FINITE ELEMENT SIMULATION OF INTACT CAPTURE OF HYPERVELOCITY PARTICLES IN MULTIPLE FILMS

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Under dense polymer foam has been studied intensively by experimentalists as a viable candidate for passive intact cometary dust collector [1,2,3]. A powerful and economical alternative to investigate the intact capture of hypervelocity particles is computer simulation. Simulation with all the microstructures of a foam considered is difficult because it will take too much computer resources. In this research, as a simplified model of foam, multiple-layered-thin-films were studied by computer simulation resulting mass recovery ratio and number of layers penetrated in good agreement with experimental data.

The impact of a particle onto a single film was first simulated on VAX11/750 computer by a program DEFEL which is a finite element program based on Lagrangian formulation designed for high-velocity impact problems. In the simulation the thin film and the sphere-shaped particle were both represented by assemblage of triangular elements. The interaction between the film and the particle was handled by the sliding line routine in the program. Element failure routine was also activated so that the mass erosion to the particle could be simulated. Figure 1 shows the geometry of active portion of the problem as the particle was half way through the film. It is clearly seen from the figure that due to impact the front part of the particle was eroded. The black dots on the figure are the nodes that were separated from the particle and leaving the particle with certain amount of mass. Mass loss ratio and velocity loss ratio were calculated for impact with different particle velocities. The results are shown in Figure 2. It is found that mass loss ratio $\mathbf{R_M}$ increases approximately linearly with the increase of impact velocity while the velocity loss ratio $\mathbf{R_V}$ does not vary significantly with impact velocity

Direct simulation of impact of a particle into several hundred layers of film is not realistic even on a supercomputer so that an interpolation technique was developed to determine the mass recovery ratio and number of films penetrated as a particle impacts a multiple-layered-thin-film structure. Let $\mathbf{M_i}$ and $\mathbf{V_i}$ be the mass and velocity of the particle after impacting the ith layer of film, $\mathbf{R_M(M,V)}$ and $\mathbf{R_V(M,V)}$ be the mass loss ratio and velocity reduction ratio occurred in the ith impact, which are in general functions of $\mathbf{M_{i-1}}$ and $\mathbf{V_{i-1}}$. Then two recurrent equations can be written as:

$$\mathbf{M_i = M_{i-1}[1 - R_M(M_{i-1},V_{i-1})]} \qquad i = 1,2,3,... \tag{1}$$

$$\mathbf{V_i = V_{i-1}[1 - R_V(M_{i-1},V_{i-1})]} \qquad i = 1,2,3,... \tag{2}$$

In equation (1) $\mathbf{R_M}$ may be evaluated for any impact velocity by interpolating the results of computer simulation of single film impact shown in Figure 2. In equation (2) $\mathbf{R_V}$ is found independent of $\mathbf{V}$ as mentioned before. To determine how $\mathbf{R_V}$ is related to $\mathbf{M_{i-1}}$ momentum conservation during the single film impact needs to be considered. Assuming the impact is completely inelastic momentum conservation is written as:

$$\mathbf{M_{i-1}V_{i-1} = (M_{i-1} + m_{i-1})\, V_i} \tag{3}$$

where $\mathbf{m_{i-1}}$ is the mass of portion of the film that is in the path of the particle. Therefore

$$\mathbf{R_V = 1 - V_i/V_{i-1} = 1 - M_{i-1}/(M_{i-1} + m_{i-1}) \approx m_{i-1}/(M_{i-1} + m_{i-1}) \approx m_{i-1}/M_{i-1}} \tag{4}$$

considering $\mathbf{m_{i-1} \approx m_i << M_{i-1}}$. It is easy to see that $\mathbf{m_{i-1}}$ and $\mathbf{M_{i-1}}$ are proportional to second and third power of the radius of the particle when, for simplicity, assuming the particle is always a sphere in the sequence of impacts. Therefore $\mathbf{R_V \sim 1/R_{i-1}}$ or $\mathbf{R_V \sim (M_{i-1})^{1/3}}$. It is assumed that

