with the orientation of industrial sectors to the production and use of precisely nano-structured materials and nanocomposites [4].

Recently, studies related to the use of nanosystems are developing quite actively. To date, three main branches have been outlined in this area of research: 1) from nano- to macrocomposites (obtaining binders, materials from melts, etc. by means of substance synthesis); 2) from macro- to nanosubstances (due to disintegration), and, 3) by using various nanomaterials (nanotubes, fullerenes, etc.) as microadditives for compositional binders [5].

For example, nanotechnology is increasingly used in various technological processes in the chemical and other industries, in particular, in chemical and oil and gas engineering. Nanocoatings have broad prospects for increasing the efficiency of the oil and gas complex. The latter is used for hydrophobizing surfaces of a wide range of structures and equipment. For example, these are antistatic coatings for fuel pipelines, as well as for various structural metal products. This operation is carried out in order to provide these structural elements with chemical resistance, water repelling and antifriction properties for a long time of operation.

Another area of application of nanotechnology in chemical engineering is the preparation of polymer compositions that strengthen stress concentration zones (in the form of holes, cutouts, fillets, thickness differences, etc.) in various power structures. No less effective is the use of such nanomodified polymer compositions for "healing" defects, microcracks and other damages that occur during the manufacture and operation of such structures, as well as to eliminate and seal gaps in the holes and joints of bolted and riveted joints.

In addition to the manufacture of multifunctional nano-structured coatings and compositions, nanotechnologies have the prospect of using in improving the manufacturing technology of various high-strength and corrosion-resistant body and structural elements based on reinforced thermoplastic PCMs, in particular, carbon plastics [6]. Moreover, an increasing number of researchers come to the conclusion that the most promising method for improving the properties of reactoplastic PCMs is their modification by carbon nanostructured components, including CNTs. The latter possesses a number of unique properties that allow solving the problems arising in the production of nanomodified (NM) reactoplastic PCMs, that is, NM PCMs.

Therefore, in contrast to classical PCMs, the physico-chemical properties and technological aspects of the preparation of which have been studied comparatively comprehensively, NM PCMs are increasingly being considered as their real alternative. This is mainly due to the increased rigidity and strength, as well as the electrical conductivity of NM PCMs with a small bulk content of NM fillers. Fullerenes, CNTs, diamond-like and fullerene-like structures have unique and substantially different physico-chemical properties. This allows them to be used as modifiers of polymer binders and to obtain on their basis NM PCMs with wide ranges of performance values [7].

Another trend of modern development and application of nanomaterials and derivatives based on them is the use of aerogels. The view of the huge variety of aerogels, the most interesting for further study are aerogels based on carbon nanomaterials. The latter is a class of ultralight substances in which the liquid phase (at the lattice sites) is completely replaced by a gaseous phase. That is why GA was named modern ultra-light material. He thus outstripped the air-graphite record, which for a long time retained the “palm tree” in this category.

Aerogels are characterized by a whole complex of unique properties. First of all, it is low density, high specific surface area, and high hydrophobicity index. No less important indicators of aerogels are low thermal conductivity, high elasticity (the ability to restore the shape after multiple compression and stretching), as well as the ability to sorb organic liquids. Moreover, depending on the purposes of the application, aerogels based on carbon nanomaterials can exhibit magnetic and electrically conductive properties, while retaining the flexibility of their 3D-structure.

Therefore, it is not surprising that the impressive properties of new aerogels based on graphene are of great interest to scientists around the world. At the same time, it is urgent to find the most effective application of GA in various fields. Among the latter – environmental protection, medicine, electronics, military, biology, chemistry and many others. For example, the ability of GA to sorb organic liquids can be used to eliminate oil spills in aqueous media.

When obtaining NM PCMs, one of the main problems is to ensure high-quality wetting and uniform distribution of the nanofiller in the liquid polymer matrix. On the one hand, nanosuspension is incorporated into the composition of the polymer binder of CNTs for the subsequent fabrication of a nanocomposite on its basis, which substantially increases the strength properties of the finished (polymerized) products. Moreover, the optimal concentration and uniform distribution of CNTs in the binder play a decisive role in the final strengthening of NM PCMs.

On the other hand, due to the peculiarities of the nanoparticles used (their propensity to mutual attraction and agglomeration), problematic situations in the production of NM PCMs are de-agglomeration and further dispersion of the used nanoparticles in liquid polymer media. It is obvious that the incorporation of CNTs into the structure of the polymer composite affects not only the structure and properties of the liquid polymer binder but also the NM PCM as a whole.

For example, the dimensions of the agglomerate in nanofluids can significantly affect the thermal conductivity and viscosity of nanofluids and lead to different heat transfer characteristics. Analysis of the literature data on the elastic, strength, rheological, electrical properties of composites filled with CNTs shows that neglecting the quality of dispersion generates, in the end, a large dispersion of the service (operational) properties of nanomodified PCMs [8]. However, we have to state that at the moment there are no unambiguously and clearly formulated industrial-technological principles concerning the incorporation, distribution, and stabilization of CNTs dispersions in NM PCMs.

