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Redogic Studies of Bio-Nanocomposites

Biyo-Nanokompozitlerin Redogik Çalışmaları

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ABSTRACT

The rheological studies of nanocomposites obtained from biopolymers, addressed herein, have been explained with the support of various studies. Various colloids, carbon nanotubes, multi-walled nanotubes, micellar solutions, and granular flows obtained from bio nanocomposite materials are explained in the literature in this chapter. It has been reported that colloids shift towards mixed proportional regimes and volumetric interactions are more effective. Organic elephants have an independent angular velocity and their complex state behaved like a solid. Epoxy forms of carbon nanotubes are emphasized. When trisodium phosphate, titanium dioxide, and nanoparticles are combined with organic fillers, a structure that gives more hardness is formed. In the characterizations made on multi-walled carbon nanotubes, the structure of these materials was examined and the rhedogical behavior was tried to be expanded. In the structure of granular flows, some images were weak in resonance images, while different results were obtained in others. In the future, the expansion of these studies will further illuminate the academic studies of the rheology of nanomaterials.

Keywords: Rhedogical studies, nanocomposites, bio-nanocomposites

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Özet

Burada ele alınan biyopolimerlerden elde edilen nanokompozitlerin reolojik çalışmaları çeşitli çalışmalarla desteklenerek açıklanmıştır. Bu bölümde literatürde biyo nanokompozit malzemelerden elde edilen çeşitli kolloidler, karbon nanotüpler, çok duvarlı nanotüpler, misel çözeltileri ve granüler akışlar açıklanmıştır. Kolloidlerin karışık oransal rejimlere doğru kaydığı ve hacimsel etkileşimlerin daha etkili olduğu bildirilmiştir. Organik filler bağımsız açısal hıza sahiptir ve kompleks halleri katı gibi davranmıştır. Karbon nanotüplerin epoksi formları vurgulanmıştır. Trisodyum fosfat, titanyum dioksit ve nanopartiküller organik dolgularla birleştirildiğinde daha fazla sertlik veren bir yapı oluşmaktadır. Çok duvarlı karbon nanotüpler üzerinde yapılan karakterizasyonlarda bu malzemelerin yapısı incelenmiş ve redogik davranış genişletilmeye çalışılmıştır. Granüler akışların yapısında rezonans görüntülerinde bazı görüntüler zayıf iken bazılarında farklı sonuçlar elde edilmiştir. Gelecekte, bu çalışmaların genişletilmesi nanomalzemelerin reolojisinin akademik çalışmalarını daha da aydınlatacaktır.

Anahtar kelimeler: Redogik çalışmalar, nanokompozitler, biyo-nanokompozitler

1. INTRODUCTION

Nanoscale materials (nanocomposite materials) are reinforced to increase the allergens, usage areas, efficiency, and properties of films formed by biopolymer materials and to make them more advantageous. When nanocomposite materials are reinforced to the films of biopolymers, bio-nano composites are obtained (1-3). Gelatin films obtained from gelatin biopolymer by thermal methods play an important role in food packaging in the industry. At the same time, gelatin films play an important role in the transport and transmission of oxygen, carbon dioxide, and various functional groups. Gelatin films also play an important role in the transport of agents such as antioxidants, antimicrobials, and antifungals (1,4). In other words, bio-nano composites or nanocomposites are reinforced while producing biopolymer films to improve their properties (5-7). It is supported by fillings in biopolymer materials with bio-nano composite materials or only nanocomposite materials. These supported bio-nanocomposite or nanocomposite materials act as a bridge between biopolymer materials and nanoparticles. In other words, they strengthen physical properties such as mechanical and thermal properties with this bridge function (5,8,9). The reason why gelatin films are popular in the food packaging and industry in the world can create a 3-dimensional network with intermolecular crystals in the gelatin zone belts. It provides a network configuration that enables the transition from a disorderly state to an orderly state (5,10). The thermal properties of bio-nano composite materials are difficult to maintain at high temperatures and pressure to preserve their rheological properties (11,12). In desorption, due to dehydration or hydrophilic groups in supplements, maintaining rhedogical properties can be some troubles (13,14). Rhedological properties, wettability change can be improved for smart liquids and rhedogical studies of bio-nanocomposites are important for material science (13). Carbon nanotubes have high thermal stability of rhedogical properties at about 2800 ^{0}C. This situation is about twice as much electrical and thermal conductivity compared to diamond (15-18). In this chapter, the rehdogical properties of bio-based nanocomposite materials are explained in detail.

