Numerical Simulations of Rod Plate Interaction

Meir Mayseless¹, Gabi Luttwak¹ and Naury K. Birnbaum²

¹Rafael P.O.Box 2250, Haifa 31021, Israel
²Century Dynamics Inc., 2333 San Ramon Valley Blvd., San Ramon, CA, USA

Abstract. The 30° oblique impact between a high speed copper rod and a moving steel plate is investigated. The numerical simulations are carried out in the second order, multi-material Euler-Godunov processor of Autodyn V4. The full three dimensional calculation is compared to an approximate, two dimensional plane strain simulations. The results are compared to available experimental data. The three dimensional effects are considered and the validity of using the 2D approximation is discussed.

INTRODUCTION.

There are two main phases of interaction between a fast jet and a moving oblique plate. The first contact phase between the plate and the jet is a head on collision while the second one is a sideways interaction. In between the two phases there is a momentary loss of contact, during which a small portion of the jet emerges without interaction. This part of the jet is called the precursor. The length of the precursor is determined by the kinematics parameters of the plate and the jet, such as obliquity and velocity, as well as by the physical characteristics of the two materials involved, such as thickness and material properties.

The motion of each plate can be either in the direction of the jet, the forward moving plate (F-plate), or opposite to the jet moving direction, the backwards moving plate (B-plate).

As soon as the interaction between the plate and the jet is resumed, the plate impacts the jet laterally and pushes it sideways. If the impact pressure is strong enough the plate will "penetrate" the jet by pushing a small jet segment sideways, creating a "wave" of disruption. The plate material is now in the jet's way and it is penetrated by the jet. A new cycle of interaction starts: plate penetration and jet disruption. This is the phenomena that was named “pebble-stone” interaction in (1). This phenomena is usually observed experimentally, during the interaction of a jet with a forward moving plate, where the plate is moving in the direction of the jet (1). If the impact pressure is not strong enough, the cycle may be too short the disruption amplitude will be too small and the result will be a smooth deflection of the jet. This phenomenon is typical for the interaction with a backward moving plate which moves toward the jet (1).

To study this phenomenon the oblique impact between high speed copper jet and a moving steel plate is investigated. The question one has to answer first is what kind of numerical simulation to use. Will a 2D planar configuration give an adequate result, or should we use a full 3D simulation? The study presented here was started with the goal to answer this question. Numerical simulations are carried out in the second order, multi-material Euler-Godunov processor of Autodyn V4. The full three-dimensional calculation is compared to approximate, two-dimensional plane strain simulations. The results are also compared to available experimental data. The three dimensional effects are considered and the validity of using the 2D approximation is discussed.

To reduce the size of the computational domain, instead of using the laboratory frame of reference (LFR), we are simulating the jet-plate interaction in a frame of reference where the interaction point is stationary. In this frame of reference (fig. 2) the plate is moving along its surface with a velocity of \( \pm \frac{v_P}{\sin \alpha} \), while the jet is moving forward with a velocity of \( \pm \frac{v_J}{\sin \alpha} \), for the B-plate and \( - \frac{v_P}{\sin \alpha} \) for the F-plate. \( V_P \) is the plate velocity in the LFR (normal to its surface), \( V_J \) is the jet velocity in the LFR, and \( \alpha \) is the angle between the velocity...
vectors of the plate and the jet.

\[
\begin{align*}
V_J &= V_P \sin \alpha \\
V_p/ \tan \alpha & \leq V_J 
\end{align*}
\]

**Figure 2** Moving frame of reference

**NUMERICAL SIMULATIONS**

**Numerical scheme**

**AUTODYN V4** has Eulerian, Lagrangian and SPH (Smooth particle hydrodynamics) solvers. It’s new, multi-material Eulerian processor uses a second order Godunov scheme\(^3\) to solve the conservation equations. The implementation closely follows Hancock\(^4\). The 3D code has some additional advanced features\(^5\), a virtual memory scheme\(^6\), a high resolution multi-material interface and a Lagrange to Euler remap. The SPH technique, which uses Lagrangian particles, with no grid, has some advantages for the simulation of high speed impact. The SPH solver\(^6\) of AUTODYN 3D V4 is also applied to investigate the problem.

**Results**

We consider a copper jet with a diameter of 3mm moving with \(V_J = 5000\) m/s and hitting a plate moving forward at a speed of \(V_P = 1000\) m/s. The plate has a width of 3mm. The angle between the jet and the plate was 30°. We have also investigated the effect of changing the jet velocity to \(V_J = 6000\) m/s. In the 3D SPH simulations the 30° and 45° impact of the copper jet into a reactive armor plate was investigated.

The 2D simulations were with plain strain symmetry. The 2D calculation can use a much finer mesh, and were carried out till 150\(\mu\)s. The results are shown in Figure 3. The interaction is between a jet moving at a velocity of \(V_J = 5000\) m/s and a forward plate moving at 1000m/s. Both the jet and plate were moved into the mesh using inflow boundary conditions. The jet is moving from left to right in the picture. At 20\(\mu\)s, the plate is fully perforated and the plate is virtually disconnected from the jet. Soon after it the plate hits again the jet from its side and starts to slide backward along the jet. Two disruption waves are observed at 50\(\mu\)s. The first one immediately behind the tip and the second one is just beginning to be created, forming a small dent. This small dent is already fully developed at 75\(\mu\)s, while the next dent is being formed. The disruption waves on the jet are clearly seen at 110\(\mu\)s.

We have carried out two 3D simulations using the second order Euler-Godunov solver of Autodyn V4 for a jet moving with respectively 5000 and 6000m/sec. The 3D calculations were continued only till 18\(\mu\)s. This time is too early to see the development of the disruption waves in the jet, but we may already see at this stage causes for differences between the 2D and the 3D simulations. In figures 3-5 we can see the simulations for the jet moving at 5000m/sec. In Figures 6-8 we can see the
simulations for the jet moving at 6000m/sec. These simulations did not include inflow conditions for the plate. We see that at higher velocity, the interaction time is shorter.

**Figure 3.** T=11.6μs 5000m/s 3D rod-on-plate

**Figure 4.** T=15μs 5000m/s 3D rod-on-plate impact

**Figure 5.** T=18.1μs 5000m/s 3D rod-on-plate impact

**Discussion**

The interaction time between the jet and the plate depends on their relative velocity, the impact angle and the width of the plate. As the jet penetrates the plate, a hole is formed in the plate. The precursor escapes through the hole. As the plate continues to move toward the jet the interaction resumes. At a higher jet velocity, the interaction time is shorter and the hole diameter is larger leaving a larger portion of the jet unperturbed. Qualitatively, there is a striking similarity between plate on plate and rod on plate impact. The rod on plate impact has a symmetry plane. If we look at the flow and the pressure field on the symmetry plane, it seems quite similar to the respective solution for plate on plate.
Two-dimensional simulations are much quicker, so it is interesting to examine the limit of what we can learn from the two dimensional simulations. The hole formed in plate on plate impact has a larger diameter than the hole for the corresponding rod on plate penetration, although the penetration velocity is the same. This has been noticed in the past also for lower speed penetrations\(^{(2)}\). Thus, the two dimensional simulations overestimate the hole diameter and predict a weaker perturbation for the jet and a longer precursor segment.

REFERENCES