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Invited Paper

Impact force measurement of a plastic sheet using drop ball test by the Levitation Mass Method (LMM)

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Abstract. Drop ball test by the Levitation Mass Method (LMM) was carried out on a plastic sheet made of PMMA. Impact response of PMMA was measured with high accuracy and accurately evaluated. In this test, the velocity of the center of gravity of a metal spherical body is accurately measured using an optical interferometer. The acceleration, displacement, and inertial force of the spherical body are calculated from the velocity. In other words, the impact response of a plastic sheet is calculated from the velocity of a sphere dropped onto a plastic sheet. The uncertainty in this measurement is estimated to be 7.4 mN. This corresponds to 0.03% of the maximum force of approximately 27 N. However, the result has an uncertainly point which is a period to receive a constant impact force. Change of the boundary condition during the test is the components of an uncertainly point.

1. Introduction

Most impact testers for plastic sheet defined by JIS K7211 uses force transducers. However, force transducers can't measure dynamic force with high accuracy because it is difficult to evaluate the uncertainty of dynamic force measured by the transducer. Therefore, impact testers for plastic sheet without transducer is needed.

We have previously developed a method for precision mechanical measurement known as the Levitation Mass Method (LMM). The force is directly calculated according to its definition, that is, the product of mass and acceleration. Impact force of a spherical body dropping onto a water surface is also measured using a drop ball tester by the LMM [1, 2].

In this paper, we developed a method for measuring the impact force of a spherical body dropping onto a plastic sheet by modifying the LMM. As an example, drop ball tests by the LMM for PMMA was carried out. The validity of this impact force measurement method is experimentally demonstrated.

2. Experiment

Fig. 1 shows the experimental setup of a drop ball tester using the Levitation Mass Method (LMM). A spherical body with cube corner prism is used in this tester instead of rigid body in the LMM. The spherical body is made of SUS440 stainless steel. The total mass of the spherical body M, is approximately 93.88 g. A cube corner prism (CC), 12.7 mm in diameter, is inserted into the spherical body with an adhesive agent so that its optical center coincides with the center of gravity of the whole body.

The spherical body is held by a hollow circular electromagnet. By turning off the power of the electromagnet, the spherical body gently falls down by gravity force. Measurement is started when the optical switch is interrupted by the spherical body. Drop distance is approximately 24 mm in this test. A high-speed camera (Nikon 1 V2) is used to capture the images of the impact test with a resolution of 320×120 pixels and a frame rate of 1200 fps. The time of the photograph taken by this camera is decided by the LED which emits light when the optical switch is turned on. Measurement is stopped when the spherical body falls on the test piece and the CC embedded in the spherical body deviates from the optical axis.

The direction of the coordinate system for the velocity, the acceleration, and the force acting on the body is upward in Fig. 1. The total force acting on the spherical body is equivalent to the product of its mass and acceleration as

$$\boldsymbol{F}_{\mathbf{mass}} = \boldsymbol{Ma}. \tag{1}$$

The acceleration is calculated from the velocity of spherical body, and the velocity is calculated from the measured value of the Doppler shift frequency of the signal beam of interferometer $\boldsymbol{f}_{\mathbf{Doppler}}$, which can be expressed as

$$\boldsymbol{v} = \lambda_{\mathbf{air}} \, (\boldsymbol{f}_{\mathbf{doppler}}) \, / \, 2, \tag{2}$$

$$\boldsymbol{f}_{\mathbf{doppler}} = - \, (\boldsymbol{f}_{\mathbf{beat}} - \boldsymbol{f}_{\mathbf{rest}}), \tag{3}$$

