Getting Fuel Cell Vehicles Fit for Use

Material Improvements Make Fuel Cells More Reliable

In addition to the purely battery-powered electric drive, the fuel cell is regarded as an alternative to the internal combustion engine. In order to bring them into series production, however, improvements in the reliability of the cells are still necessary. Especially in ion leaching and hydrolysis resistance with corresponding long-term mechanical properties of the materials used so far, there is still some catching up to do. One possibility are specially developed PPS compounds.

Fossil fuels contribute significantly to air pollution and greenhouse gases. The WHO estimates that 25% of deaths from heart disease, stroke and lung cancer can be correlated to air pollution. CO_2 and other greenhouse gases are directly responsible for climate change – leading to a shift to renewable zero-emission resources. The transport industry is one of the biggest emitters of greenhouse gases. Burning of fossil fuels in combustion vehicles accounts for around 4% of total annual emissions. Alternatives to fossil fuels in the transport sector – synthetic fuels, pure battery vehicles and fuel cells – have distinct limitations and have therefore not yet found broad market acceptance. In the case of fuel cells, for example, significant improvements are still needed in engineering materials that enable the production of reliable and efficient cells.

Unlike fossil fuels, hydrogen-based fuel cells produce pure water as the only by-product. In addition, their efficiency exceeds that of internal combustion engines. With a given input power, fuel cells can offer 2.3 times the range of a diesel or gasoline engine.

The global hydrogen market is estimated to grow by USD 117 billion in 2019 and is expected to grow by an average of 4.3% a year by 2027 [1]. Hydrogen can be produced either from fossil or renewable energy sources, with the gasification of fossil fuels being the current dominant mode of production. Hydrogen production via electrolysis of water using renewable energy sources would eliminate the production of greenhouse gases throughout the fuel cell operating cycle.

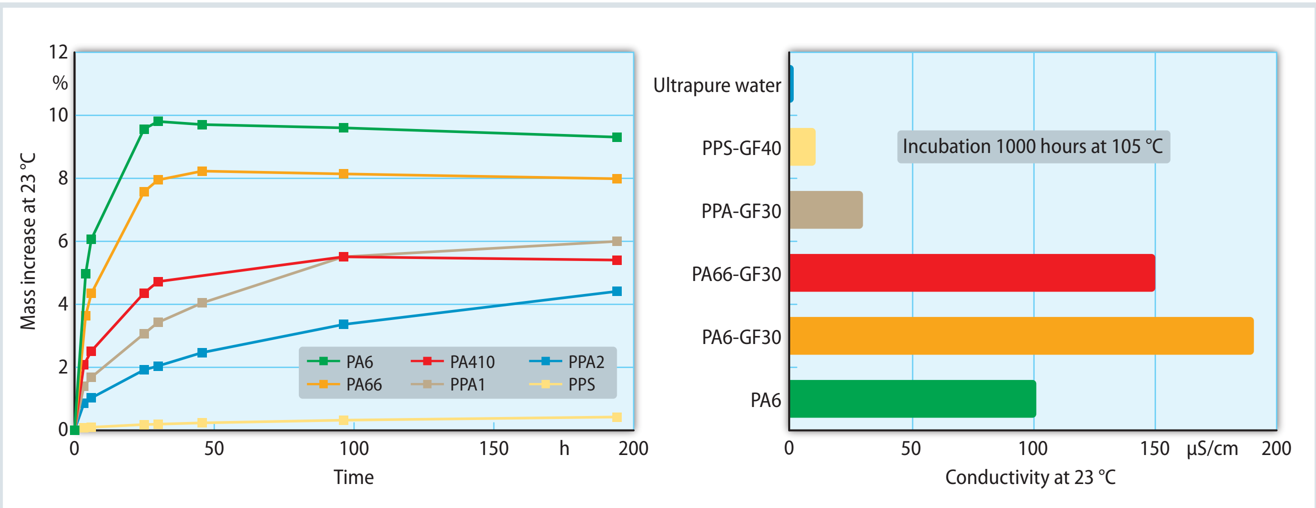

Fig. 1. PPS shows the lowest moisture absorption (left) and ion leaching (right) compared to PA6, PA66 and PPA Source: DSM; graphic: © Hanser

