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ON THE NUMERICAL MODELING OF METAL FORMING PROCESSES USING THE PARTICLE FINITE ELEMENT METHOD

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Summary. In this work a Lagrangian finite element approach for simulation of metal forming is presented, based on the so-called Particle Finite Element Method (PFEM). The governing equations for the deformable bodies are discretized with the FEM via a mixed formulation using simplicial elements with equal linear interpolation for displacements, pressure and temperature. The use of PFEM for modeling of metal forming processes includes the use of a remeshing process, α-shape concepts for detecting domain boundaries, contact mechanics laws and material constitutive models. The merits of the formulation are demonstrated in the solution of 2D thermally coupled metal forming processes using the particle finite element method. The method shows good results and is a promising method for future simulations of thermally/coupled forming processes.

1 INTRODUCTION

In the last year's particle finite element (PFEM) have gained considerable interest in the CFD community as a method to tackle fluid mechanics problems using a Lagrangian description of the motion of the continuum medium. Their main advantages are found in modelling fluids exhibiting moving free surfaces. Other features e.g. large deformations and rapidly changing free boundaries are here considered for mechanical processes of solid material. Numerical solution methods that can handle these factors will both open up new possibilities to predict highly non-linear problems and increase the accuracy of mechanical response computation.

2 FUNDAMENTALS OF THE PARTICLE FINITE ELEMENT METHOD

The particle finite element method emerged as a natural result of previous exploration in the context of the meshless methods[1,2,3]. In the present work, the implementation of PFEM consists of the following steps.

1. Fill the solid domain with a set of points refereed to as 'particles'. The accuracy of the numerical solution is clearly dependent on the considered number of particles.
2. Generate the finite element mesh using the particles as nodes. This is achieved using a Delaunay triangulation.
3. Identify the external boundaries to impose the boundary conditions and to compute the domain integrals.
4. Solve the non-linear Lagrangian form of the balance equations finding displacement, pressure and temperature.
5. Update the particle position using the computed values of displacements.
6. Go back to step 2 and repeat for the next time step.

In this solution scheme, not only the numerical solution of the equations is critical from the computational point of view, but also the generation of a new mesh and the identification of the boundaries. For this purpose, a Delaunay Triangulation scheme is adopted together with the so-called alpha shape method for boundary identification

3 GOVERNING EQUATIONS FOR A LAGRANGIAN CONTINUUM

Consider a domain containing a deformable material which evolves in time due to the external and internal forces and prescribed displacements and thermal conditions from an initial configuration at time $t = 0$ to a current configuration at time $t = {}^{n}t$. The volume V and Γ its boundaries at the initial and current configurations are denoted as $({}^{0}V, {}^{0}\Gamma)$ and $({}^{n}V, {}^{n}\Gamma)$, respectively. The aim is to find a spatial domain that the material occupies, and at same time obtain velocities, strain rates, stresses and temperature in the updated configuration at time ${}^{n+1}t = {}^{n}t + \Delta t$. In the following a left super index denotes the configuration where the variable is computed.

3.1 Momentum equations

The equation of conservation of linear momentum for a deformable continuum are written in a Lagrangian description as

$$\rho \frac{Dv_i}{Dt} - \frac{\partial^{n+1}\sigma_{ij}}{\partial^{n+1}x_j} - {}^{n+1}b_i = 0,\ i, j = 1, ..., n_s\ in^{n+1}V \tag{1}$$

In Eq. (1) ${}^{n+1}V$ is the analysis domain in the updated configuration at time ${}^{n+1}t$ with boundary ${}^{n+1}\Gamma$, V_i and b_i are the velocity and the body force components along the Cartesian axis, ρ is the density, n_s is the number of space dimensions and σ_{ij} are the Cauchy stresses in ${}^{n+1}V$.

3.2 Thermal balance

The thermal balance equation in the current configuration is written in a Lagrangian framework as

$$\rho c \frac{DT}{Dt} - \frac{\partial}{\partial^{n+1} x_i}\left(k \frac{\partial T}{\partial^{n+1} x_i}\right) + {}^{n+1}Q = 0 \ , \ i,j = 1,...,n_s \ in \ {}^{n+1}V \quad (2)$$

where T is the temperature, c is the thermal capacity, k is the thermal conductivity and Q is the heat source. Eq. (1) and (2) are completed by the standard boundary conditions.

