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Self-Healing Fundamentals and Applications: A Review

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Abstract

Self-Healing polymers are those polymers that sustain the capability of recovering the material from any prevailing physical damages by creating an active response to the cracks within the material and healing the damages. The self-healing ability gives polymers to recover the cracks at very early levels by creating prevention of these materials from catastrophic failures, which enhances the potential usability of these materials and polymers in multiple applications. The review paper will focus on giving the polymer by making the comparison with the healing efficiency, benefit, and challenges that might arise in the potential future development and then addressing the future scope that these self-healing polymers might have in the engineering industry.

Keywords: Self-Healing Polymers, Hydrogel Polymers, Thermoplastic Materials, Ketone

Introduction

Self-healing polymers are studied and applied in multiple industries, including space industries, construction businesses, robotics and many more. With the constant evolution, these polymers are taking a huge hold in these industries. The history of self-healing polymers goes back to near about 70 years, which has revealed the healing properties within the polymers, which increase the strength in the relaxation phase, which is highly relevant to the healing temperature that is to be maintained (Wang & Urban, 2020). The self-healing polymer's efficiency was constantly improved since then, thus accelerating the interface diffusion. Self-healing is categorized into majorly five stages as stated the first stage is of the polymer chain rearranging on two major surfaces, the second phase is the surface approach by making the damages to be planned along, the third phase is of the wetting, the fourth phase is of diffusion in the small area, and the final stage is of randomization where the material is

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healed after the diffusion (Terryn, et al., 2021). Self-healing polymers are an alternative to protect structural parts from the damages that might occur.

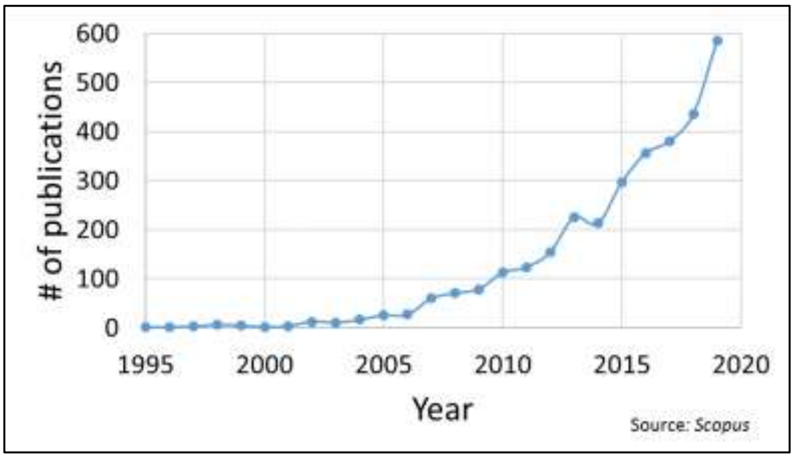

Figure: Constant growth in self-healing polymers

Source: Scopus

Cracks can occur at any stage due to material weakness. The load over the material reduces the concrete toughness, which enhances the permeability and leads to a decrement in the lifespan and durability of the material (Idumah, 2021). In the medical industry, the major impact is noted in the distortion of the material and the excessing usage, which will lead to implants and biomedicals. In the applications of coating, surface stretching is on stimulates the creation of defects, which in damages and losses. The review paper will focus on giving major emphasis on self-healing polymers, their healing mechanisms and their application of these to draw effectiveness in the field of spacecraft and construction and the future prospects and improvement that can comply with in the engineering industry.

Self-healing Polymers Classification

These polymers sustain the capabilities to deal with the damages that might arise. The focus is on making the discussion on the micro-level and the damages in making the self-healing processes in three stages which shows the requirement for the immediate reaction to the damages by the medium of healing (Hornat & Urban, 2020). While the second stage is of the travelling polymers, travel, and the stage of repairing is the final one, where it can restore the damages.