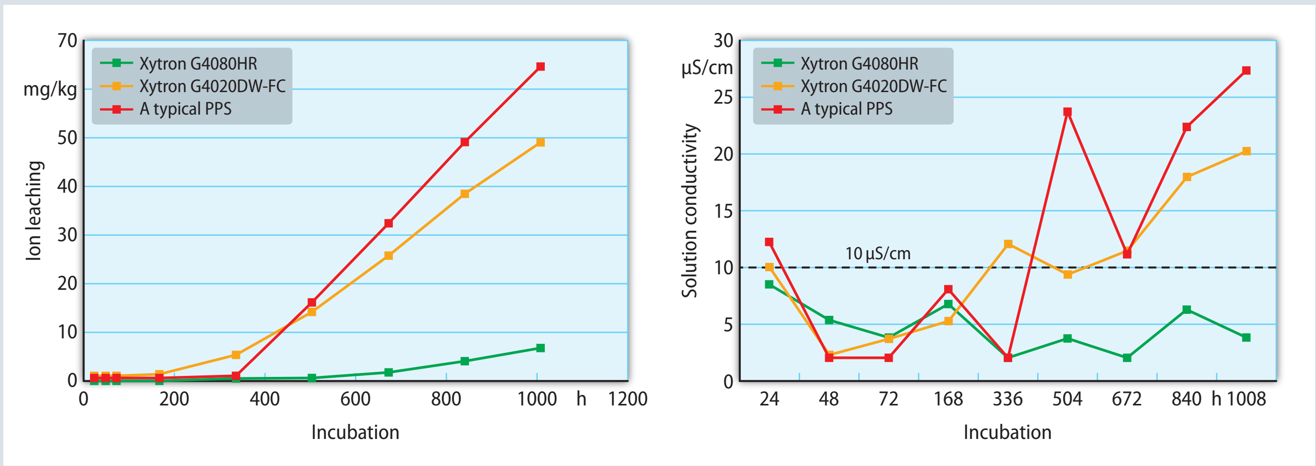

Fig. 2. Xytron G4080HR has the lowest ion leaching (left) and solution conductivity (right) compared to other 40 % glass fiber-reinforced PPS connections. A solution conductivity of 10 µS/cm as an indication of low ion leaching is considered the ideal level to ensure a long cell life

Source: DSM; graphic: © Hanser

The consulting firm Wood Mackenzie predicts that the cumulative installed capacity for the production of green hydrogen will increase 12-fold in the near future – from 253 MW in 2000 to 3205 MW by 2025.

Fuel Cells Are Ideal for Transport

In the transport sector, the electrification of the powertrain is the only viable long-term solution to the challenge of increasing emissions. Hydrogen fuel cells are the most efficient technology for vehicles with a high daily travel requirement – such as buses, trucks, trains and also for ships.

Fuel cells offer the following advantages over pure battery technology:

- Refueling times and ranges comparable to internal combustion engines.
- No heavy additional battery loads.
- Performance has only limited weather dependence.

In heavy transport, battery weight, range and refuelling time are clear disadvantages of a pure battery-powered drive trains. With higher capacities, the battery weight increases significantly, making pure battery technology less suitable for the transport sector and would lead to high costs per kilogram of transported weight. Instead of transporting heavy batteries in the vehicles, the energy required can be generated directly on board using fuel cells. While batteries also have geopolitical concerns about the availability of lithium and cobalt, hydrogen can be produced regionally, and existing truck filling stations can be easily converted to hydrogen filling stations for fuel cells.

