

Setting up a Hot Stamping Simulation considering Tool Heating with OpenForm

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1 Introduction

The steadily growing requirements regarding the carbon footprint of vehicles has motivated the deployment of quenching (hot stamping) as a promisingly manufacturing process for lightweight car bodies in the series production of structural components. Very high part stiffnesses as well as formabilities can be achieved by means of this quenching process with significantly less forming energy and material consumption. This sets new standards both in vehicle safety and vehicle crash performance as well in sustainable and resource-saving mass production of car body components.

Until recently, in the process of designing quenching tools, the main focus was on the feasibility of the produced parts. During the method planning phase, the forming process is simulated by means of numerical calculation software, and only those surfaces of the forming tools in contact with the hot blank (the „active“ surfaces) are considered. Thus, a temperature transfer into the tools during the forming and the holding steps from the heated component can not be considered sufficiently, as well as the cooling of the tools due to the integrated cooling pipes. Without a sufficiently accurate consideration of the temperature balance of the whole tools/blank system during the forming process, it is not possible to make a reliable statement about, for example, the cycle time necessary to ensure that the part no longer exceeds the predetermined maximum temperature. Such a statement is very important for an efficient design of the quenching tools and for the optimization of the integrated cooling networks. Fig.1 shows the calculated cycle time which is set as soon as a quasi-stationary temperature state in the whole system tools/blank is reached.

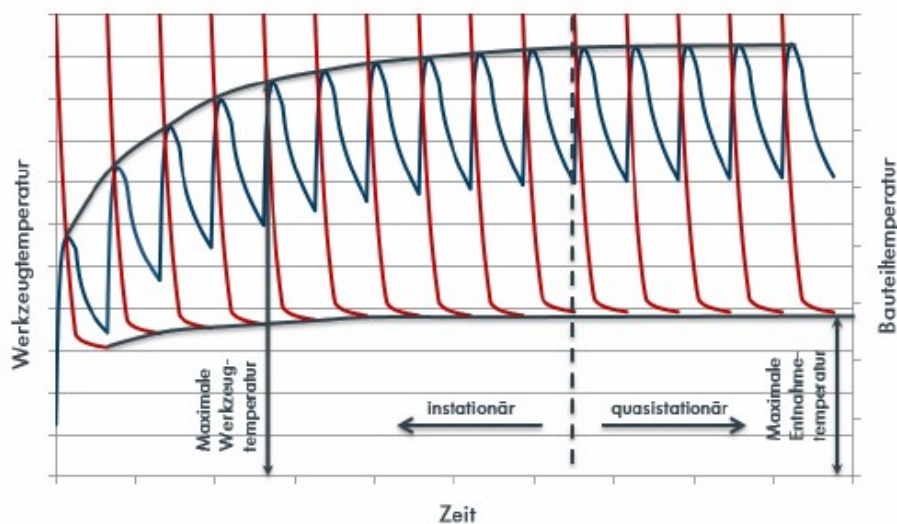


Fig.1: Temperature of tool and component over several forming cycles

In this paper we will describe the various possibilities provided by the forming GUI **OpenForm** to set up appropriate inputdecks for the simulation software **LS-Dyna** with which, among other things, the above mentioned cycle time can be computed, taking into account the temperature balance of the whole system.

2 Geometry preparation

To be able to take into account the temperature transfer during a quenching process between blank and tool on one hand and within the tool between the tool body and the integrated cooling pipes on the other, it is imperative, that the geometric modelling satisfies both the mechanical as well as the thermal requirements of the process. For the mechanical part of the process it is necessary that the active surfaces, i. e. the shape giving surfaces, of the dies are sufficiently finely discretized to accurately reproduce all the details of the part geometry. For this purpose it is common to apply some curvature criterion while meshing these surfaces to keep the deviations between the CAD geometry and the corresponding mesh on it within a given tolerance. For the thermal part of the process, which takes place in the three-dimensional tool body, it is necessary to achieve a 3D mesh that consists of solid elements (Tetra and Hexas) satisfying the geometric qualities required to achieve good results, is fine enough to map the integrated pipes with sufficient accuracy but is as coarse as possible to avoid too large calculation times. **OpenForm** provides the user with different functionalities to generate a curvature-dependent tool mesh starting from CAD data, as well as interfaces for the import of meshes in all common formats.

To avoid larger losses in the thermal transition between the cooled dies and the hot blank, it is recommended to use both above mentioned discretizations together: the 3D meshes are used to simulate the thermal process of die cooling and heating whereas the shell surfaces are used to simulate the thermo-mechanical process of quenching, including the heat transfer between the die surfaces and the blank. In Fig.2 a modelling as described here is shown in which the surfaces „Die“, „Punch“, „PunchInsert“ and „Guidepins“ are the additional shaping shell surfaces.

