FINITE ELEMENT SIMULATION OF THIXOFORMING

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Thixoforming is an innovative technology in metal processing, which combines the advantages of casting and forging. Thixoformed material is formed in the semi-solid state. The processed alloy is heated to the transition temperature between solid and liquid in order to obtain improved material properties.

Computer simulations for thixoforming technology are logically divided into solution approaches in fluid dynamics and solid mechanics codes, rare in combination of both physics areas.

The aim of the research was to verify the suitability of simulation programs and find effective procedure of computer modeling for real mini-thixoforming equipment.

For the simulation of solidification, mechanical and thermo-physical properties of materials was selected thermodynamic modeling tool JMatPro. For the simulation of the main process the approach of solid mechanics' solution was selected and program DEFORM™ was used. In this study, the results of numerical simulations were verified by experiments of semi-solid processing technology with mini-thixoforming equipment.

KEYWORDS
Mini-thixoforming, computer simulation, FEM, JMatPro, DEFORM, experiments

1 INTRODUCTION

The pilot analysis of using DEFORM™ was designed to verify the possibilities of input, simulation and evaluation of a technology, which is technically called thixoforming. Thixoforming is a thermal deformation flow system of forming at high temperatures and at high speed [Atkinson 2008]. Mini-thixoforming uses a small testing specimen which was used in the simulation.

Forming materials in a thixotropic condition is the heating of the material between the solid and liquid temperature at which the material contains approximately 10-30% of the liquid form. The material then has rheological characteristic which causes that the highly viscous material decreases its viscosity during the forming process due the supplied deformation. The process highly reduces the needs of the forming forces, which are in our experimental device 7kN (Fig. 1).

The method of mini-thixoforming is focused on the products of very small size [Aisman 2009]. This method is associated with the achievement of extremely steep gradients, heat and high rate of solidification and cooling. These conditions fundamentally affect the development of emerging structures and the characteristics of the material. The simulations could be used for determining the limiting conditions for forming of mini-thixoforming. The advantage would be the reducing of the time and energy costs.

Test specimen is inserted into die, fastened by mandrel in a home row so that there it is not in contact with a vertical wall of the die and then it is resistively heated to a semi-solid state of sample material. After reaching the desired temperature is following a forming process using a displacement of mandrel inwardly die. In the middle of die is a channel into which is pressed a sample material. This channel has nearly circular shape in a horizontal section. The reason for this shape is a test of ability to fill a die.

The input boundary conditions of the system were given, for example the temperature of all elements, which was designed for the expansion process. The position of the elements, thermal and mechanical contact including friction was defined. The movement of the elements against each other was set according to the real system [Jirkova 2010]. The experiment was held at room temperature, which is why thermal exchange with the environment was considered.

2 SIMULATION MODEL

Solid geometry was created in a CAD program, Siemens NX10 and in format STL imported into the FEM environment of DEFORM™ (Fig. 2). The analytical software JMatPro was used for the calculation of material models.

The quality of the results is directly dependent on the use of distribution of the structures by finite elements. Tetrahedral elements were used for creation of the mesh. It was set up not only the appropriate number of elements in a single body, but also the size of the smallest and largest element with a size factor with regard to compliance with the precise geometry of the body, and also with regard to temperature and deformation (Fig. 3).

The calculations consider large geometric nonlinearity. That is why parameters of the volume control of the objects have been set during the global process. The function of the tracking maintaining the volume of the forming specimen by the primary geometry at the beginning of the simulation was used.

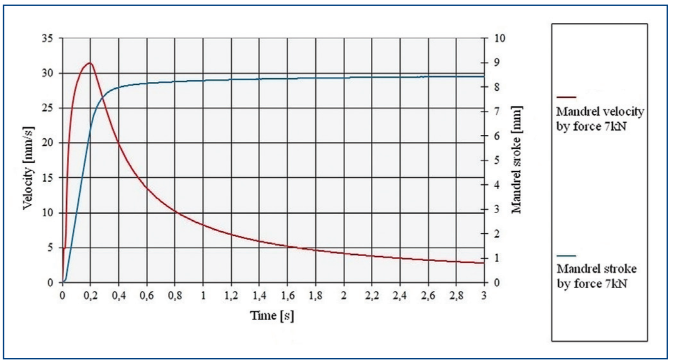

Figure 1. Real operating conditions of the system are boundary conditions for the simulation

The rigid and plastic objects were used. These objects have the relevant material properties such as deformation resistance, Young's modulus, Poisson's ratio, thermal expansion, thermal conductivity and heat capacity.

