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Application News

High-Speed Video Camera Hyper Vision™ HPV™-X2

High-Speed Imaging of Hypervelocity Microparticle Impact
–Development of Laser-Induced Particle Impact Test–

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User Benefits

- High-speed video camera HPV-X2 enables high-speed imaging of up to 10 Mfps/sec.
- It can image the flight behavior of microparticles, from several to several tens of μm, in high resolution.

■ Introduction

The macroscopic plastic deformation of metals and polymer materials is known to depend on the strain rate. This is because it greatly depends on the local deformation behavior of the microscopic structure of materials. Although the plastic deformation behavior in the ultra-high strain rate range of polymer materials is particularly rate-dependent, it has not been clarified. Therefore, a mechanical investigation is considered to be important in the development of lightweight and shock-resistant materials. For this reason, the Laser-Induced Particle Impact Test (LIPIT) was developed to achieve high-speed flight and impact experiments of micro-nanoparticles.[1)] In addition, the use of the high-speed video camera Hyper Vision™ HPV™-X2, which has recording speeds of up to 10 Mfps/sec, enabled detailed observations of microparticle flight and collision behavior in LIPIT.

This article describes how a high-speed video camera was used to image the high-speed flight and collision of microparticles. First, impact experiments were conducted on polymer materials using various kinds of particles to investigate the shape of impact marks using LIPIT. Then nanoscale analysis was performed on high-speed collision phenomena using the coarse-grained molecular dynamics method and discussed the mechanism of plastic deformation behavior from the viewpoint of molecular chain deformation.

■ Laser-Induced Particle Impact Test[1)]

In this article, laser ablation was used as a driving force to launch tiny micro-nanoparticles at high speed. Fine particles collided with the target material, causing indentations due to plastic deformation. The deformation strength at high strain rates was evaluated from the formation process of this indentation. Fig. 1 shows an overview of the developed LIPIT. A pulsed laser from an Nd: YAG laser passed through a condenser lens and hit the launch pad. The launch pad consisted of a transparent rigid constrained layer and a black energy-absorbing layer that expanded rapidly in volume due to the ablation phenomenon. The momentary large deformation caused fine particles scattered on the surface of the energy-absorbing layer to be launched straight up.

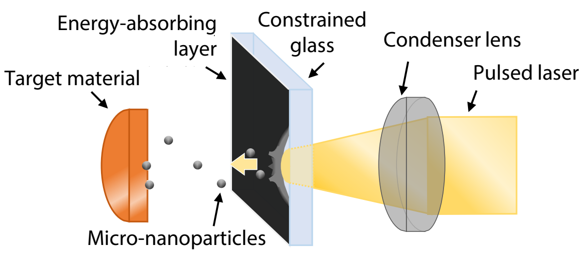

Fig. 1 Laser-Induced Particle Impact Test (LIPIT)

■ Imaging Results of Flying Particles with High-Speed Video Camera HPV-X2

Flying particles were visualized using the high-speed video camera (HPV-X2) shown in Fig. 2, and the speed of the flying particles was measured. The imaging devices are listed in Table 1. The behavior of the flying microparticles was imaged using the shadowgraph method. The target material was polycarbonate, one of the engineering plastics with excellent impact resistance. Four types of flying particles were used: high-speed steel particles HSS (40 μm in diameter), zirconia ZrO_2 particles (30 μm in diameter), and silica particles SiO_2 (15 and 6 μm in diameter).

An example of the imaging results is shown in Fig. 3. The field of view of the camera (horizontal) is about 1 mm. The images 1–7 in Fig. 3 show clearly the flight behavior of the flying particles until they collide with the target material. In image 8, flying particles collide with the target material and then rebound, as shown in images 9–12. By being able to image the flight, collision, and rebound process multiple times, the coefficient of restitution and the work of plastic deformation can be calculated. Microparticles of various sizes and masses were used to visualize such flying particles and calculate their flight speeds. The results showed that flight speeds could reach a maximum of 800 m/s.[2)]