1.1. Nanocomposite Materials

A composite material is a combination of two phases or multi-phase materials. The reason why these composite materials are made composite in phases is to optimize their physical properties. As can be seen here, at least two phases are required to form nanocomposite materials. However, when one of these phases is nanoscale, these materials are nanocomposite materials. 1 nm equals 10^{-9} meters. The term nanocomposite was first used in 1986. In addition, in 1986, 2 papers on google scholar nanocomposites were reported. In 2004, 1690 papers were reported on nanocomposites. Ceramics, metals, plastics, biomaterials, electronic materials, etc., nanocomposites are in almost every field. As can be seen here, at least two phases are required to form nanocomposite materials. However, when one of these phases is nanoscale, these materials are nanocomposite materials. 1 nm equals 10-9 meters. The term nanocomposite was first used in 1986. In addition, in 1986, 2 papers on google scholar nanocomposites were reported. In 2004, 1690 papers were reported on nanocomposites. Ceramics, metals, plastics, biomaterials, electronic materials, etc., nanocomposites are in almost every field. Home and office paints are in a lethal structure in terms of content and have nanocomposite materials (19). Numerous academic studies conducted by *Sen Research Group* and team with nanocomposites have been reported in the literature (20-22).

1.2. Bio-nanocomposite materials

Nanocomposite materials (bio-nano composite materials) obtained from natural origin polymers have gained importance to reduce the damage to the environment, and foods(19, 23). Examples of bio-nanocomposite materials are cellulose, chitin, chitin derivative chitosan, alginate, polycaprolactone (PCL), polylactic acid (PLA), polyhydroxyalkanoates, etc (24). Bio-nano composite materials obtained from these sources are biodegradable, edible, and biocompatible. Thus, it plays an effective role in reducing the emission of gases that harm the environment. It is also an important resource to minimize the damage of fossil fuels (25). Particles and ashes that are inorganic, such as metals, metal oxides, salts, etc. tend to be modified to natural polymers. These steps can be done by processes such as the sol-gel method, layer-by-layer (19,26). The most important feature of bio-nano composite materials is that they are materials consisting of low, or almost zero toxic and harmful effects. Bio-nano composite materials adapt easily, do not damage the system, and are environmentally friendly materials by recycling elements such as carbon, nitrogen and sulfur to the environment. Because of these properties, bio-nano composite materials are materials used in food, and environment, sensor applications, cosmetics, and medical fields (19,27). Gelatin is obtained by denaturation of collagen in bio-nanocomposite sources. This, like other bio-nanocomposite materials, has properties such as biocompatibility, non-oxic and degradability. Gelatin can also be supplemented with various inorganic materials (19,29,30). Bio-nano composite materials are prepared with the modification of natural or synthetic minerals or by supporting them with filling materials without modification (19,30).

1.2.1 Cellulose-based bio-nano composite materials

Cellulose, which is a natural resource used in the production of the most abundant bionanocomposites in the world, is linked to each other with 1,4-β-D glucosidic bonds. It has a biodegradable, compatible and environmentally friendly structure. It has a high molecular weight. Because the cellulose structure contains quite a lot of crystalline at high temperatures. Cellulose has an insoluble structure. For this reason, its processability in industry and trade has turned into a great advantage. Cellulose is referred to as "MC" in most sources. Cellulose has various derivatives because it can be processed. These derivatives are branched into ethers of cellulose and esters of cellulose. Carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC), hydroxypropyl methylcellulose (HPMC), etc are ether derivatives of cellulose. cellulose acetate (CA), cellulose acetate propionate (CAP), cellulose acetate butyrate (CAB), etc are ester derivatives of cellulose. Nanofibers and bristle crystals are produced from cellulose. Nanofibers are also called microfibrils. Nanofibers are nanomaterials between 2 nm - 20 nm in size (31). Amorphous regions of cellulose are sensitive to acids due to the morphological structure of cellulose. It has been reported in the literature that bristles crystals produced from cellulose can be used as additives and fillers to develop some proteins in their mechanical structure (26,32).

