Numerical Tool Path Optimization for Conventional Sheet Metal Spinning Processes

Benedikt Rentsch[a,*], Niko Manopulo[a] and Pavel Hora[a]

[a] *ETH Zurich, Institute of Virtual Manufacturing, CLA F9, Tannenstrasse 3, 8092 Zurich, Switzerland*

Abstract. To this day, conventional sheet metal spinning processes are designed with a very low degree of automation. They are usually executed by experienced personnel, who actively adjust the tool paths during production. The practically unlimited freedom in designing the tool paths enables the efficient manufacturing of complex geometries on one hand, but is challenging to translate into a standardized procedure on the other. The present study aims to propose a systematic methodology, based on a 3D FEM model combined with a numerical optimization strategy, in order to design tool paths. The accurate numerical modelling of the spinning process is firstly discussed, followed by an analysis of appropriate objective functions and constraints required to obtain a failure free tool path design.

Keywords: INCREMENTAL SHEET FORMING; OPTIMIZATION; FEM

INTRODUCTION

This study presents and discusses a numerical optimization strategy for the first forward pass tool path of an industrial aluminum component. A 3D FE-model is introduced, based on which a multitude of tool paths are processed. The results are captured in the form of objective functions and their corresponding values are used to generate meta-models. On one hand these meta-models can be used to find a constrained optimum, on the other for a global analysis of the process.

LS-DYNA 3D Model & Material Characterization

The simulations are conducted using the commercial FEM software LS-DYNA. Figure 1 displays the setup of the 3D model. Involved components are: Mandrel (red), DuraspinR23 roller (blue), Tailstock (yellow) and blank (green).

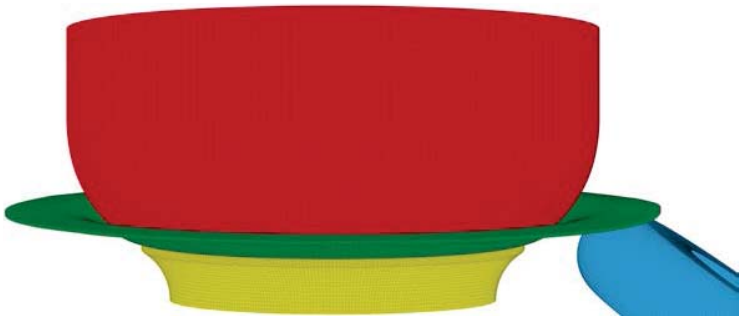


FIGURE 1. Model setup for numerical 3D analysis in LS-DYNA [1]

All components are meshed using quad shell elements. The tools are modeled as undeformable rigid structures. For the blank, the Belytschko-Lin-Tsay shell element formulation with five integration points in thickness direction is applied. The material properties are characterized by an elasto-plastic material model which is based on an arbitrary stress versus plastic strain curve with the von Mises yield criterion and isotropic hardening behavior. The material data is determined by conducting uniaxial tensile tests under quasi-static conditions and hydraulic bulge tests, in order to retrieve material hardening characteristics for plastic strains up to twice the uniform elongation. For extrapolation of the hardening behavior the Ghosh-hardening model is found to be suitable:

$$\bar{\sigma} = k(\epsilon_0 + \bar{\epsilon})^n + C \tag{1}$$

* *Corresponding Author*

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

where $\bar{\sigma}$ and $\bar{\epsilon}$ are equivalent stress and strain. The Parameters k, ϵ_0, n and C are identified as 132.35, 0.0027, 0.29 and -12.83. The experimental data and the results of the fitting procedure are shown in Figure 2.

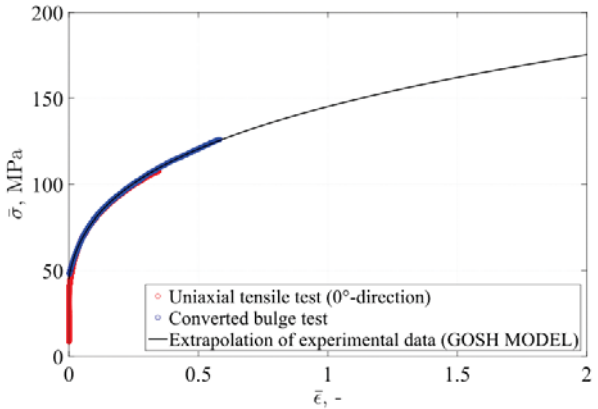


FIGURE 2. Al EN AW-1050A H111 Experimental Data and Ghosh-model fit [1]

The presented FE-model provides an efficient method to map conventional metal spinning process. A more detailed discussion and validation can be found in [1].

Meta-Model & Optimization

In this section a meta-model based methodology to design tool paths is discussed. The process is executed with the optimization tool LS-OPT 5.2 in combination with MATLAB R2016a (Figure 3). To make the analysis most efficient, an iterative strategy is chosen. This enables sequential adding of points until a minimum meta-model accuracy is attained. The iterations are structured into the sub steps: a) Sampling, b) Preprocessing, c) Simulation, d) Postprocessing, e) Build Meta-models and f) Optimization.

