RESILIENT PRODUCTS MADE POSSIBLE BY CHEMICAL GELS

— FROM DIAPERS AND COSMETICS TO PAINTS, BATTERIES, AND ROBOTS —

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SUMMARY

- Chemical gel is a material currently used mainly for personal care products such as cosmetics and diapers, but it is also expected to become an increasingly important material for batteries and heat insulating applications in the future.
- A chemical gel is a composite material formed by a combination of a chemical substance that creates a network and a substance contained therein. This combination enables a wider range of functions to be performed than would be possible with a single chemical substance.
- The chemical gel market was valued at US$11.8 billion in 2018, and is projected to expand at an average annual growth rate of 6.5% between 2019 and 2025. The creation of databases and utilization of artificial intelligence (AI) are accelerating development, and chemical gel has the potential to contribute to solving important social issues in the future.

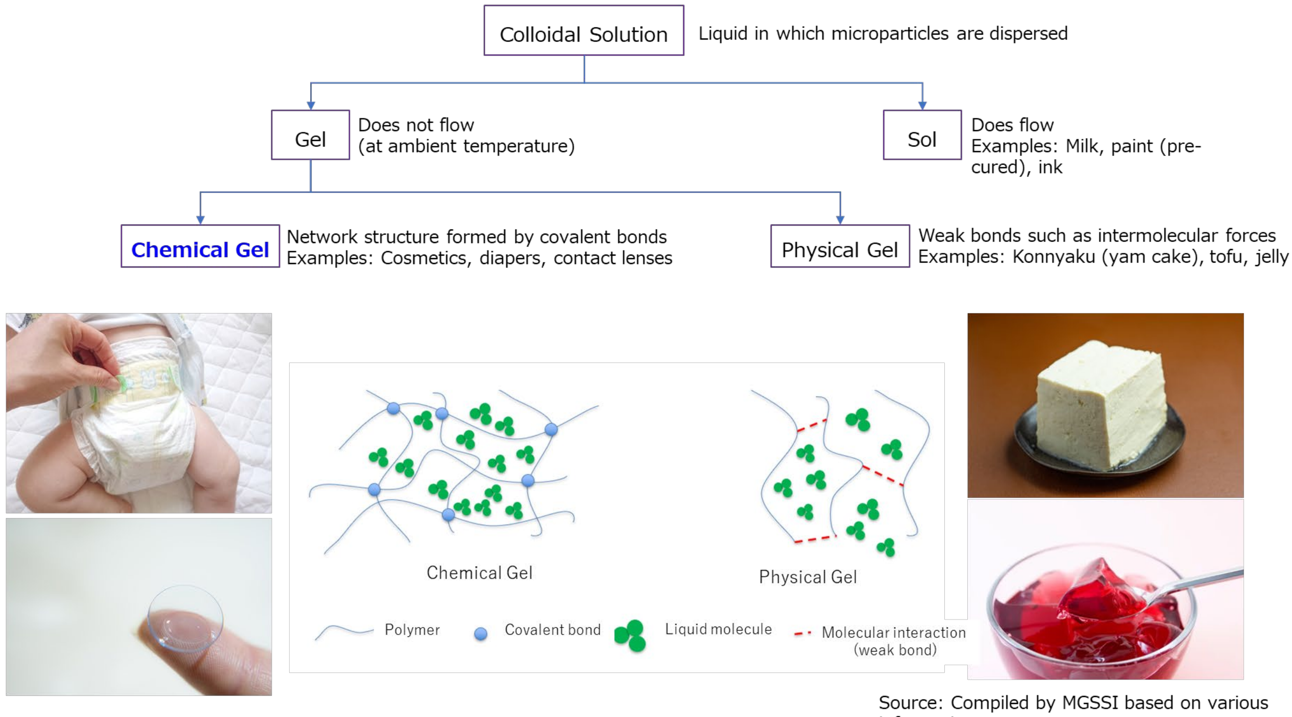
1. WHAT IS A CHEMICAL GEL?