Among fuel cell technologies, the Proton Exchange Membrane Fuel Cell (PEMFC) is becoming increasingly popular. It offers a very good balance between efficiency and emissions at low operating temperature, short start-up time and the ability to work with pure hydrogen and normal ambient air as an oxidizing agent. Fuel cell systems for commercial vehicles, which often last more than 15,000 hours in operation, must be very robust. This requires careful consideration in material selection, design, manufacturing and quality control.

Thermoplastics Essential for High Performance and Reliability

Technical thermoplastics are ideal for fuel cell systems due to their ease of processing, low weight and intrinsical electrical insulation. However, constant direct contact with gases and liquids in fuel cell systems leads to hydrolysis of thermoplastic components, which significantly impacts their mechanical strength. Moreover, the accompanying ion leaching may results in membrane contamination, pin-hole formation, bi-polar plate corrosion and clogging, a decrease in insulation in the thermal management system, and component deformation and creep at the sealing interface. The net effect on the fuel cell system is a reduction in efficiency, reliability and service lifetime.

In particular, contamination kations such as Na^{+}, Ca^{2+} and Fe^{2+}, which are washed out from the materials used in the fuel cell system, are absorbed by the membrane and migrate through it. They gather at the cathode and replace the protons locally as a result of electroneutrality. This strong suppression of the proton concentration near the cathode significantly reduces the potential generated by the fuel cell, the so-called Nernst potential. This also greatly increases the cathodic activation potential. Moreover, in the worst case, excessive ion leaching also leads to the formation of pin-holes in the membrane and consequently to hydrogen cross-over to the cathode.

Such effects significantly reduce fuel cell efficiency and lifespan. DSM Engineering Materials has developed special materials with a very high purity that intrinsically reduce ion leaching and greatly improve mechanical performance, even in extreme hydrolytic environments.

High Hydrolysis Resistance Necessary

Fuel cell systems typically operate at temperatures of 70 to 90 °C in almost 100 % humidity and mild-acidic conditions. This can greatly degrade material performance and, in particular, affect long-term mechanical properties such as creep resistance. Components made of materials with low hydrolysis resistance tend to deform and leak at the sealing boundary. To improve the performance of fuel cell components, DSM has developed high-performance plastics and also offers »

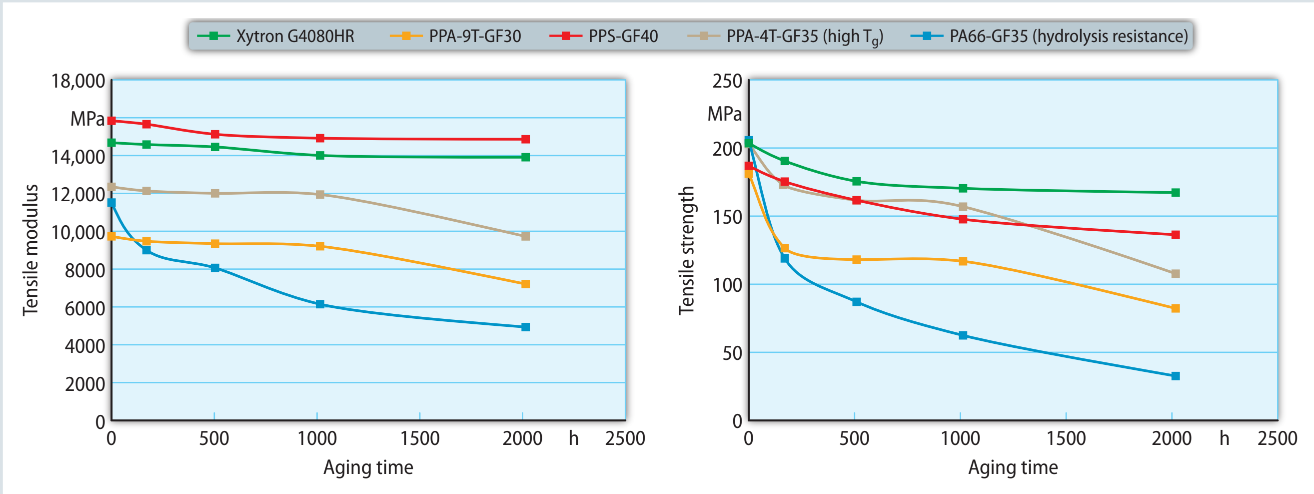

Fig. 3. Comparison of the tensile modulus (left) and the tensile strength (right) of different polymer compounds: the aging resistance of the two PPS compounds is higher than that of the PA and the two PPA Source: DSM; graphic: © Hanser