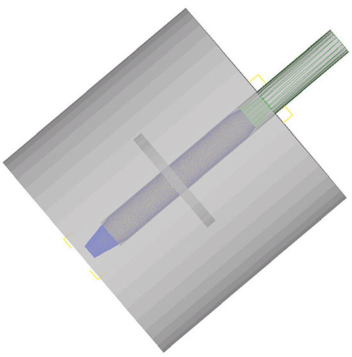

Figure 2. Complete computational model: die, mandrel and the test specimen

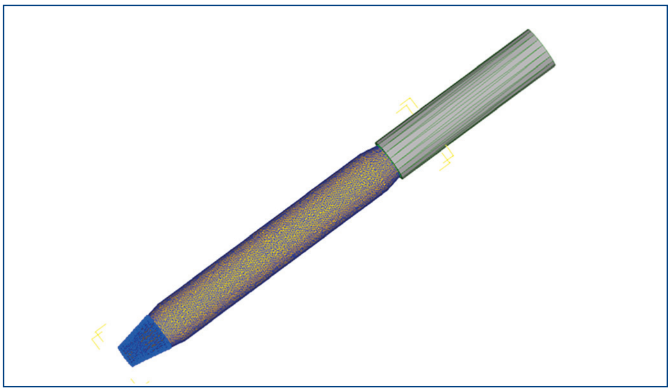

Figure 3. Overview of FEM mesh: Contact of test specimen and die at the beginning of the simulation before forming is blue labeled

3 MATERIAL MODEL FOR SIMULATION

JMatPro software was effectively used to create material models. The software enables to calculate the model of the material. An easy export of the computed material model in a compatible format for the system DEFORM was used. JMatPro is for DEFORM software fully compatible. It is very powerful tool for analysis and optimization.

An example of the chemical composition of the test specimen, along with a basic description of this special material is shown in Fig. 4. Material model was calculated by option for the data export DEFORM Forming and besides contains mechanical properties like flow stress i.e. stress-strain curves for given material, strain rate and temperature (Fig. 5). The complex material models have been created for tools and for specimen it means for materials, Titan Grade 5 – Titanium alloy with elements 6Al-4V, tool steel X210Cr12 and for specimen CPM15V.

CPM® 15V — CRUCIBLE DATA

CPM 15V is Crucible's highest vanadium, abrasion resistant CPM tool steel. It contains 50% more hard vanadium carbides in its microstructure than CPM 10V, to provide even higher wear resistance.

CPM 15V is intended for applications requiring exceptional wear resistance. Applications where CPM 10V is successful, but even longer tool life is desired, or applications where sintered carbide tooling is prone to fracture or difficult to fabricate, are likely to be well-served by CPM 15V.

Typical Chemistry

Carbon	3.40%
Manganese	0.50%
Silicon	0.90%
Chromium	5.25%
Vanadium	14.50%
Molybdenum	1.30%
Sulfur	0.07%

Typical Applications

Powder Compaction Tooling:
Punches, Dies, Core Rods
Plastic Processing Equipment:
Barrel Liners, Screw Tips, Wear Inserts
Dies and Punches for:
Forming, Cold Extrusion, Drawing, Piercing
Industrial Knives — Granulator Blades
Slitter Knives — Woodworking Tools
Ceramic Dies — Wear Parts

Figure 4. Chemical properties of CPM 15V material

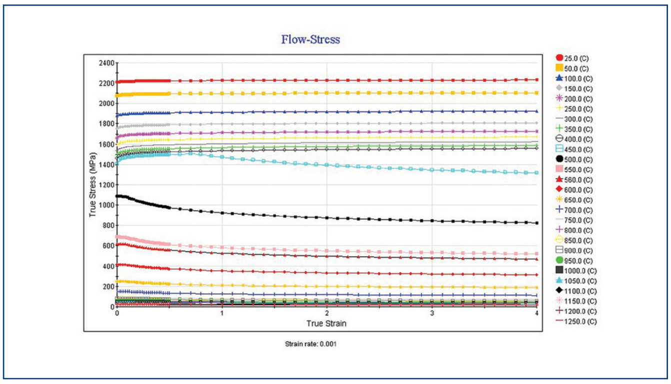

Figure 5. Flow stress of the material CPM15V calculated by JMatPro

4 FINITE ELEMENT SIMULATION

The pilot simulation of using DEFORM™ was supposed to verify the possibility of entering, calculation and evaluation system with very high temperature material test specimens at high speed. Input options for boundary conditions, its own simulation and results were evaluated as very good and created models were refined in the future.

