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SIMULATION OF HOT EXTRUSION PROCESSES

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Abstract

Throughout the manufacturing industry, process simulation has been accepted as an important tool in product design, process development, improving yield and in solving processing problems. Rapid development in process simulation software and the increase in speeds of personal computers has led to the success of these technologies in industrial applications.

The DEFORM™ software is frequently being used to solve more and more complex manufacturing problems which require a highly flexible and sophisticated model definition. The software is based on the finite element method (FEM) where, for simulating the transient behaviour employs the updated Lagrangian approach using an automated re-meshing procedure, and for simulating steady state processes uses the Arbitrary Lagrangian Eulerian (ALE) approach. It was originally designed for the transient behaviour of bulk metal forming applications but has since been developed into a more general purpose software which is capable of modelling many metal forming and material manufacturing processes. The software, with the introduction of parallel processing and increased developments to the solvers, has undergone huge improvements in processing speed which has allowed the software to model the most challenging problems.

Clearly one of the most difficult problems in process modelling is the simulation of hot extrusion processes. This is due to the very large deformations, complex flow behaviour and unknown contact conditions in the die. In the paper, the issues relating to extrusion processes are discussed, capabilities of DEFORM™ are shown and the developments which allow for simulating these processes are presented. Various industrial examples of extrusion simulations are shown.

Keywords

Extrusion, Metal Forming, Process Simulation, DEFORM™

1. Introduction

Shape extrusion processes are associated with very large deformations at high temperatures in order to produce profile sections of simple bars, tubes and complex shaped thin walled sections. Due to the continuous need to produce new extruded products rapidly, there is a strong demand for designing extrusion dies quickly and efficiently. The properties of profiled sections have to be designed within close tolerances and produced at very high production rates. In die design, many production parameters have to be carefully determined in order to find an optimal working condition for the process. Some of these include, design of the die cavity, bearing length, bearing angle, die surface finish, temperature of the feed material, temperature of the die and casting speed. The development with regard to simulation software has been quite phenomenal over the past decade with capabilities in simulating cold, warm and hot extrusion processes. This has been complemented by the rapid developments in the processing speeds of personal computers.

During the start up of an extrusion process, the first metal which will exit the die will be influence by the non-steady state conditions of metal flow and temperature. It is only after some time when these conditions stabilise and the steady state conditions exist. Even in the steady state condition, any fluctuations in processing parameters can easily disturb the process and produce unacceptable products. In the past, no software was really suited for simulating both transient (non-steady) conditions and steady state condition. In general, cold or warm extrusion produces discrete components (non-steady state), while hot extrusion is typically used to manufacture long, straight products where the steady state condition dominates.

The DEFORM™ software has been developed to model both these conditions using two different methods, the updated Lagrangian for the transient behaviour and the Arbitrary Lagrangian Eulerian (ALE) for the steady state condition. The updated Lagrangian approach of the finite element method is used to model the transient behaviour of a complete process and is therefore suited for non-steady state solutions. In the Arbitrary Lagrangian Eulerian approach the solution is quite rapid and is therefore used to simulate processes where the steady state conditions dominate. This means that in hot extrusion, the complete production cycle, the start-up and transient phase, the steady state phase and any conditions which may disturb the steady state conditions, can be simulated within DEFORM™.

2. Comparison of simulation approaches

Both the updated Lagrangian and the Arbitrary Lagrangian Eulerian approaches can be used to simulate hot extrusion processes but each of them have their advantages and disadvantages. Using both approaches can certainly be an advantage which will allow one to get a better understanding of the complete process.

As shown in **Figure 1**, the transient behaviour of the metal during the start-up phase of a hot extrusion process is simulated depicting the metal moving out of the die **[1]**. In order to optimise the start-up phase and determine defects resulting from unfavourable flow behaviour, the effects of the transient condition is important. This approach can also describe the contact conditions in a fairly flexible and accurate manner, using either the Coulomb, shear or user defined friction model, each can be defined as a function of time, temperature or pressure. Although the Lagrangian approach is an elegant way of modelling the transient behaviour of the metal during start-up, there is limitations with regard to the simulation time. Due to the large deformations, the evolving geometry requires frequent re-meshing in order to represent the moving free surface. It is usually not practical to model the complete transition from the non-steady state to the steady state conditions using this approach.