1.2.2. Starch based bio-nano composite materials

Starch is one of the sources of bio-nano composite materials and is common in nature. Bionanocomposite materials sourced from starch are very useful in the industry in order to eliminate the damage caused by plastic materials that are not shredded. Starch-based biopolymers are degradable, edible, and are in an important position because they are economical. Pure starch is considered to have thermoplastic properties, since it is not thermoplastic, but acts like thermoplastics. Starch is a very durable source. It is water-resistant, not dissolved in water. Its physical properties are weak. Its use as a filler without touching its biodegradability properties has been considered by the researchers (26,33).

1.2.3. Chitin and chitosan based bio-nano composite materials

Chitosan is the most abundant polymer in the world after cellulose. Chitosan is obtained from chitin (26). Chitin is a polymer found in the shell of crustaceans such as insects, shrimps, crabs, etc. There are 70% and 80% deacetylated forms in nature. Chitosan has glucosamine and 1,4 glucosidic bonds as morphological structures and consists of linked N-acetylglucosamine (33-35). It is insoluble in water and therefore has hydrophilic properties. but it can be dissolved at high temperatures. According to the reports in the literature, a certain ratio of chitosan has been reported to have antibacterial and antifungal effects and this study has been reported in activities against *Escherichia coli, Fusarium, Alternaria, and Helminthosporium* microorganisms (26,36).

1.2.4. Protein-based bionanocomposite materials

Interesting films are the most important part of the protein-based bio-nano composite materials. Edible films made of proteins are the most interesting ones. Because the inspirational values of foods increase through proteins and they form a protective barrier. For this reason, protein-based bio-nano composites are of great interest. Since soy protein has a low density to other polymers such as starch, cellulose, pectin, etc, its functional and mechanical properties are superior and effective compared to these sources. Proteins such as casein, milk proteins, and corn germ also possess these advantageous properties (36,37).

1.3. Rhedogical Studies

This title is explained concerning the investigation of rhedogical properties of bio-nano composite materials in the literature. When the rhedogical properties of different epoxy bio-nano composite materials were examined, it was observed that polymer-solvents showed the same properties at a certain temperature as a result of their dissolution in chloroform. As the temperatures increased, the viscosity of the epoxies also increased (38).

The properties of organic fillers: According to another study in the literature, when the DGEBA polymer is supported with filling materials (hexaglycidyl cyclotrifosfazene) and the hardener is added (methylene diianiline and its derivatives), the product is reformulated. Mixtures behaved independent of angular velocity and behaved like a solid (33,39).

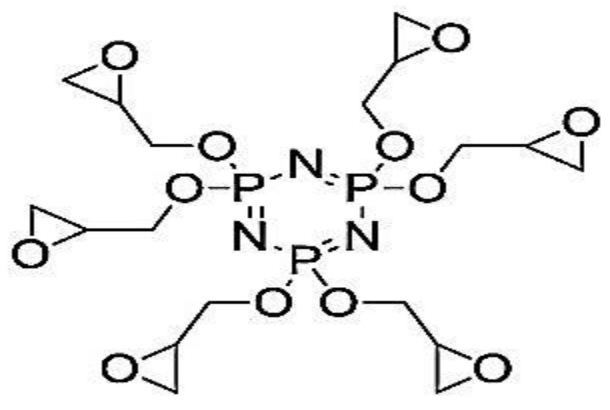

Figure 1. The structure of hexaglycidyl cyclotrifosfazene (38).

