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NOVEL APPROACHES IN CHARACTERIZATION AND MODELLING OF FABRICATION PROCESSES FOR SRF COMPONENTS

J.S. Swieszek,[1,2], M. Garlasché, A. Gallifa-Terricabras, D. Smakulska,
[1]CERN, Geneva, Switzerland, [2]Kraftanlagen Nukleartechnik GmbH, Heidelberg, Germany

Abstract

In the past years, FEM have been increasingly applied at CERN, with the aim of modelling fabrication processes for SRF components. Currently, many large deformation processes are being simulated. Taking the initial trials out of the workshop to the simulation has proven very efficient for steering the fabrication strategy, avoiding unnecessary trials, and helping to reduce the time and costs. This contribution presents a novel approach for studying fabrication process feasibility and failure prediction using numerical tools, based on the Forming Limit Diagram method developed for OFE copper sheets. The mentioned method is used to study tubular hydroforming, as an alternative way to produce seamless elliptical RF cavities, together with the analysis of past hydroforming trials and the comparison of different fabrication strategies.

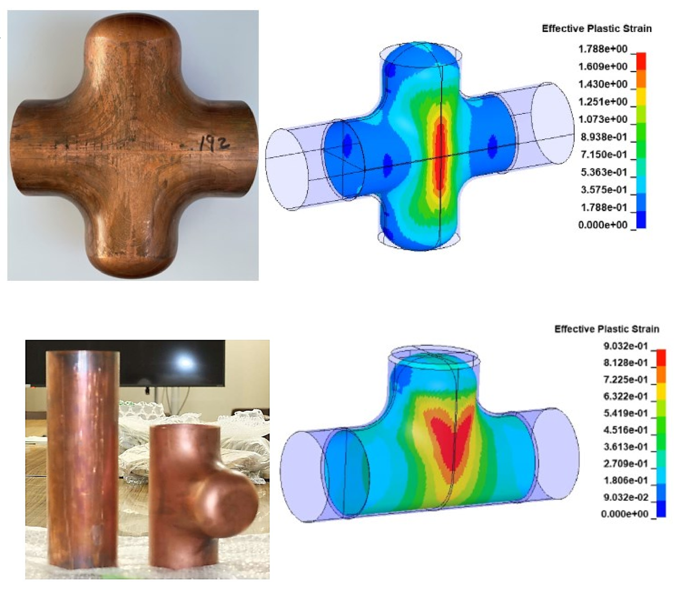
Forming Limit Diagram FLD

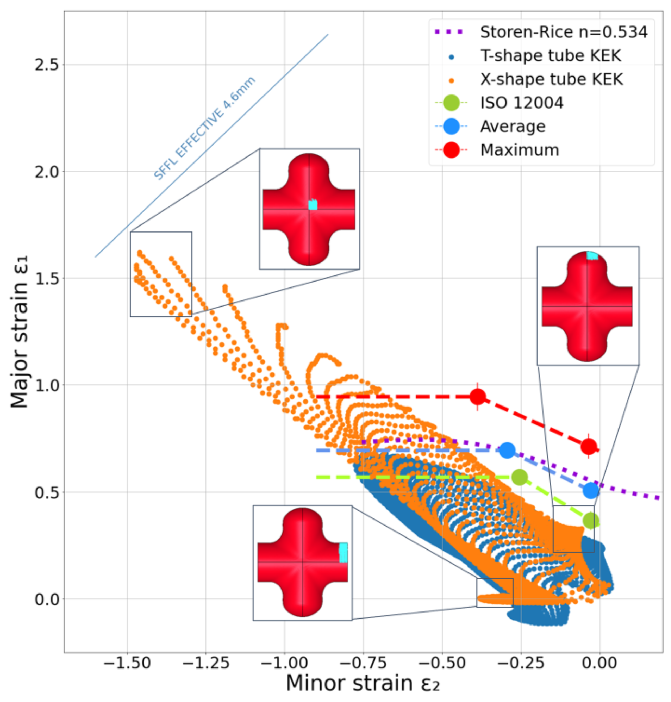
To assess the feasibility of a given process through FEM, an appropriate failure criterion is needed. FLD is a standard approach to predict failure in metal sheet forming. It corelates the minor vs. major principal strains for every volume in the formed piece. FLD for thick OFE-copper sheets was recently developed at CERN, in the view of studying and optimizing fabrication processes for cavity substrates.