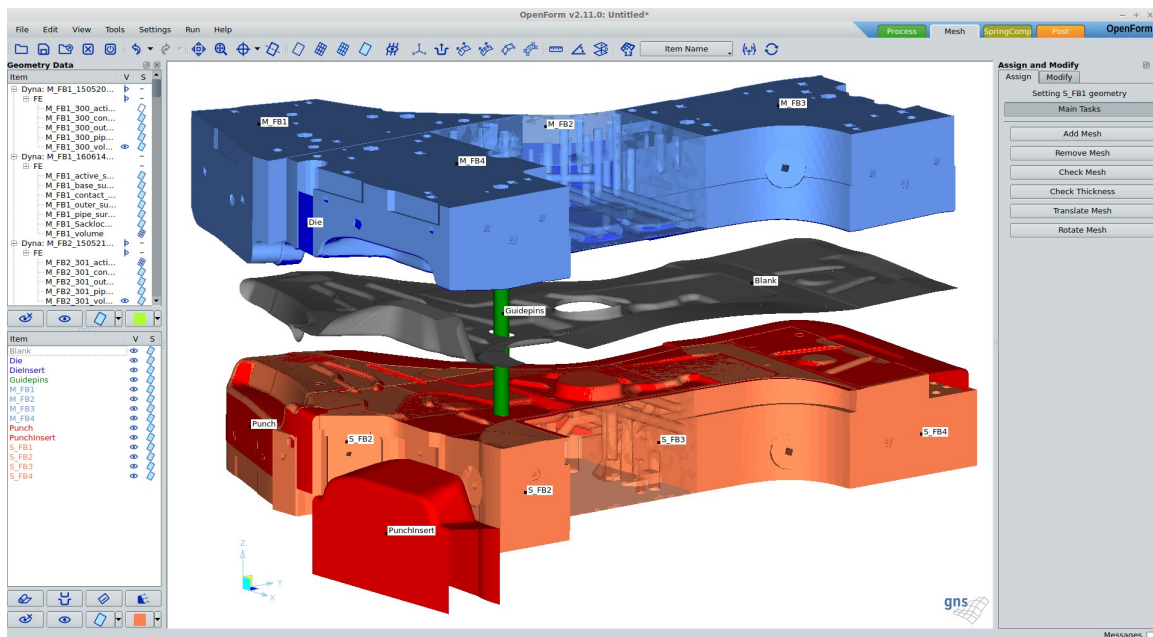


Fig.2: Modelling including 3D die bodies and shaping shell surfaces

As the cooling of the tools is realized via several separate cooling networks, it makes sense to divide the overall geometry of the tool bodies accordingly into individual forming blocks (Fbi).

In the present example, there are 4 forming blocks for each the Die (M_FB1-4) and the Punch (S_FB1-4).

In order to facilitate the assignment of the various thermal boundary conditions, an appropriate classification of the affected areas of the forming blocks was done. This is defined as follows for each single forming block (see Fig.3):

- „pipe-surface“ comprises the surfaces of the integrated cooling pipes
- „active-surface“ comprises the surfaces that are in contact with the shaping shell surfaces
- „contact-surface“ comprises the internal front faces in contact with the neighboring blocks
- „outer-surface“ comprises the remaining surfaces exposed to the ambient air.

