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Application of Smart Polymer Materialsarts

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Abstract:

With the wide application of polymer materials, the performance of ordinary polymer materials gradually cannot meet the shortcomings of use in special environments, such as limited strength, insufficient wear resistance, poor stability and so on. And can not adjust and repair according to changes in the environment. Therefore, the demand for intelligent polymer materials has gradually expanded, and has been applied to a variety of fields after research. This paper introduces the information and application of three kinds of intelligent polymer materials: targeting, shape memory and self-healing. Targeting is mainly used in cancer or other diseases that require precise drug delivery; The characteristics of shape memory can be applied to plaster and surgical sutures in the medical field, and can also be applied to the performance upgrade of traditional manufacturing industry. Self-healing can be used to improve the service life of composite materials by using different methods according to the requirements of different material use scenarios.

Keywords: Gene delivery; shape memory; self-healing.

1. Introduction

For ordinary polymer materials, they usually have the characteristics of low price, easy processing and good formability, but at the same time, these materials are also susceptible to problems such as light, heat and oxidation. According to the shortcomings of common polymer materials, the concept of intelligent polymer materials is put forward. Smart polymers are characterized by changing the arrangement or composition of molecules to form different structures, so that the material can autonomously adjust and repair its own function as external conditions change. Therefore, it can be used in different specific environments, not only has higher durability, but also can be applied in a wider range of fields. In this paper, three applications of smart polymer materials with different properties are listed: gene delivery polymer materials, shape memory polymer materials, and self-healing polymer materials. Gene delivery polymer materials are mainly introduced in the medical field, which uses the targeting of materials to deliver genes to different target locations and environments in the body to treat diseases. Smart polymer materials with shape memory properties are relatively widely used in many fields, such as medicine, manufacturing, etc., by adding auxiliary materials based on nanoparticles to the polymer to achieve the shape memory characteristics of the material. Self-healing smart polymer materials can be produced by hollow fiber method, microvascular network and microcapsule method. Different repair methods are used to achieve different performance requirements.

2. Application

2.1 Gene delivery

2.1.1 Nucleic acid templates

The International Union of Pure and Applied Chemistry (IUPAC) defines “template” as “a single strand of nucleic acid that is copied during replication or transcription,” and the term is now widely used in the chemical sciences to denote the process by which molecular information is copied or translated in a new chemical entity. Nucleic acid templates can be used to synthesize macromolecular polymers. Nucleic acids, as informative and easily accessible biomolecules, can be used to template functional polymers by controlling their size, composition and sequence [1]. There are two specific modes of action of nucleic acid templates, the first can be self-assembled by base pairing, and the second can be self-assembled by salt-bridge interaction. By studying diaminotriazine template self-assembly on oligothymine ssDNA [2], Schenning’s group developed a model explaining that the distribution of bound molecules on nucleic acid templates depends on the free energy of binding of the guest to the template site, the free energy of interaction between the guest when the guest binds to the template, temperature, and nucleic acid template length [3]. Homopolymers with precise length control and dispersion are prepared by nucleic acid template polymerization, as well as polymers with sequence selectivity [4]. Synthesis of precise polymers polymerizes by polymerizing nucleic acid templates to form dynamic covalent polymer carriers and promotes the internalization of cells by using excess positive charges or ligands that recognize cell membrane receptors [5].

Therefore, using these properties, smart polymers can be used for gene delivery, nucleic acids as important active ingredients of drugs, and it is crucial to develop specific vectors. Polymers synthesized from nucleic acid templates can be used as gene delivery vectors, representing a new form that complements a large library of polymeric vectors for combinatorial screening. By utilizing the template effect of nucleic acids, it can be used to create polymers that copy and translate the information encoded in nucleic acid templates, or to use template polymers as carriers for therapeutic nucleic acids. In gene delivery applications, nucleic acids make their own vectors, mimicking the template self-assembly of viral capsids [6]. Different molecular designs have all been successful in triggering nucleic acid template polymerization, and future challenges include better control of the polymerization and depolymerization kinetics of template vectors in complex biological media, as well as increasing their complexity to develop multi-component vectors.

