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# A Numerical Investigation into the TensileSplit Hopkinson Pressure Bars Test for Sheet Metals

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**Abstract.** Determination of theflow stress of materials at high strain rate is very important in automotive and military areas.The compressive flow stress at high strain rate can be obtained relativelyexactly by SHPB(Split Hopkinson Pressure Bars) tests. However, it is difficult to determinethe flow stressexactlyin the tensile state by using the SHPB tests. The difficulty in the tensile SHPB tests is how to fix a specimen on two bars. So, the design of a specimen and holders is needed to obtain more accurate measurement of the flow stress. In this study, the accuracy of the tensile SHPB tests results was numerically investigated. Finite element analyses of the tensile SHPB were carried out for various cases of fixing bolt location and bolting force. From the analysis results, a design guide for the fixing structure was obtained and the causes of error were investigated.

## Introduction

The SHPB tests are widely used to measure the flow stress of materials. The SHPBtest was first proposed by Hopkinson[1] and further developed by Kolsky [2]. Nicholas [3] and Nemat-Nasser et al. [4]successfully employed the SHPB test to measure the flow stress. Cha et al. [5] investigated the effect of friction on measured flows stress and proposed a compensation method. Recently, Kang et al. [6] proposed a tensile SHPB test to measure the tensile flow stress of sheet metals. They fixed a specimen on the incident and transmit bars using bolts. Lee et al. [7] also measured the tensile flow stress of a round bar.

In this study, the accuracy of the tensile flow stress of sheet metals measured by tensile SHPB tests was investigated. The effects of pin hole and fixing structure on the accuracy have been numerically analyzed with ABAQUAS/Explicit [8].In the tensile SHPB test, many issues have to be considered such as specimen shape, thicknesses, andthe number of bolts. These factors have an effect on the results of experiments. The effects of these factors on the accuracy were investigated by numerical experiments and the causes of measurement error were investigated.

## Model Description and Material Properties

Fig. 1 shows the tensile SHPB apparatus and sheet specimen. The striker bar moves right and strike the anvil. Then, the tensile shock wave propagatesto the left and induces tensile deformation in the specimen. The specimen bolted to the transmitter and incident bars as shown in Fig. 1(a). Therefore, the force is transferred to the specimen from the incident bar. The shape of the specimen, assembly view, and element discretization are shown in Fig. 1(b) and (c). The thickness of the specimen is 2.0 mm and the velocity of the striker bar is 20 m/s. The material properties used in the analysis are shown in Table 1.

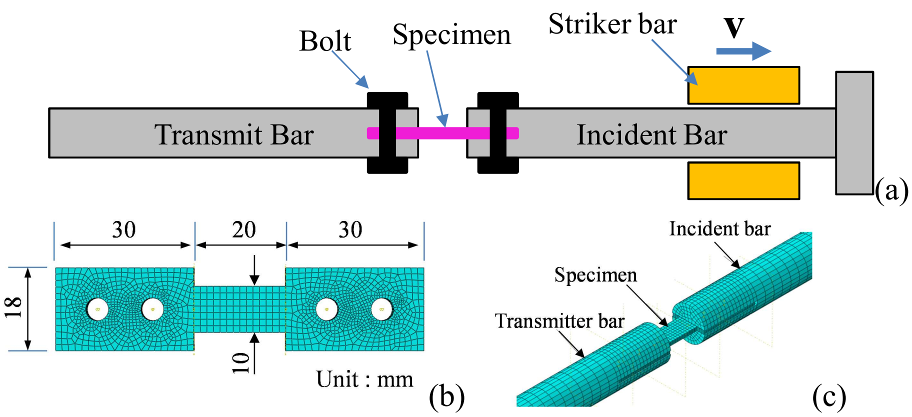


Fig. 1(a) Schematic illustration of tensile SHPB test; (b) Specimen shape and element discretization; (c) Assembled view of specimen to transmit and incident bars.

Table 1 Mechanical properties used in the analysis

| Part | Property | |
|---|---|---|
| Striker (Steel)<br>Incident bar (Steel)<br>Transmit bar (Steel) | Young's Modulus | 200 GPa |
| | Poisson Ratio | 0.3 |
| | Density | 7000 Kg/m$^3$ |
| Specimen (Ta) | Young's Modulus | 100 GPa |
| | Poisson Ratio | 0.3 |
| | | |
| | Density | 1,897 Kg/m$^3$ |
| | Yield Stress (Elastic-perfectly plastic) | 800 MPa |

## Results and Discussions

The effects of the joining parameters, i.e., clearance, joining force, and bolt arrangement, on the measuring accuracy were investigated. At first, analyses were carried out for various values of clearance between bolts and specimen. Next, analyses were carried out for various values of joining force. Finally, the number of bolts and the arrangement of the bolts were changed to obtain more accurate results. In order to check the accuracy of the tensile SHPB test, the stress-strain relation of the specimen was monitored and the values were compared with those calculated using the incident, reflected, and transmitted strain signals.