Self-healing polymers can sustain the position of self-healing, which can be attained by the multiple mechanisms which are applied for the damages. On the basis of the ability, the self-healing processes can be categorized into intrinsic and extrinsic ones (Xu, et al., 2020). Internal cues, including pressure, temperature, pH, light, and other factors, cause intrinsic self-healing to occur. Due to the fact that healing can occur throughout several cycles, a catalyst is not required (Dai, et al., 2020). The fact that intrinsic self-healing can only be used with thermoplastic materials like acrylic, polyester, etc., reduces its strength and makes the connection weaker. At the same time, the extrinsic ones are based on external self-heling, which is primarily dispersed in the vascular networks. The initiation of this can be marked with both external and internal damages. These two mechanisms impose a huge control on the processes and the approaches that are identified and applied and highlighting the self-healing procedure and plans (Xu, et al., 2020).

The intrinsic mechanism does not require any external substance to repair the damages that might occur, while the external ones need the vascular network for their healing. Both mechanisms integrate the fast-healing process with multiple healing possible (Idumah, 2021). The intrinsic method applies the chemical bond for healing, while in the extrinsic ones, the healing agents and catalysts are required.

Self-Healing Polymers and The Mechanisms

Self-healing polymers have the characteristics of smart materials that can repair internal flaws in any matrix, restore mechanical properties like tensile strength, as well as extend the life of materials and enhance performance when used in a variety of applications, such as construction, medicine, aerospace, and defence (Nik Md Noordin Kahar, et al., 2021). The basic idea of a polymer's self-repairing mechanism is dependent on comprehending and creating efficient polymerization processes.

Several strategies, including exposing them to chemical, physical, or thermal stimuli, have been developed to impart properties to synthetic self-healing polymers (Zhang, et al., 2021). So, a polymer's high chain mobility and glass transition temperature play a role in how effective it is in healing. It is usual practice to gauge a material's capacity for healing by comparing the hardness of damaged and unharmed samples.

Self-Healing Assisted by The Process of Photo-Irradiation

This process is referred to as the technique which uses the energy of light to promote and accelerate the process of its repairs. The process will integrate photoactive elements within the material that can lead to the response to chemical reactions. The concept of this is to create a system that is autonomous in repairing the damages without getting into any external interventions (Talebian, et al., 2019). It integrates the material design into the transformation. The focus then will be on making the damage detection, making the photoirradiation process to be introduced, the healing interventions to be applied, and then getting in the process of repair completion.

The benefit of using this process is that it can offer a non-contact and remote method for initiating healing within the materials (Shah & Huseien, 2020). The target of the damaged area can be made precisely targeting the damaged area and allowing local repairs without making intervention. The faster healing rate needs to be compared with the traditional self-healing techniques. This process has been in high progress, and making recent years to be given with the explored areas and refining the industries, it can be applied in (Reddy, et al., 2020).

Hydrogel polymers for damage healing

In the field of science and engineering, this method has got immense success and growth because of its unique properties that it has and the potential of damage healing that prevails within (Shah &

Huseien, 2020). The Hydrogel process of self-healing is a three-dimensional process that can retain and absorb a huge amount of fluids and water while maintaining strategic integrity. The benefits of this method applied potentially will include the swelling behaviours, biocompatibility, controlled releases, and the tunable properties that prevail (Talebian, et al., 2019).

Schiff based reactions

It is a primary amine with a ketone in it. The reaction proceeds with the addition of a nitrogen atom for the amine to the carbonyl, followed by dehydration to get into the imine. This is primarily applied in the biochemistry field and the organic field (Xu, et al., 2020). These bases are also playing a significant role in playing the biological systems and formation of the prosthetics groups.

Applications of Self-Healing Material in Multiple Industries

The auto-healing feature of the self-healing material, when the structure is encountering drastic scenarios, has made them sustainably adopted and made them grow. The constant evolution of this has made its applications to go broader and sustain its potential position in the market.