Benchmark pieces: hydroformed T-, X-shapes*

- Compare the real process with simulation
- Validate material and failure model

The fabrication process was simulated using LS-Dyna explicit code. The simulation outcome was compared with metrology results, showing very good match in the piece final geometry, thickness, and strain.





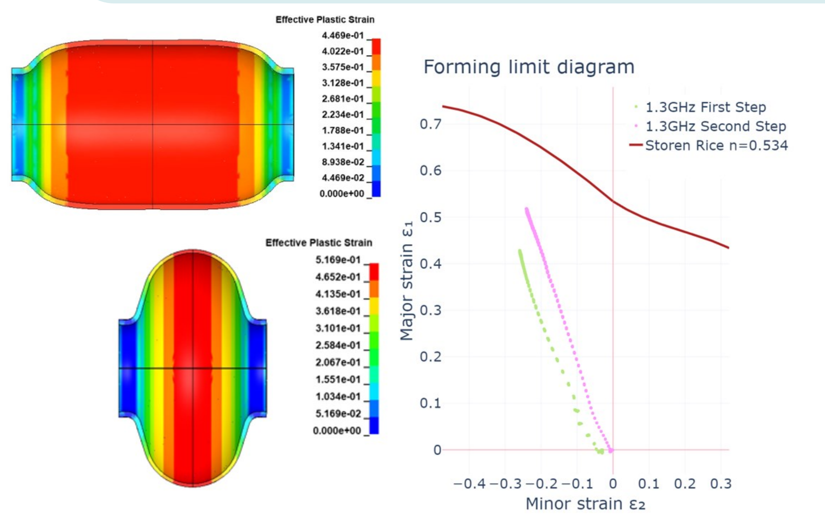
The analysis of in-plane true strains using FLD shows how such forming reproduces "pure shear" - like deformation, thus allowing for extensive feasibility to be reached. This study validates the shear fracture limit (SFFL) and onset of necking (FLC) which is in line with analytical Storen-Rice model.

Strategy for Hydroforming

Process guidelines for manufacturing 1.3 GHz copper substrate as proof of principle, were defined: apply internal pressure simultaneously with the axial displacement, while closing the molds. Within this baseline process two options were identified and:

- optimized through simulations,
- studied based on detailed material characterization,
- proved feasible, verified against failure model.

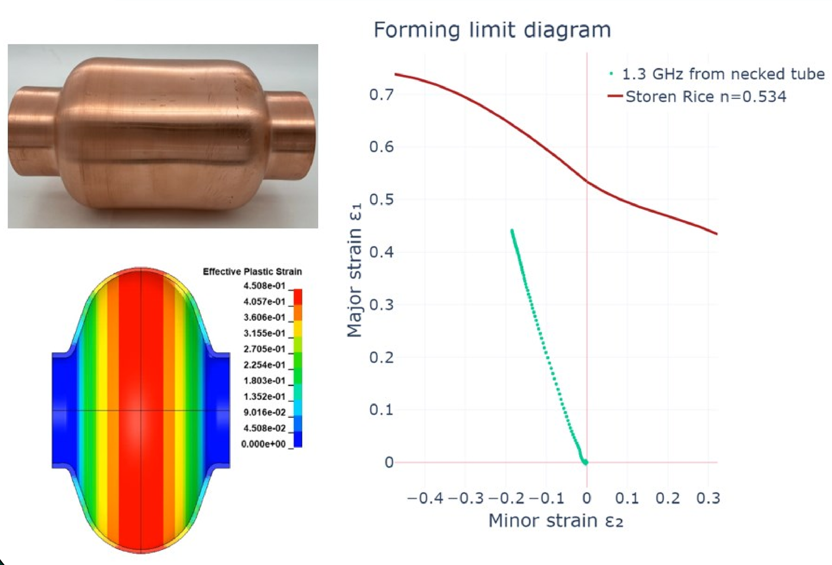
1) Hydroforming– Annealing – Hydroforming