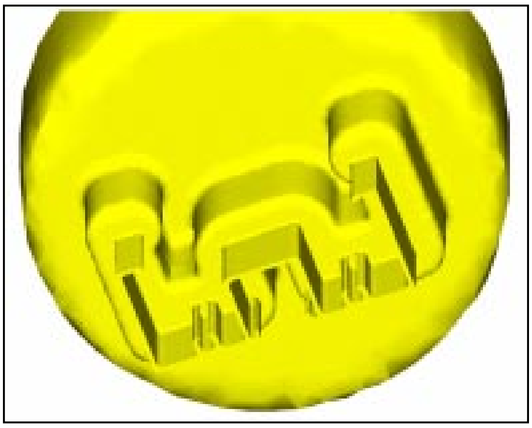

Figure 1* *Above*:** *The transient behaviour of the non-steady state condition is simulated showing the first metal to leave the die* ***[1].

Figure 2* *Right*:** *The steady state condition in the process is simulated using the Arbitrary Lagrangian Eulerian approach* ***[1].

An alternative approach, Arbitrary Lagrangian Eulerian, is dedicated to simulating processes in the steady state condition as solutions from this approach can be obtained fairly rapidly **[1]**. In the Eularian formulation the mesh is fixed in space. This can reduce the numerous re-meshings required if the Lagrangian approach would be used. The state variables such as strain and temperature are further calculated to account for convection. In **Figure 2**, the steady state behaviour of the metal is simulated using the ALE approach. This method also uses a free surface correction scheme in order to update the geometry. Effects such as bending and twisting can also be predicted fairly accurately. Figure 3 shows a comparison of profiles showing evidence of bending. Since, in hot extrusion processes the steady state condition dominates, this approach is most suited. However, during transient conditions, such as during the start-up of the extrusion process or when conditions arise in the process which can disturb the steady state condition, then the updated Lagrangian method would be more suitable.

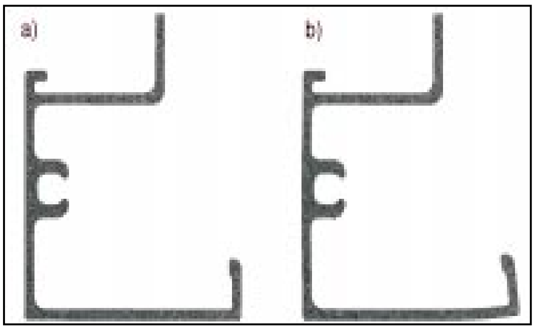

***Figure 3**:**a)** The desired profile section. **b)** The predicted profile section using the free surface correction algorithm of the steady state solution, showing bending **[1]**.*

3. Examples of extrusion simulations using the transient solution (updated Lagrangian)

Simulating the transient behaviour of an extrusion section using the updated Lagrangian approach usually requires frequent re-meshing in order to predict the evolution of the geometry **[1]**. The software can either control the mesh refinement through setting mesh density windows, or totally automatically through the use of parameter controlled refinement, like for instance geometric shape, strain, strain rate or temperature. This allows the simulation to precede quickly while still maintaining accuracy.

Simulation of an extruded H-profile section

The process simulation of a non-steady state H-profiled section, is shown in **Figure 4**. The animated images show the evolution of the extruded geometry and the temperature contours of the metal during the start-up phase. In this case, mesh density windows are used to generate very fine meshes in the deformation zone, an intermediate size mesh in the extruded product and a coarse mesh in the workpiece, resulting in improved computational efficiency. The temperature of the first metal to exit the die is much cooler than the metal which comes out at a later stage. This can have a large influence on the metal flow behaviour during the start-up phase. The temperature in the extruded metal is influenced by contact with the die, heat generated through deformation and heat transferred to the environment. As the extrusion process progresses the temperature contours will stabilise and a steady state condition will eventually be reached.

