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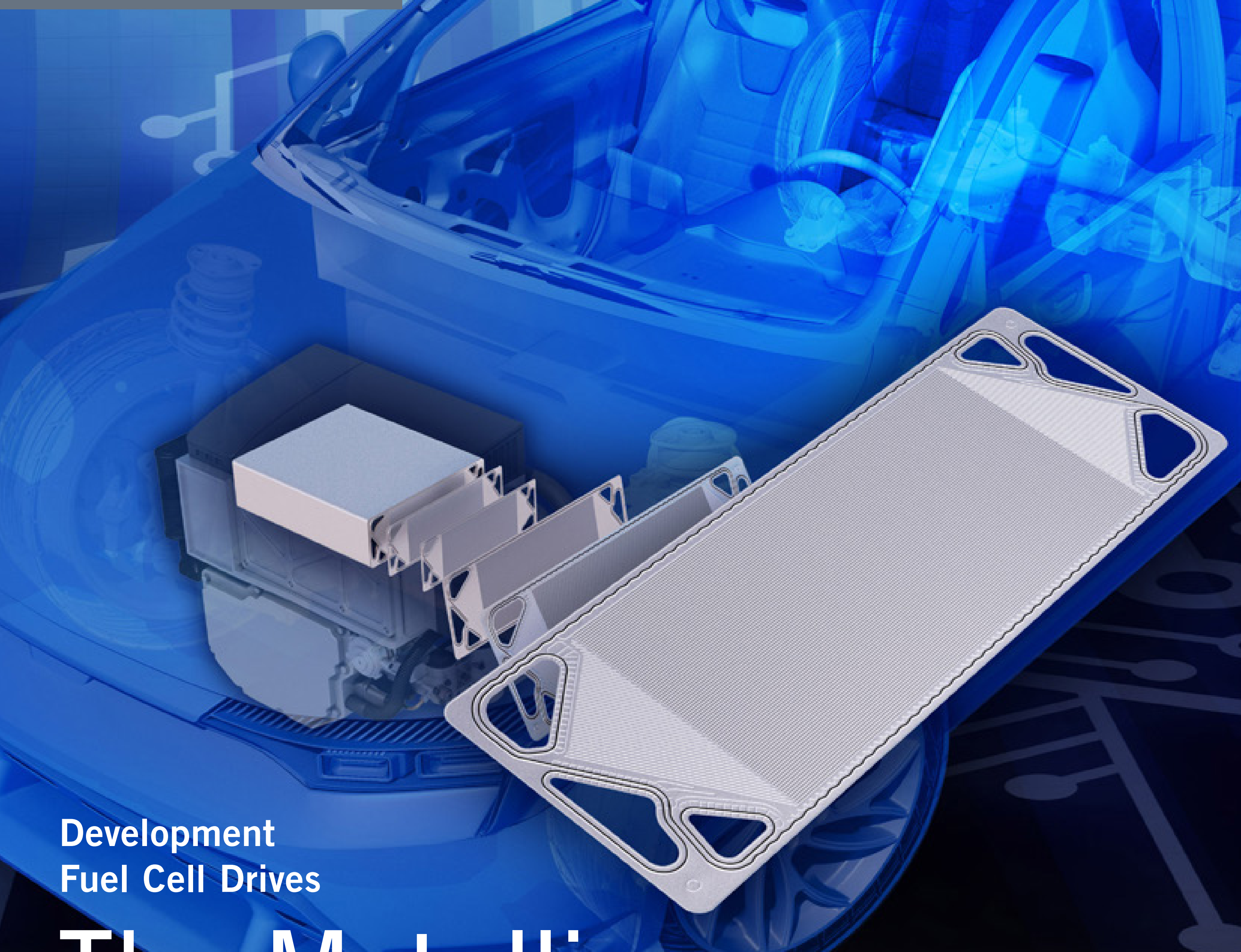
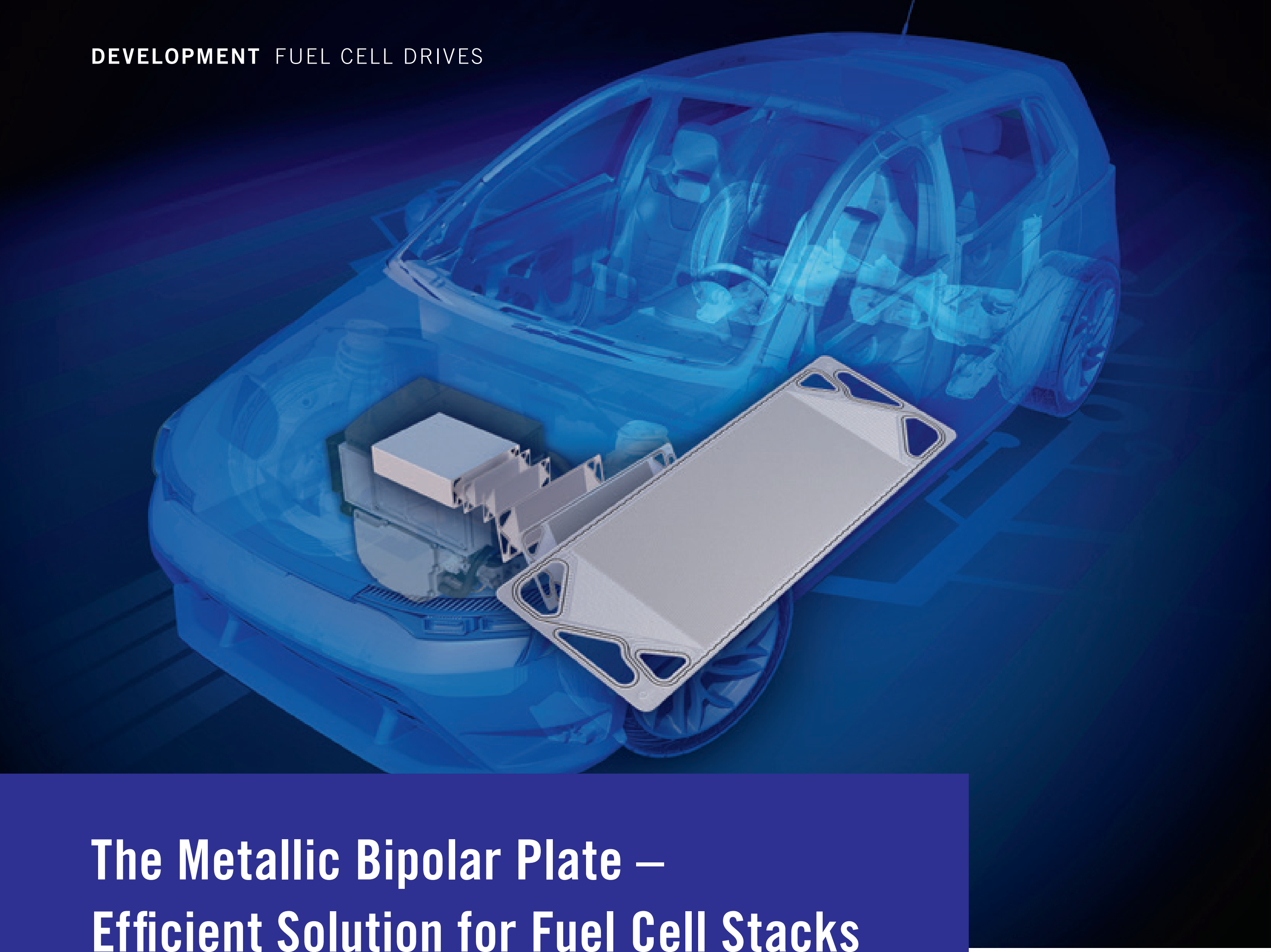