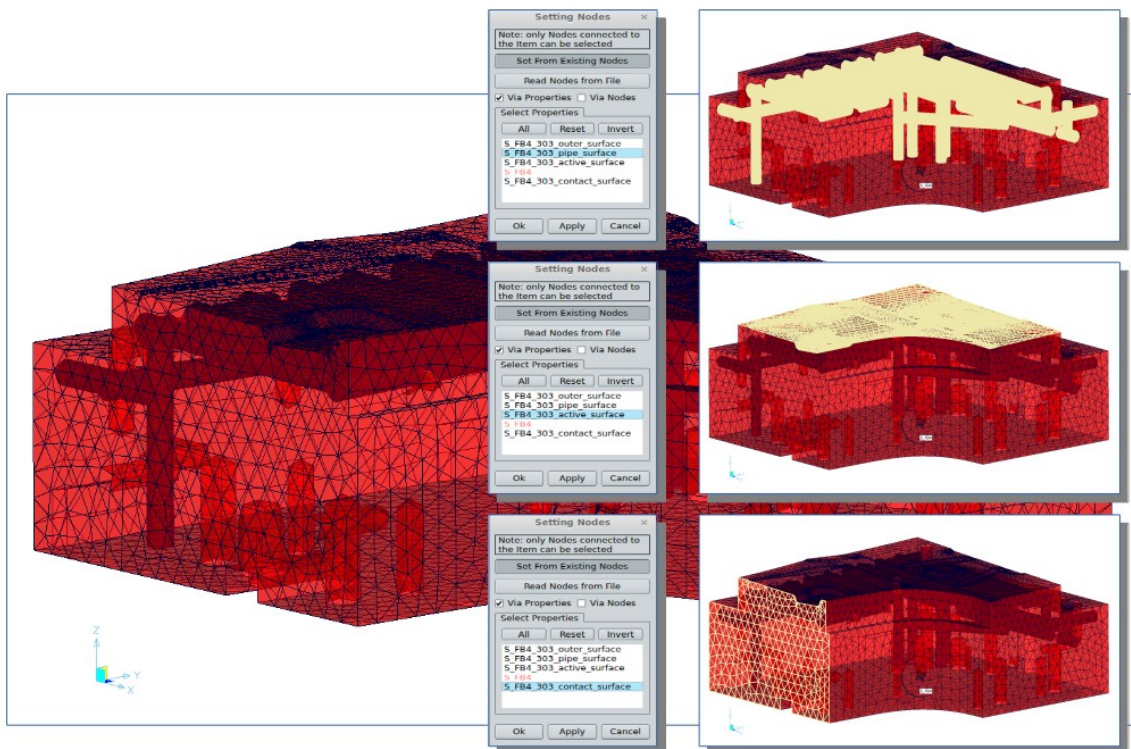


Fig.3: Surface definitions (from the thermal point of view) for a forming block

The geometry preparation described above should serve to determine the temperature distribution within the 3D tools by means of a pure thermal simulation and taking into account the tool heating via the „active“-surfaces and tool cooling via the „pipe“-surfaces. Also the effects of heat radiation and convection via the „outer“-surfaces as well as the heat transfer between the single blocks via their „contact“-surfaces are considered. This temperature distribution is then used as input for the actual quenching simulation. A description of the set up for this „Tool Heating“ process is done chapter 4.0.

3 Set up of the quenching process

When setting up the quenching process in **OpenForm**, the procedure is exactly the same as used for the cold forming process: all process STEPs that belong to the forming process are defined and they may be grouped in process OPERATIONS. The forming process described in Fig.4 consists of only one operation called OP20 and 5 steps. Subsequently, to every process step the acting process ITEMS are assigned, consisting of the blank, the shaping shell surfaces of the tools and possibly draw beads, symmetry lines etc. Finally, the physical parameters of the process are defined in the „Parameter Editor“: for a STEP these are the closing stroke or time, initial positioning etc. and for an ITEM the friction coefficient, working direction, the tool control type etc. This would already complete the set up of a runnable input deck for **LS-Dyna**.

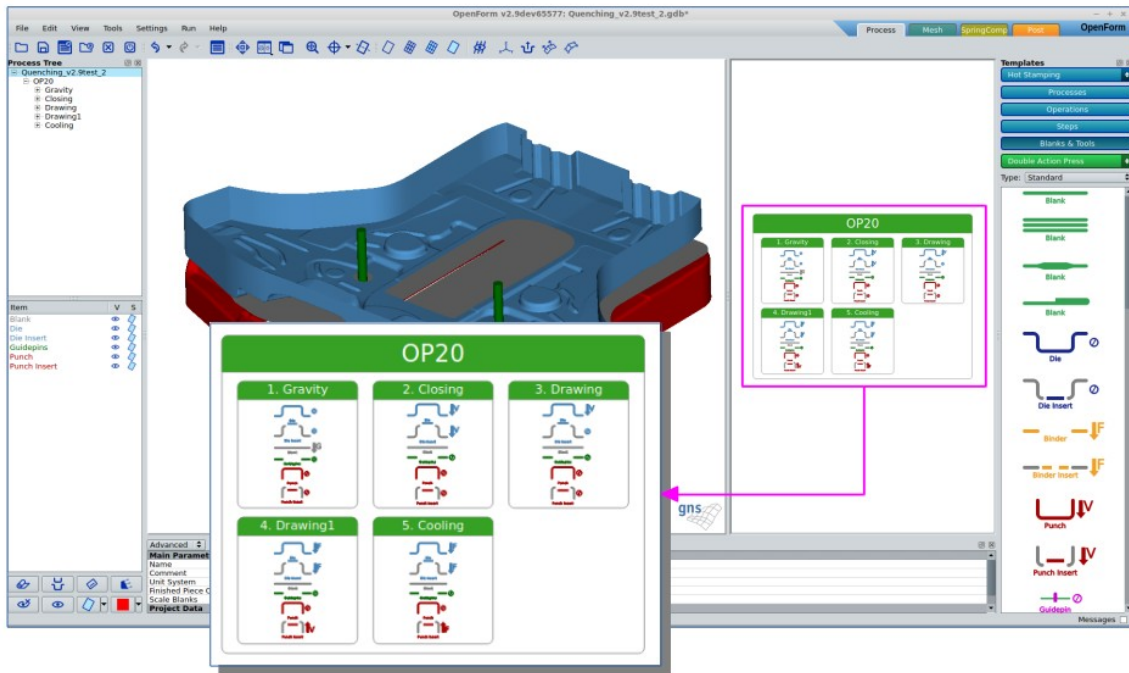


Fig.4: Set up for a cold forming process

Using this cold forming set up as a base, **OpenForm** allows the user to define an ambient temperature in every process STEP as well as an initial temperature and a material file describing the thermal properties of every process ITEM. If these values are defined, the above input deck is automatically extended to a conventional thermo-mechanically quenching input deck i. e. without consideration of the tool heating and cooling. If the latter thermal behaviour is also to be taken into account, then the 3D mesh (forming blocks) of the relevant tools must also be added to the process description. In the present example these are the Die and Punch (for a better illustration, only the forming blocks of the Punch are shown in Fig.5).