First, it was considered a mathematical model for visco-plastic behavior of material for single phase solid material model of test specimen for the analyzed system with regard to the physical nature of the process [Masek 2010]. That means a model of the internal state of the material, when between different parts of the real body the friction occurs. This friction, which occurs in the material is referred to as internal. Internal friction is markedly reflected, for instance flow of real liquids. Fluid with a higher internal friction flows slowly. On the body moving in a fluid with a higher internal friction exerts a greater resistive force.

This internal friction comes from the fact that this phenomenon is similar to friction during movement of solids. For viscous liquids, however, this friction occurs inside the liquid and not on the surface. Internal friction occurs not only in fluids, but also in solid state, which causes e.g. change the elastic properties of the substance. Physical quantity characterizing the internal friction is called viscosity.

For all tools were used rigid body and for the test specimens the plastic body with the respective material properties. The rigid body has also a mesh of finite elements so as to be able to monitor the distribution of the temperature field in the process in rigid tools too. This variable cannot be without mesh of finite elements in rigid body evaluated.

Solved combination of initial temperature of tools, materials of tools and heat transfer coefficient between the formed material and tools:

- initial temperature of the tools 20°C
- initial temperature of the tools 300°C
- the material of the tools – Titan Grade 5, titanium alloy with elements 6Al-4V
- the material of the tools – tool steel X210Cr12
- heat transfer coefficient between the molded material and tools 5 [N/sec/mm/C]
- heat transfer coefficient between the molded material and tools 11 [N/sec/mm/C]

Simulations were performed for all combinations mentioned above. Considering the large number of results achieved are additionally selected only examples of results of the temperature distribution for the final step of the process with the heat transfer coefficient between the molded material and the tools 11 [N/sec/mm/C]. This interface heat transfer coefficient specifies the coefficient of heat transfer between two objects in contact. This can be specified as a constant or a function of time or interface pressure. The interface heat transfer coefficient is generally a complex function determined by the interface pressure, amount of sliding, and interface temperature. If this data is available, it can be entered as a table.

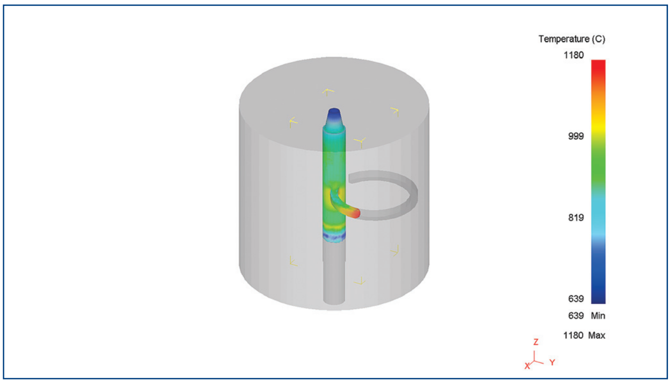

Figure 6. Results for initial temperature of the tools 20 °C: material of the tools – Titan Grade 5

If no data is available, values of 11 should give reasonable results, which was confirmed by the changes of this coefficient.

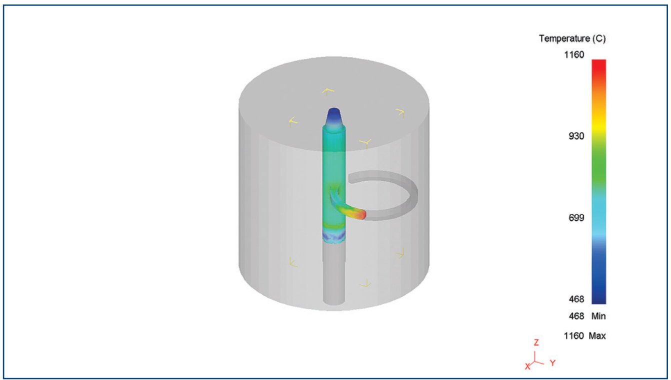

Figure 7. Results for initial temperature of the tools 20 °C: material of the tools – steel X210Cr12

Figure 8. Results for initial temperature of the tool 300 °C: material of the tools – Titan Grade 5

Figure 9. Results for initial temperature of the tool 300 °C: material of the tools – steel X210Cr12

As the previous results (Fig. 6–9) shown, there is evident difference resulting temperature field system, which is due to different materials of tools and of course, the preheating. The achieved results and knowledge will be applied to the operation of a real system.

The work required to overcome the frictional force varies in increase of internal energy, which results in an increase in temperature. This increase of the heat in the system or its parts can have a major impact on the results of the simulations.