Self-healing material in spacecraft

In space, the crafts suffer from the variable of the harsh environment, which includes multiple uncontrollable factors of debris, atomic oxygen issues and many others that affect their use of it. These self-healing materials have gained a lot and offer potential improvement in reliability, validity and durability for the components and the structures as planned (Wang & Urban, 2020). Systems with microencapsulated components, as the material contains microcapsules that are implanted with healing agents like adhesives or resins. When a material is damaged, the capsules burst, releasing the healing agent, which subsequently fills in any holes or cracks and solidifies, repairing the material's integrity (Zhang, et al., 2021). Modelled after the circulatory system of the human body, vascular self-healing

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materials have a network of implanted channels or tubes that are loaded with curative substances. When a channel is injured, it bursts, enabling the healing agent to enter the area and restore the material, thereby solidifying it.

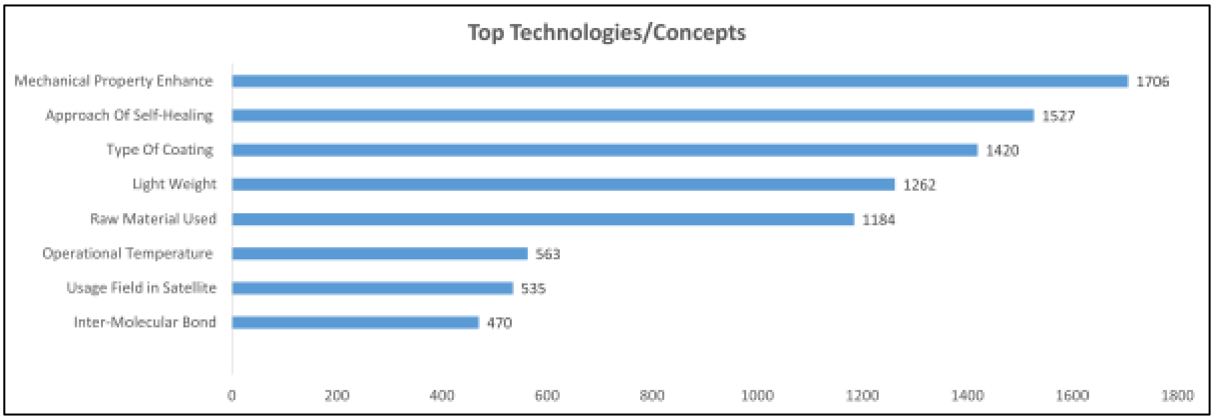

Figure: Technologies applied in spacecraft self-healing

Source: TT Consultants

Three different structural materials that are used in space applications and play a significant part in the self-healing process are included. Materials for current conductors include metal alloys, ceramics, and composite materials (Wang & Urban, 2020). The composite material has a wide range of applications for self-healing coatings, actuators, compartments, and antennas. It offers higher specific strength, improved corrosion resistance, and fatigue resistance. It is also applicable to some engine parts in addition to application parts. High-temperature thruster components are made of ceramic materials, and a hard coating is also an option. Aside from wires and electrical circuits, metal alloys for current conductors are also used. Furthermore, it is founded on both inherent and extrinsic characteristics (Lai, et al., 2019). But because of the impact load, composite materials sustain structural damage. Deep tiny cracks and delamination are caused by the production of a microscopic void, which is what first causes the damage.

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Self-Healing Material in Construction

The usage of construction has been around since the dawn of civilization, and it is the foundation of the construction industry. Because of its unique qualities, including good fire resistance, high compressive strength, ease of casting, and cost-effectiveness, concrete is consistently the material of choice for building structures. Construction has a lot of good qualities, but one of the biggest concerns is that it has a low tensile strength and is, therefore, brittle (Dai, et al., 2020). Concrete in the construction industry is susceptible to damage and cracking due to environmental factors, including the alkali-silica reaction, in addition to poor design and incorrect material selection. Aggressive substances like chloride, carbonate, or sulphate can seep through cracked concrete (Reddy, et al., 2020).