While chemical gels have been widely used in everyday life, particularly for personal care products such as diapers and cosmetics, as well as for medical applications, thanks to recent technological innovations, they are expected to play a key role in helping to realize carbon neutrality and SDGs (Sustainable Development Goals) when used for applications such as functional coatings, battery materials, and wearable robotics. This report provides a basic explanation of what chemical gels are, and introduces their expected future applications in society and the course of their development.

1-1. Chemical gels and physical gels

Figure 1 shows the classification of gels and illustrations depicting chemical gels and physical gels. A gel is a state of matter that contains both liquid and fine particulates (a colloidal solution) and that does not flow. Familiar examples of gels include jelly and tofu. In contrast, a colloidal solution that flows is referred to as a sol. Jelly and tofu are physical gels held together by a weak binding force, and they fall apart easily. When tofu is placed on a plate, the water and other liquid contained within it seeps out over time. This is because its binding force as a gel is weak. On the other hand, a chemical gel has a three-dimensional network structure (like a jungle gym) formed by covalent bonds that provide stronger bonding than a physical gel, and by designing this type of structure in specific ways, it is possible for the liquid and the constituents dissolved therein to be tightly confined or to be released when placed in a particular environment. Polymers, which are compounds with a high molecular weight, are used as the chemical substance forming a chemical gel's network structure.

Figure 1. Chemical gels and physical gels



Source: Compiled by MGSSI based on various information sources

1-2. How chemical gels are made and their characteristics

Chemical gels are made by impregnating the polymer with liquid or by a method such as solidifying a sol by means of covalent linkage. When a chemical gel absorbs liquid, it does not decompose and instead can expand to accommodate the liquid, while conversely, it shrinks when liquid is removed as a result of drying or other cause. Moreover, by applying a particular method for extracting the liquid, it is possible to create a structure wherein the space vacated by the liquid is filled with gas instead of shrinking. Since a chemical gel as a composite material formed by a combination of a chemical substance that creates a network and a liquid that enters and exits that network, it is possible to equip chemical gels with functions that differ from those of the simple chemical substance expressed by the chemical formula.

1-3. Various chemical gels

While there are various methods for classifying chemical gels depending on their constituent substances, the names of gels classified according to the content of the network structure are given below, along with examples of products.

(1) Hydrogel: A gel containing water. Contact lenses are a typical example. By using water, soft contact lenses are designed to retain moisture and to allow the passage of oxygen, thereby realizing a product that is gentler on the eye.

(2) Organogel: A gel containing a solvent other than water. Although there are no familiar examples of a chemical organogel, gel-type face sheet masks can be cited as an example as they can be referred to as a hydrogel or an organogel because they contain both water and another solvent. The sheets, which retain their shape due to the network structure, contain beauty ingredients and achieve a well-balanced adhesion that fits well when being applied and does not cause pain when removed.

(3) Xerogel: A gel that does not contain a liquid. A typical example is a superabsorbent polymer (SAP) used for products such as diapers. These products contain no liquid when they are displayed for sale in the store. SAP can absorb water and retain it so that it does not leak out. Because the ease with which SAP can absorb and

retain a liquid depends on whether that liquid is acidic, neutral, or alkaline, i.e., on its pH value, the most suitable type of SAP is designed for use in specific applications.

2. THE CHEMICAL GEL MARKET AND APPLICATIONS LIKELY TO BECOME INCREASINGLY IMPORTANT IN THE FUTURE

Most of the chemical gels currently manufactured are for personal care applications such as cosmetics and diapers. Types of polymers used to form the networks include polyacrylic acid, which is used as a water absorbent and for contact lenses, and polyvinyl alcohol, which is used in moisturizing creams and jelly-textured skin care products. According to an estimate by the US company Market Research Future, the global chemical gel market was valued at US$11.8 billion in 2018, and is expected to expand at an average annual growth rate of 6.5% between 2019 and 2025[1]. Some of the applications that are likely to become increasingly important in the future are described below.