- only two hydroforming steps with one intermediate heat treatment needed to form a 1.3 GHz cavity shape from a straight tube
- balanced approach, reaching similar levels of deformation in each step
- sharp increase of pressure to initiate bulging and then pressure decrease
- displacement increased linearly

Baseline strategy, considering manufacturing of 400 MHz cavity.

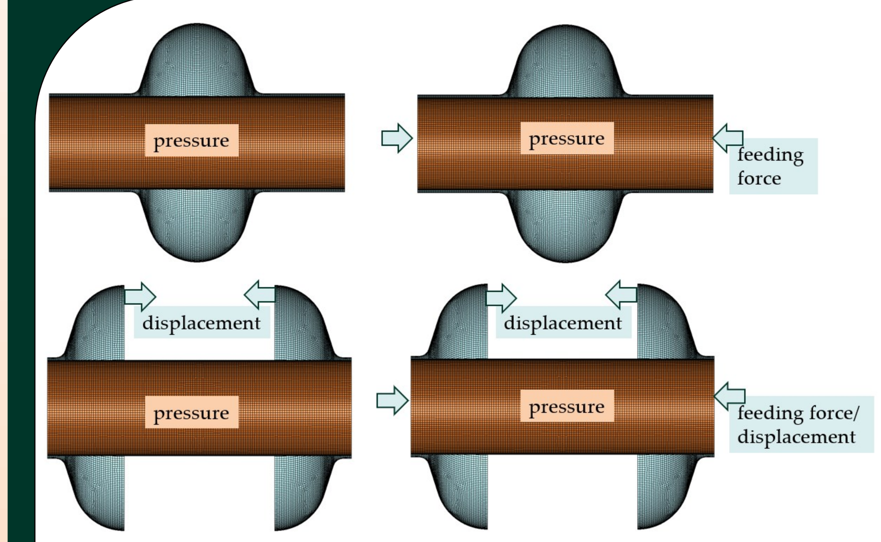
2) Spinning – Hydroforming



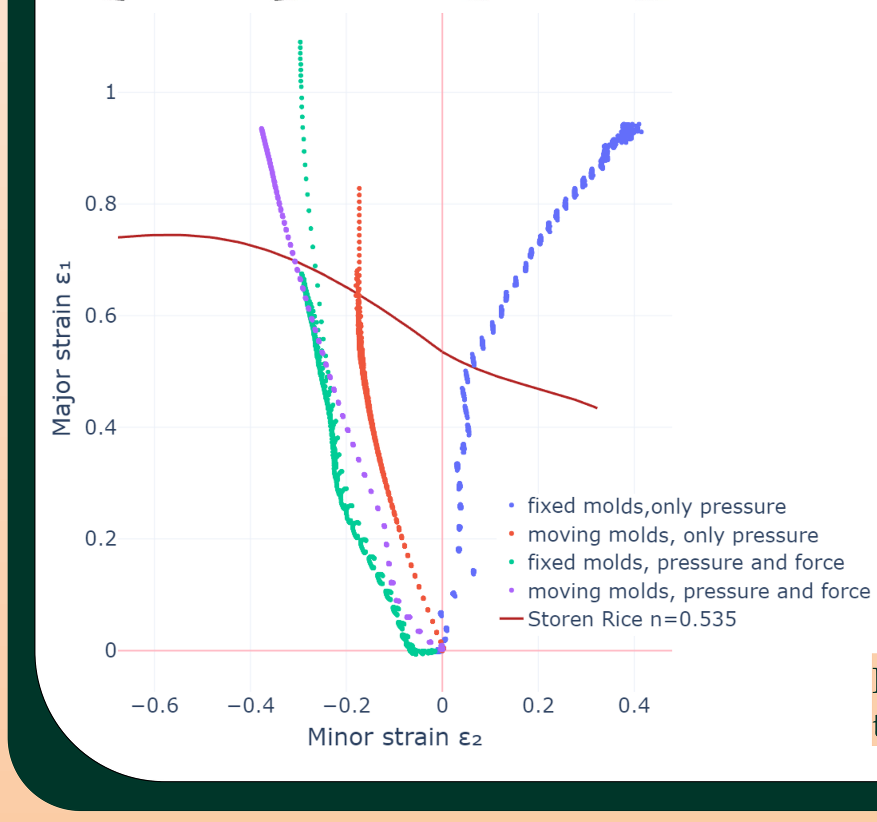
- start with bigger tube initially deformed into an intermediate shape by spinning
- one hydroforming step to reach final shape
- target necked shape studied and optimized
- potentially eluding the need of any intermediate heat treatment
- Less thinning w.r.t 1) but two fabrication processes need to be mastered

