Numerical Simulation of Initial Perturbation Growth with Oblique-angle Impact of Metal Slabs

Samuil M. Bakhrakh*, N. A. Volodina, P. N. Nizovtsev, Valentin F. Spiridonov

RFNC-VNIIEF, ITMF
37, Mira av., Sarov, 607190, Russia

Key words: Kelvin-Helmholtz instability, Plate collision, Parallel computations.

The problem of studying instabilities, including Kelvin-Helmholtz instability [1], is very pressing at the present time. This instability type shows up, for example, in oblique collision of metal plates.

The oblique collision of metal layers in the contact zone develops intense shear strains, the near-boundary metal layers become dramatically heated, shaped jets form. These effects distort the interface profile. Regular waves, asymmetric distorted waves appear.

The subsonic oblique collision conditions, $U_{contact\ points} < C_{sound\ speed}$, have been studied comprehensively. In these loading conditions, a shaped jet always forms, if pressure in the vicinity of the collision point is higher than metal strength.

The initial perturbation growth is known to occur under the supersonic collision conditions in the gas-dynamic approximation. The matter is more involved in the supersonic collision of strong plates.

When the collision angle is constant, there is a critical velocity U_{crit}. If $C_{sound}<U_{contact\ point}<U_{crit}$, detached oblique shock waves form. In its transition across the wave front the supersonic flow transforms into the subsonic one. Both the flows arrive at the contact point with subsonic velocity. In the collision zone a shaped jet forms and the perturbations grow like in the subsonic collision.

When $U_{contact\ point}> U_{crit}$, attached oblique shock waves are established at the contact point and no jet formation is observed. Also, it is believed that no perturbation development is possible in that case, as there is no major perturbation generator, i.e. shaped jet.

The interface state in this type of supersonic conditions is poorly known.

One of VNIIEF divisions [2] has conducted experiments to study aluminum plate collisions. Essentially prompt cessation of the perturbation development process was anticipated in the transition to the jet-free conditions of the plate collision. That is, as soon as $U_{contact\ point}= U_{crit}$, no perturbations should appear. However, it was found in the experiments that the perturbation amplitude monotonically decreased with further increase in the contact point. That data was obtained for the first time.

All the computations were performed with program complex implementing technique LEGAK [3,4,6].

In the work reported in this paper, collision of two aluminum plates was simulated for experiments with different conditions of strong plate collisions. In the upper rod, initial velocity U_0 was given. On the lower rod surface, sinusoidal perturbation with $\lambda = 0.5mm$ wavelength and $a_0 = 0.01mm$ amplitude was given.

The computational grid was taken so, that there were about 20 computational cells for the wavelength. The total number of points was 1120x740=828800. The computations in the scalar (one-processor) mode are problematic. Therefore the computations were conducted on a multi-processor distributed-memory computer in complex LEGAK-MP [6].

*E-mail: smb@vniief.ru

The material state was described in the elastic-plastic approximation . Pressure was evaluated by Mie-Grueneisen equation of state [5] with the following parameters:

$\rho_0 = 2.64\frac{g}{cm^3}$, $c_0 = 5.55\frac{km}{s}$, $n=3.2$, $\Gamma=2.14$.

Yield strength was included as a function of pressure and temperature:

$$Y=\left(Y_0+\alpha\cdot P\right)\left(1-\beta\cdot\frac{E_T}{E_m}\right),$$

where $Y_0=0.3$, $\alpha=\frac{1}{3}$, $\beta=1$, E_T is the heat energy, $E_m = 1.1\frac{kJ}{g}$ is the melting energy, $\vartheta=0.33$ is the Poisson ratio.

First the computations were conducted for the plate collision in the liquid approximation. In such collision conditions the interface instability occurs and the perturbations grow.

The computations in the elastic-plastic approximation are of particular interest. The critical collision velocity for the given angle is 1.4 km/s. At the subcritical collision velocity of 1.0 km/s the perturbations develop and grow.

