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Discretization Approaches to Model Metal Cutting with Lagrangian, Arbitrary Lagrangian Eulerian and Smooth Particle Hydrodynamics formulations

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With significant technological growth and computing power it is possible to simulate metal cutting processes with different discretization techniques. Classically the Lagrangian or Eulerian finite element formulations are used to model metal cutting process. Lagrangian approach is accurate with it's representation of the domain boundary, but requires a re-meshing procedure to avoid element distortions. Eulerian approach provides a steady state solution of the chip-workpiece separation, however its limitation lies in the treatment of convective terms during motion. The Arbitrary Lagrangian-Eulerian method can be used to combine the advantages of both methods and avoid the disadvantages. In the Lagrangian framework, use of a meshless technique - Smooth Particle Hydrodynamics (SPH) has its advantage in large strain deformation problems without the need for re-meshing algorithms. This work compares the LAG, ALE and SPH approaches by modelling a turning process.

1 Introduction

Metal cutting is a complex process with a multitude of simultaneously occurring mechanisms. Cutting simulations are performed to understand these effects by changing different process parameters and tool geometries. The method of choice is often the Finite Element Method (FEM), although it must be noted that numerous difficulties arise in the application of large strain deformation problems. Hence the choice of the discretization is a fundamental question to be answered during modelling. The Lagrangian(LAG) approach is suitable, where the displacement vector tracks the individual material points. However it's inability to follow large deformation leads to simulation failure. Possible solutions are either element deletion, which would lead to a reduction of mass from the simulation, or adaptive re-meshing, which would lead to increased computational times. In the Arbitrary Lagrangian-Eulerian (ALE) approach, the mesh is neither constrained to a fixed spaces (Eulerian approach) nor does it moves along with material points (Lagrangian approach). The ALE approach would help maintain the mesh topology and avoid iterative meshing. A smoothening algorithm is applied to relocate the nodal positions of the mesh to avoid problems of mesh distortions and hour-glass effect. Although the method is computationally effective, the accuracy is still limited to the underlying mesh and the choice of the smoothening algorithm. It is to be noted that a failure criterion is required for chip-work piece separation for both the LAG and ALE approaches. The SPH method is devoid of all the above techniques as it is categorized as a meshless-FEM method. Due to loose connectivity of the neighbouring particles, application of failure criterion is not necessary as the material separation takes places due to loss of cohesion between the particles. However, an artificial bulk viscosity and an equation of state is required to be applied to ensure the accuracy of results.

2 Experiment and Simulation Framework

The simulation model parameters of a turning process were chosen according to Mabrouki et al. [1]. Subsequently the results are validated with the experiments performed. A straight turning operation was performed on A2024-T351 aluminium alloy by a carbide insert with the orthogonal rake angle $\gamma = 17.5°$, clearance angle of $\alpha = 7°$ and a tip radius of 20 µm. The feed per revolution was set to $f = 0.3$ mm, with a constant depth of cut of $a_p = 4$ mm and a cutting speed $v_c = 200$ m/min.

In the simulation framework, the 2D LAG, ALE and SPH models consist of a rigid tool and a workpiece (FEM/SPH elements). The rigid tool is given an imposed motion in the negative x-direction and the workpiece is fixed along its left and bottom nodes as shown in Fig.1. The discretization was performed with quadrilateral continuum elements with element spacing (d_e) for the LAG/ALE models and the 3D particle spacing (d_p) for the SPH model, where $d_e = d_p = 0.025$ mm.
As to the constitutive material model, the Johnson Cooke model in conjunction with the Johnson Cooke failure model is chosen as per the simulations performed by [1, 2]. The penalty based contact model was applied between the tool-workpiece interface with a low coefficient of friction $\mu = 0.17$. The tool speed was set to $v_c = 200$ m/min in the direction parallel to the workpiece and was kept constant in all simulations performed.

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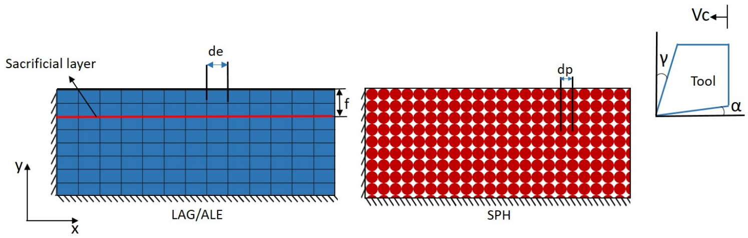

Fig. 1: Simulation framework of the LAG/ALE and SPH models

3 Results and Conclusions

The cutting simulations performed on A2024-T351 are compared with the experiments performed by [1] based on the chip morphology, stress distribution and cutting forces.

Fig.2 shows a similar chip form for all models, which agree well with those experimentally obtained. Looking at the stress at the shear zone between the tool tip and the chip region, the models predict a similar stress distribution of around 600 Mpa.

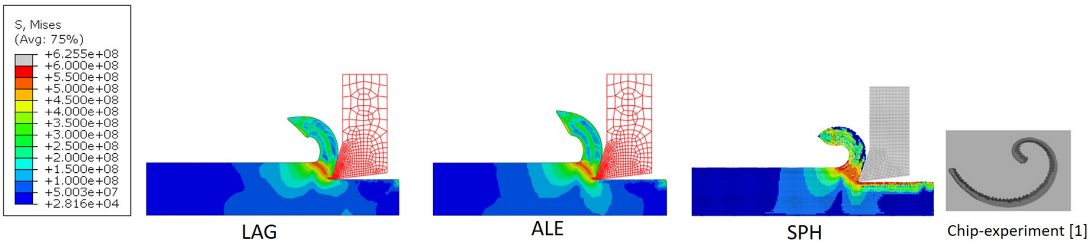

Fig. 2: Simulated chip morphology for a turning process using LAG, ALE and SPH formulations

Comparing the average cutting forces (Fig.3) the LAG model predicts a higher cutting force, while the SPH model tends to predict lower cutting forces than the experimental value. However the SPH model is closest to the measurements.

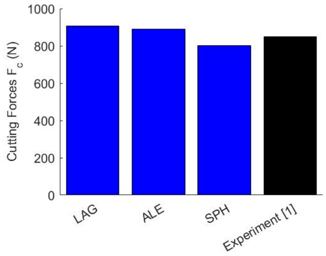

Fig. 3: Comparison of mean cutting forces with experiment

In conclusion, a quantitative analysis of three discretization approaches was performed on metal cutting simulations for a turning process of A2024-T351 aluminium alloy. Based on the simulations, all three models were able to predict a similar chip morphology. However the SPH model was able to predict the cutting forces than the LAG/ALE models, when compared with the experiments.

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