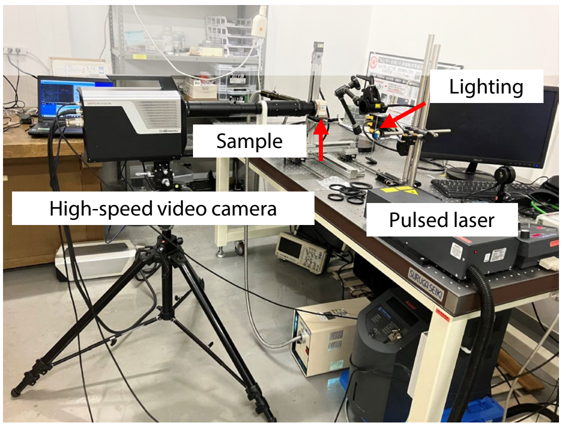

Fig. 2 Imaging with High-Speed Video Camera

Table 1 Imaging Devices

High-Speed Video Camera:	HPV-X2
Microscope:	Z16 APO
Lighting:	Cavilux

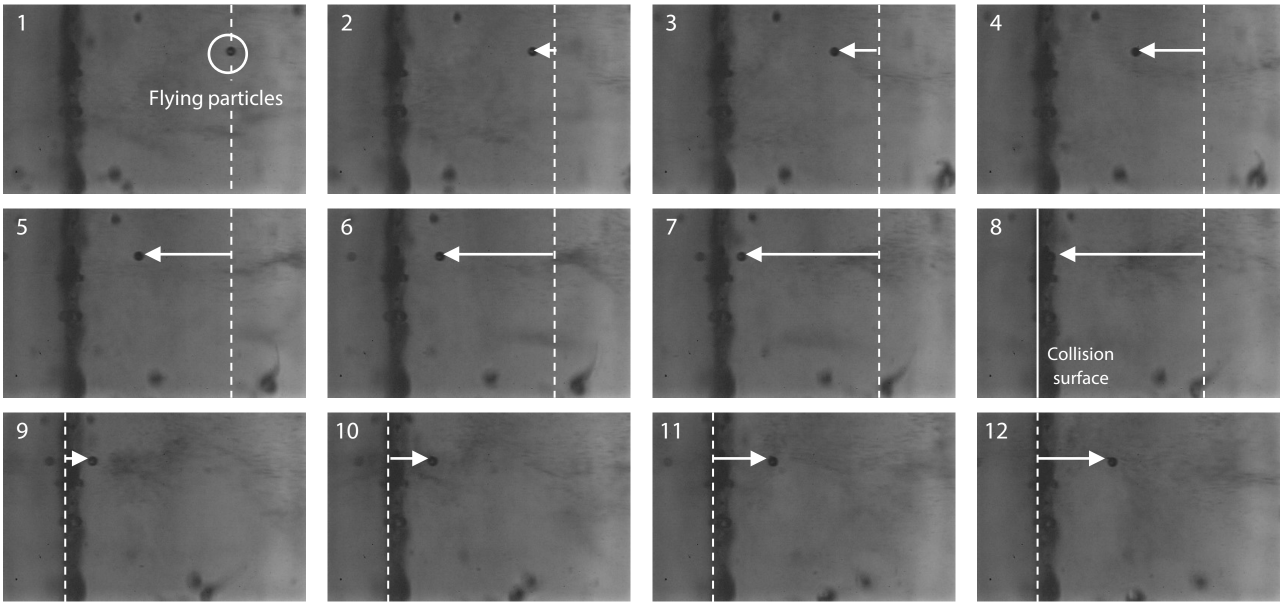

Fig. 3 Visualization of the Flight and Restitution Behavior of Microparticles
(The imaging interval between images was 200 ns.)

■ Results and Discussion[3), 4)]

Fig. 4 shows the relationship between the momentum of a microparticle and the indentation depth. The indentation depth was obtained from the collision marks made by LIPIT. As shown in Fig. 4, this experiment demonstrated that the greater the momentum the greater the indentation depth. In addition, it was found that the yield strength in the high-speed particle collisions in this experiment, obtained from the difference in kinetic energy measured from the results in Fig. 3, was more than 10 times the value of the quasi-static load as shown in Fig. 5 (the spherical indenter indentation test, referred to as Refs in the figure).