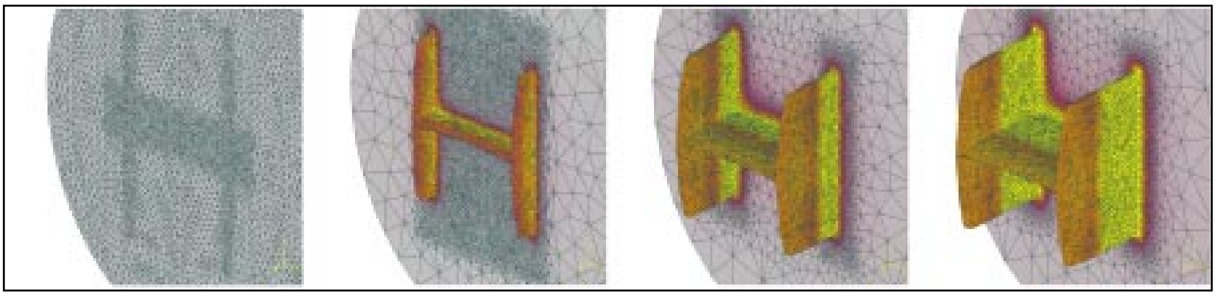

***Figure 4**: Simulating the transient behaviour of an extruded H-profile section. Colours indicate contours of temperature (yellow is hot and orange is cold). Sophisticated re-meshing controls are used for mesh refinement.*

Simulation of a U-profile section

In the simulation of an extruded U-profiled section, DEFORM™ was used to demonstrate the ability to predict bending and twisting in a less than optimal die design. In **Figure 5**, the simulation demonstrates how the material flow is bending from left to right as the shape is being extruded from the die. Correcting this behaviour can be very expensive and time-consuming. This is usually done based on experience and trial and error. Simulation can be used to determine an optimal die design prior to production by visualising the flow behaviour on the computer and determining the effects of die design changes.

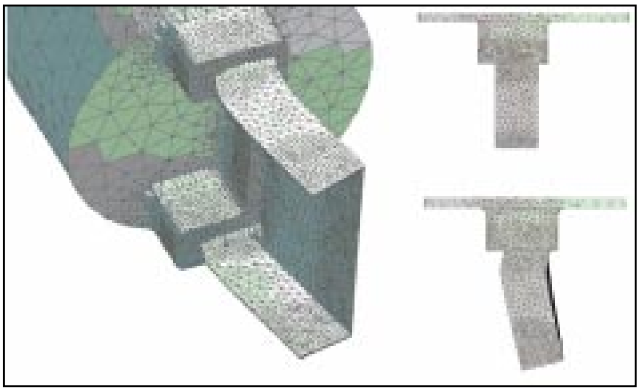

Figure 5:*The material flow in this shaped extrusion simulation clearly shows twist in the isometric and top views* ***[2]***.

Piping defect in extrusion

While analysing the transient stage of an extrusion process, it is important to have efficient and automated mesh generation and re-meshing schemes. These mesh generators should be able to handle the mesh density, based on the state variables and geometric features to be able to correctly model the processes transients. With the software, based on the criteria set by the user, all the meshing and remeshing activities gets triggered and carried out automatically without any user intervention. **Figure 6** shows how accurately the software is able to capture a piping defect in a part extrusion using the updated Lagrangian approach. The cross-section of the actual part showing the defect is depicted in **Figure 7**.

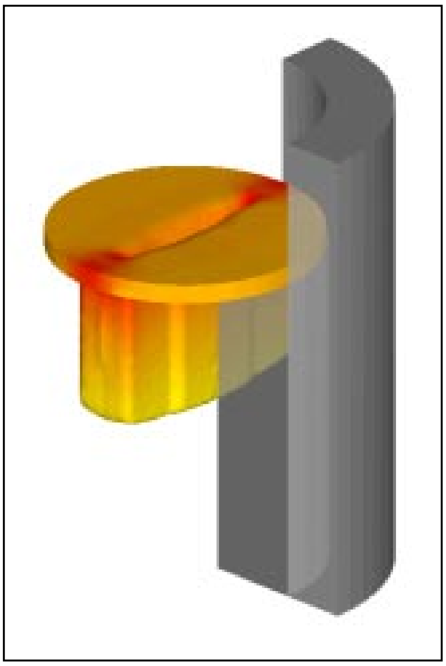

Figure 6 Left: *Piping defect in an extrusion process modelled using conventional Lagrangian approach. The colours indicate contours of strain (red indicates high strain while yellow indicates lower levels of strain* ***[2]***.