comprehensive simulation tools to predict long-term hydrolysis performance even under extreme conditions. For this purpose, a complete material and simulation platform based on the polyphenylene sulfide (PPS) Xytron PPS was created. This makes it possible to select the right material to obtain a low ion leaching and a very high hydrolytic resistance.

Avoid Ion Leaching

All polyamides (PA) absorb a certain amount of moisture that attacks glass fibers and degrades interfacial chemistry, resulting in increased ion leaching. Moisture absorption also reduces the glass transition temperature (T_g), which reduces dimensional stability and creep resistance at high temperatures. In contrast, PPS absorbs little moisture (**Fig. 1**). The non-polar molecular structure of the semi-crystalline plastic allows a very good chemical resistance, a low ion leaching and an improved dimensional stability.

DSM has been working to improve interfacial chemistry between glass fibers and polymers during the development of PPS compounds. In this way, the bond between plastic and glass fibers is strengthened and the ion wash-out is reduced to a level that is far lower than any alternative PPS plastic. The ion leaching of the high-performance Xytron G4080HR has been tested and compared to standard Xytron G4020DW-FC and typical competitive PPS compounds. Xytron G4080HR with the special polymer fiber glass interface technology shows the lowest ion leaching and with it the lowest electrical conductivity in the liquid solution (**Fig. 2**).

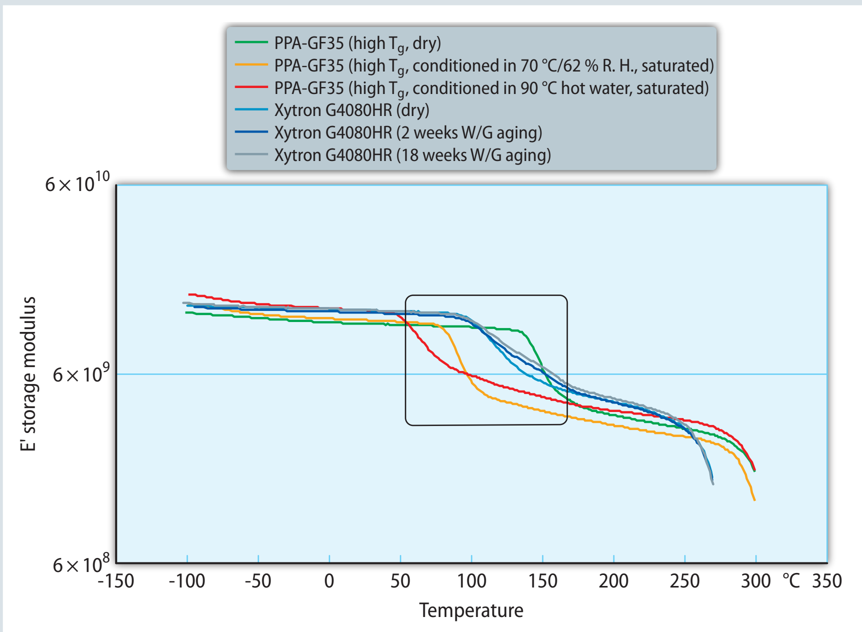

Fig. 4. Comparison of the DMTA storage modulus (elastic modulus) between PPA with high T_g and PPS at different stages (dry as molded, after moisture absorption until saturation and after hydrolytic aging; W/G = water/glycol) Source: DSM; graphic: © Hanser

PPS instead of PA for Fuel Cells

Hydrolysis resistance, as mentioned above, is critical to the high mechanical integrity of fuel cell components exposed to harsh environmental conditions. In general, PPS connections show better mechanical performance compared to any PA. Xytron G4080HR also has higher tensile strength (**Fig. 3**) and better mechanical properties compared to other PPS compounds to ensure the reliability of long-life fuel cell components.

