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Effect of tensile waves on impact erosion at a solid/liquid interface

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Abstract

Impact erosion tests were carried out in mercury by using a direct tension Split Hopkinson Bar to investigate the formation behavior of pits. A stainless steel specimen was screwed to the end of the elastic bar and immersed in mercury. The polished surface of the specimen was eroded by tensile waves propagating through the interface of the solid and liquid metals. The relationship between the mass loss due to pit formation and the shot number can be described by a linear function on a logarithmic graph. The mass loss depends also on the applied stress amplitude. The largest pits were formed around the center of the specimen and the pits developed with increasing shot number. The distribution of relatively large pits was very dependent on the position of the specimen in the mercury container.

Keywords: Impact erosion; Tensile wave; Eroded pit; Negative pressure; Localization of pitting

1. Introduction

High-power spallation neutron sources are being developed worldwide and are expected to produce innovative science in terms of materials and life. In Japan Proton Accelerator Complex (J-PARC) promoted by JAERI and KEK, a MW-scale mercury target will be installed as the spallation neutron source. A pulsed proton beam is injected into a mercury filled stainless steel

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vessel. The mercury is locally heated by the pulse of protons. Pressure waves are generated due to thermal expansion of the mercury, and these interact dynamically with the vessel. A negative pressure might be caused by the pulsing pressure waves propagating through the interface between the solid vessel wall and the liquid mercury. Cavitation can be induced by the negative pressure, and then the following cavitation collapse will bring about a localized high-energy impact to form pits on the inner wall of the vessel. The structural integrity and the lifetime of the vessel will depend on the damage induced by pitting formation [1,2].

In order to examine the impact erosion damage at the liquid/solid metals interface, which might be produced on the inner wall of a target vessel filled with mercury, plane strain wave incident experiments have been carried out using a Split Hopkinson Pressure Bar apparatus (SHPB) for compression tests. Many pits due to erosion have been observed on the specimen surfaces after impact loading and the damage was found to depend on the hardness of the specimen [3]. However, the quantitative relation between the negative pressure and erosion damage has not been sufficiently clarified from the experimental results obtained by compressive SHPB apparatus. Therefore, in order to investigate the relation between the formation behavior of the damage and the tensile wave propagating through the interface between the solid and mercury, impact erosion tests were carried out in a direct tension SHPB apparatus. Additionally, we investigated the effect of placing the stainless steel specimen at five different positions with respect to the wall of a mercury container to examine the effect of the complicated interference between the pressure waves and the target vessel on the impact erosion damage induced by the complicated-shaped vessel.

2. Material and experimental method

A schematic of the direct tension test apparatus is given in Fig. 1. The apparatus was composed of the specimen, mercury container, elastic bar, impact tube, impact block and momentum trap. The impact tube is accelerated using compressed air and collides with the impact block producing a tensile wave which propagates into the elastic bar towards the specimen. The tensile wave generates a negative pressure at the interface between the specimen and mercury and propagates back to the impact block. At the other end, the compressive wave generated in the impact block is absorbed by the movement of the momentum-trap. We confirmed that the tensile wave formed by the reflection from the free end of the momentum-trap did not propagate back into the elastic bar again.

The length and diameter of the elastic bar were 3000 and 15 mm, respectively. The diameter and width of the austenitic stainless steel (316L type) specimen were 15 and 10 mm, respectively. The impact face of the specimen was polished using polishing paper and diamond paste with a diameter of 3 μm. The specimen was screwed through a spring washer to the end of the elastic bar. Three impact stresses of 50, 60 and 70 MPa were applied at the interface of the solid and the liquid. Repeat shots were carried out by the collision of the impact tube with the impact block, the maximum number of shots on the specimen being 50. The impact stress was measured by a strain gage with a gage length of 1 mm. The gages were glued at positions of 1500 mm from both ends of the elastic bar. The output voltage of the strain gages was magnified by an amplifier and measured and analyzed by the storage scope and microcomputer.