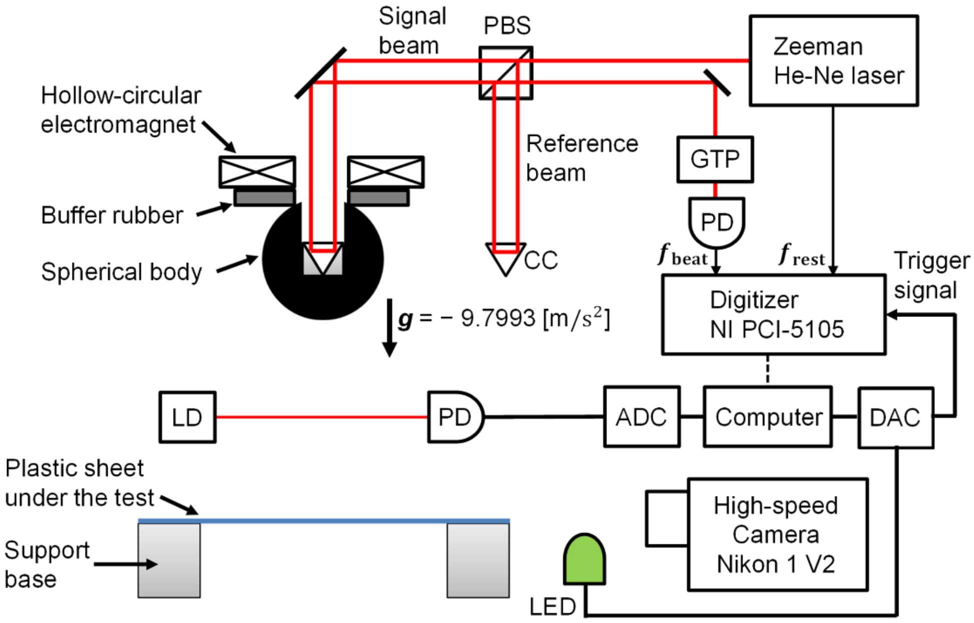
where $\lambda_{\mathbf{air}}$ is the wavelength of the signal beam, $\boldsymbol{f}_{\mathbf{beat}}$ is the beat frequency, and $\boldsymbol{f}_{\mathbf{rest}}$ is the rest frequency. The beat frequency $\boldsymbol{f}_{\mathbf{beat}}$ is the frequency difference between the signal beam and the reference beam. The rest frequency $\boldsymbol{f}_{\mathbf{rest}}$ is equivalent to the beat frequency $\boldsymbol{f}_{\mathbf{beat}}$ when the spherical body is at rest and no Doppler shift is added to the signal beam. Frequencies $\boldsymbol{f}_{\mathbf{beat}}$ and $\boldsymbol{f}_{\mathbf{rest}}$ are measured by interferometer, converted into a voltage signal by a digitizer, and recorded in a computer. Zero-crossing Fitting Method (ZFM) is a method for obtaining frequency from electric signal data [3, 4]. In ZFM, all zero-crossing times inside each sampling interval are used to determine the frequency. In our analysis, the sampling interval is defined by N = 500 periods of the signal waveform.

The total force, $\boldsymbol{F}_{\mathbf{mass}}$, consists of the gravitational force acting upon the body, $-\boldsymbol{Mg}$, and the impact force acting from the water, $\boldsymbol{F}$, if other forces, such as the air drag and the magnetic force, are negligible. Then, the total force is

$$\boldsymbol{F}_{\mathbf{mass}} = - \boldsymbol{Mg} + \boldsymbol{F}, \tag{4}$$

where $\boldsymbol{g}$ is the acceleration of gravity, approximately 9.799 m/s^2 at the experimental room. Therefore, the impact force acting from the water can be calculated as

$$\boldsymbol{F} = \boldsymbol{F}_{\mathbf{mass}} + \boldsymbol{Mg}. \tag{5}$$



PBS : Polarizing beam splitter, LD : Laser diode, PD : Photo diode,
CC : Cube corner prism, GTP : Gland-Thompson prism,
ADC : Analog to digital converter, DAC : Digital to analog converter.

Fig. 1 Experimental setup

A Zeeman-type two-wavelength He-Ne laser, the two frequencies of which have orthogonal polarization, is used as the light source.

A plastic sheet which is the specimen of this test is put on a support base made of SUS304 stainless steel. Each experimental condition such as test piece shape and support base shape was decided with reference to JIS K 7211.

This experiment was conducted on PMMA plates as typical plastic material, and its impact response was measured. Experiments were carried out on three specimens, measurements were carried out five times on the same specimen. The specimen shape is square like JIS K7211, and its thickness is 0.5 mm.

Table 1 shows the dimensions of each part. The dimensions of each part were determined according to the ratio of the diameter of the falling part, the inner diameter of the supporting base, the outer diameter of the supporting base and the length of one side of the test piece of JIS K7211. Chamfering of the inner circumference of the support base was set to R1 so that the contact portion between the test piece and the support stand was not worn out while the experiment was repeated.

Table 1 Experiment condition: dimensions

Standard	Height [m]	Diameter [mm]	Inner diameter [mm]	Outside diameter [mm]	Specimen [mm]
JIS K7211	0.3−2	20	40	60	60
Drop ball test	0.024	30	60	90	90

3. Result

Fig. 2 shows the ***F*** against time for the 5 drop measurements in the same test piece. The results of the 5 drop measurements in the same test piece coincide well, indicating a high reproducibility of the measurements.

Fig. 3 shows the ***F*** against time for the drop measurements in the different 3 test pieces. The results of the drop measurements in the different 3 test pieces coincide well, indicating a high reproducibility of the measurements.

