Addressing the Challenge of Hydrogen Embrittlement in Metallurgy

White Paper

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Hydrogen Embrittlement

In the quest for a decarbonised society, there is no doubt that hydrogen will play an important role as an environmentally friendly fuel source. Hydrogen-based technologies are evolving rapidly, entering the market on a large scale and becoming part of our daily lives. From clean power generation to environmentally friendly cars, the possibilities are endless.

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The transportation sector is a prime example of how hydrogen technologies are taking off and making truly sustainable mobility more tangible than ever. Heavy trucks with hydrogen-powered cells are already hitting the roads. Although developing a global hydrogen refuelling infrastructure might take several years or even decades, the commitment to hydrogen economies from governments all around the world is accelerating its pace.

As a leading manufacturer in motion and control technologies, Parker offers a wide range of products orientated to the hydrogen transportation market, from fuel cell platforms for trucks and buses to hydrogen storage. Our comprehensive product portfolio covers a wide variety of pressures to help design engineers overcome some of the technical challenges of such critical and demanding applications.

The Hydrogen Challenge

Hydrogen is the most abundant element in nature and its versatility can offer compelling advantages as an accessible, sustainable, and efficient alternative source of energy. However, it can be very damaging for most metallic materials, causing what is known as hydrogen damage or hydrogen attack. Being extremely small, hydrogen degradation is directly connected to its capability to be easily absorbed by metals coupled with the high mobility it has on the microstructural level.

Nearly every metallic material can be susceptible to hydrogen damage and there are several forms of hydrogen degradation. Hydrogen embrittlement cracking is the most common and affects the three main areas of industries that use hydrogen, which are production, transportation, and storage.

The hydrogen atoms find preferential places in the structure of the material, modifying its physical properties and mechanical behaviour. The result of the diffusion of hydrogen into the material is a loss of ductility, making it more brittle and more susceptible to cracking.

Hydrogen can be a silent assassin, weakening the material slowly and without any clear signs of damage, often leading to critical failure. The collapse of the San Francisco-Oakland Bay Bridge is one case in point. During the infamous Loma Prieta earthquake in 1989, the top deck on the eastern side collapsed onto the deck below, crushing a number of vehicles. The cause of the collapse was that the bolts failed because of environmentally induced hydrogen embrittlement.

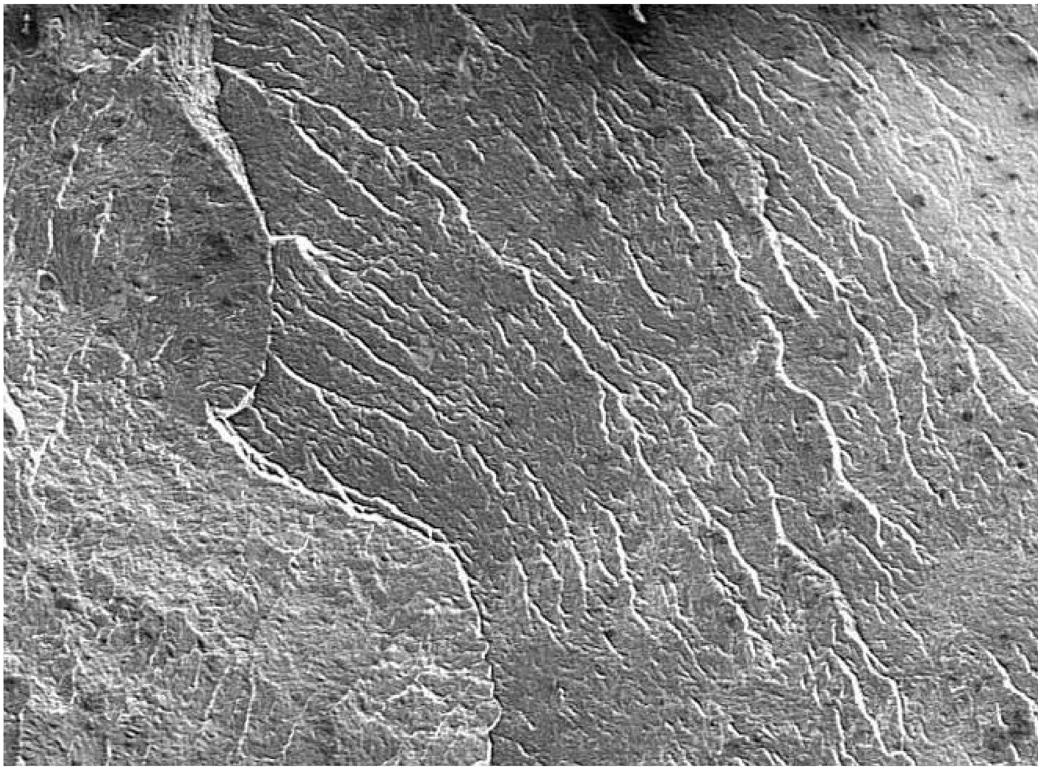
Understanding Hydrogen Embrittlement

Hydrogen and stress need to be present on a susceptible material for a hydrogen-assisted fracture to occur. Firstly, hydrogen absorption can happen during the production and service stages. Processes such as uncontrolled melting, electroplating, or welding can promote the pre-charge of hydrogen into a given metal. In terms of microstructure, and as a rule of thumb, materials that bestow high mechanical strength or show a great number of defects and inclusions are likely to be more susceptible to this type of failure.