4 REPRESENTATIVE NUMERICAL SIMULATIONS

In Figure 1, Figure 2 and Figure 3 three forming processes (machining, extrusion and shearing) illustrate the proposed methodology. In both cases a large strain elasto-plastic model has been used to model the forming material.

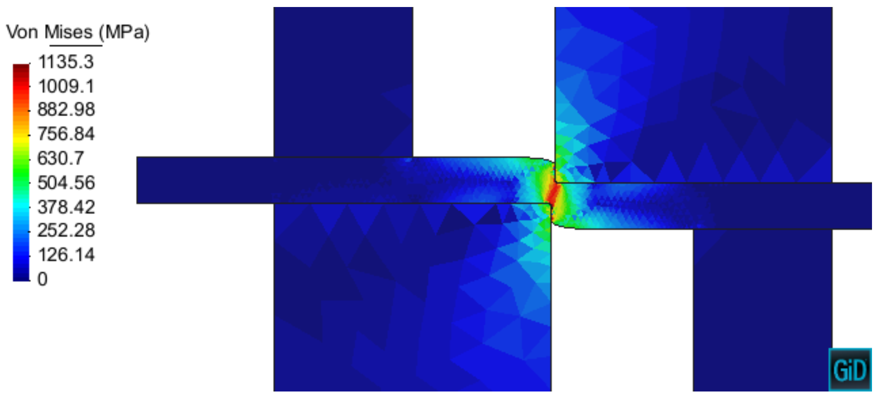

Figure 1: Representative numerical simulation of metal forming processes using PFEM: shearing

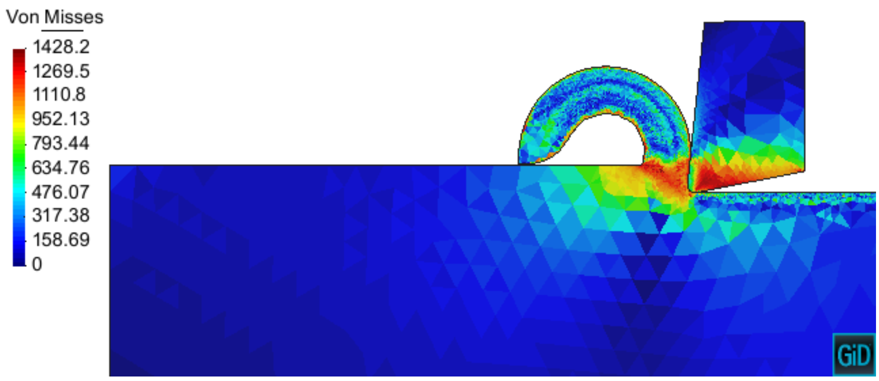

Figure 2: Representative numerical simulation of metal forming processes using PFEM: machining

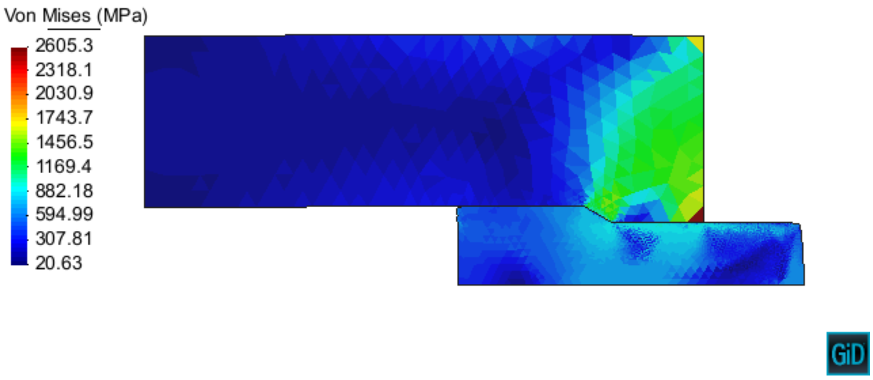

Figure 3: Representative numerical simulation of metal forming processes using PFEM: extrusion

5 CONCLUSIONS

A Lagrangian formulation for analysis of industrial forming processes involving thermally coupled interactions between deformable continua is presented. The governing equations for the generalized continuum are discretized using elements with equal linear interpolation for the displacement and the temperature. The merits of the formulation in terms of its general applicability have been demonstrated in the solution of a variety of thermally-coupled industrial forming processes using the PFEM.

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