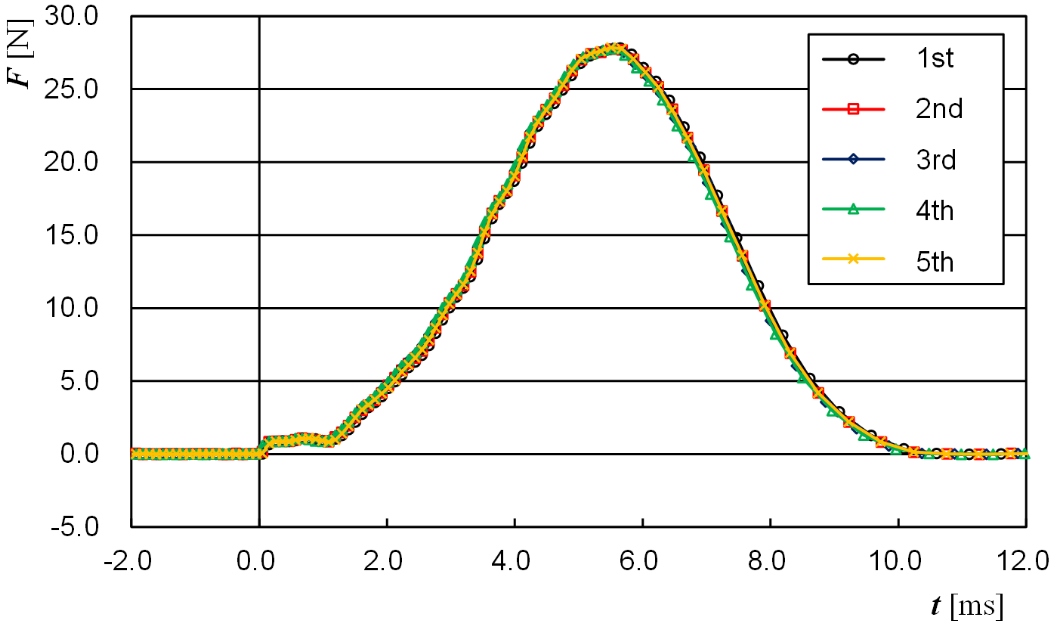


Fig. 2 Results in the PMMA-1

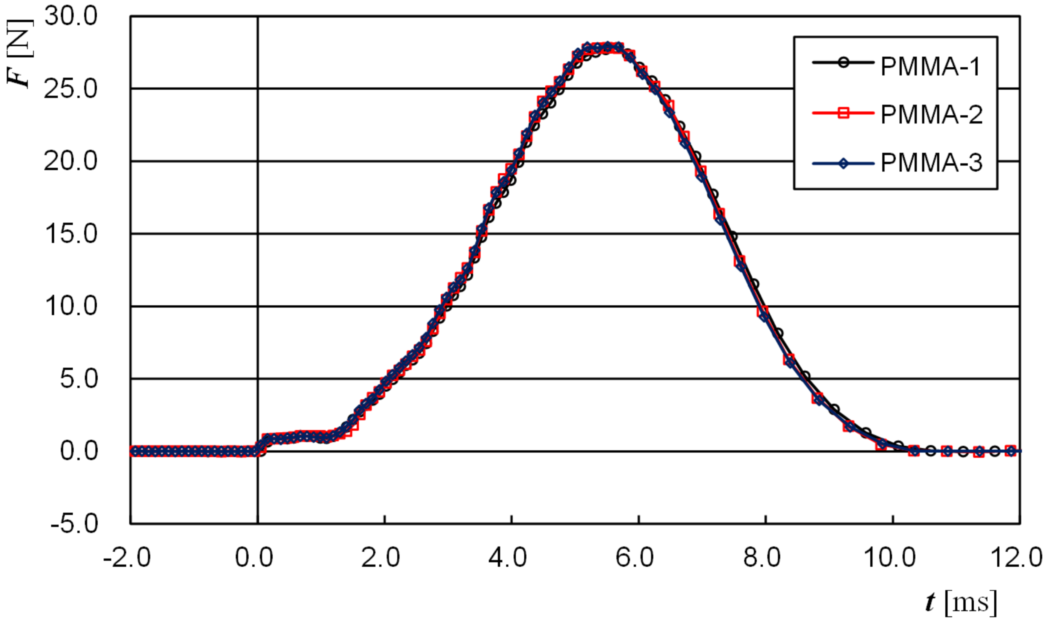


Fig. 3 Results in the 3 specimens

4. Discussion

An uncertainly point which is a period to receive a constant impact force during 0.0−1.23 ms is observed in the all results. The components of an uncertainly point is thought as follows. The contact portion between the specimen and the support base shifts from the upper surface of the support base to the circumference of the inner circumference of the support base as the specimen deforms. So the boundary condition is not constant at the start of the test.

5. Conclusion

Drop ball test by the Levitation Mass Method (LMM) was carried out on plastic sheets made of PMMA. In this experiment, impact response of PMMA was measured with high accuracy and accurately evaluated. But an uncertainly point at immediately after the increase time of ***F*** in the test result. Therefore investigating factors by numerical analysis such as Finite Element Method (FEM) and Computer Aided Engineering (CAE) is required to clarify this uncertainly point. And the mechanical properties of plastic materials will be investigated by this method.

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