Friction coefficient between the individual parts of the system like die, mandrel and the test specimen has been changed for the more physical models of friction. In this case it is a dry friction i.e. sliding contact, when there is no added lubricant. The friction coefficient in DEFORM specifies the friction at the interface between two objects. The friction coefficient may be specified as a constant, a function of time, temperature, pressure, pressure temperature surface stretch, pressure dependent, strain rate, and sliding velocity or special user program i.e. routine.

The friction model according to Tresca was used first. Constant Tresca friction is used mostly for bulk-forming simulations. The frictional force in the constant Tresca definition is defined by then according to:

$$F_T = m\,k$$

The parameter m is called the friction factor. This states that the friction is a function of the yield stress of the deforming body.

Coulomb friction model was tested as second:

$$F_c = \mu\,F_N$$

The Coulomb friction force F_c is a force of constant magnitude, acting in the direction opposite to motion. Where F_N is the force pressing surfaces together and μ is the frictional factor. μ is determined by measurements under certain conditions. One of the biggest problems of the Coulomb model is, that it cannot handle the environment of zero velocity, hence the properties of motion at starting or zero velocity crossing, i.e. static and rising static friction. The advantage of the Coulomb friction model is its simplicity and versatility. Though in general the relationship between normal force and frictional force is not exactly linear and so the frictional force is not entirely independent of the contact area of the surfaces.

The reason why friction in metal forming is not fully discovered yet is that is very difficult to enter into the boundary interface between the specimen and the die, to make in situ observation of what takes place there. Friction model parameters were therefore adjusted by reversible method of measuring of the length of real testing specimen after mini-thixoforming process in comparison with measuring of the length of simulated testing specimen. Every single change in the value of friction or friction model required to perform an additional new simulation.

Hybrid friction model combines the two previous ones and after setting the appropriate parameter values perform the best results of the length of simulated testing specimen.

The following Fig. 10 shows the results for the following combination of input boundary conditions:

- initial temperature of the tools 20°C,
- the material of the tools– Titan Grade 5, titanium alloy with elements 6Al-4V,
- heat transfer coefficient between the formed material and tools 11 [N/sec/mm/C],
- hybrid friction model

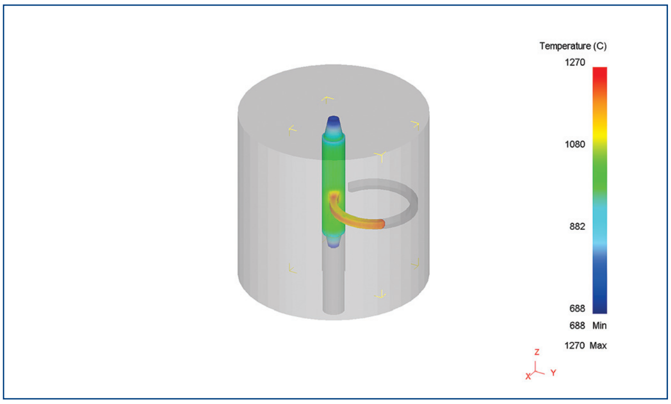

Figure 10. Results for the hybrid friction model

5 DISCUSSION

The work required to overcome the frictional forces in the mini-thixoforming system friction varies predominantly in the temperature rise, i.e. on the heat generated by the operation of the system. This increase in heat can have a major impact on test specimens, because the temperature of the surface layers where friction occurs has a significant impact on the status of these layers. It turned out, however, that in the case analyzed at very high temperatures of these test specimens, the temperature rises by friction in the system by one operation only negligible.

6 CONCLUSIONS

Knowledge and achieved results will be applied in a real experiment, which will also contain, compared to the simulations, the phases of heating and cooling the system. The temperature effect on the entire system is simplified. The phase of heating is solved only by thermal expansion of the tested specimen at the zero step of the calculation. The test results were used to assess the results of the simulation. A good agreement with the real results was achieved despite the simplistic simulation conditions. Preheating resistance system will be modelled as follow up research to achieve more accurate results. The obtained computational model will be ready for simulation of different specimens of different materials of the whole process of forming the mini-thixoforming [Novy 2015].

Figure 11. Example demonstration products produced by mini-thixoforming

It was discovered that for the forming in the semi-solid state, when very high temperatures are reached by heating from the room temperature, a single-phase material i.e. solid model of the testing specimen can be successfully used. Developed simulation model will be refined by modelling of preheating resistance system and then applied for the optimization of real mini-thixoforming (Fig. 11).

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