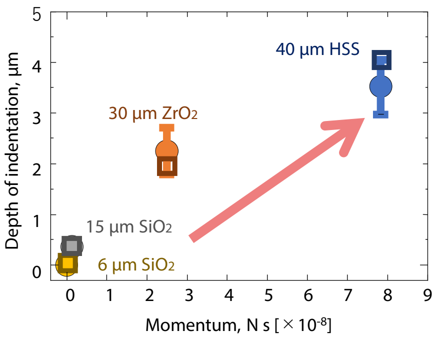

Fig. 4 Relationship between Momentum and Indentation Depth from LIPIT Experiments

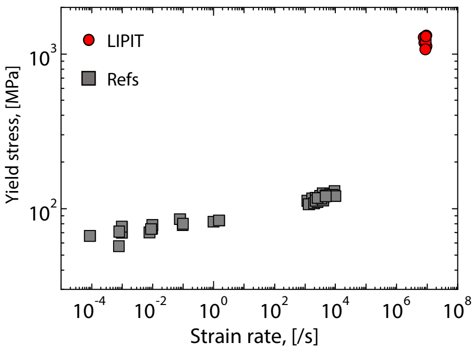

Fig. 5 Relationship between Yield Strength and Strain Ratio[3)]

Using the coarse-grained molecular dynamics method, mechanical analysis was performed on the high-speed collision phenomenon assuming LIPIT. Details of the analytical model can be found in references 3) and 4). The polycarbonate to be tested was composed of 500 molecular chains with a degree of polymerization of 100. Molecular dynamics simulations were performed using the commercial software J-OCTA. Fig. 6 shows the relationship between momentum, indentation depth, and maximum load (maximum reaction force) in the analysis, as shown in Fig. 4. As in the experiment, it was found that the greater the momentum, the greater the indentation depth, and the greater the maximum load.

Next, focusing on the deformation behavior of the molecular chains, the energy distribution of the bond stretch and the bending angle of the molecular chains during the collision were investigated. The results of low-velocity particle collisions are omitted, but Fig. 7 shows the results of high-velocity particle collisions. In low-speed loads, the energy was distributed from the time of the collision, but in high-seed collisions, the energy was concentrated just below the particles, and the energy was then distributed. This suggests that high speed collisions localized the deformation of the molecular chain at the impact site and limited its range, which concentrated the energy and increased the yield strength.

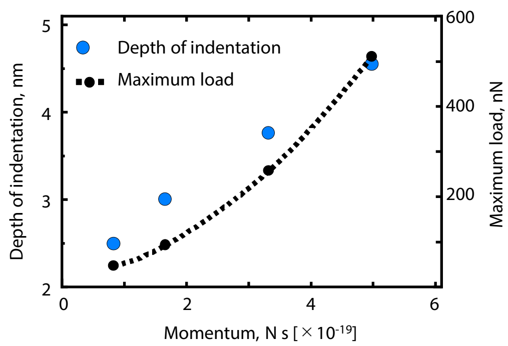

Fig. 6 Relationship between Momentum and Indentation Depth from the Molecular Dynamics Method

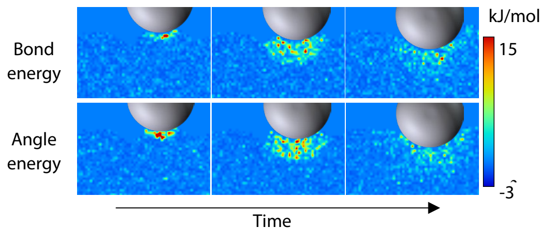

Fig. 7 Deformation Behavior of Molecular chains from the Molecular Dynamics Method
(Focusing on bond stretching and bond angles of molecular chains)

■ Conclusion

Using LIPIT, which can induce local ultrafast deformation at the micro and nanoscale, a mechanical study of the collision resistance of polymer materials was conducted. LIPIT is a unique technology that allows a single or small number of fine particles to collide at high speed, but it is necessary to measure the flight and restitution velocities of the particles for further practical applications. Therefore, a high-speed video camera (HPV-X2) was used to image and calculate the flight speed of the particles. These results made it possible to estimate the relationship between momentum and indentation shape, as well as yield strength, in high-speed collisions. In addition, molecular dynamics methods were used to analyze the mechanism of plastic deformation during collisions. LIPIT technology enables minute collision tests and has features that provide dynamic mechanical phenomena at a micro scale and nanosecond time. This will allow us to understand the properties of new materials and unknown mechanical phenomena, as well as to develop various surface modification and processing technologies. Therefore, the further miniaturization and speeding up of particles is needed. Visualization technology of particle flight behavior is essential for this purpose. And this study found the high-speed video camera HPV-X2 to be capable of visualizing the supersonic flight behavior of fine particles.

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Photography cooperation: Department of Precision Engineering, Graduate School of Science and Engineering, Chuo University

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