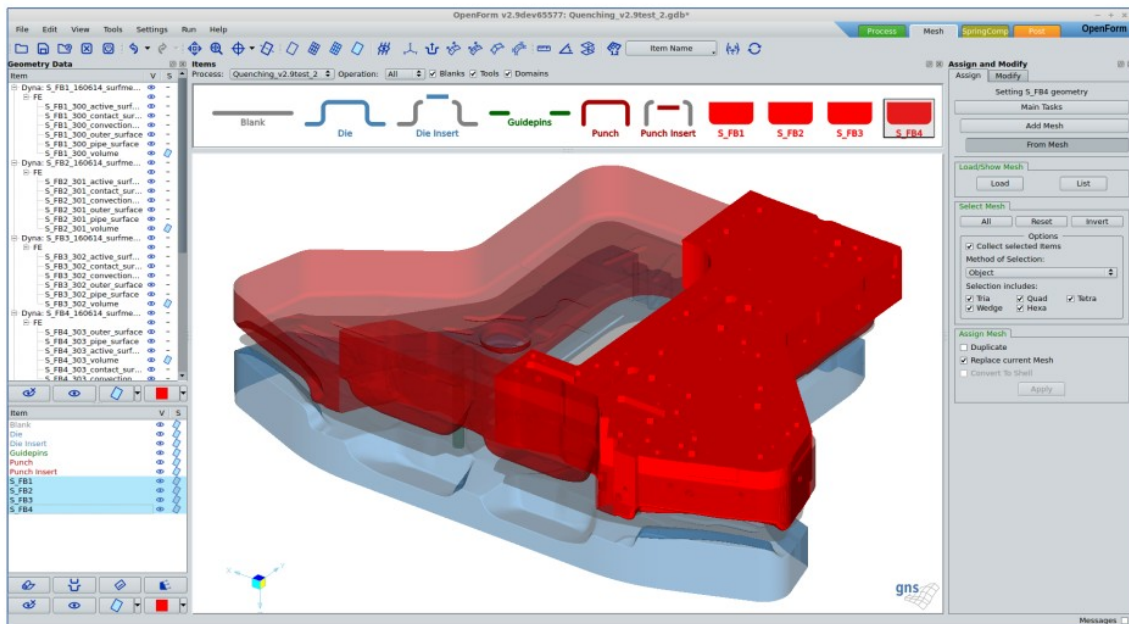


Fig.5: Extension of the cold forming process with the 3D forming blocks.

In the next chapters of this paper we will describe in more details the options **OpenForm** provides to define the different thermal boundary conditions for a quenching process.

3.1 Definition of the initial Temperatures

The initial temperatures are defined for the blank as well as for the shaping surfaces as follows:

- a constant temperature of 800 °C for the blank assumed to be reached after transfer from the oven and before insertion in the opened tools.
- the real temperature distribution in the shaping shell surfaces is determined by a previous thermal simulation considering the thermal balance of the whole tools/blank system. Several computation cycles are necessary here to attain a quasi-stationary temperature state (see chapter 4.0). Fig.6 illustrates, for example, the temperature distribution within the shaping shell surface of the tool Die reached after 12 cycles.
- for the forming blocks a constant temperature of 28 °C at the „pipe-surfaces“ and 30 °C in the block body are assumed. At the „active-surfaces“ a constant temperature of 75 °C corresponding to the desired part removal temperature is assumed.

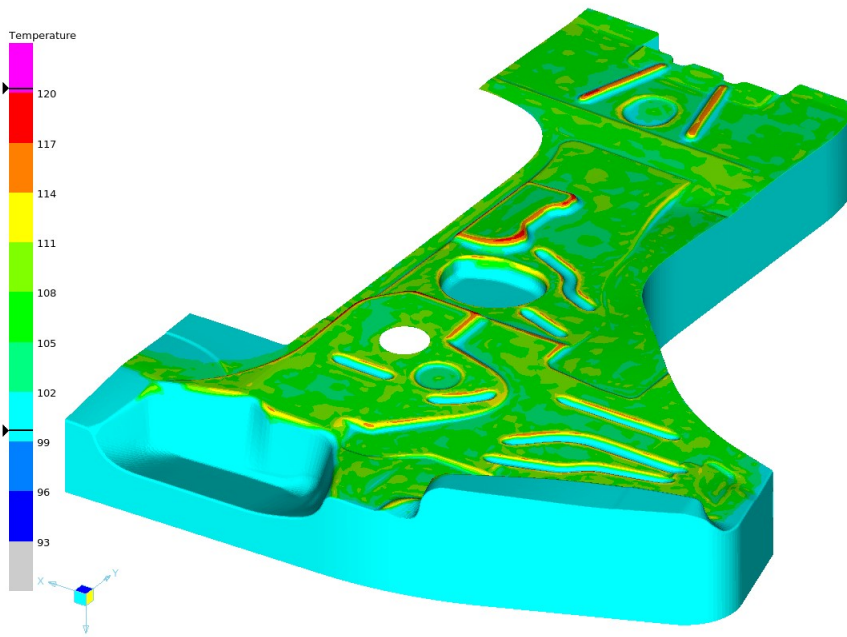


Fig.6: Temperature distribution within the shaping shell surfaces of the tool Die

