A NEW FRONT TRACKING METHOD FOR SIMULATION OF HIGH-VELOCITY IMPACT PROBLEMS

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Summary In the present paper, a new front tracking method is proposed for tracking material interfaces and describing the formation and propagation of a crack. Combined with an improved CE/SE scheme and a void growth model considering the Bauschinger effect (BE), the new front tracking method can simulate the high-velocity impact problems with large deformations, high strain rates and spall fracture. Numerical simulation of spall fracture in a plate when impacted by a spherical projectile at a velocity of 6.0 km/s is carried out. The results are in good agreement with the experimental data.

INTRODUCTION

The computer codes which are used in the study of high-velocity impact problems can roughly be classified as Eulerian or Lagrangian methodology. If combined with efficient numerical methods for describing moving interfaces, Eulerian methodology is more attractive as the Lagrangian methodology is difficult to deal with problems with large deformations and high strain rate. Our previous work [1] proposed an Eulerian scheme combined with the level set method for numerical simulation of high-velocity impact problems. For reckon in Bauschinger effect in spall fracture at very high strain rate, A void growth model considering Bauschinger effect was proposed [1]. In order to describe the formation and the propagation of a crack, our previous work chosen to delete the element whose damage factor reaches the critical value.

Numerical methods for describing moving interfaces can be grouped into Lagrangian and Eulerian approaches. Among the first group are the so-called front-tracking methods which represent the interface explicitly by a set of marker particles. Eulerian schemes distinguish phases by characteristic functions defined on the computational grid. Level-set methods represent the phase boundary implicitly as the zero level-set of a scalar grid function. In the present paper, we combined the front tracking method and the level set method. The front tracking method is adopted to track material interface and represent the crack while the level set function is used to reconstruct the interface. As the front tracking method can not describe the fracture straightforward, we propose an automatic crack growth algorithm which can describe the cracks very well with marker particles. This algorithm can be easily combined to front tracking methods.

NUMERICAL METHODS AND RESULTS

Using cylindrical coordinates (r,θ,z), the Eulerian governing equations for the homogenous media without heat conducting, thermal diffusion and external forces can be written in the form of conservation laws as

$$\frac{\partial \mathbf{Q}}{\partial t}+\frac{\partial \mathbf{E}(\mathbf{Q})}{\partial r}+\frac{\partial \mathbf{F}(\mathbf{Q})}{\partial z}=\mathbf{S}(\mathbf{Q}), \tag{1}$$

where $\mathbf{Q}$ is the vector of conserved variables, $\mathbf{E}$ and $\mathbf{F}$ are the conservation flux vectors in x and y directions respectively, and $\mathbf{S}$ is the source term vector. In Eulerian representation, these vectors are

$$\mathbf{Q}=\begin{bmatrix}\rho\\ \rho u\\ \rho v\\ E\\ s_{\mathrm{rr}}\\ s_{zz}\\ s_{\theta\theta}\\ s_{\mathrm{rz}}\\ \varepsilon^{\mathrm{p}}\\ T\\ \xi\\ D\end{bmatrix},\quad \mathbf{E}=\begin{bmatrix}\rho u\\ \rho u^2-\sigma_{\mathrm{rr}}\\ \rho uv-\sigma_{\mathrm{rz}}\\ u(E-\sigma_{\mathrm{rr}})-v\sigma_{\mathrm{rz}}\\ us_{\mathrm{rr}}\\ us_{zz}\\ us_{\theta\theta}\\ us_{\mathrm{rz}}\\ u\varepsilon^{\mathrm{p}}\\ uT\\ u\xi\\ uD\end{bmatrix},\quad \mathbf{F}=\begin{bmatrix}\rho v\\ \rho uv-\sigma_{\mathrm{rz}}\\ \rho v^2-\sigma_{\mathrm{zz}}\\ v(E-\sigma_{\mathrm{zz}})-u\sigma_{\mathrm{rz}}\\ vs_{\mathrm{rr}}\\ vs_{zz}\\ vs_{\theta\theta}\\ vs_{\mathrm{rz}}\\ v\varepsilon^{\mathrm{p}}\\ vT\\ v\xi\\ vD\end{bmatrix},\quad \mathbf{S}=\begin{bmatrix}S_{\rho}\\ S_{\rho u}\\ S_{\rho v}\\ S_{\mathrm{E}}\\ S_{s_{\mathrm{rr}}}\\ S_{s_{zz}}\\ S_{s_{\theta\theta}}\\ S_{s_{\mathrm{rz}}}\\ S_{\varepsilon^{\mathrm{p}}}\\ S_{\mathrm{T}}\\ S_{\xi}\\ S_{\mathrm{D}}\end{bmatrix}, \tag{2}$$

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were ρ is the density, u and v are the r and z components of the velocity respectively, E is the total energy per unit volume, s_{rr}, s_{zz}, $s_{\theta\theta}$ and s_{rz} are the components of the deviatoric stress tensor, ε^{p} is the equivalent plastic strain, T is the temperature, ξ is the void volume fraction, D is the cumulative damage in the Johnson-Holmquist model, the other components are the same in Reference [3]. The Johnson-Holmquist constitute equation, the Mie-Gruneisen equation of state and our void growth model considering the Bauschinger effect [1] are adopted here.