Development
Fuel Cell Drives

The Metallic Bipolar Plate

DANA



The Metallic Bipolar Plate – Efficient Solution for Fuel Cell Stacks

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Fuel cell technology has the potential to change mobility in the long term. So far, however, this form of powertrain has not been able to gain widespread acceptance, not least because of the high cost of fuel cell stacks. The metallic bipolar plate from Dana is intended to change this and drive forward the commercialization of the fuel cell.

The bipolar plate is a critical component of a fuel cell stack that Dana has been designing and manufacturing for more than 20 years. The research and development team of the U.S.-based company uses the technological know-how of multi-layer steel cylinder-head gaskets in the design of the component – including perfected steel processing, bead seal technology, and coating technology. The result is a highly integrated component solution that allows stack costs to be reduced. Currently, nearly 100,000 metallic bipolar plates are produced per year at the German site in Neu-Ulm. Management expects an increase in demand on the passenger and commercial vehicle markets in the coming years and is aligning production capacity accordingly.

FUNDAMENTAL DESIGN

The bipolar plate largely determines the power density, weight, and cost of a fuel cell stack. The basic layout of the metallic bipolar plate therefore decides the efficiency of the fuel cell system. Throughout the fuel cell's life cycle, the bipolar plate must maintain the sealing integrity and ensure that the hydrogen, air, and coolant (fluids) are evenly distributed. The seal itself must allow little media permeation. In addition, the plate must have high electrical conductivity with low contact resistance, highly efficient thermal management, and great chemical stability against corrosion. All this has to be provided at low production

AUTHORS

Bernd Gaugler
is Project Manager Research and Development Fuel Cell at Dana Incorporated in Neu-Ulm (Germany).

Rainer Glück
is Project Manager Application Fuel Cell at Dana Incorporated in Neu-Ulm (Germany).

Andre Speidel
is Project Manager Research and Development Fuel Cell at Dana Incorporated in Neu-Ulm (Germany).

Thomas Stöhr
is Project Manager Application Fuel Cell at Dana Incorporated in Neu-Ulm (Germany).

costs in extremely high quality for use in large series [1].

The bipolar plate forms the basic stack structure and framework. The compression level of seals and active layers throughout the stack is determined by the plate design. The development team uses a wide range of simulation models, from Computational Fluid Dynamics (CFD) to the Finite Element Method (FEM) to optimize the basic design to individual customer specifications at an early stage.

The model calculation for even distribution of the three fluids encompasses the circa 300 intricate channels of the metallic bipolar plate – circa 100 per medium, **FIGURE 1**. The second step is to calculate the cell to cell flow distribution. Channel design and harmonization is extremely important to ensure optimum operation of the fuel cell in the long term.