3.2 Definition of the parameter for Heat Transfer

Heat transfer takes place between the blank and the shaping shell surfaces as well as between the shaping shell and the „active“ surfaces of the forming blocks. The heat transfer can be defined individually for each Master-Slave pair of blank/shell or shell/„active-surface“ by means of the Heat Transfer Conductance (HTC), thermal conductivity (K) in the gap and the minimum (for HTC) and maximum (for heat transfer) value for the gap width. In addition, the heat transfer between the different forming blocks along the „contact-surfaces“ can also be defined.

3.3 Definition of the parameter for Radiation and Convection

Heat radiation and heat convection take place in the forming blocks at the contact surfaces of the integrated cooling pipes („pipe-surfaces“) to the cooling fluid. In this case, the heat transfer conductance is not a constant value but shows a variable distribution along the cooling channels depending on the flow conditions at each point. In **OpenForm** the user can choose between different possibilities for a practical determination of the HTC values for radiation and convection (see chapter 4.1 and 4.2)

By determining the above mentioned thermal boundary conditions, the description of a quenching process is complete and can be exported as an input deck for **LS-Dyna**. Fig.7 illustrates the set up for a quenching process taking into account tool heating and cooling.

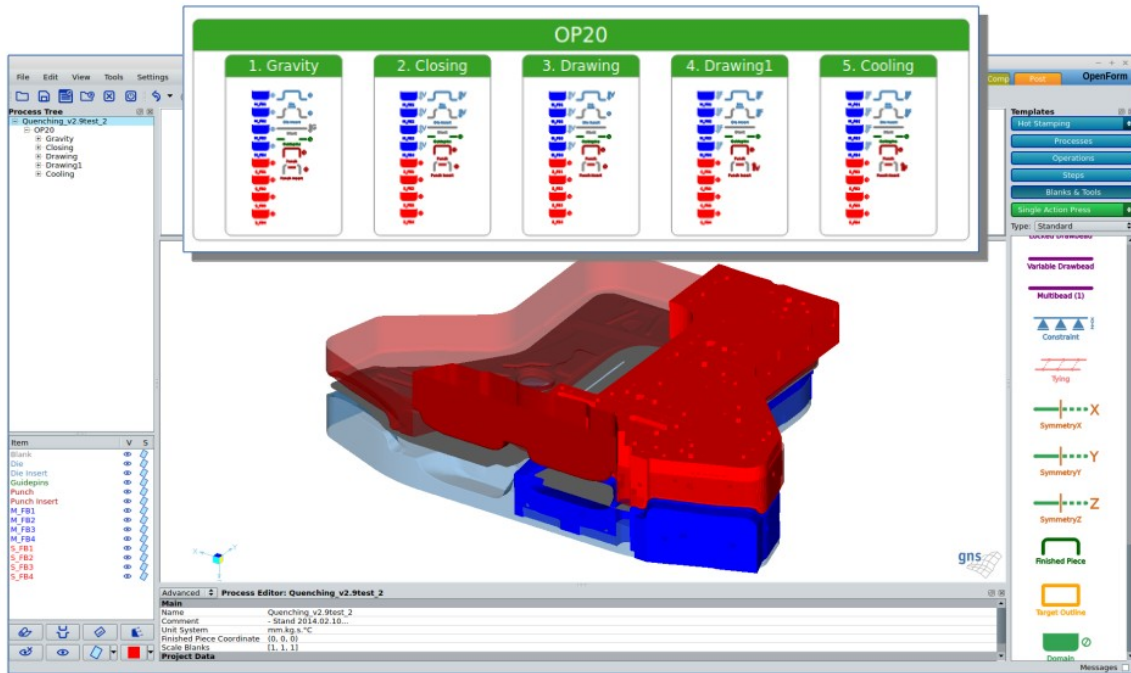


Fig.7: Set up for a quenching process considering tool heating

4 Computation of the temperature distribution within the 3D tools

To compute a realistic temperature distribution within the tools of a quenching process, a pure thermal process, hereinafter referred to as „Tool Heating“, is carried out in advance of the actual quenching process. The user of **OpenForm** has here the opportunity to easily create an appropriate input deck for the **LS-Dyna** solver. The model set up is identical to the geometry preparation as described in chapter 2.0. The initial temperatures used as boundary conditions for the first cycle of the „Tool Heating“ process are determined from a first conventional quenching simulation but without considering the last „Cooling“ step. Therefore an initial temperature of 800 °C for the blank and 100 °C (near the desired part removal temperature) for the tools are assumed. Based on the resulting temperature distributions in blank and tools and using the values mentioned in chapter 3.1 as initial temperatures for the forming blocks, all the necessary boundary conditions for a pure thermal „Tool Heating“ process are defined. This computation must be carried out in several cycles until a quasi-stationary temperature state in the tools/blank system is reached. For each cycle, the temperature distribution in the tools and blank computed in the previous one are used as the new initial boundary condition.