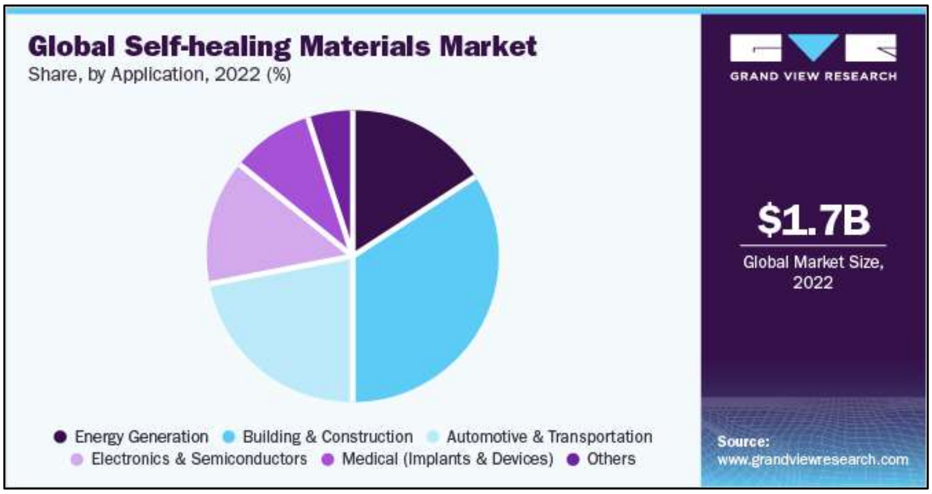

Figure: U.S. Self-healing materials market

Source: Grand View research

In the event of injury, self-healing materials have the capacity to repair themselves, partially or completely regaining their original qualities. Self-healing mechanisms have been investigated for various kinds of materials, including polymers, metals, ceramics, and composites. These mechanisms are modelled after natural systems (Nik Md Noordin Kahar, et al., 2021). In the past few decades, significant progress has been achieved in the research and development of self-healing polymeric materials, and the current self-healing polymers are now regarded as smart materials capable of recovering their properties either autonomously or non-autonomously (Dai, et al., 2020). A number of applications for these materials have been proposed, including water membranes, lithium batteries, energy transducers, biomedical devices, flexible electronics, and soft robotics.

In a perfect world, self-healing polymers wouldn't be able to drastically alter the original material's original qualities. Furthermore, there is still room for improvement in the standardization of procedures used to evaluate the effectiveness of healing agents. An enormous amount of interest in research has been generated by a new class of smart materials called self-healing materials (Reddy, et al., 2020). Over the past few decades, a variety of self-healing methods have been created and studied.

Conclusion

The self-healing polymers are versatile and can be applied as an agent of self-healing for applications in the construction business, spacecraft, and biomedical sciences. These materials are self-healing promising materials as they are helpful in the repairs for structural cracks and damages that might occur which is an excellent agent of repairs. This review paper gives an overview of these polymers as applied in the spacecraft and the construction industry and how these can be demonstrated as considerable ways of improvement of stressed structures in these areas.

Future Prospects and Improvement

Although every technology that has been created has been deemed promising, it also has drawbacks and restrictions. To use the processes for production at an industrial scale, modifications are still required. The need for additional research and inquiries still prevails. Even yet, in order to obtain a long service life for a self-healing material, some environmental elements like temperature, pressure, light, and others do present some difficulties that must be properly handled during the various phases of the material's development. Thus, it is important to assess performance characteristics, including low-temperature cracking, rutting, and self-healing, in the future. It is necessary to develop more sophisticated healing methods that go beyond simple intrinsic and extrinsic healing, and it should also be investigated how to use more cutting-edge polymeric materials. But more advancements are required because this study is still in its early stages. In future researchers, the criteria for tests and applications need to be applied and focused upon to make a more detailed analysis of the self-healing polymers in the engineering industry.

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