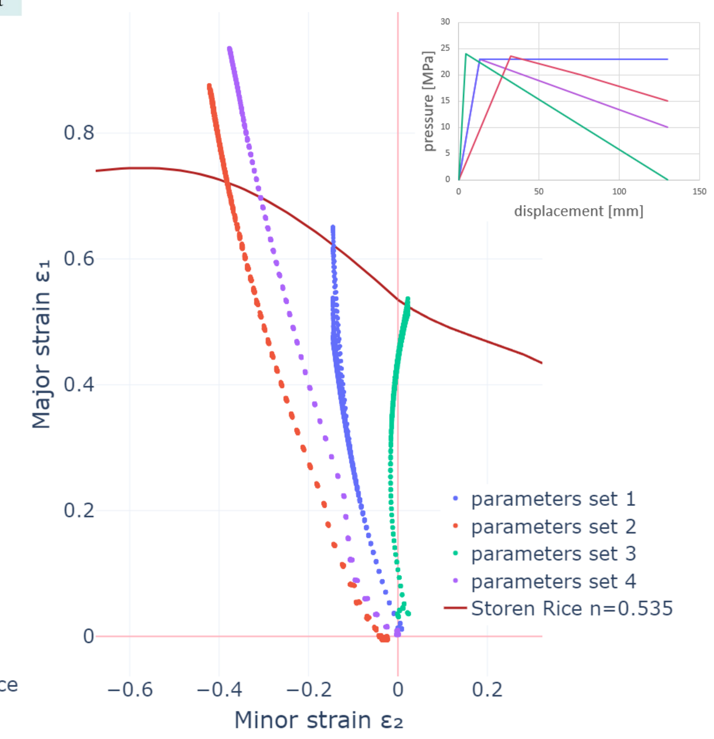
FEM vs. history of hydroforming for SRF cavities

Four different types of hydroforming (HF) processes are simulated and compared, assuming one-step hydroforming starting from an initial straight tube, to 1.3 GHz cavity shape.



The most efficient way to hydroform the cavity shape is by applying internal pressure simultaneously with axial displacement of each end of the tube, and with coinciding closing molds. It can be observed how, just by changing the process parameters slightly, the straining paths change significantly.