In the present paper, the interface is represented by a set of linked marker particles (see Fig. 1). The level set function φ is adopted to reconstruct the interface in fixed grids, and it is commonly defined as the signed distance of $\mathbf{r}$ to the phase boundary, being positive in one and negative in the other phase. In this work, we do not need to solve the transport equation of the level set function. The level set function value of an arbitrary grid point A can be given as $\varphi_{\mathrm{A}} = \mathbf{n} \cdot \overrightarrow{\mathrm{BA}}$, where $\mathbf{n}$ is the normal vector of marker particle B which is closest to grid point A, and $\overrightarrow{\mathrm{BA}}$ is the vector from B to A, as shown in Fig. 1.

In the simulations, we monitor the spatio-temporal evolution of the damage factor. When the damage factor of a grid point reaches the critical value, a set of marker particles are put around the grid point, as shown in Fig. 2. They represent the newly-formed crack surface. Once a marker particle is added in the simulation, it will be tracked in every time step after that. When two sets of marker particles are close enough, they were merged together (see Fig. 2). As the damage factor of more and more grid points reaches the critical value, the crack becomes longer and longer. The formation and the propagation of a crack can be simulated successfully.

In this work, the experiment [2] that an aluminum 1100 target plate impacted by a spherical soda-lime glass projectile at a velocity of 6.0 km/s is simulated. The problem is simulated by our improved CE/SE scheme [3] with the new front tracking method proposed in this work. The mesh size is 0.067mm×0.067mm. Numerical results are shown in Fig. 3. The geometric parameters which describe the key deformation characters of the plate after impact, as shown in Fig. 3, are compared with the experiment [2] in Table 1. The result calculated by the newly proposed front tracking method agrees well with the experiment data and gives errors less than 10% while the result calculated by the level set method [1] gives errors of 21%. The mass of the plate at t=15μs is 93.23% of original mass for the present method. It means the present method has better mass-conversation properties.

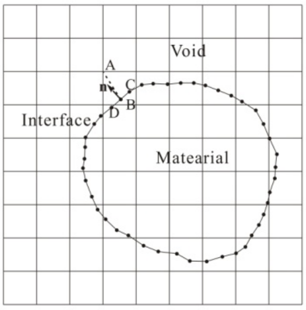

Fig.1. Interface represented by front tracking method

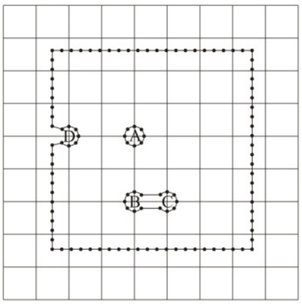

Fig.2. Cracks represented by marker particles

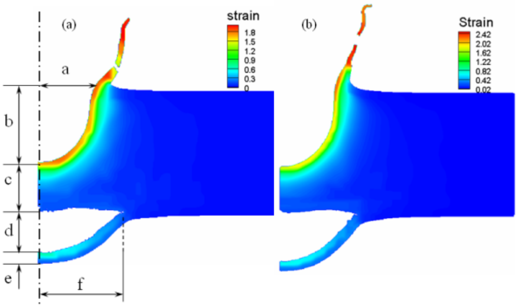

Fig.3. Contour plot of the equivalent plastic strain at t=15μs. (a) by present method; (b) by level set method

Table 1. Comparisons of damage features between the experiment and the simulations.

	a(mm)	b(mm)	c(mm)	d(mm)	e(mm)	f(mm)
Experimental data [2]	5.9	7.5	4.8	4.2	1.4	8.6
Results calculated by present method	5.65	7.15	4.55	4.5	1.25	8.65
Results calculated by level set method [1]	5.6	7.4	4.7	5.0	1.1	8.0

CONCLUSIONS

Combined with an improved CE/SE scheme and a void growth model considering the Bauschinger effect (BE), the newly proposed front tracking method can simulate the high-velocity impact problems with large deformations, high strain rates and spall fracture very well.

References

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