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Experimental research on a waterjet to simulate erosion by impact of a water drop

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ABSTRACT

In this research, an experimental study on a waterjet to simulate erosion by impact of a water drop is performed. When a waterjet impacts a specimen, a high pressure is generated at the instant of impact. This high pressure is known to effect the erosion of the material. Photon Doppler velocimetry is used to estimate the maximum pressure in the impact velocity range up to approximately 700 m/s. The maximum pressure is compared to that by the impact of a water drop. From this comparison, it is found that the waterjet can accurately reproduce the high pressure generated by the impact of a water drop. The present waterjet is applied for erosion tests of an aluminum alloy and infrared windows, such as ZnS and sapphire. For the aluminum alloy, craters that form on the surface of the specimens are measured in the velocity range up to Mach 3.0. For the infrared windows, repetitive tests are conducted until a linear or circumferential crack is found to create damage threshold curves that define a material's erosive resistance. Test data for the aluminum alloy and the sapphire window are compared with those obtained from erosion tests using a water drop. From this comparison, the existing conversion relation between the waterjet and water drop is validated in the higher velocity range for various materials, such as metals and infrared windows.

1. Introduction

When it rains, there are mm-sized water drops in clouds. If a high-speed vehicle flies through these clouds, the water drops repeatedly impact the vehicle's surface. Surface materials can be eroded, and in the worst cases, certain materials, such as infrared windows, can be broken. Consequently, the performance of the vehicle can be severely deteriorated [1,2].

A material's resistance to erosion by the impacts of water drops has been studied mainly by experimental studies using various test facilities. Among them, the free-flight range is the most realistic test facility because a specimen is accelerated into a field of falling water drops that is very similar to real flight conditions [3,4]. However, the range test is expensive, and recovering the accelerated specimen without any damage is technically difficult. A whirling arm is also commonly used [5–8], in which a test specimen is rotated to a design speed, and water drops are supplied to the rotating path of the specimen. This facility is relatively cheap, but the test speed is limited because of limited material strength of the rotating arms. The available maximum speed is a Mach number of approximately 2.0.

There is another type of test facility using waterjets ejected onto a stationary specimen. This facility is cheap and simple enough to be used for lab-scale tests. The waterjet has a spherical front shape like that of a water drop. When this front part of the waterjet impacts the specimen, a high pressure on the order of GPa occurs for a short period of time of the order of microseconds. After this high pressure is propagated, a relatively low pressure follows. Therefore, the high pressure occurring at the very instant of impact mainly effects the erosion of the material. This is the reason why a waterjet can simulate erosion by water drop [2,9,10].

In this research, the maximum pressure obtained by a waterjet impact is measured and compared with those in the literatures. Until now, the maximum pressure has been measured using a polyvinylidene difluoride (PVDF) piezoelectric film [11,12]. However, because of the spherical front shape of the waterjet, the accuracy of the measurement using PVDF is limited. Therefore, photonic Doppler velocimetry (PDV) has been developed to estimate the pressure in the velocity range of up to approximately 700 m/s. The maximum pressure estimated by PDV is approximately 2.21 times the water-hammer pressure. This pressure is compared with that of the impact of a water drop [13]. From this comparison, it can be concluded that developed waterjet can reproduce the high pressure resulting from the impact of a water drop.

The developed waterjet is used for erosion tests for aluminum alloys and infrared windows, such as ZnS and sapphire. For Al

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alloys, the crater depths are measured for impact velocities from approximately 400 m/s to 1100 m/s. For infrared windows, repetitive impact tests are conducted until the window has a linear or circumferential crack. The test results of infrared windows are compared with those found in the literature [2].

As mentioned previously, the possibility of a waterjet simulating erosion by a water drop impact is found by the comparison of the impact pressure level. However, to apply a waterjet to simulate the impact of a water drop, an accurate conversion relation between the waterjet and water drop is needed. This conversion relation is already developed in Ref. [10]. The existing conversion relation is derived from erosion tests for polymethyl-methacrylate (PMMA) in the velocity range lower than 500 m/s. In this research, the existing conversion relation is applied to aluminum and sapphire window test results for comparison with those from water drop impacts. From these comparisons, it is proven that the existing conversion relation is applicable to various materials, such as metal and infrared windows, in the higher velocity range up to a Mach number of approximately 3.0.

2. Experimental facility

The waterjet is ejected using the experimental facility shown in Fig. 1. This facility was developed with the help of Cavendish Laboratory [2]. High-pressure gas is used to accelerate a lead slug inside a pump tube with a diameter of 5.5 mm. This lead slug is used to pressurize water filled in a nozzle. The nozzle with a throat diameter of 0.8 mm is manufactured using stainless steel 420 J2, which has high strength and impact resistance. Pressurized water is ejected in the form of a discrete waterjet slug and impacts the specimen.

Diode lasers are used to measure the velocity of the lead slug and waterjet. The laser signals are cut off by the lead slug and waterjet and measured using a detector and oscilloscope.