Figure 7 Right below: *Piping defect encountered in the actual part* ***[2]***.

Helical gear extrusion

For parts having cyclic geometries in the hoop direction rotational symmetric boundary conditions can be prescribed in DEFORM™, which allows a surface to be coupled with a complimentary surface at a prescribed angle from the original surface. In fact, the symmetry surfaces are not required to be planes. This approach can help to save simulation time and thus allows for an efficient analysis of this type of processes. The extrusion of a helical gear section using this type of boundary condition is shown in **Figure 8**.

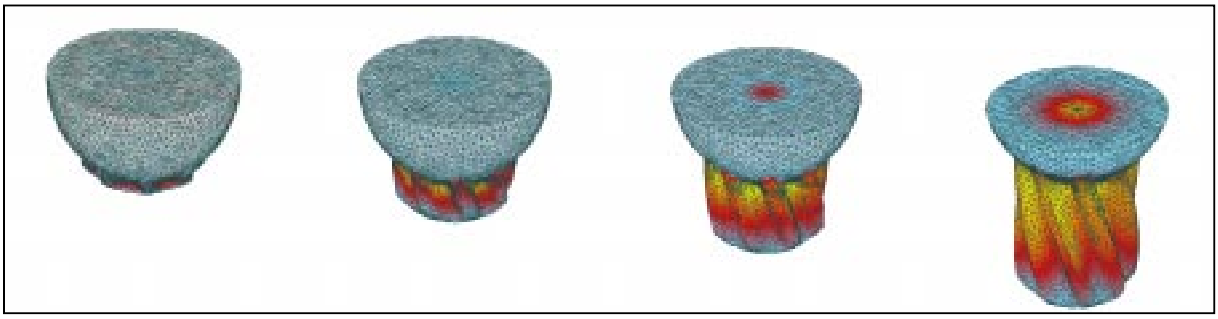

***Figure 8**:This helical gear extrusion was simulated using a very efficient rotational symmetry algorithm. The colours indicate contours of strain (red indicates high strain while yellow indicates lower levels of strain) **[2]**.*

Fully coupled die stress and workpiece analysis

Determining the stresses in the die and optimising the geometry in order to improve die life is a great advantage which can result in huge cost savings. The software has the ability to complete a fully coupled workpiece and die stress analysis, determining the evolution of stress in the die, with effects from the variations in temperature and increasing pressure during deformation, as shown in see **Figure 9**. In order to obtain an improved stress distribution in the die, multiple deforming dies can be simulated using the software, showing the effects of shrink rings and various die assemblies.

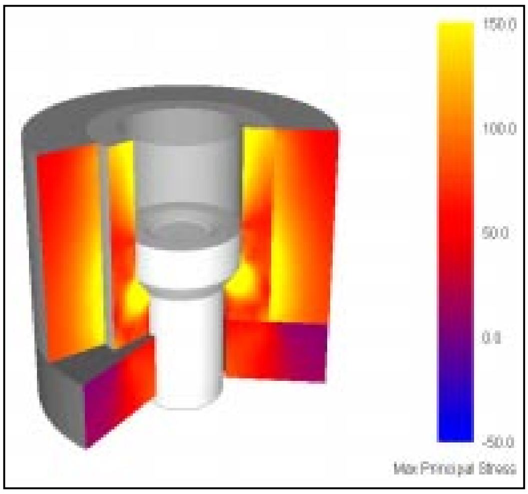

***Figure 9**: Fully coupled die stress and workpiece analysis was completed of an extrusion process with multiple deforming bodies.*

4. Example of an extrusion simulation using the steady state solution (ALE)

When simulating processes where the steady state dominates, the Arbitrary Lagrangian Eulerian approach is preferred due to the shorter computational times **[1]**. This method can quickly provide processing information, such as bending and twisting of the workpiece, temperature distribution in the die, stresses and strains, to the die design engineer when determining the optimal extrusion die geometry.

