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Polymer Science: A Promising Future in the Automotive Industry

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The automotive industry is the locomotive of the global economy due to its feeder industries, especially with the increasing use of polymer-based components. Chemical polymers, along with automation, mechatronics and materials sciences, play a fundamental role in industrial progress across various life sciences.[1-2] The editorial explores the development of chemistry over the ages, the role of polymers in the design and manufacturing of many modern automotive components, and the promising future of the automotive industry.

Anciently: Modern humans originated in Africa thousands of years ago, where they threw small stones into fire and observed the resulting color changes, then used them in their primitive lives. More than 3,000 years BC, cultural exchanges were recorded between the Indus Valley civilizations in India and the Nile Valley in Egypt. Ancient Egyptian "Pharaonic" civilization arose on the banks of the Nile Valley. Driven by the idea of honoring the dead or immortality and life after death, especially for nobles or officials favored by the people, the Pharaohs used linen scrolls and threads, which survive to this day thanks to their chemical treatments and the still-secret chemistry of embalming. Some contemporary Egyptologists believe it relied on the chemistry of natural gums, oils, and aromatic plant extracts, following microscopic analysis and radiocarbon dating based on examining the chemical fingerprint of each component of the embalming agent. Scientists see this as a unique opportunity to study uncontaminated ancient Egyptian chemistry.

Modernly: Jabir ibn Hayyan is considered the father of modern chemistry. His research covered a wide range of topics and was translated into Greek, becoming the first reliable reference, laying the foundations for the science of chemistry in the eighth century AD. The path of chemistry first saw a breakthrough at the dawn of the industrial revolutions. During the First Industrial Revolution in the late 18th and early 19th

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centuries, prominent figures including Joseph Priestley, Antoine Lavoisier, and Robert Boyle helped establish modern chemistry. However, chemical engineering did not crystallize as an independent discipline until the Second Industrial Revolution (late 19th and early 20th centuries). Early developments during this era focused on the industrialization of chemical processes, including the production of synthetic dyes, which spurred the rapid development of automotive coating systems. This was when chemists realized the possibility of synthesizing long-chain molecules—polymers—from simple monomers. In 1920, German chemist Hermann Staudinger proposed the concept of macromolecules, paving the way for modern polymer science.[3] Thus, it can be said that polymer science began as a new field in the early 20th century, with the emergence of several prominent figures, including Wallace Carothers, who invented nylon in 1935, and Otto Bayer, who invented polyurethane in the second half of the 1930s, paving the way for the production of distinct types of polymeric materials.[4] Plastic and rubber are made from the same family of polymer compounds. This was followed by a series of significant contributions from scientists such as Wallace Carothers, who developed nylon, and John Wesley Hyatt, who invented Bakelite—the first synthetic plastic. By the end of the twentieth century, chemical engineers continued to develop polymer compounds, with the emergence of new materials that were stronger, lighter, and more versatile than traditional materials, replacing metals and glass. Innovations in polymer chemistry, such as Giulio Natta's invention of polypropylene and the development of high-density polyethylene (HDPE), made it possible.[5] Many scientists have won the Nobel Prize in Chemistry for the synthesis of polymers, including Hermann Staudinger in 1953, who experimentally demonstrated that polymers are long molecules. Giulio Natta and Karl Ziegler were also awarded the prize in 1963 for their experiments in developing the Ziegler-Natta catalyst used in polymer synthesis. Ahmed Zewail's achievements, for which he won the Nobel Prize in Femtosecond Chemistry in 1999, opened new horizons for understanding chemical reactions at the atomic level, facilitating the development of analytical tools and equipment used to understand polymers and their interactions. Thus, there are many types of plastics in the automotive industry, such as polypropylene (PP), polyurethane (PU), polyvinyl chloride (PVC), polyamide (PA), acrylonitrile butadiene styrene (ABS), high-density polyethylene (HDPE), polycarbonate (PC), and polybutylene terephthalate (PBT).[6]