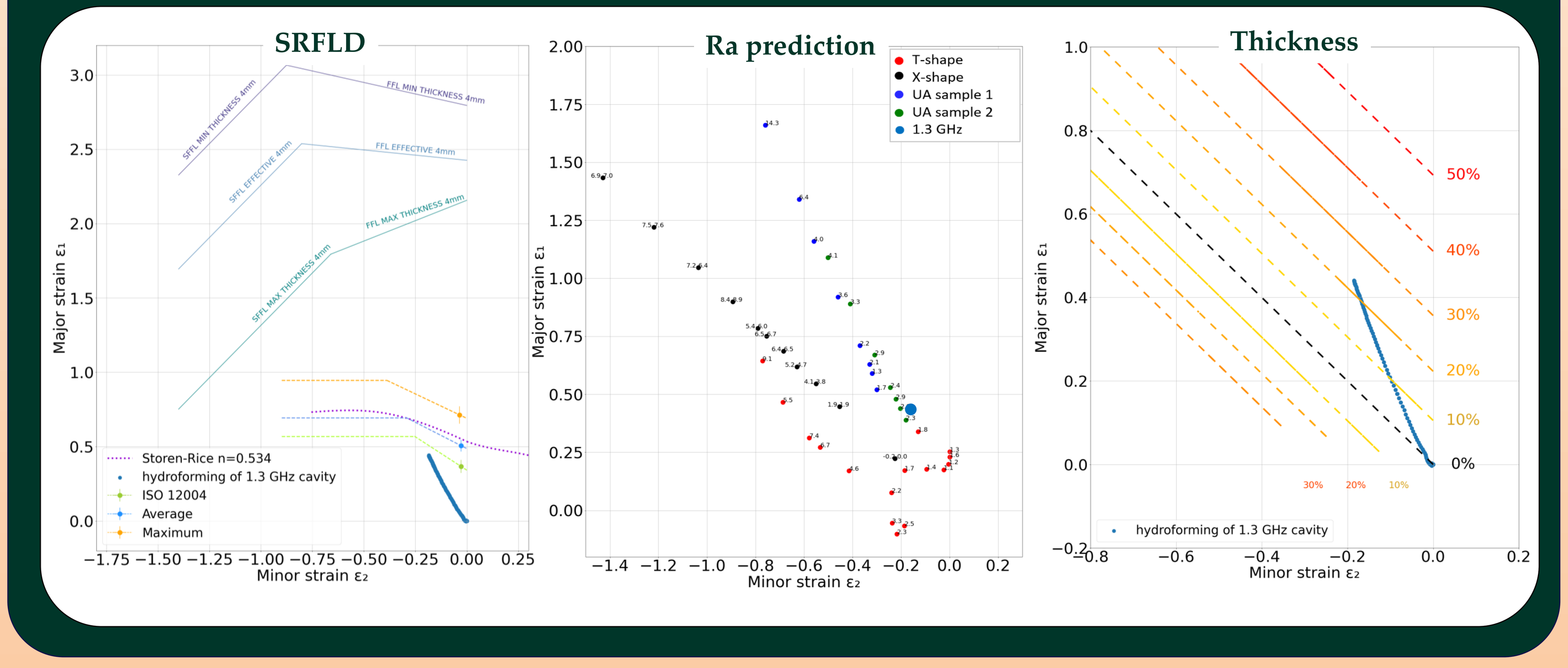




Feasability is highly dependent on the process parameters.

Novel approach of failure for SRF application: SRFLD

Recent advancements at CERN in the field of fabrication modelling and feasibility studies have been directed towards expanding the scope of the standard FLD to accommodate SRF applications. This is achieved through the introduction of a novel framework named SRFLD, which aims to provide not only the 'standard' forming limit failure model, but also a comprehensive tool for predicting key parameters of interest, including final surface roughness and thinning, thus embedding failure considerations for both fabrication processes and for SRF scenarios, within the same set of visual forming limit diagrams.



Conclusions

This study gives an overview of the numerical methods for modelling large deformation processes, focusing on the HF seamless substrates. HF, as for other large deformation processes, can be optimized, by exploiting advanced simulation and novel material characterizations. It has been shown that HF is highly dependent of the combination of its main input parameters. Two strategies were identified for manufacturing 1.3 GHz copper substrates. Considering manufacturing of 400 MHz cavity, two-step HF was chosen as the baseline and has been successfully applied for fabrication of 1.3 GHz. A novel approach of studying failure in view of SRF application was introduced, the SRFLD, thanks to which the formed part final parameters, can be predicted numerically; such promising tool can be used for any large deformation metal sheet forming process.

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