The heat transfer parameters between blank and shaping shell surfaces and between shell surfaces and „active-surfaces“ of the forming blocks are defined exactly as described in chapter 3.2. To determine the HTC values for radiation and convection along the integrated pipe surfaces („pipe-surfaces“), several options are available to the user in **OpenForm**:

4.1 Determining of the HTC values using „Formula“

Here, the computation of the HTC values are based on the evaluation of the Gnielinski formula which takes into account the pipe geometry and the physical properties of the cooling fluid. Giving a mean diameter and an absolute wall roughness for the pipes as well as a volumetric flow rate and a bulk temperature for the fluid, the formula computes for different temperatures along the pipe walls the corresponding film temperature in the boundary layer of the fluid and the corresponding HTC value depending on the physical properties of the fluid (in most cases water). These computed values are then exported in a table to the input deck (see Fig.8).

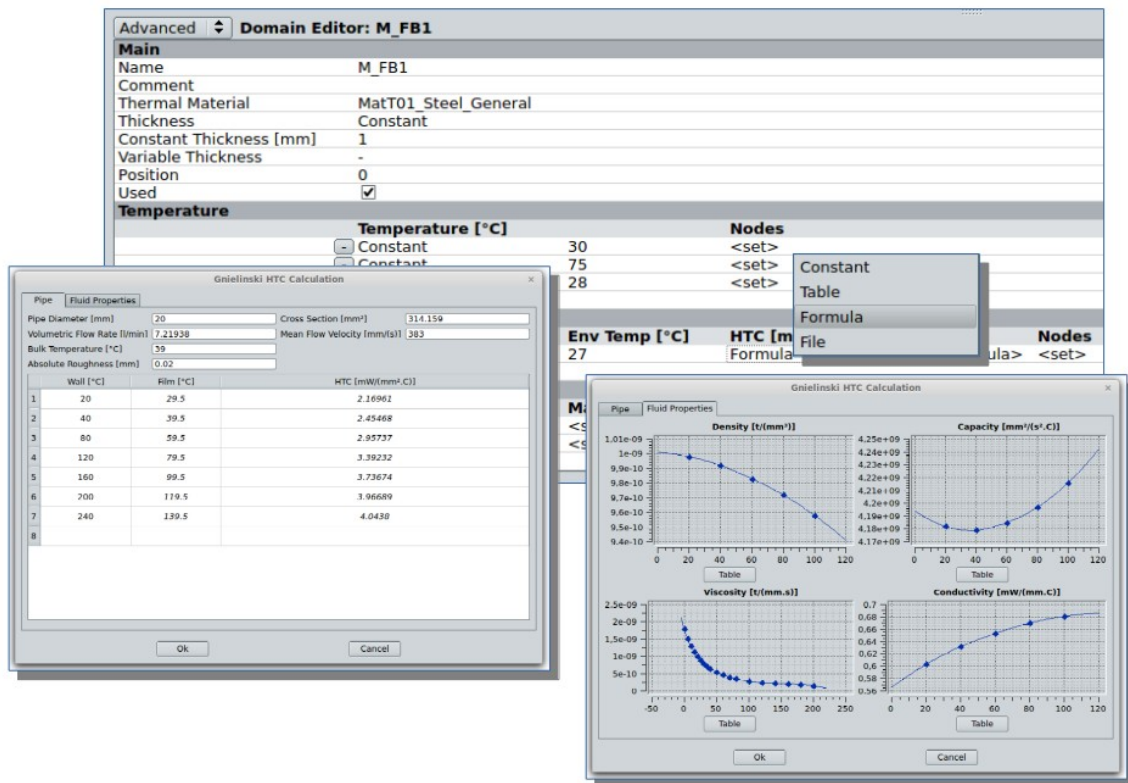


Fig.8: Gnielinski formula for HTC values along cooling pipes

4.2 Determining of the HTC values using „File“

A more accurate, due to being better adapted to the real conditions of the cooling system, possibility to determine the heat transfer coefficient is to compute these values at every point of the cooling pipes by means of a CFD simulation. For this purpose, **OpenForm** provides a simple and practical support for the creation of an appropriate input deck for the CFD simulation as well as for the efficient post processing of the computed results to be used in an input deck for the „Tool Heating“ simulation. For the computation of the HTC values, a reduced input deck is made available consisting of the essential parameters needed to determine the HTC values by means of the **LS-Dyna** integrated CFD solver „icfd“. For a pipe network composed of an inlet and outlet, some bases and the actual network of pipes, and for a given temperature and control type (velocity or pressure) of the fluid, an input deck for the „icfd“ solver is created that instructs the solver to generate an appropriate fluid mesh and to compute among other things the HTC values at every point of the pipe system. Fig.9 illustrates an example for such a process set up in **OpenForm**.