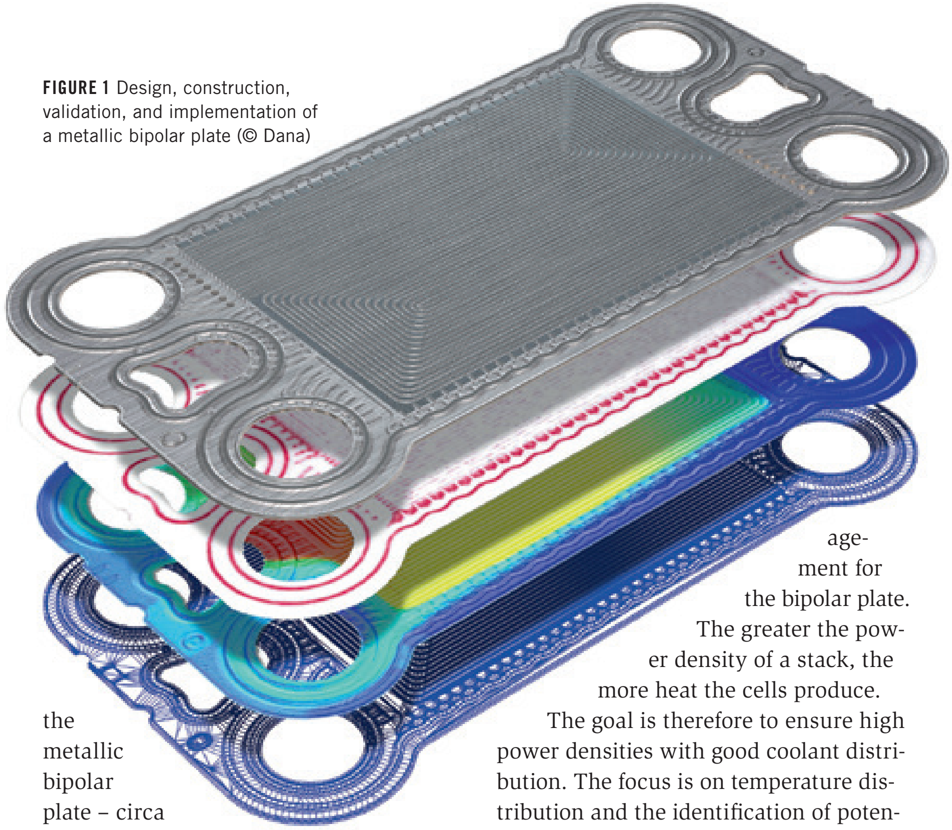

FIGURE 1 Design, construction, validation, and implementation of a metallic bipolar plate (© Dana)

The goal of flow simulation is to achieve an even flow through all individual channels in the stoichiometrically correct ratio across all operating conditions. A typical stack has 300 plates for a total of around 90,000 individual channels. The media is separated via the stamped plates' integrated sealing system and the bead seals.

Stamping the intricate channels in 75-µm stainless steel film requires high degrees of deformation. It is especially challenging to calculate the bead seals with homogenous pressure distribution, since the seal system affects adjacent stack components and the clamping system. Hydrogen, the smallest chemical molecule, creates additional quality demands of the sealing system. The force distribution between active layers and bead seals must be ensured within defined limits in continuous operation under the influence of temperature, even after thousands of working hours, so that the fuel cell continues to produce energy without significant performance loss.

The trend toward packaging space reduction is affecting fuel cells as well. This increases demand on thermal management for the bipolar plate. The greater the power density of a stack, the more heat the cells produce. The goal is therefore to ensure high power densities with good coolant distribution. The focus is on temperature distribution and the identification of potential hotspots that could cause such problems as damage to the membrane.

The strength and deformation analysis, combined with numerical fluid mechanics, is among the core competencies of the company working in the sealing systems area. This expertise is available without restriction for developing and designing metallic bipolar plates.

STAMPED SEALS

The metallic bipolar plate consists of two formed and connected stainless steel foils, the inner surfaces of which form a cooling layer. Each individual foil is 75 µm thick. The two original foils together are about 150 µm high, but the construction resulting after the channels and metallic ribs have been stamped is almost seven times that. The robust, leak-proof stainless steel foil connection is made with a high-speed laser welding process.

The tool technology used for stamping the integrated bead seals and the flow field is a refinement from multi-layer steel cylinder head gasket production. Each individual plate of circa 40 × 15 cm has about 4 m of stamped seals – accordingly, around 1200 m in the entire stack.

Bead seals are stamped, and the plate punched in a single stroke, so that all punching, and stamping processes are

