3D modelling approach

The 3D modelling campaign was divided into two models: a purely thermal and a coupled thermo-mechanical model. The purely thermal model represents the heating by friction in the initial phase of the process, and serves as initial thermal boundary condition for the thermo-mechanical model. This last one is modelled using a single plastic body, representing the central slice of the two half chain links; and two rigid dies responsible for the oscillating and forging movements. The axial load was provided using a “retrospective analysis”, hence experimental data of amplitude and burn-off were used as process inputs for the model. This enables the use of the Conjugate Gradient Solver, which is computationally more efficient.

Selected results

The 3D model is invaluable to understand the multi directional material flow behaviour of the process, and figure 1 shows the morphology of the flash at different time steps. Figure 1(a) shows the flash appearance in the early stages of the process. Until approximately t = 0.35s, the flash distorts severely upwards and downwards with the oscillating movement. However, at a certain point despite the flipping movement of the flash, a preferential flow towards the moving part is acknowledged and is shown in figure 1(b). This tendency might be related to the constant constraints imposed on the flash by contact with the workpiece and tooling, promoting local shearing on the base of the flash, which, coupled with the pressure increase at high amplitudes, redirects the flash to the moving side. Furthermore, the deflection of the flash might also be a product of the tooling effect entitled “micro-swinging”. This has a significant effect on the extrusion manner, as the swinging part ends up digging into the other promoting deflection of the flash from its centre point. This phenomena was also be observed in the experimental flash. A further consequence of the flash extrusion evolution has to do with the self-contact observed at a certain point of the simulation process as the flash contacts the workpiece. As a result, conduction heat transfer occurs locally, causing the uneven cooling of the flash.
as shown in figure 1(c). Moreover, by the end of the equilibrium phase $t = 0.90 \text{s}$ illustrated in figure 1(d), one can intuitively acknowledge that the flash further away from the extrusion zone is locally colder when compared to other regions due to convection and the influence of conduction from earlier stages.

**Fig. 1: Appearance of the formed flash through different time steps (a) to (d)**

### Impact and effects

The partial unbonding phenomena was observed in the developed 3D model at low burn-off values, as depicted in figure 2. This particularity is known to compromise mechanical properties, ultimately leaving a notch that acts as a crack propagation site. Unbonding was observed solely in the corners of the cross-section with lower radii, suggesting that there might be a critical radius at which partial unbonding is prone to occur for a certain set of parameter. Nonetheless, as the model progressed the heat provided to these regions caused the corners to soften and plastically deform, thus resulting in a defect free bond. Although the modelled chain is notch free in the end of the process, the knowledge gained from the observed unbonding can be transported to chains which are prone to notching effect.

Due to the rapid nature of the LFW process and the fact that the interface of the workpieces cannot be observed during welding means that using physical experiments alone may fail to provide adequate insight into the process fundamentals. Computational modelling offers a pragmatic method to understand what is happening throughout the rapidly evolving process.

**Fig. 2: Partial unbonding phenomena**

To sum up, modelling can indeed support continuous knowledge build-up towards LFW of chains, without the need of exaggerated experimental campaigns. For this reason, the successful numerical investigation comprised in this research has resulted in the direct implementation of FEM in the pewag Hero chains production line.

### Contact and information

K-Project JOIN P3
IMAT - Institute of Materials Science, Joining and Forming
Kopernikusgasse 24/I, 8010 Graz, Austria
+43 (0) 316 873 7181
office@imat.tugraz.at, www.imat.tugraz.at

**Project coordinator**
Assoc. Prof. Dr. Norbert Enzinger

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMAT TU Graz</td>
<td>Austria</td>
</tr>
<tr>
<td>pewag Austria GmbH</td>
<td>Austria</td>
</tr>
<tr>
<td>voestalpine GmbH</td>
<td>Austria</td>
</tr>
</tbody>
</table>

This success story was provided by the consortium leader/centre management for the purpose of being published on the FFG website. FFG does not take responsibility for the accuracy, completeness and the currentness of the information stated.