The severity of hydrogen embrittlement is also a function of the operating temperature, with low temperatures being the worst-case scenario in terms of material ductility.

The factors that can affect the quality of the microstructure are numerous and have been widely documented by the materials society. Due to the complexity of the subject, the effect of microstructure (as a major contributing factor to hydrogen behaviour) cannot be evaluated in simplistic terms. Taking one variable in isolation is not enough to guarantee the quality or performance of a given component and can be misleading. For example, a material grade with a 'perfect chemistry' or with high levels of a particular ingredient can still result in a very low-quality product.

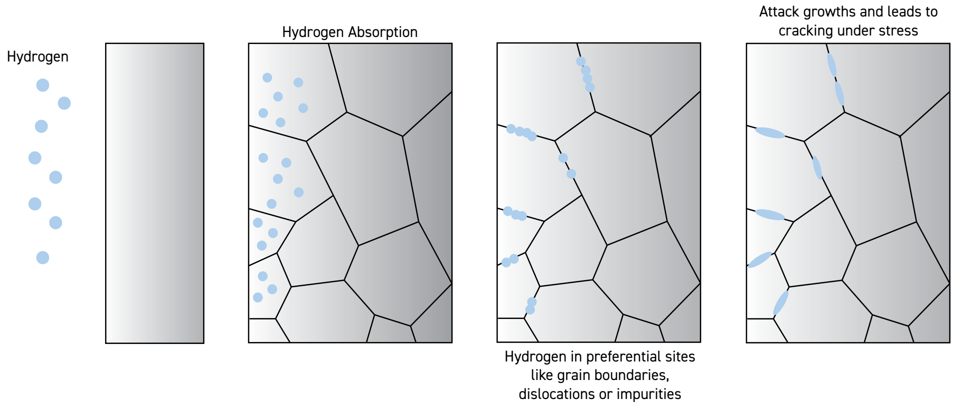
The common consequences of improper and non-controlled material processing, heat treatment and / or manufacturing operations are high densities of undesirable phases and inclusions in the raw material. These will inevitably lead to premature hydrogen-assisted cracking during service, particularly in demanding H2 environments. Material processing is therefore key.



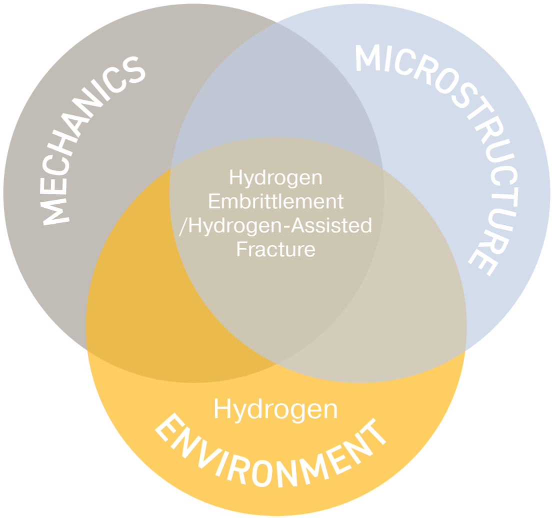
Crack Propagation Detail on A Brittle Fracture Surface due to Hydrogen

Also, the mechanics of the application play a major role. Stress states in components can be caused by the presence of residual stresses associated with certain fabrication techniques as well as stresses applied during service. Improper product design and improper installation can cause overloading of stress onto the material.

All of these factors can cause premature failure of components in hydrogen service. When it comes to handling hydrogen, therefore, material and equipment selection becomes, more than ever, an essential ingredient for success.



Innovating the Hydrogen Sector



The International Industry Standard ISO 15916-2015 provides guidelines for the use of hydrogen in its gaseous and liquid forms as well as its storage. Most metals are susceptible to different levels of hydrogen embrittlement. To avoid failure, material construction and suitable equipment must be carefully selected, especially when hydrogen exposure is anticipated. The positive news is that hydrogen embrittlement can be prevented.

As a manufacturer of pressure containing equipment, Parker has decades of experience in serving hydrogen applications. The Parker Bestobell range of valves are designed and engineered for the transportation, storage, and processing of numerous cryogenic liquified gases, including hydrogen and, since the early 1980s, Parker has been producing valves to the BOC specification for use with hydrogen.

Parker products are designed to minimise the risk associated with corrosion and hydrogen attack, providing safe and reliable operation, minimising leak paths and ultimately delivering successful performance in the field. The raw materials used are fully traceable and closely controlled from melting stage to the finished product.

In addition, Parker's manufacturing processes are selected to ensure minimum operating risk in hydrogen environments. As well as stainless steel, which is the material of choice for the hydrogen transportation sector, a variety of nickel alloys are available for a wide range of other applications.

Parker's portfolio also includes EC-79 approved products, which is an EU regulation for components and systems that are installed on hydrogen-powered vehicles. Product ranges certified to this regulation, including the two ferrule compression fittings A-LOK® series, are tested extensively to guarantee the safety and performance of hydrogen equipment under different pressures, electric, mechanical, thermal, or chemical conditions.

For more information about how Parker Hannifin is supporting the energy transition and safe deployment of hydrogen as an environmentally friendly alternative fuel source, please visit: www.parker.com/hydrogen-service

A-LOK® two ferrule tube fittings EC-79 approved for use on-board hydrogen-powered vehicles up to 350 barg.

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