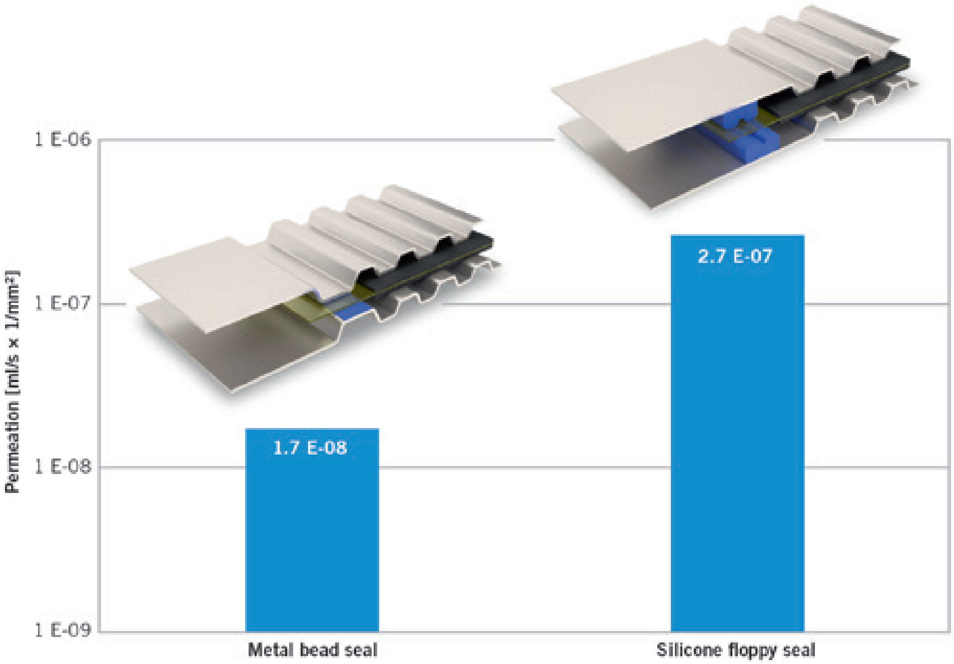

FIGURE 2 Permeation values for metallic bead seals compared to those for elastomer seals (© Dana)

performed in a single work step. This is a huge cost advantage over conventional solutions involving subsequent integration of sealing technology. Finally, an elastomer is applied to the rib as a microseal.

The metallic bead seal also has excellent gas tightness and very low permeation, **FIGURE 2**. The metal bead makes up 90 % of the seal height, elastomer 10 %. The stable sealing system is attractive because of its very great adaptability and optimum resilience thanks to the metallic bead seal.

Another advantage is the repeatability that comes from the precision tools used for punching and stamping. Any deviations due to systematic errors can often be traced back to insufficient precision. This leads to so-called banana stacks which make reliable sealing difficult, since errors propagate when the plates are stacked.

Beside their sealing function, the bead seals offer a unique solution for fluid transfer. The seal cross-sections are tunneled horizontally on both the anode and cathode side to conduct hydrogen, air, and coolant, **FIGURE 3**. The circumferential bead seal concentrates the gases optimally in the active area of the metallic bipolar plate.

FUNCTIONAL COATING

The stainless-steel foil that serves as starting material is designed to handle the fuel cell's operating conditions. But the stainless steel's chromium oxide layer has high contact resistance. That is why the bipolar plate is partially – about 40 % of the surface – coated with a carbon-based material at the active contact points to the gas diffusion layer, **FIGURE 4**. This coating ensures great electrical conductivity, and its partial application keeps material and production costs low. The coating procedure can be carried out in the normal production environment. Stainless steel's protective properties remain intact even at uncoated areas. The 300 bipolar plates of the stack are coated over a total surface of around 7 m².

The coating is an in-house development and reduces the overall resistance from the plate to the coating to the Gas Diffusion Layer (GDL) by up to 90 %. The measurement is made in a Through-plate Resistance (TPR) test procedure.

DEVELOPMENT-RELATED VALIDATION

During the course of development various test procedures for quality control are used. The focus is on the sealing functions. Electrochemical analysis of the stainless steel's chromium oxide layer and TPR test processes to determine the character of the electrical resistance are the basis