A high-speed camera (FASTCAM SA-X2) is used to capture images of the ejected waterjet. Images of 256 × 80 resolution were taken at 3.33 μsec intervals with an exposure time of 300 nsec. Fig. 2 shows successive images taken when the velocity of the waterjet is 1093 m/s. From the figure, the waterjet is shown to have a spherical front shape like a water drop. Therefore, it is believed that the ejected waterjet can simulate erosion by the impact of a water drop [2,9].

In the last image of Fig. 2, a light flash can be observed. This is because of a shock wave that occurs at the instant of impact. In the following section, the pressure from this shock wave is estimated using photonic Doppler velocimetry (PDV).

3. Impact pressure measurement

Photonic Doppler velocimetry was developed to measure a particle velocity of specimen induced by impact of a waterjet.

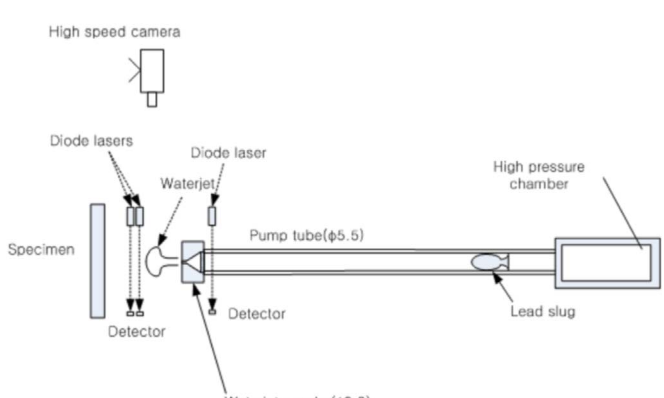

Fig. 1. Schematic of experimental facility.

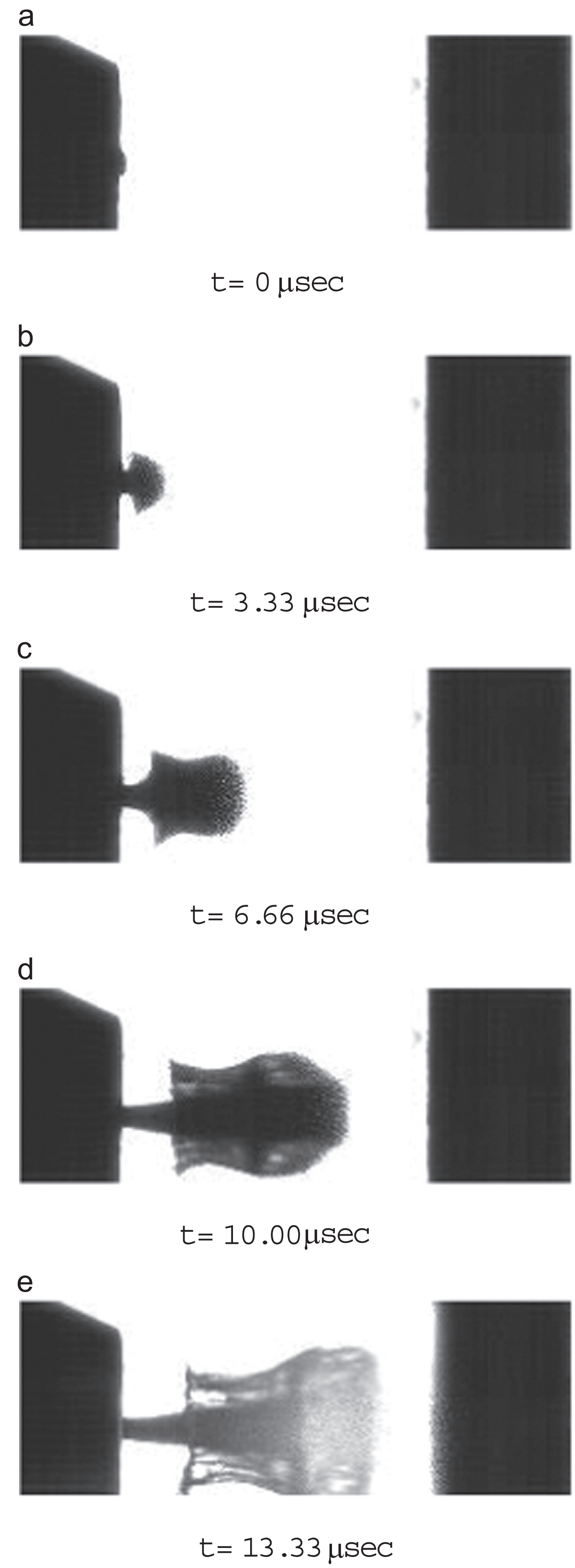

Fig. 2. Successive waterjet images taken by the high-speed camera for impact velocity of 1093 m/s. (a) $t=0$ μsec, (b) $t=3.33$ μsec, (c) $t=6.66$ μsec, (d) $t=10.00$ μsec, (e) $t=13.33$ μsec.

From the measured particle velocity, the maximum impact pressure can be estimated and compared with that of the impact of a water drop.