It is known that low-frequency ultrasonic (US) is one of the most common methods of decomposition of CNTs agglomerates [9]. In addition, its use facilitates the dispersion of nanoparticles in base liquids in the preparation of nano-based liquids, both on the basis of organic solutions and on the basis of liquid polymers. It is also known that the synthesis of aerogels based on graphene is promising the formation of a three-dimensional structure under the influence of low-frequency US. Numerous studies have found that the use of US contributes to the intensification of the basic operations of the technological process of producing classical PCMs [10].

This, in turn, leads to an improvement in the operational characteristics of the sonicated classical PCMs and NM PCMs.

Among them – sonication (sounding) of the polymeric binders (PBs), impregnation, winding, dosed application in the preparation of fibrous prepregs. Also, positive results of using the optimal modes of US treatment are: reduction of the time of hardening of composites and obtaining of defect-free PCM structures.

The above confirms once again that the study of effective methods and the determination of the degree of their influence on the qualitative parameters of the final polymer product, as well as the development of hardware-technological schemes for obtaining classical PCMs and NM PCMs is an urgent and priority area of modern research. In turn, the new technological methods developed as a result of the research will undoubtedly find wide application in the production of structural and functional both classical PCMs and NM PCMs. For such materials, reducing the mass of the product, due to the improvement of their physico-mechanical and operational characteristics, is an urgent task for resource and energy saving on an industrial scale [11].

Thus, the aforementioned brief analysis of the different aspects of molding of US treatment in the production of classical PCMs and NM PCMs brings out the actual directions of investigations. The following directions can be identified:

- technical means of US cavitation treatment for classical epoxy oligomers (EOs), epoxy compositions (ECs), epoxy binders (EBs) and PCMs based on them;

- US dispersing of nanoparticles in solutions and liquid polymeric media;
- preparation of nanosuspensions for the production of polymeric nanocomposites with US treatment;
- US treatment in the production of graphene and graphene oxide (GO);
- epoxy composites based on GA with exceptional operational properties;
- production of NM polymer compositions and prepregs based on them.

The above aspects are shortly described in this chapter.

Conclusions

The survey material in the present chapter confirms that US technology in the production of classical PCMs and carbon NM PCMs is one of the dominant methods for synthesizing new and physical modifications of existing polymer composites to improve their operational (functional) properties. And the main physical phenomenon associated with US, which has to do with the synthesis of new materials, is low-frequency acoustic cavitation. It manifests itself in the formation, growth and implosive collapse of bubbles in the liquid. This phenomenon creates extreme conditions inside the collapsing bubble and serves as the source of most sonochemical phenomena in liquids or in liquid solutions with fillers.

The main problematic situations in the production of NM PCMs is the need for dispersing (deagglomerating) nanofillers in a liquid matrix. In many cases, US is practically a non-alternative method for solving the above-mentioned problem situations. Besides, use of intense US allows for the tailoring of unique materials from sol-gel processes. This makes high-power US a powerful tool for chemistry and materials' research and development.

At the present stage, CNTs, graphene, GO and GAs are the most important carbon nanofillers for constructing functional NM PCMs. At the same time, the use of each of the above-mentioned nano-fillers in the polymer composite has its own characteristics. For example, it was found that the addition of graphene to epoxy composites leads to an increase in the rigidity and strength of the material compared to composites containing only CNTs. Graphene is better combined with an epoxy polymer, more effectively penetrating (incorporating) in the structure of the composite. Therefore, according to its unique structure and properties, graphene became a universal nano-dimensional building block material for the self-assembly of new materials with new properties and functions.

It is noted that the method of freeze-drying is more promising and quite versatile so that it can be used for the dispersion of graphene in a wide range of other composite precursors. Another promising type of nanofillers for polymer composites, namely GAs, not only maintain the unique structural advantages of graphene sheets, but also explore outstanding properties, including lower density, excellent electrical conductivity and mechanical strength, and unusual adsorption properties.

Especially it is necessary to note the most perspective directions of application of carbon nanocomposites as functional materials. Namely – as substrates for catalysts, artificial muscles, electrodes for supercapacitors, light conductors and insulating materials, sensor batteries, sorbents (environmental protection) and gas sensors, materials for bulletproof vests, medicine and others. Also, graphene-based nanocomposites can be used in the manufacture of aircraft components, which must remain light and resistant to physical impact.

Finally, for the sake of fairness, it should nevertheless be noted that in spite of the successes achieved in the synthesis and modification of both existing classical and new NM PCMs, the basic successes in this direction so far fall to the stage of laboratory research. So when going to the industrial scale of production of such materials, among other things, it will also be necessary to take into account the so-called scale effect. That is, when the automatic transfer of the results of laboratory research to the production level, there will certainly be obstacles and "undercurrents" that can not be simulated in "ideal" laboratory conditions. Obviously, given the pace of development of modern science and technology, this is a matter of the near future.

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