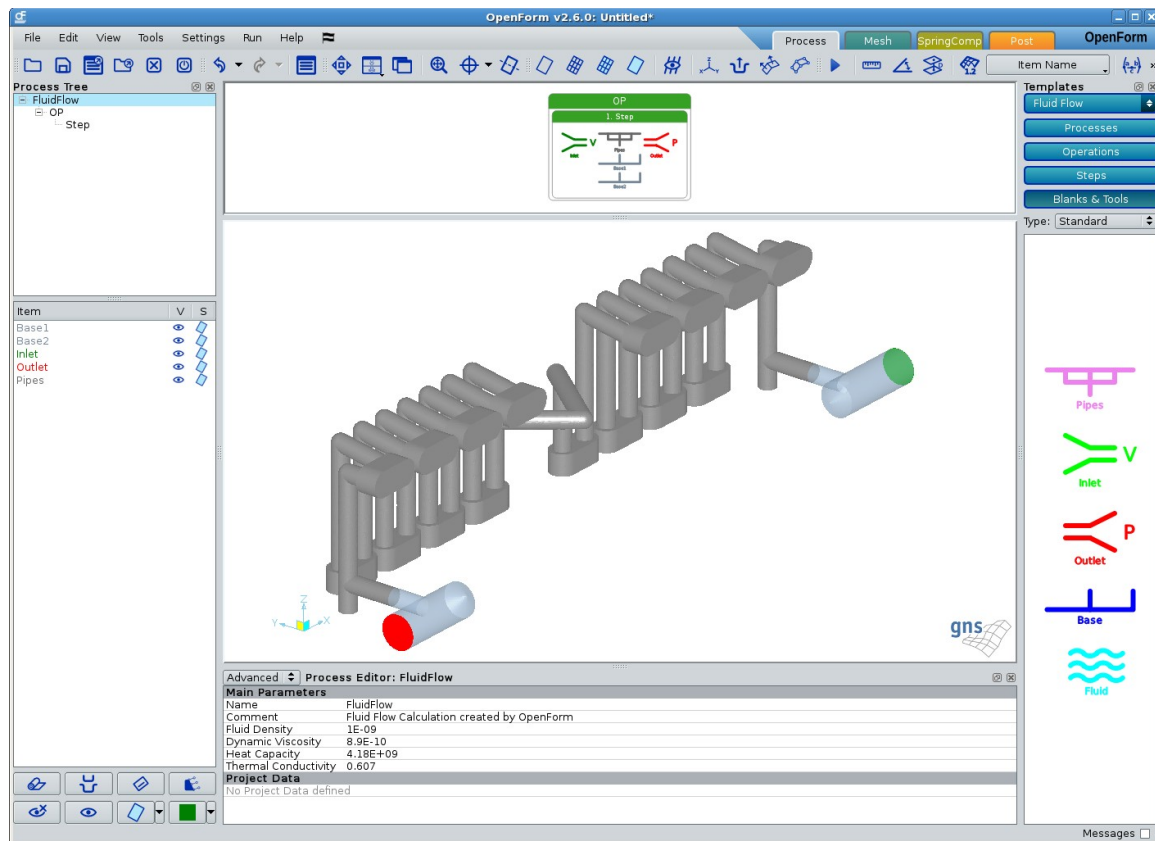


Fig.9: Set up for a simple CFD Simulation used to determine the HTC values

The large amount of computed HTC values (one scalar per mesh node) resulting from the CFD simulation must now be reduced to reasonable smaller amount to be able to list them as parameter definition card within an input deck. **OpenForm** provides for this purpose a practical possibility to subdivide the value range of the HTC data into classes and to assign the nodes belonging to every class into so called „Node Sets“. Thus the number of parameter definition cards is reduced to the number of chosen classes and for every class a new node set is defined. Fig.10 illustrates the dialog for this function: one the the HTC data has been imported, the possibility to define the number of classes and their individual value ranges („Equidistant“ oder „Customized“) is provided. Further the possibility to flatten some unnatural peak values or even negative values that may occur because of some defects in the fluid mesh is available. Fig.10a shows the raw data as they were imported from a result file and sorted in 10 equidistant classes. About 70% of the values lay in the range between 0 and 15 for the HTC value. Reducing the admissible range to [0. - 4.], which correspond to the values computed using the Gnielinski formula, and choosing a non-equidistant distribution of the class ranges leads to the subdivision shown in Fig.10b.