2.1.2 Nanoparticles

Malignant tumors pose a great threat to human health. There are limitations in traditional cancer treatment. Gene therapy brings hope for cancer treatment. Gene therapy including virus mediated gene transfer and gene delivery, non viral vectors such as nanoparticles with high stability, biocompatibility, non-toxicity and transfection efficiency, etc [7]. Multifunctional nanoparticles are nanocarriers that combine different functions into one stable structure, allowing simultaneous delivery of multiple components for therapeutic and diagnostic purposes. The ideal gene delivery vector should have the advantages of protecting gene material, overcoming cellular and internal barriers, low toxicity, biodegradability and high transfection efficiency [8]. Commonly used materials are polycations such as polyethylenimine (PEI), poly-L-lysine (PLL), chitosan, poly (amide amine) (PAMAM), etc. which can interact with DNA to form compact nanoparticles. The gene delivery efficiency was improved by hydrophobic/hydrophilic modification of PEI and the introduction of proton sponge effect [9], such as PEgging, the introduction of hydroxyl groups, the connection of hydrophobic segments, the formation of degradable PEI polymers, and the addition of low molecular weight PEI to biocompatible polymers. The combined delivery of therapeutic drugs and genes for cancer has synergistic effects. Nanoparticles targeting mechanisms include targeted passive and active targeting, targeting ligands can according to the function can be divided into therapeutic and diagnostic reagent or barrier to avoid agent, also may be classified according to the composition. Different cancers have specific targeting designs, such as prostate cancer, non-small cell lung cancer, brain tumors, and breast cancer. Multifunctional nanoparticles in cancer treatment have great potential, but have yet to reach standard for clinical application [8]. Co-delivery of genes and chemotherapeutic drugs and hybrid nanoparticles are promising therapeutic approaches. Apoptosis plays an important role in cancer treatment, and gene therapy targeting apoptosis mechanisms has great potential. The risk assessment and regulatory issues of nanoparticles need further research, and the clinical application of multifunctional nanoparticles in cancer treatment is still a long way off.

2.2 Shape memory

In smart polymer materials, shape memory is also one of the special properties, and is widely used in medicine and manufacturing fields. By adding nanoparticles of different materials to increase the performance of materials in different special environments, the material has the function of shape memory.

2.2.1 Orthopedic treatments

There are many patients with bone injury, and the traditional orthotics made of gypsum and fiberglass have many problems, such as uncomfortable, heavy, causing asthma reactions [10]. Shape memory polymer is a kind of smart material that can be used in the biomedical field, but there is less research in external biomedical applications, and there is a usability gap for SMP materials in application-oriented research and development [11]. Jeewantha synthesized A novel hybrid SMP nanocomposite, smart plaster (SP), for non-invasive orthopedic fracture fixation. It is based on bisphenol A epoxy resin, reinforced with E glass fiber, and incorporated TiO_2 nanoparticles to improve its bioinspired properties. The in vitro properties of SP were verified, including temperature and pressure measurements, to ensure its safe use in orthopedic treatment. The results showed good thermal stability and durability of SP between 40 and 70°C, and storage of SP at room temperature or below had no significant effect on its viscoelastic properties. And through the finite element analysis model of output strain closely matched with the experiment, after the validation of the model can be used to predict the shape memory effect of SP and optimize their use [12]. The synthesized SP not only performs well in environmental durability, but also agrees well with the experimental strain model in Abaqus finite element model. In vitro experiments show that SP has superior properties and is expected to replace traditional fracture treatment methods.

2.2.2 Self-tightening suture

Shape memory polymers (SMPs) have applications in minimally invasive surgery, but the recovery temperature of the material should be close to physiological temperature, and polyurethane as SMPs has some problems, such as low refractive index limited recovery rate and low melting point soft segment [13]. Arpan Biswas found that nano-fillers can improve the performance of polyurethanes, and biodegradable SMPs are expected to replace shape memory alloys (SMA) as self-tightening sutures. Polyurethane (HPL) and nano-compound (HPL-NH) were prepared by in-situ polymerization, in which the nano-compound contained 4 wt% of organically modified nano-clay (30B). Through various properties and characterization of the materials, it can be found that the base plane of the nano-hybrid changes significantly. The insertion of nano-clay increases the layer spacing and forms a sandwich-like structure, which improves the self-assembly from nano to macro scale, significantly enhancing the toughness and thermal stability. There is a wide range of interactions between the nanoclay and polymer chains, revealed by spectroscopic measurements and thermal studies, and these interactions lead to enhanced properties. The shape memory phenomenon of nanohybrids at physiological temperatures (91% recovery) is significantly improved, making them suitable for many biomedical applications [14]. In vivo studies have shown that nano complex compound as the tightening stitches in the keyhole surgery has the potential to properly close the injured lip by restoring the programmed shape at physiological temperature, accelerating wound healing without forming any scars. The hybrid has excellent shape memory behavior, biocompatibility and degradability, and can be used as self-tightening suture and self-expanding stent in the biomedical field.