$$R_V(V,M) \approx R_V(M_{i-1}) = 0.2\% \times (M_0/M_{i-1})^{1/3} \quad (5)$$

where the proportional coefficient is selected as $0.2\% \times (M_0)^{1/3}$ so that for the first impact, when mass is M_0, R_V is equal to 0.2% that is obtained from calculation of single film simulation as shown in Figure 2. With $R_M(M,V)$ and $R_V(M,V)$ determined for any value of M_{i-1} and V_{i-1}, using the equations (1) and (2) recurrently until V_i is small enough that the particle does not have the energy to penetrate any film, mass recovery ratio and number of films penetrated can be obtained. A computer program was written to perform the calculation for different initial particle velocities. Results are shown in Figure 3 and Figure 4 along with experimental results from reference [4]. It is believed that with computer simulation of impact onto several consecutive films with the temperature and pressure cumulation taken into consideration, more accurate R_M and R_V determined, the proposed interpolation model will be able to offer insights about the mechanism of intact capture of cometary dust particles, and guide the design of collectors.

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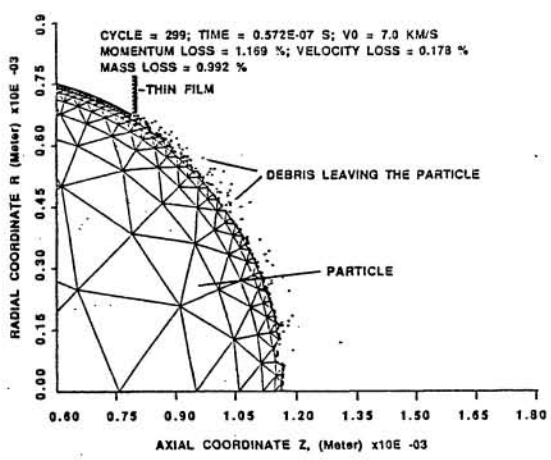

Fig. 1 COMPUTER SIMULATION OF SINGLE FILM IMPACT

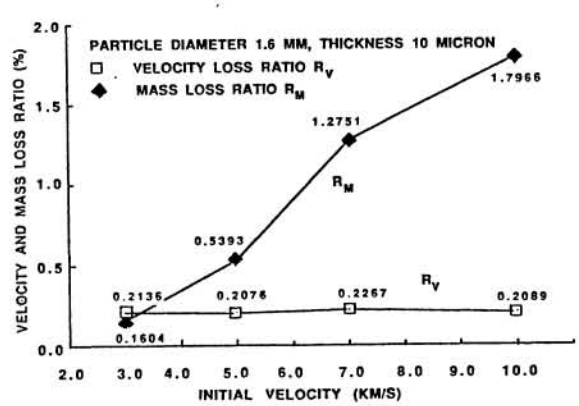

Fig. 2 VELOCITY LOSS RATIO AND MASS LOSS RATIO DUE TO SINGLE FILM IMPACT

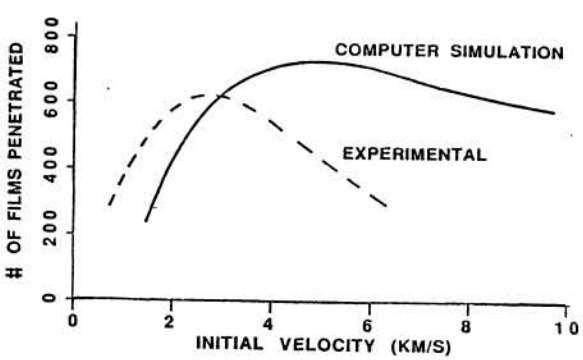

Fig. 3 NUMBER OF FILMS PENETRATED

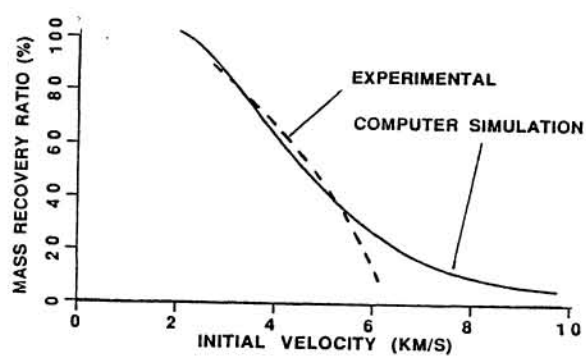

Fig. 4 MASS RECOVERY RATIO