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The rhedogical properties of carbon nanotubes: According to the academic studies reported in the literature, rhedogical studies of carbon nanotubes in functionalized epoxy DGEBA were carried out (33,40-42). In these studies, relations of global structures arising from carbon nanotubes are reported. Hydrated nanoscale composite materials increased proportionally as the percentage of the load used. Rhedogical studies of carbon nanotubes have become a separate focus of researchers (33,43).

The rhedogical properties of trisodium phosphate, titanium dioxide, and nanoparticles: Angular rhedogical studies of two nanocomposites based on triglycidyl ether trimercapto ethanol phosphorus and decaglycidyl pentamethylene dianiline have been reported in the literature (figures 2 and 3). Matrix morphology of nanocomposites with triglycidyl ether trimercapto ethanol phosphorus was investigated. To these matrixes, 4,4-diaminodiphenyl benzene was added as a hardener and was observed after the addition of hardener. Then trisodium phosphate and titanium dioxide were combined with support fillers. Inorganic loads were observed to increase in the results (33).

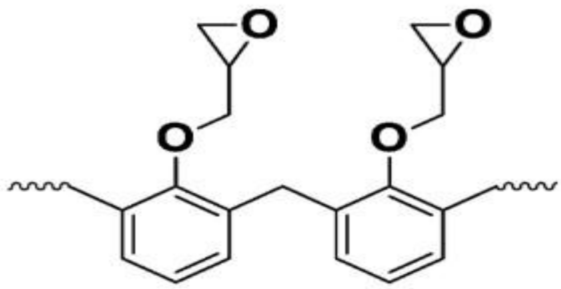

Figure 2. The structure of NEP (38).

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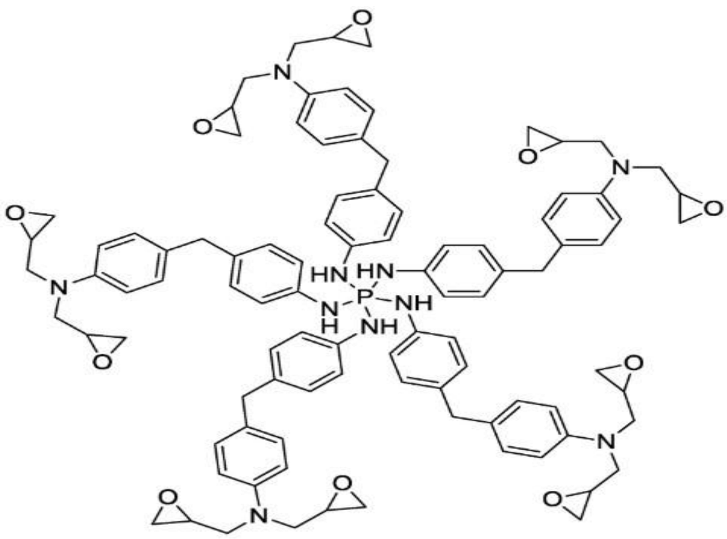

Figure 3. The structure of decaglycidyl pentamethylene dianiline of phosphorus (38).

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The rhedogical properties of multi-walled nanotubes: In high amplitude oscillator shift studies, the non-proportional responses of gold nanocomposite materials have been investigated by academic studies. Under COGA, poly nanoscale composite materials have been studied with different applications. The factors that do not increase proportionally in FTIR characterization techniques were examined in the literatüre (33,44).

The rhedogical properties of micellar solutions: Rhedogical studies of the linear and nonlinear forms of cetyl trimethyl ammonium bromide salt ide cationic surfactant and 3-hydroxy naphthalene-2-carboxylate (HNC) and cetyl trimethyl ammonium bromide cationic surfactant and 3-hydroxy naphthalene-2-carboxylate (HNC) salts have been reported in the literatüre (33,45). The high hydrophobicity of carbon nanotubes has been proven to be largely caused by cetyl trimethyl ammonium bromide (33,46). There are also studies composed of sodium salicylate and cetylpyridinium chloride rhedogical in micellar solutions (33,47)

The rhedogical properties of colloids: Semi-dilute and dilute colloid materials have been reported in the literatüre (33). The rhedogical properties of flexible polymer bio-nano composite materials are one of the academic subjects studied (33). Linear viscoelastic studies shift to complex proportional regimes. It has been observed that the volumetric interactions are more efficient. In colloids, complex viscosities of slow-release materials have been investigated (33,50).