2.2.3 Electroactive Shape Memory Polymer Nanocomposite

The traditional paper industry imposes a heavy burden on the environment, and current paper alternatives have some problems, such as loss of reflected light intensity of electrophoretic inks, lack of bistable electrowetting displays, monochromatic color of bile liquid crystal displays, and toxic and unstable dyes for reprintable paper coatings [15]. Yu Xie‘s proposed nanocomposites combine the advantages of multiple polymers to meet the needs of rewritable paper. Experiments were performed by selecting Fe3O4@C core-shell nanoparticles synthesized by ferrocene hydrolysis as the building blocks of photonic crystals, BSEP (photocurable copolymer composed of stearyl acrylate and carbamate diacrylate) as the polymer matrix, and SA and UDA monomers were mixed with crosslinkers and photoinitiators. The prepared Fe3O4@C powder was added to form the photonic precursor of thick slurry. Under the action of the magnetic field, the superparamagnetic Fe3O4@C nanoparticles were arranged into the nano-chain structure, and then UV curing was carried out [16]. The properties at low temperature, high temperature and transition state can be found through the characterization of the experimental materials. Found that adding nanoparticles had no significant effect on mechanical properties of polymer matrices. And the material has obvious color contrast and long-lasting pattern stability.It can be concluded that the nanocomposite is a kind of durable information storage medium, can retain information indefinitely, without energy input, high color contrast and high resolution.

2.3 Self-healing

Polymer matrix composites play an important role in many industries, but they are prone to micro-cracks. Self-healing materials can solve problems such as micro-cracks, improve the service life and performance of materials, and are widely used in many fields [17]. Self-healing materials can recover their initial properties spontaneously after being damaged by external factors, which can be divided into intrinsic and non-intrinsic types according to repair methods. Intrinsic repair is based on physical, chemical and supramolecular reactions [18], while non-intrinsic repair is repaired by restaurants stored in compartments [19]. The performance of self-repair aims to restore the lost or reduced properties of the material after damage, and the repair efficiency is calculated based on the ratio of the physical properties of the material after healing to the physical properties before damage [20]. Non-intrinsic self-healing matrix coatings have some limitations, such as temperature dependence of self-healing ability, increased fabrication complexity, and decreased mechanical properties [21].

The main repair methods of composite structures are as follows: first, non-intrinsic methods: Non-intrinsic repair methods include encapsulation of repair agents, the use of hollow fibers and the creation of microvascular networks. In these methods, restaurants are stored in containers and released when the material is damaged to repair the damage [22]. Second, evolution of hollow fiber repair methods: In 1991, Dry first investigated the application of hollow fiber in the repair of building components, and the method has since been developed in polymer materials. Subsequent studies continue to improve the performance of hollow fiber in composite materials, through this method to improve repair efficiency, improve mechanical properties and so on [23]. Third, microvascular network repair method: Toohey et al. designed the first microvascular system in 2007, which can improve the repair efficiency and the number of cycles by increasing the catalyst content and optimizing the network structure. The subsequent study further explored the influence of factors such as the diameter and location of the microvascular network on the repair efficiency [24]. Fourth, microcapsule repair method: In microcapsule repair, the reactive liquid reagent is encapsulated in a polymer coating and distributed in a polymer or composite material to achieve self-healing. Microcapsules need to meet certain conditions, such as sufficient strength, easy to break, and can release repair agents. Subsequent studies have improved and optimized the performance of microcapsules in many aspects [25].

Through the studies on the classification of the self-healing systems, repair performance evaluation and extrinsic self-healing of development are discussed. Different self-healing methods have their own characteristics and advantages, such as microvascular network repair can be repaired multiple times, microcapsule repair uniform distribution and convenient structural design, and hollow fiber can play a role in strengthening and repairing. Factors such as the placement type of the restorer chamber, catalyst, solvent and the penetration rate of the restorer have a great impact on the selection of the system type and the efficiency of the restorer [26]. This kind of intelligent polymer materials are widely used, and will to a certain extent, improve the material of use fixed number of years.

3. Conclusion

In summary, smart polymer materials can make outstanding contributions in the treatment of genetic diseases and cancer, and improve the utilization rate of drugs. It makes the treatment more accurate and efficient, but its safety performance still needs to continue to be studied and explored. Smart polymer materials with shape memory properties can be used in medical development to develop smart gypsum to help fracture patients recover; It can also be used for self-tightening sutures in minimally invasive surgery. It can also be applied to the production of information storage media that are more suitable for storing information. For materials that need to have self-healing properties in applications, hollow fiber method, microvascular network method and microcapsule method can be tried to improve the performance of the material to improve the service life of the material. It can be found from these applications that smart polymer materials because of their special properties, often in the application can improve the service life of materials or can help related products to improve the utilization rate, on the other hand, improving the utilization rate of materials can also promote the sustainable development of the environment and reduce related pollution by reducing production. In the long run, this is a very promising research direction that will help the sustainable development of more fields in the future.

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