In the supercritical region at 1.5-km/s collision velocity no jet forms and, as assumed previously, the interface instability should not appear. However, as the experiments and computations suggest, quite complex nature of material deformation takes place under these conditions in the interface-adjacent zone. A region of a high velocity gradient and, hence, high deformation rate forms near the contact point. Because of intensive deformation the local zone heating leads to significant softening of material. Kelvin-Helmholtz instability occurs at the interface between liquid and elastic-plastic material.

The velocity gradient decreases with increasing collision velocity, as when the collision velocity is 1.75 km/s, there is essentially no velocity gradient and instability does not occur.

The computations studied effects of different medium model parameters and melting heats on the perturbation growth.

Also, the metal interface instability evolution was simulated at different initial perturbation wavelengths. The computations showed that the perturbations of ~0.5-mm wavelength grew most intensively under the considered collision conditions. This can account for the fact that of the entire spectrum of perturbations that take place on “smooth” plates from their processing those of $\sim 0.5 \div 0.6$ mm wavelength grow and are detected in the experiments.

Thus, the computations agree with the experimental data, which will allow us to study these processes more comprehensively later on.

To conclude with, we would like to note the following.

1. The numerical simulation of the Kelvin-Helmholtz instability in oblique collision of metal plates suggests that the process can be described properly from the standpoint of the agreement with the experiment using the Eulerian approach on a substantially refined computational grid. In its turn, this requires high-performance equipment. Therefore, the computations were conducted on multi-processor distributed-memory computer ARGUM within the program complex LEGAK-MP.

2. The results of the computation for the oblique plate collision are in a good agreement with the experimental data. In particular, it has been shown that the perturbation growth is observed at a collision velocity higher than U_{crit}. It has been therewith confirmed numerically that the perturbations of λ=0.5mm wavelength grow most intensively in the experimental conditions. The numerical simulation has revealed the effect of wavelength growth in low-strength material, which needs more comprehensive study.

3. Studies of the complex processes, such as the Kelvin-Helmholtz instability in metals, are of undoubtful scientific and practical interest. Hence, more perfect models describing solid deformation in conditions of high deformation rates and high pressure levels have to be implemented within the complex LEGAK.

Acknowledgements

The work was carried out under the financial support of Russian Fund for Basic Research (Grants No. 99-01-00812, 02-01-00796).

References

1. Deribas A.A. Physics of explosive strengthening and welding. Novosibirsk, Nauka Publishers. 1980.
2. Drennov O.B., Mikhailov A.L., Nizovtsev P.N., Rayevsky V.A. Perturbation development at metal interface in oblique collision with the contact points moving at supersonic velocity. VANT. Ser. Teoreticheskaya i Prikladnaya Fizika. No.1, 2001, p. 34-41.
3. Bakhrakh S.M., Spiridonov V.F., Shanin A.A. A method for computing heterogeneous medium gas-dynamic flows in Lagrangian-Eulerian coordinates. DAN SSSR, 1984, V. 278, No. 4, p. 829-833.
4. Bakhrakh S.M., Kovalev N.P., Pavlusha I.N. A method for computing elastic-plastic flows// Proceedings of All-Union Conference on Numerical Methods of Elasticity and Plasticity Theory. Part I. Novosibirsk, Nauka Publishers, 1974, p. 22-36.
5. Zel'dovich Ya.B., Raizer Yu.P. Physics of shock waves and high-temperature gas-dynamic phenomena. Moscow, Fizmatgiz Publishers, 1963, 632з.
6. Avdeev P.A., Artamonov M.V., Bakhrakh S.M., Velichko S.V., Volodina N.A., Vorobyeva N.M., Yegorshin S.P., Yesayeva E.N., Kovaleva A.D., Luchinin M.V., Pronevich S.N., Spiridonov V.F., Taradai I.Yu., Tarasova A.N., Shuvalova E.V. Program complex LEGAK and principles of its parallelization on multi-processor computers. VANT. Ser. Matematicheskoye Modelirovaniye Fizicheskikh Protsessov. 2001, No.3.