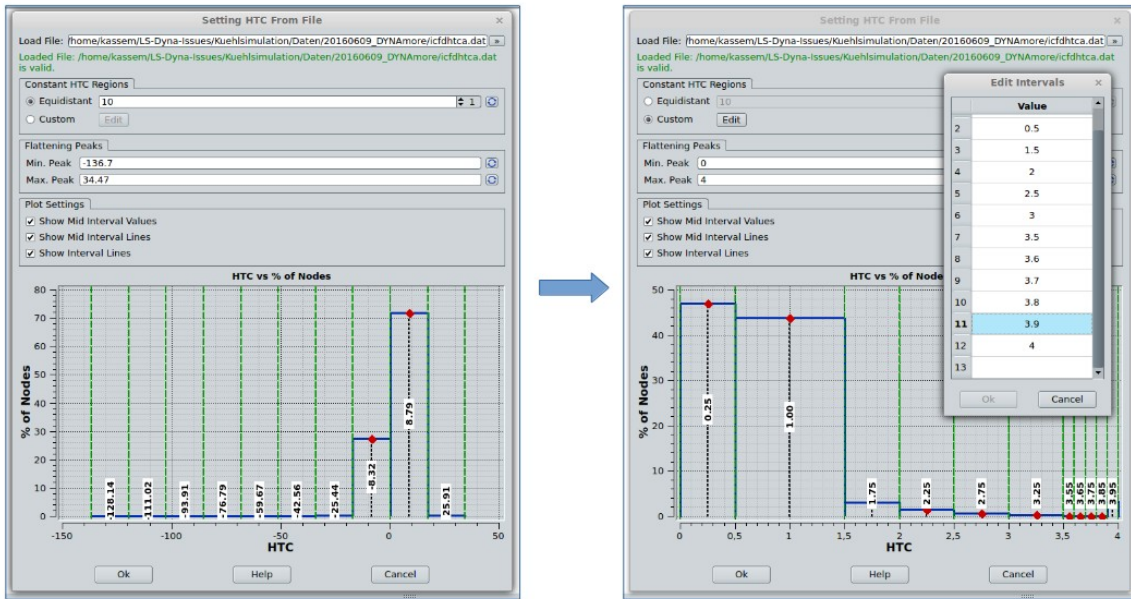


Fig.10: Post-processing of the HTC value: a) Import raw data b) Flattening and classification

5 Summary

The cycle time, at which a formed part will attain the requested removal temperature, plays an essential role in the process of designing and optimizing quenching tools. To achieve such statement by means of numerical simulation, it is imperative, that the thermal balance of the whole tools/blank system is considered in a sufficiently accurate way. In the present paper we have shown how **OpenForm** could be used to generate **LS-Dyna** the input decks for a continuous process chain consisting of a preliminary CFD simulation for the determination of the HTC values along the walls of the cooling pipes, a „Pre-Forming“ thermo-mechanical simulation to determine the initial temperatures for the subsequent pure thermal „Tool Heating“ process, the latter carried out iteratively in several cycles until the required removal temperature for the part is reached, and last but not least the actual quenching process to obtain additional statements about the feasibility of the hot formed part. In Fig.11 this process chain is depicted.

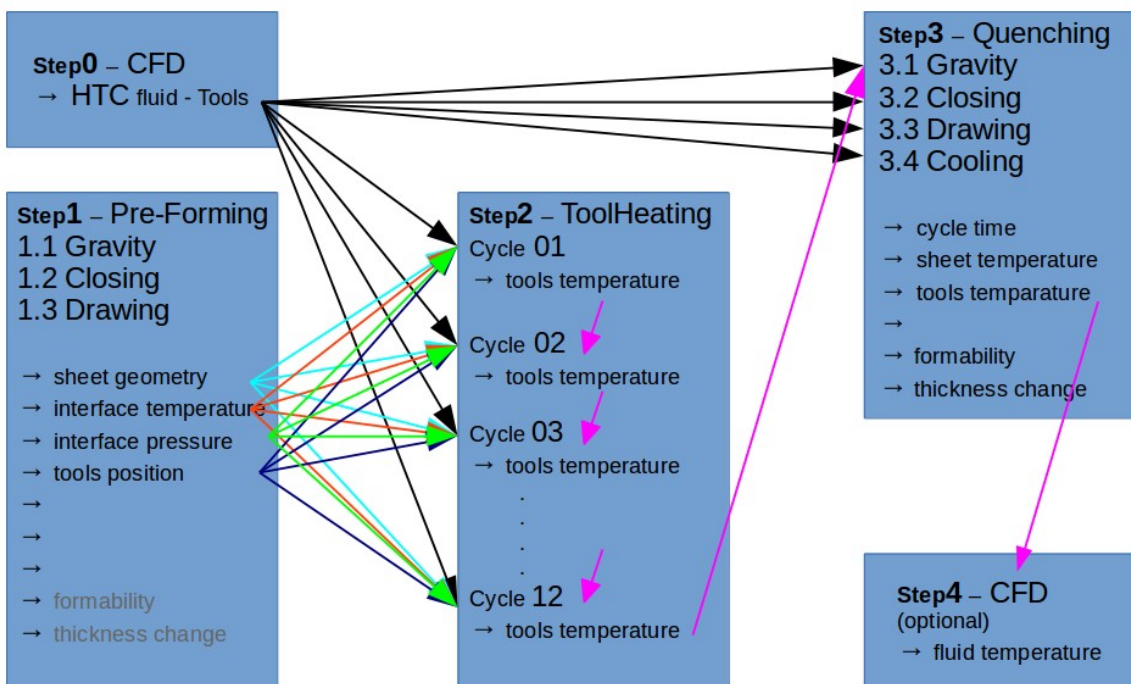


Fig.11: Process chain CFD – Pre-Forming – ToolHeating - Quenching

6 Literature