Today, polymers have increasingly been used to manufacture a wide range of parts inside and outside the car, under the hood such as engine parts, sealants, pipes, electrical components, brake and transmission systems, interior furnishings and body. Polymers are also widely used in seats, seatbelts, airbags, dashboards, and thermal and sound insulation systems. For example, polyurethane foam is widely used in seat manufacturing due to its comfort and durability, while thermoplastics are increasingly used in dashboard and console components due to their versatility and aesthetic properties. Carbon fiber reinforced polymer (CFRP) composite panels are now used in high-performance vehicles. CFRP is strong and lightweight, making it ideal for improving performance and reducing energy consumption. This also contributes to improved fuel economy and increased dynamic balance during driving. While rubber has been used in the manufacture of automobile tires for over a century, advances in polymer chemistry have led to the production of advanced synthetic rubbers that improve the quality and durability of tires, as well as their rolling resistance, enhancing ride comfort-ability and vehicle performance in various weather conditions.[7] Rubber is also used in the manufacture of steering and suspension system bussing, as well as engine mounts, which have proven their ability to absorb dynamic vibrations and shocks. These chemicals can make cars lighter, providing occupational health and safety benefits that make them safer and more efficient. Because, lighter vehicles require less energy to move, this has revolutionized the performance of automobiles. The chemistry behind the development of polymers and composite materials has not only significantly improved automotive performance but has also contributed to sustainability efforts by reducing fuel consumption, improving passenger comfort, and limiting environmental impacts. Meanwhile, the latest statistics confirm that the automotive plastics market has witnessed significant growth in recent years. It is expected to grow from USD 43.29 billion in 2024 to USD 47.52 billion in 2025, at a compound annual growth rate of 9.8%.

Recent advances in self-healing polymer technology and high-performance composite materials have achieved a new breakthrough, one that holds great promise for the automotive industry. These polymers have the ability to spontaneously repair minor damage, such as scratches or cracks, significantly extending the life of some automotive parts. Researchers have developed polymeric binders containing microcapsules filled with repair agents. When the material is damaged, the microcapsules open, releasing the repair agents that adhere to and repair the cracks or scratches. This technology could be applied to both exterior and interior components of cars in the future, providing long-term durability while reducing maintenance costs. Furthermore, the emergence of advanced thermoplastic polymers will revolutionize the way many automotive parts are produced. These materials can be melted and remolded multiple times with minimal additives, making them more sustainable than traditional thermoplastic polymers. This reusability reduces waste in the manufacturing process and facilitates recycling, a critical aspect for the automotive industry, given their environmental and social concerns. The automotive industry is also currently embracing 3D printing technologies that utilize a variety of polymer materials. This has opened the door to rapid prototyping and the production of complex spare parts with minimal waste. 3D printing using polymers is not only cost-effective but also allows for greater control over the precise execution of many part designs, enhancing the capabilities and operational efficiency of vehicles.

One of the most important modern discoveries in the field of polymer chemistry is the development of dynamic covalent bonds. Prof. Ali et al. developed polymeric materials reinforced with carbon nanotubes (CNTs) to improve the tribological properties of automotive brake surfaces.[8] Chemists such as K. Barry Sharpless have created these bonds to generate powerful and useful chemical reactions that can be linked in innovative ways. This could lead to the development of polymers with highly controlled structures, which can be tailored to specific applications, such as durable non-metallic cylinders for storing gaseous fuels that withstand high pressures in the automotive industry. Furthermore, dynamic covalent bonds enable the production of polymers that are reconfigurable under heat or pressure. This opens new horizons for self-assembling and self-healing materials, potentially transforming them into reconfigurable automotive parts. This combination of advanced chemical bonds is expected to revolutionize the automotive industry by enabling the development of smart materials that respond to environmental influences. Recent discoveries in the field of polymer, announced by Ali et al. paved the way for a new design for the next generation of vehicles. They demonstrated that the use of CNTs will revolutionize the manufacture of engine pistons, a topic that has been studied in detail.[9] The study confirmed that inserted CNTs chemistry is very useful in producing new magical composite materials in the automotive industry. Moreover, Prof. Ali et al. during the year, revealed important details about the use of polymers in the production of green hydrogen, which will revolutionize the automotive industry.[10]

Conclusion

- Advanced chemical engineering, represented by polymers and their derivatives, has brought about radical changes in the automotive industry, from improving the quality of oils and fuel, to designing lighter vehicles and reducing fuel consumption, to enhancing performance, rid-comfort, and sustainability. This is in addition to lowering the initial cost of purchasing new cars.
- The historical development of polymer chemistry has laid the foundations for numerous innovations, with pioneering figures and discoveries continually shaping the future of automotive technology. As this field evolves, new chemical bonds, such as dynamic covalent bond chemistry, will continue to emerge to drive advances in the properties of polymeric materials, supporting the design and manufacture of automotive parts, making them more efficient and sustainable in the future. This with coupled with metrology, nanotechnology, and mechatronics, will enhance performance and environmental responsibility, contributing to the improvement and prosperity of the global economy.
- The use of polymer chemicals in the automotive industry has seen significant growth in recent years, increasing by approximately 10% annually, and efforts are ongoing.
- Eventually, in the near future, it can say in another article that the secret to the development and power of electric cars lies in the chemical composition of their batteries.

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