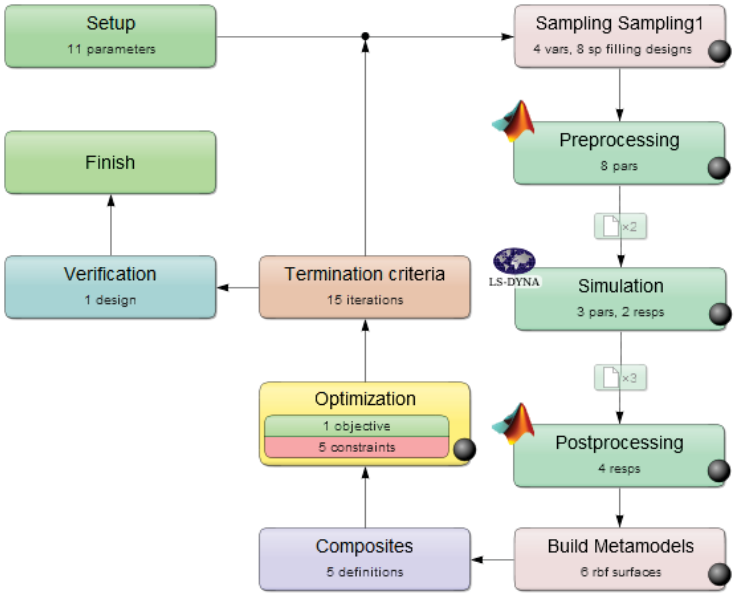


FIGURE 3. Iterative strategy for meta-model based optimization in LS-OPT 5.2

The content of the sub steps is shortly discussed:

a) A space filling sampling design has been chosen, it is obtained by maximizing the minimum distance between any two points. With this method the points are evenly distributed in the parameter space.
b) In the preprocessing step, the tool path load curve is generated based on the parametrized template shown in Figure 4.

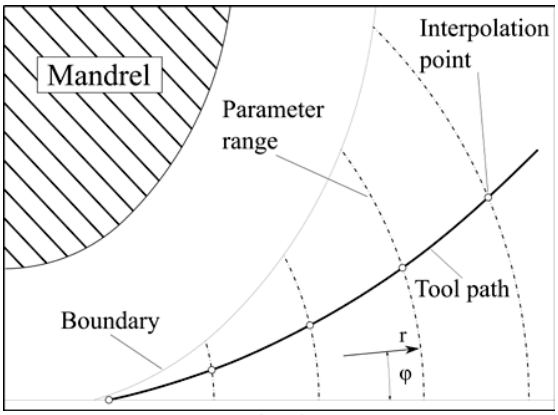


FIGURE 4. Tool path parametrization

Five interpolation points whose coordinates are defined by their radial and angular components (r, φ) are used. This allows the points to move on radial paths (parameter range represented by the dashed lines). The data between the points is interpolated using a Piecewise Cubic Hermite Interpolating Polynomial (PCHIP).

c) The simulation introduced in the previous section is run with the settings for the given iteration.
d) In the step postprocessing, the simulation results are extracted and the objective functions are evaluated as system responses. The main objectives are maximizing the forming and minimizing wrinkle formation.
e) Combining the system responses of all iterations, meta-models are built using neural networks with radial basis functions.
f) Based on the metal-models a constrained optimum is found.

Results

In each iteration eight points are added. After 15 iterations the meta-model accuracy does not significantly increase anymore and the cycle is interrupted. Based on the final configuration, the search for a constrained global optimum is started. Aiming to maximize the forming in in the first forward tool path without wrinkling failure, the result illustrated in Figure 5 arises.

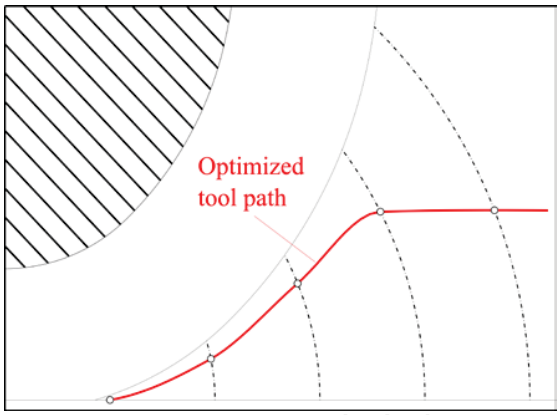


FIGURE 5. Optimized tool path

The introduced methodology provides an effective strategy to design failure free tool paths for the conventional sheet metal spinning process. The method can also be chained and used to design multi-pass processes.

ACKNOWLEDGMENTS

The present work is carried out in the scope of Project Nr. 17231.1 PFIW-IW funded by the Swiss Federal Commission for Technology and Innovation (CTI).

REFERENCES

1. B Rentsch, N Manopulo, P Hora. “Numerical modelling, validation and analysis of multi-pass sheet metal spinning processes”. *International journal of material forming.* 2015, submitted for 2nd review