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Flying Fuel Cells and the challenges for bipolar plate forming

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Flying fuel cells as enabler for sustainability in aviation

The impact of increasing resource scarcity and climate change has significant implications for aviation. As a result, the European Commission has set ambitious targets of a 75 percent reduction in CO_2 and a 90 percent reduction in NO_x as part of the Flightpath 2050 vision. Achieving these goals requires the use of breakthrough technologies in aviation, especially in propulsion systems. In so-called urban air mobility, all-electric battery-powered concepts are favored. For short- and medium-range flights, in addition to hybrid propulsion concepts, fuel cell concepts in particular are being developed. For medium- to long-range flights, the use of sustainable aviation fuel (SAF) as well as the direct combustion of hydrogen in turbines are suitable.

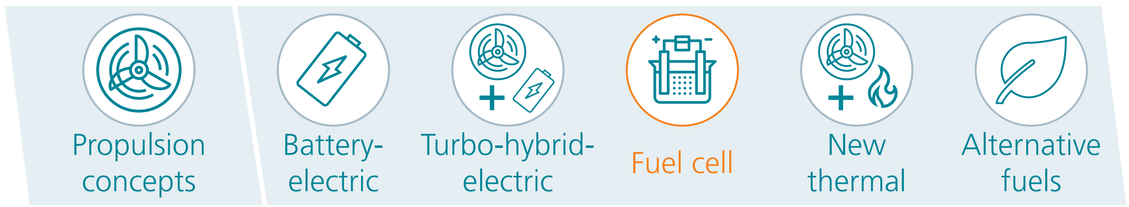

Illustration of the sustainability goals of aviation and the required propulsion concepts

Disruptive propulsion concepts are necessary to achieve the sustainability goals in aviation, especially the use of a fuel cell as an energy converter

Challenges for flying fuel cells and bipolar plates

A fuel cell integrated into an aircraft acts as an energy converter so that the primary electric drives can be supplied. As in already known applications, the basic structure of the flying fuel cell consists of a coated polymer membrane enclosed by two bipolar plates which, being stacked, form a fuel cell stack. The use in aviation requires a lightweight and powerful fuel cell, so that an increase of the gravimetric power density is necessary. As well as the fuel cell, this also affects all necessary components (balance-of-plant, BoP) of the overall system, such as tanks, pumps, compressors, etc. Furthermore, different power profiles for take-off/landing or cruise and very high safety and certification requirements must be considered.

The bipolar plate is manufactured in a complex process chain with forming at its core. The requirements for the overall system imply that in particular due to the use of very thin materials (< 100 µm) and the complex geometry of the bipolar plates, high degrees of forming must be achieved. The tolerances are very close due to the high number of bipolar plates in the stack and the resulting tolerance chain. Furthermore, anisotropy and material discontinuities must be considered due to the high safety requirements.

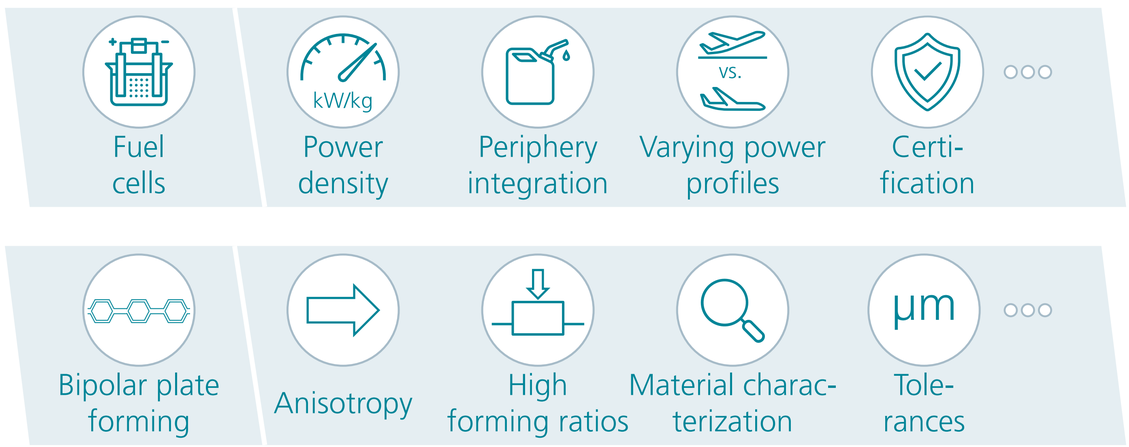

Illustration of the challenges for the flying fuel cell and the resulting challenges for the bipolar plate forming process

The challenges for bipolar plate forming require intensive activites of material characterization, forming simulations and process monitoring

Material characterization

The objective for bipolar plate forming is to use materials that are as thin as possible while ensuring the required properties, considering necking or thinning. Using the Nakajima and Erichsen test, forming limit diagrams can be generated as a function of the plate thickness. For this purpose, several specimens are formed to the point of failure using a hemispherical or round punch, allowing an analysis of the maximum form changes. The forming limit diagrams can be used to investigate the influence of the sheet thickness on the forming process and the damage development by considering relevant properties such as contact and corrosion resistance or electrical conductivity. Thus, the material characterization is used to determine input variables for the simulation.