The rhedogical properties of granular flows: Resonance images of magnetic granules have been examined in the literatüre (33). It has been observed that the strength of dry granular systems is weak (33, 50). In another source, high cutting speeds supported rheogical features (33,52). In another academic study, the soft vitreous rheology model of the shear rhedogical properties of complex fluids was defined (33)

2. CONCLUSION

Because composite materials produced from conventional plastics and synthetic chemicals are non-biodegradable, environmentally harmful, and costly, there is an increasing interest in bio-nanocomposite materials, which offer sustainable, eco-friendly, cost-effective, biocompatible, and biodegradable alternatives. These materials are derived from natural biopolymers and incorporate nano-scale components, making them highly promising for various industrial and biomedical applications.

Bio-nanocomposite materials are fabricated using polymers sourced from renewable biological resources. Examples include chitin and chitosan, cellulose and its derivatives, starch, pectin, and natural proteins such as casein, zein, and soy protein. Chitin, primarily extracted from the exoskeletons of crustaceans such as crabs, lobsters, and insects, is a polysaccharide with notable film-forming and antimicrobial properties. Through partial deacetylation, chitin is converted into chitosan, which is available in various degrees of deacetylation (e.g., 70%, 80%, etc.) and is the second most abundant natural polymer after cellulose.

Cellulose, the most abundant biopolymer on Earth, exists in several functional derivative forms such as carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC), hydroxypropyl methylcellulose (HPMC), cellulose acetate (CA), and its modified versions like CAP and CAB. Similarly, starch, another plant-based polysaccharide, is widely studied despite its relatively hydrophobic character and weak mechanical strength. Proteins from renewable sources, including milk proteins (casein, zein) and plant-based proteins (soy), offer further versatility in composite formulations due to their functional groups and biodegradability.

Composite materials are defined by the integration of two or more distinct phases, typically consisting of a matrix (organic or inorganic) and filler components. When at least one of these phases is in the nanometer range (1 nm = 10^{-9} m), the material is referred to as a nanocomposite. When both the matrix and filler are sourced from natural origins and the structure contains nanoscale components, the resulting system is termed a bio-nanocomposite.

In this chapter, the rheological properties of bio-nanocomposite materials are analyzed in detail, with reference to recent scientific studies. The rheological behavior of systems containing organic fillers, carbon nanotubes (CNTs), multi-walled carbon nanotubes (MWCNTs), micellar solutions, colloids, and granular materials is discussed.

Rheological analyses reveal a broad range of behaviors among these materials. Some bio-nanocomposites exhibit weak shear-thinning or viscoelastic patterns, while others demonstrate unique angular velocity responses or non-Newtonian flow characteristics. For instance, colloidal systems tend to shift toward mixed regime behaviors, where volumetric interactions dominate the flow dynamics. Interestingly, some organic filler systems exhibit independent angular velocities and solid-like complex moduli, indicating strong internal network structures.

The incorporation of epoxy-functionalized CNTs has been shown to significantly enhance the rigidity and mechanical strength of nanocomposites. Moreover, combining trisodium phosphate, titanium dioxide, and other nanoparticles with bio-based polymers results in a stiffer and more robust matrix. Rheological characterization of MWCNTs suggests that these structures contribute to improved energy dissipation, mechanical stability, and thermal resistance in composite systems.

In granular flows, resonance imaging techniques revealed variability in the structural integrity of different samples. Some exhibited weak resonance profiles, while others displayed distinctive flow and deformation behaviors.

Through such rheological evaluations, the structure–property relationships of bio-nanocomposites are better understood, providing insights for optimizing formulations for biomedical, packaging, drug delivery, and environmental applications. These findings underscore the potential of bio-nanocomposite materials as next-generation sustainable solutions in the field of material science.

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