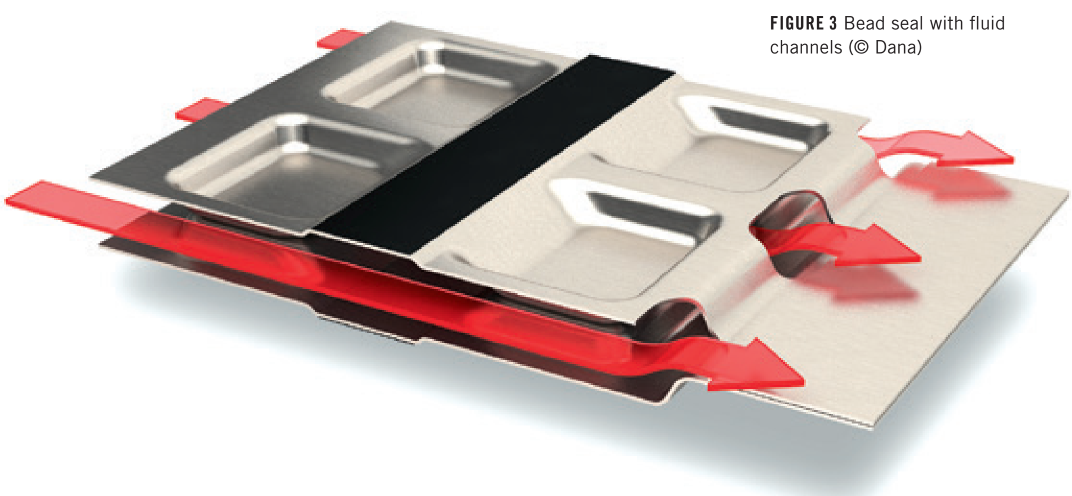

FIGURE 3 Bead seal with fluid channels (© Dana)

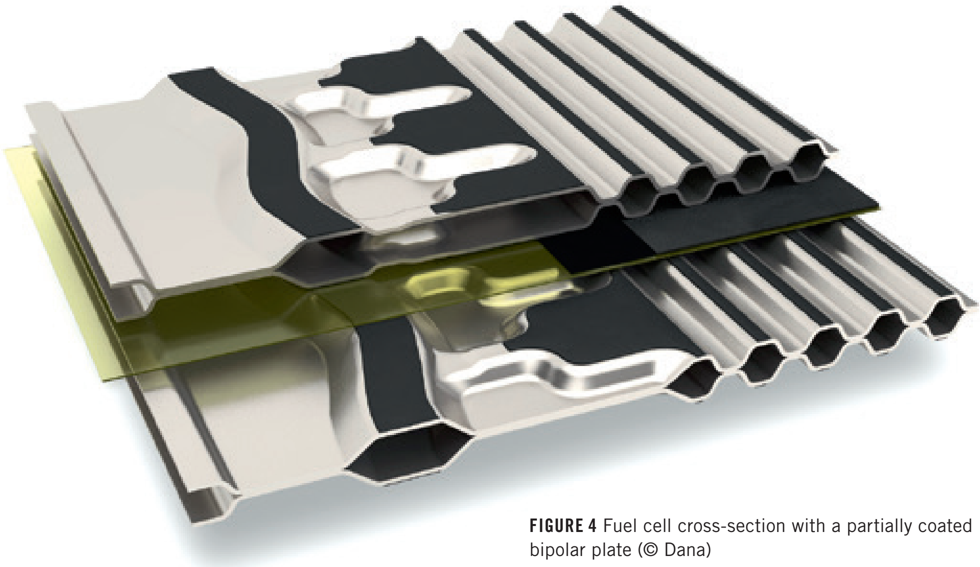

FIGURE 4 Fuel cell cross-section with a partially coated bipolar plate (© Dana)

of development and are monitored throughout the process.

During helium leakage measurement, the metallic bipolar plate is placed in a vacuum chamber and subjected to fluctuating temperatures from -40 to +110 °C and various gas pressures and compression conditions to confirm the required leakage values, **FIGURE 5**.

FIGURE 5 Fuel cell stack helium leakage measurement (© Dana)

To evaluate plate performance in practical application, in situ measurements with fully functional fuel cell stacks on fuel cell test rigs are performed, **FIGURE 6**. The goal is testing the bipolar plate together with stack components in a realistic setting.

COST SAVINGS

The highly integrated metallic bipolar plate reduces the total cost for fuel cell stack by up to 10 %. The two reasons are the integration of the sealing system and the design of the conductive functional coating.

The stamped bead seals are an integral part of the plate and contrary to inlay seals, do not require any further assembly processes. What is more, additional sealing material is not required except for the elastomer for the microsealing. The complete sealing system is basically supplied as add-on. Since stamping of the bead seals and punching of the plate are performed with a single stroke, the energy costs in the production process are reduced as well.

This also applies for the partial conductivity coating that is applied using a particularly efficient process. Thanks to the partial coating of only 40 % of the plate surface the material costs are also clearly reduced.