Material characterization is required to form the thinnest possible material thicknesses

Forming simulation and optimization

Numerical FE process simulation based on the tool used can be applied to analyze the following characteristic values during the forming process:

- Von Mises equivalent stress
- Stress triaxiality
- Maximum in-plane logarithmic strain
- Out-of-plane logarithmic strain

Based on the simulated stresses, various geometry elements and parameters such as material, embossing speed and friction coefficients can be analyzed. Examples at the WZL show that an evaluation of the occurring process forces and critical stresses of workpiece and tool is possible.

Process parameters can be optimally configured by means of FE simulations

Process monitoring and digitization

Digitization is the enabler for high-performance process monitoring. Sensors are required for data acquisition. Data preparation is then required to correct tilts and drifts as well as for segmentation and the application of autoencoders, etc. Subsequently, a technological analysis and process monitoring can be performed.

Investigations at the WZL show a good example: Sensors are used to acquire acoustic emissions as raw data. Afterwards, further data processing can be performed using autoencoders, so-called unsupervised learning algorithms, so that the mean square error (MSE) can be plotted over the number of strokes. The result is a correlation of the acoustic emissions with the wear states during the forming process.

Process monitoring using process noise enables analysis of the wear condition

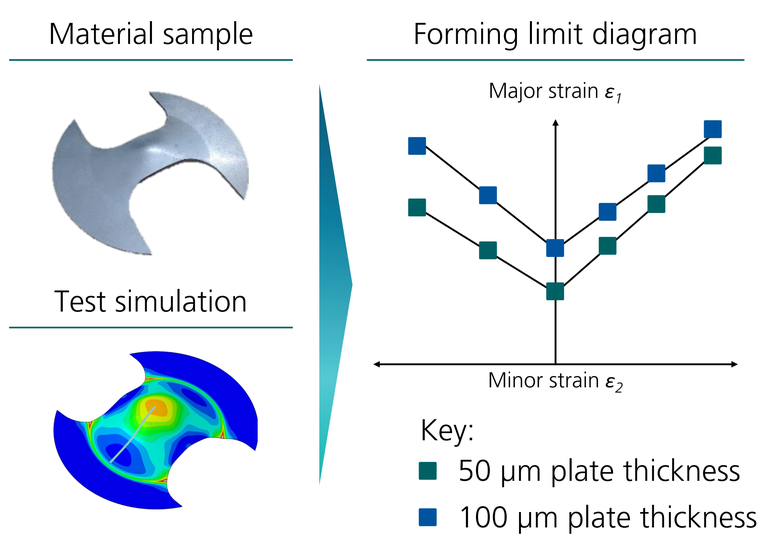

Illustration of a formed Nakajima specimen, a simulation of the test procedure, and a forming limit diagram

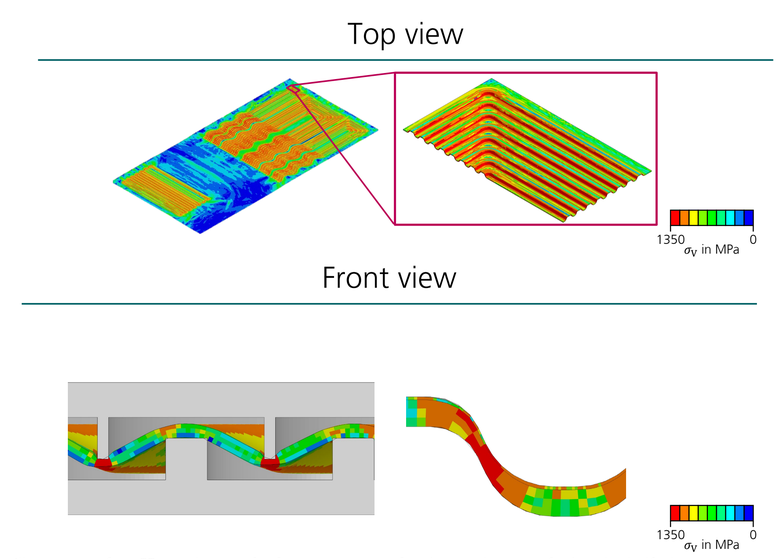

Illustration of an FE simulation of a forming process for the production of a bipolar half-plate in different views

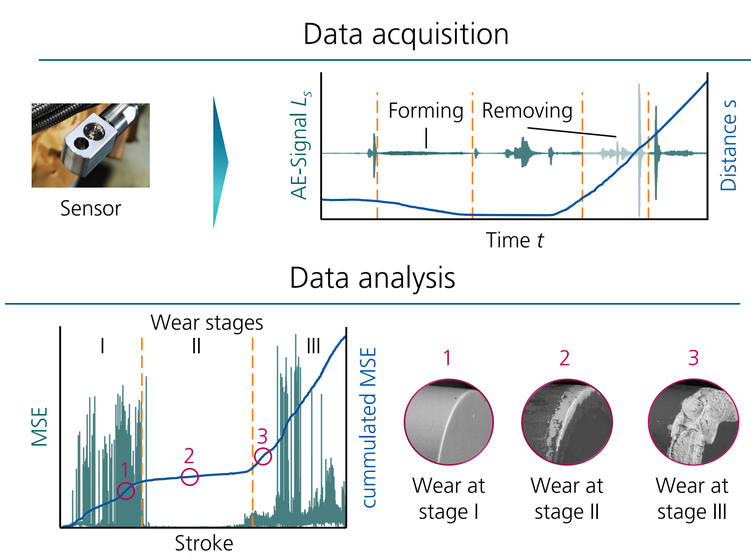

Illustration of a sensor for the acquisition of noise emissions, a plot of the processed AE signal over time and the mean squared error (MSE) over the number of strokes

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