2-1. Batteries

A gel polymer electrolyte is confined within a gel for the purpose of improving the safety of batteries. It replaces the liquid electrolytes conventionally used for batteries, and helps to improve the safety of electronic devices such as smartphones. Vinylidene fluoride copolymers are mainly used for the network polymers. They are designed and synthesized to ensure that the electrolyte remains stably confined even in the event of a change of temperature or pressure without causing a chemical reaction with the electrolyte.

2-2. Insulation material

Silica aerogel is a type of xerogel that has been used for adsorbing volatile organic compounds (VOCs) in oil and gas plants because it contains large voids and has no catalytic effect. As the name suggests, the chemical compound forming the network is silica (also known as silicon dioxide), and silica aerogels are generally manufactured by drying silica containing a solvent under high temperature and pressure to replace the solvent with gas. Because it contains large voids, silica aerogel has a low weight per volume and possesses excellent thermal insulating properties, which means that it has potential applications in buildings, electric vehicles, and electrical appliances.

3. INCREASED FUNCTIONALITY DRIVES RESEARCH INTO NEW APPLICATIONS

Because it is not possible to precisely control the position of the covalent bond in conventional chemical gels, their use was previously limited to applications for which mechanical strength is not required. However, recent advances in techniques for controlling covalent bond formation have made it possible to synthesize gels possessing high strength and good elasticity. Furthermore, while it is known that the volume of a chemical gel undergoes a rapid change when factors such as the temperature, solvent, hydrogen ion concentration, and voltage exceed a certain value, as knowledge of the conditions of volume changes and the method of controlling them improves, work on the application of gels to functional materials such as drive mechanisms and sensors is accelerating. Applications for which chemical gels are expected to be used in the future are summarized in Figure 2.

