ICM11

Effect of wave-front width on micro-jet from a shocked aluminum surface

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Abstract

This work investigates the relation between shock wave risetime and the amount of micro-scale fragments ejected from a grooved aluminium surface under shock loading condition. Using smoothed particle hydrodynamics, we calculate the formation of micro-jet from the groove of metal surface, and analyze the dependence on the width of loading wave front. The simulation results compare well with the experiment ones, and reveal the dependence of the micro-jet on the wave front: both the mass and the maximal velocity of the ejection will decrease with the increasing of the width of wave front. It is also found that the micro-jet originates from the folium near the groove, which can acquire axial velocity and impact at axis when the shock wave releases at the metal/vacuum interface. The folium becomes smaller as the wave front widens. This is because some matter will satisfy the lock condition of jet strength and can eject no more.

Key words: SPH; micro-jet; shock wave

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1. Introduction

When shock waves confront a free surface of metal, some metal particulate can eject from the surface. It is a very important phenomenon to understand the dynamics of material under strong shocking. Many factors can cause this destructive phenomenon, however, the ejecting mechanism is generally dependent on the shock strength. In this paper, we present the investigation on the ejecting process of a metal grooved surface, which can induce a jetting current under shock loading.

Recently, some studies on the jetting mechanism have been reported. Asay [1,2] investigated the effect of the groove angle on the total jetting mass and mass-velocity distribution. Based on the classical constant jetting theory, Han [3] presented a semi-rational formula for calculating the above jetting mass. Chen [4] investigated the dynamic process of ejection from a metal surface groove by molecular dynamics, finding that the velocities of both the ejected atoms and the free surface of the groove increase with the angle of the groove. Wang [5] calculated the jetting current form the surface groove, and obtained the relations between the jetting mass and maximum speed with the angle of the groove, which accord with the experiment dates.

Generally, the defect scale of metal surface is very small (about micron level), near the width of the shock wave front. The effect of wave-front width should not be ignored in fact. Asay [6] has discovered in experiment that the jetting mass exhibits an exponential decrease with the widening of wave-front. For a case of 5 micron defect, the jetting mass reduces by two orders of magnitude with the width of wave-front increasing to 35 ns. Han [7] also obtained the similar results experimentally. Obviously, the theory study on this phenomenon has become a interesting and needing attention project.

In this study, we have performed smoothed particle hydrodynamics (SPH) on the jetting from a grooved surface of aluminum. The dynamic properties of jetting and the shock wave-front risetime effect are discussed.

2. Simulation method

The initial configuration of a grooved surface is shown by Fig 1, where the length along x axis is 240um, the length along y axis is 320um, and the depth of groove is 80um. The diameter of particles is set 0.067um, and the total number of particles is 158520. Periodic boundary condition was employed along x directions, and loading wave was generated along y axis by a uniformly accelerated piston. When the velocity of piston reached its max value V_{max}, then keep it. Obviously, different pressure profiles can be obtained by adjusting the time of piston reaching its max velocity, as shown in Fig 2. The introduction on the SPH method can be seen in Ref. [8,9]. Here, we just give the calculated physical model and the corresponding parameters. In this work, ideal elastoplastic model was used, with shear modulus G=27.6Gpa, yield strength Y=0.2GPa. Also, a polynomial expression of state equation was adopted, p=k_1x+k_2x^2+k_3x^3+γ E, with k_1=0.7906, k_2=1.325, k_3=2.13, γ =2.13.
3. Results and discussion

To begin with, we analyze the dynamic process of jetting for the two cases of \(\Delta t = 0\) (shock loading) and \(\Delta t = 30\) ns, respectively. The calculated results are shown in Fig 3, where the pressure distribution is demonstrated. When shock wave arrives at the groove top, the groove free surface begins to move toward the symmetry axis and meantime a rarefaction waves are reflected from the groove free surface. So the region near the groove top can maintain at a high pressure, which releases continuously along the shock direction and lead to the formation of jetting. Obviously, the loading of \(\Delta t = 30\) ns can not form the high pressure as shock loading at the groove top, for the energy of waves propagates in metal continuously. Also, fragments in Fig 3 appear in shock loading (upper), which can be attributable to the two rarefaction waves reflected by the groove and the free surface.

Fig. 3. Pressure distribution for jetting procession. The upper denotes the case of shock loading, and the lower is the result of \(\Delta t = 30\) ns.
In Fig 4, we present the velocity distribution for the case of $\Delta t = 0$ ns and $\Delta t = 30$ ns, respectively. One can see the difference between the two cases for $\Delta t = 0$ ns and $\Delta t = 30$ ns. The ejection, in this paper, is judged by the velocity above that of free surface (about 2.2 km/s).

Fig. 4. Velocity distribution for the case of $\Delta t = 0$ ns (left) and $\Delta t = 30$ ns (right), respectively. The jetting zone is marked by the arrows, judged by the velocity above 2.2 km/s.

We also calculated the mass-velocity distribution and the corresponding velocity of jetting head, for different values of $\Delta t$. In Fig 5, we plot respectively the change of jetting factor $R$ and the max jetting velocity $V_{e,m}$ with $\Delta t$. The numerical results show that, both the jetting factor and the max velocity of jetting reduce exponentially, which are very consistent with the experimental results. These reveal that the capability of jet formation will decrease with the shock front ristime.

Fig. 5. (a) jetting factor change with the wave-front risetime; (b) the maximum jetting velocity change with wave-front risetime. The calculated results agree well with the experiments.
In Fig 6, we present the mass-velocity distribution for the case of $\Delta t = 0$ ns (shock loading), $\Delta t = 40$ ns and $\Delta t = 100$ ns, respectively. Horizontal ordinate denotes the ratio of jetting velocity to surface velocity, and vertical ordinate denotes the corresponding mass. One can see that, the jetting is strongest for shock loading, and there is a mass peak near the jetting head. Whereas, the jetting will reduce with the increase of $\Delta t$, and nearly vanishes for the case of $\Delta t = 100$ ns.

Fig. 6. Mass-velocity distribution for case of shock loading, $\Delta t = 30$ ns and $\Delta t = 100$ ns, respectively.

By tracking every particles, we present the formation process of jetting and its material resource, see Fig. 7. The red region has higher velocity (than free surface), which can be judged as jetting mass. From this Fig, we can see that the jet come from a very thin layer near the groove surface, and this thin layer becomes small with the increase of shock front risetime.

Fig. 7. The jetting shape (upper) and its region of source (lower) for three cases of $\Delta t = 0$ ns, $\Delta t = 40$ ns, and $\Delta t = 100$ ns.

4. Conclusion

In this paper, we present the formation of jetting from the groove of surface, and its dependence on the shock front risetime. Our simulated results show that, both the mass and the head velocity of jetting will decrease with the increase of shock front risetime. These results are very consistent with the experimental results. In addition, we find that the jet comes from the thin layer near the groove, which becomes smaller
when widening the shock front. This is because some particles will satisfy the lock condition of jetting strength, and can eject no more.

Acknowledgements

This work was supported by the Foundations for Development of Science and Technology of China Academy of Engineering Physics (No. 2009A0101007).

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