The simulation of a T-profile section

A model showing the extrusion of a T-profile section was completed using the steady state solution, as shown in **Figure 9**. The finite element mesh of the die is shown in **Figure 9a**, the bending of the T-profile section is shown in **Figure 9b** and the cross-section through the die showing contours of temperature is shown in **Figure 9c**.

Clearly, the result of using the free surface correction scheme is shown in the bending of the profile in **Figure 9b**. The steady state temperature contours in the die are also quickly determined using this approach.

a) b) c)

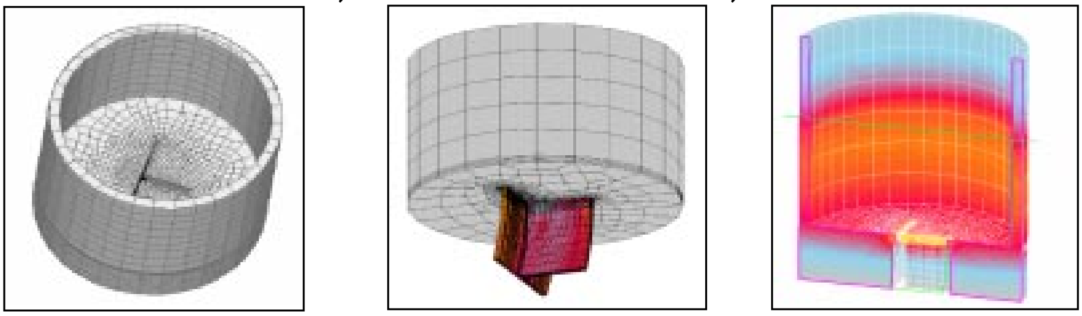

Figure 9: ***a)*** *Finite element mesh of the extrusion die.* ***b)*** *The extrusion of a T-profile section showing bending.* ***c)*** *Temperature contours in the die at steady state.*

5. Investing in Process Simulation [3]

Process simulation is in existence for more than 20 years, and it is now recognised as a standard in the aeronautic and automotive industries. However, several small and medium sized industries are still evaluating the pay-back of a potential investment in this modern technology.
A critical stage is to launch the investment at the right time. If a company waits too long, it takes the risk of being left behind by competitors, which have succeeded in making process simulation work to their advantage. On the other hand, if the company launches it too early, then it might suffer unnecessary through the painful and expensive lessons associated with deploying a technology for which the company is still immature.

An investment decision should at least rely on the following questions:
- What problems should be solved;
- Are the designs realised on a CAD system, and are they available;
- Are the right persons available, or does the company need to hire new collaborators;
- Are the process engineers ready to integrate a new tool. Do they recognise that process simulation will enhance their competence rather than replacing them.

The selection of the right partner is the second decision the company has to overcome. Indeed, several suppliers provide competing simulation packages. The reliability and the potential of a simulation software is however, difficult to evaluate before the company has actually started to work with it.

Without being comprehensive, some features are listed which need to be verified for the selection of the right software:
- Clarity of the software, friendliness of the user interface;
- Reliability of the results, stability of the results versus mesh quality, computation speed;
- Automatic mesh generation, possible CAD and CAE file transfer formats;
- Current modelling capacities and extension possibilities;
- Material database;
- Dynamic visualisation tools, web interfaced results;
- Competence of the support team;
- Reference customers in the same industry field.

Once a process simulation software has been introduced in the production department or in the development department, then it should not be used for troubleshooting right away. As any new tool, some experience is required before full profit can be taken from it. Therefore, it is important that simple cases are solved with success first, before gradually moving on more complex ones.

6. Conclusions

Simulating the transient, as well as the steady state behaviour of extrusion processes can now be efficiently modelled using two different simulation approaches. The advantages of each approach has been discussed, giving clear indications of its applications in the industry. More and more companies are implementing simulation software into their process and accepting that these technologies are a pre-requisite for successful product and process development. Choosing simulation software should be done with careful consideration to many factors, some of theses include, software capabilities, accuracy, user interface and most important the amount of development and backup support offered by the software.

7. References

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