SUMMARY

In his 1875 book "The Mysterious Island," Jules Verne writes about fuel cells: "I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable." Metallic bipolar plates are a big step toward implementing this vision, since this component for fuel cell stacks allows a higher energy density than before at significantly lower manufacturing costs and has proven to be suitable for large-scale production.

Globally, 20,000 passenger vehicles are equipped with a fuel cell drive. Currently, great interest for fuel cells is coming from long-haul cargo vehicles. The fuel cell technology outlined is designed for universal application in passenger cars, buses, utility and

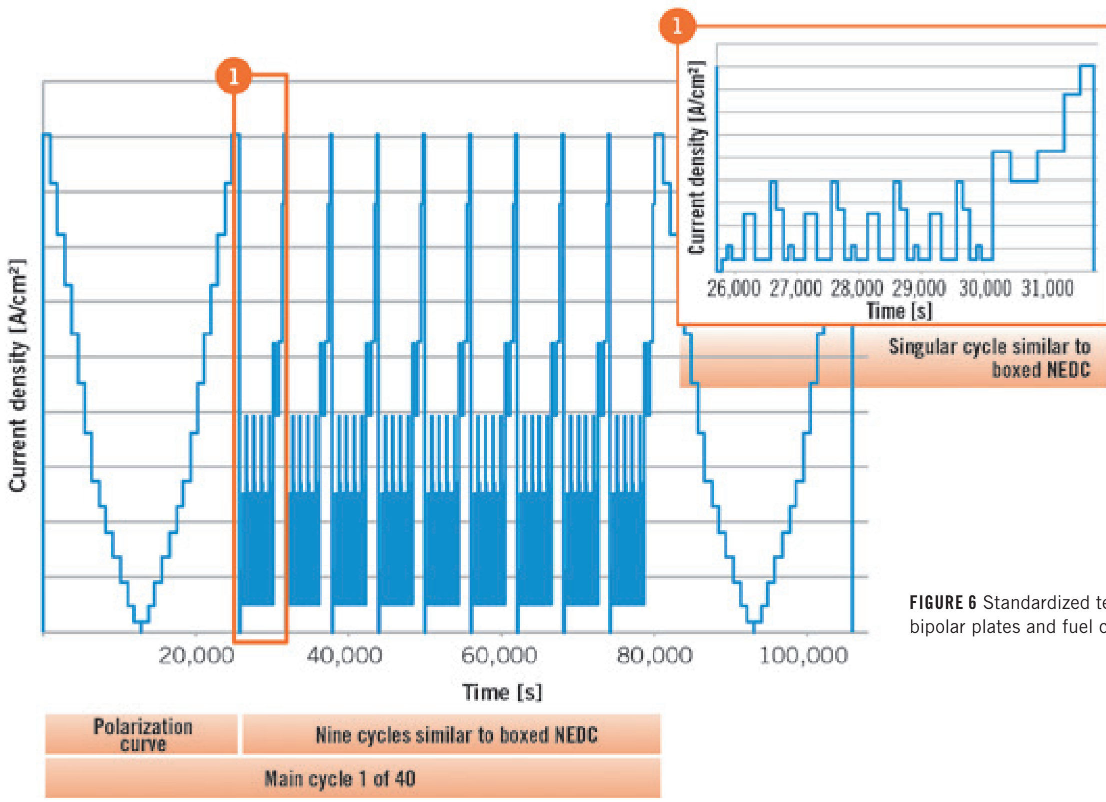

FIGURE 6 Standardized test sequence for qualifying bipolar plates and fuel cell components (© Dana)

off-highway vehicles. Fuel cells with bipolar plates are already making an important contribution to climate goal achievement in maritime applications and industry. Germany's national hydrogen strategy [2] is another important signal in favor of the fuel cell. Dana's metallic bipolar plate is creating ideal conditions for efficient commercial use of hydrogen fuel cell technology – for sustainable mobility and climate protection.

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MANAGING DIRECTORS:
Stefanie Burgmaier | Andreas Funk | Joachim Krieger

PROJECT MANAGEMENT: Anja Trabusch

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