[1] Source: Global Polymer Gel Market

Figure 2. Expected future applications of chemical gels and related SDGs

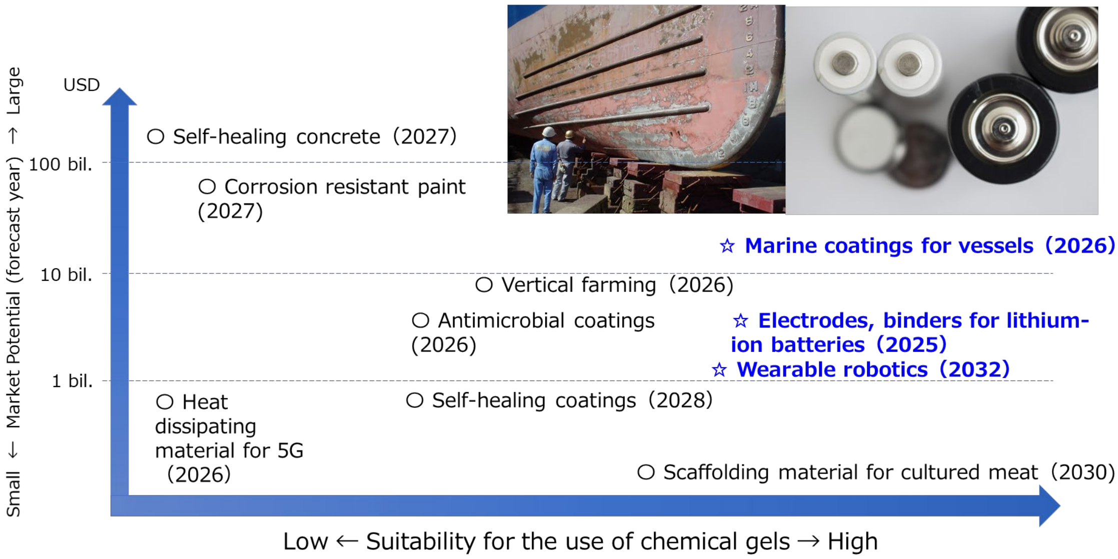
Application (projected year)	Gel Type	Advantages/Case examples	Risks	Related SDGs	Market Potential
Self-healing concrete (2027[1])	Xerogel	Alginic acid: Low environmental impact Studies with SAP (sodium polyacrylate, etc.)	Preceded by another solution using PLA (polylactic acid)	11. Sustainable cities and communities 12. Responsible consumption and production	USD305.3 bil.[1]
Corrosion resistant paint (2027[2])	Hydrogel	Development underway by startups, including LiquiGlide (US)	Competition with existing hydrophobic coating manufacturers such as NeverWet, NanoGate Technologies, and 3M	11. Sustainable cities and communities 12. Responsible consumption and production	USD18.1 bil.[2]
(Reference) Contact lenses (2028[3])	Hydrogel	Monopoly of acrylate siloxane hydrogel and silicon hydrogel	Room for improvement in the balance between oxygen penetration, water content, and wearability	3. Good health and well-being	USD12.6 bil.[3]
Marine coatings for vessels (2026[4])	Hydrogel	Developed by startups, including Repela (US)	Competition with existing marine coating manufacturers	14. Life below water	USD10.2 bil.[4]
Vertical farming (2026[5])	Hydrogel	Adaptation of medical purposes hydrogel by Mebiol (Japan)	Competition with non-film farming methods (sprays, etc.)	2. Zero hunger	USD9.7 bil.[5]
Antimicrobial coatings (2026[6])	Hydrogel Organogel	Copper-containing membrane developed by Nippon Sheet Glass (Japan)	Competition with preceding materials such as metal ion systems	3. Good health and well-being	USD6.4 bil.[6]
Electrodes, binders for lithium-ion batteries (2025[7])	Organogel	Results with vinylidene fluoride and styrene-butadiene rubber	Possibility of the emergence of new technologies such as graphene	7. Affordable and clean energy	USD5.0 bil.[7]
Wearable robotics (2029[8]-2032[9])	Organogel	Production by AssistMotion (Japan) of a prototype using a PVC gel actuator	Metal-based materials with thin membrane, high functionality	3. Good health and well-being	USD4.0 bil. (2032[8]) USD12.0 bil. (2029[9])
Self-healing coatings (2028[10,11,12])	Hydrogel Organogel	Under development	Wide variability in market forecasts	11. Sustainable cities and communities 12. Responsible consumption and production	USD46.0 mil.[10] USD2.4 bil.[11] USD62.66 bil.[12]
(Reference) Heat insulating material (2030[13])	Xerogel	Silica aerogels, polymer aerogels	Changes in insulation performance requirements due to changes in design policy	3. Good health and well-being 11. Sustainable cities and communities	USD1.69 bil.[13]
Heat dissipating material for 5G (2026[14])	Hydrogel Organogel	Flexible, dimensional freedom, adhesiveness Solid state precludes water leakage unlike water cooling	Disadvantageous compared to inorganic systems in terms of thermal conductivity Points of differentiation from existing silicone fillers are unclear	9. Industry, innovation and infrastructure	USD0.9 bil.[14]
Scaffold for cultured meat (2030[15])	Hydrogel	Studies with collagen gel	IP could be a barrier to entry	2. Zero hunger	USD0.28 bil. (Meat Alternative market[15])

Notes:1 Grand View Research, 2 Global Market Insights, 3 Fortune Business Insights, 4 Industry Arc, 5 MarketsAndMarkets, 6 MarketsAndMarkets, 7 Yano Research Institute Ltd., 8 Fact.MR, 9 Fortune Business Insights, 10 Data Bridge Market Research, 11 Market Research Future, 12 Fortune Business Insights, 13 SDKI Inc., 14 Research and Markets, 15 Allied Market Research

Source: Compiled by MGSSI based on various information sources

Figure 3 shows a mapping of the market potential of chemical gels shown on the vertical axis, and the compatibility of chemical gels with applications on the horizontal axis. Three applications for which chemical gels are particularly suitable are introduced in the following section.