Even after 3000 hours of artificial aging at 135 °C, it remains very stable and shows no T_g shift (**Fig. 4**). In contrast, high T_g polyphthalamide compounds (PPAs) with a glass fiber content of 35 % take less than 250 hours to achieve complete moisture saturation. Even PPAs with the highest hydrolysis resistance and T_g still show a strong T_g-shift from 149 °C to only 68 °C, which leads to a softening and a

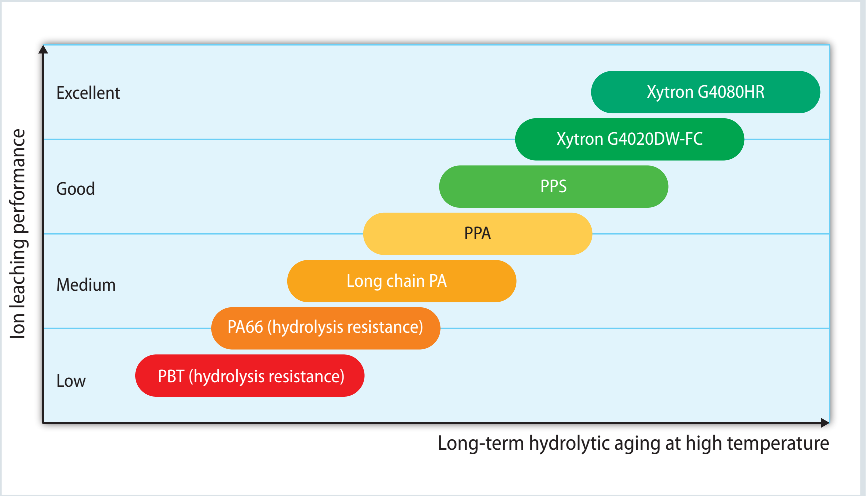

Fig. 5. Compared to other materials, Xytron G4080HR retains its mechanical properties much longer during long-term hydrolytic aging. The ion leaching is also low Source: DSM; graphic: © Hanser

significant reduction in dimensional stability and creep resistance.

At temperatures of 90 °C and a humidity of 100 % – the typical working conditions for a fuel cell system – PAs are completely saturated with moisture after the first hundred hours of operation. In addition to softening, there is therefore a risk of hydrolytic degradation.

10,000 Hours of Measurement Data

Fuel cell parts made from PAs also show dimensional expansion. Characteristics such as creep resistance, mechanical strength and modulus of elasticity also drop, leading to deformation of the components. These fuel cell systems are exposed to a high risk of failure due to creep and deformation at the sealing interfaces. After systematic examination of various polymers in a high-temperature hydrolytic solution, DSM collected over 10,000 hours of measurement data. Xytron G4080HR significantly exceeds other polymers in terms of hydrolysis resistance and retains its mechanical properties most strongly in water and water-glycol systems (**Fig. 5**).

Hydrogen is the most competitive fuel source for the transport sector. This makes it possible to produce vehicles that do not cause emissions during operation and have a low impact on the environment. As a result, they can make a decisive contribution to a climate-neutral society. PEMFC can be used throughout the transport industry.

For commercial vehicles, which typically drive more than 15,000 hours, high-performance plastics for fuel cells significantly increase their reliability. With its very good chemical resistance, dimensional stability and hydrolysis resistance as well as its low ion leaching, PPS is very well suited for fuel cell systems. In addition to suitable materials, DSM also provides design support with special forecasting and modeling options to help manufacturers avoid potential failures in fuel cell systems. ■

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