Figure 3. Mapping of promising applications



Source: Compiled by MGSSI based on data from Grand View Research and other companies

3-1. Promising application 1: Marine coatings for vessels

Marine coatings are a paints used on the bottom of a ship's hull to prevent the part of the ship that is in contact with seawater from degradation due to the formation of rust and to prevent the attachment of marine organisms such as barnacles. Because organisms adhering to a ship's hull increase the water resistance underway, applying ship bottom paint not only improves the ability of the hull to perform its role in a stable manner under service conditions, but also prevents a deterioration in fuel consumption. While traditionally biocides such as organometallic compounds have been used to prevent biofouling, in recent years, research has been progressing into paints that can prevent biofouling without killing marine organisms to prevent marine pollution. The US startup Repela has developed a biocide-free marine coating based on a chemical gel. This paint utilizes the property of a novel superhydrophillic chemical gel developed at Wayne State University in the US that forms a layer of water on the surface and makes it difficult for organisms to adhere to it.

3-2. Promising application 2: Binders for electric vehicle (EV) battery cathodes

The cathodes of EV batteries are required to be more durable than those of conventional batteries in order to withstand temperature changes and vibrations throughout the lengthy period of product lifetime. Even the binder that adheres the cathode's graphite electrode and conductive particles to the copper current collector requires the use of a material that is not peeled off or change the state of the conductive particles that are dispersed appropriately in the binder as a result of temperature changes and vibrations. Here too, the flexibility, adhesion, and heat insulating properties of high-performance chemical gels are likely to be of significant use.

3-3. Promising application 3: Artificial muscle actuator for wearable robots

Since chemical gels are flexible, lightweight, and unlike a motor, do not generate noise, they hold promise for use as actuator offering excellent human-friendliness and safety. Japan's Shinshu University has developed an actuator that is made of polyvinyl chloride (PVC) gel containing a plasticizer to enable expansion and contraction similar to that of a human muscle. This technology has been applied in the heige LS prototype back support wear by the Shinshu University startup AssistMotion (Figure 4). While contraction of the gel reduces the load on the wearer's lower back during lifting operations, there is still a technical problem to be overcome before it can be developed commercially, in that the voltage required for driving the unit must be reduced. Since it is highly likely that this device will be both cheaper and lighter than existing motors, early resolution of this problem is eagerly awaited.

Figure 4. Heige LS back support wear incorporating a PVC gel actuator

Source: Assist Motion website

4. FUTURE PROSPECTS

With the development of technology for controlling covalent bond and volume changes, chemical gels are evolving into materials that contribute to solving important social issues. What is expected in the future is the creation of databases on the combination of materials and mechanical and electrical properties. Databases creation and utilization of artificial intelligence (AI) are helping to accelerate development and spur technological breakthroughs in various fields.

Japan's Showa Denko Materials has created a database on the development of functional materials and has incorporated AI that has been developed in-house, into the database. In developing a transparent adhesive film used for verification purposes of this AI-armed database, AI successfully solved an extremely difficult technological challenge that had stubbornly confronted expert developers, and the achievements were announced in December 2021. In addition, in September 2021, researchers in Japan's National Institutes for Quantum Science and Technology quantified the structure of the monomers that are the raw materials of polymers by means of quantum chemical calculation, trained AI with this information, succeeded in predicting the reaction rate of the monomers, which is an important factor determining the physical properties of polymers obtained by radiation graft polymerization, instantly and with a high degree of accuracy.

Since chemical gels are also functional materials that are composites of polymers and a filler substance, their performance in both existing and new applications is expected to be dramatically improved by using quantum chemical calculations and AI to predict the network structure, and by optimizing the combination of a database containing predictive data and AI for development.