Fig. 2 shows the stress-strain relation for various values of clearance. All of the curves except those of the 'specimen data' were obtained from the strain signal on the incident and transmitter bars. The 'specimen data' was obtained from the specimen and compared with the calculated data. As the clearance decreases, the results become better. This means that the clearance causes a lot of measuring error. Moreover, the measured flow stress shows a lot of discrepancy from the specimen data.

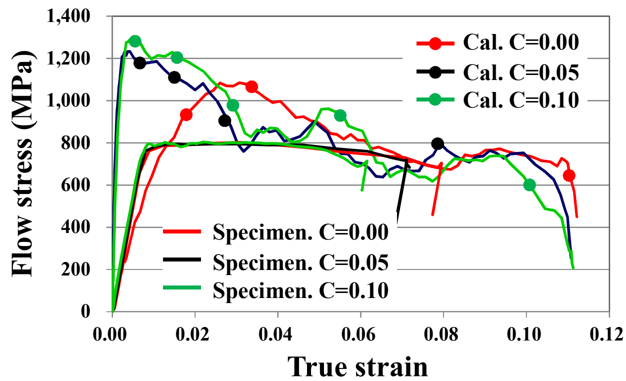


Fig. 2Comparison of the measured flow stress with the specimen data for various clearances.

To investigate the effect of bolting force on the measuring accuracy, clamping pressure was imposed on both sides of the incident and transmitter bars as shown in Fig. 3. Fig. 4 provides a comparison of the measured flows stress with the flow stress that the specimen experiences. When clamping pressure is imposed, the flow stress rises after some delay. The reason is considered to be that the friction force causes small prior deformation before the shock wave arrives at the specimen along the complex path of incident bar, bolt, and specimen. Even though the flow stress approaches that of the the specimen data as the clamping pressure increases, there still exists a lot of measurement error.

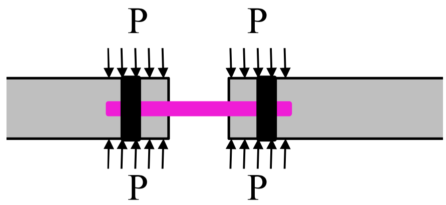


Fig. 3 Schematic illustration of clamping pressure boundary condition.

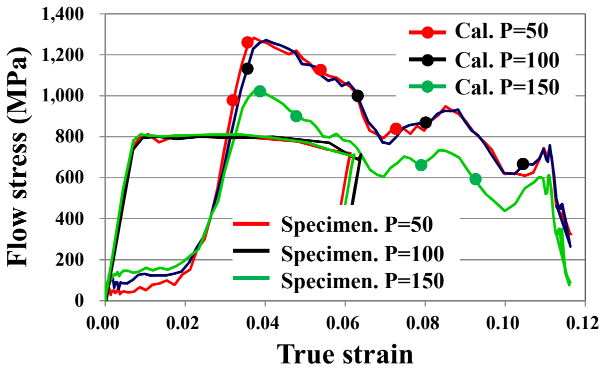


Fig. 4 Comparison of the measured flow stress with the specimen data for various clamping pressures.

A new clamping method was proposed to obtain more accurate flow stress. Fig. 5 shows the new design.The number of bolts and the array were changed as shown in Fig. 5. Fig. 6 shows the results. From the viewpoint of the flow stress, the calculated (measured) flows stresses are in good agreement with the specimen data. However, the calculated total strains are far greater than those in the specimen data. This is because a lot of plastic deformation takes place near the bolts instead of in the central region of the specimen.

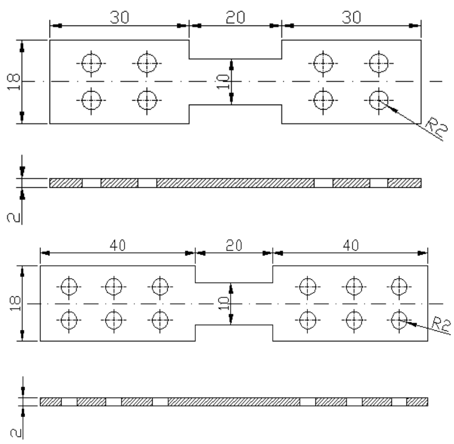


Fig. 5 Clamping structures modified by changing bolt arrays.

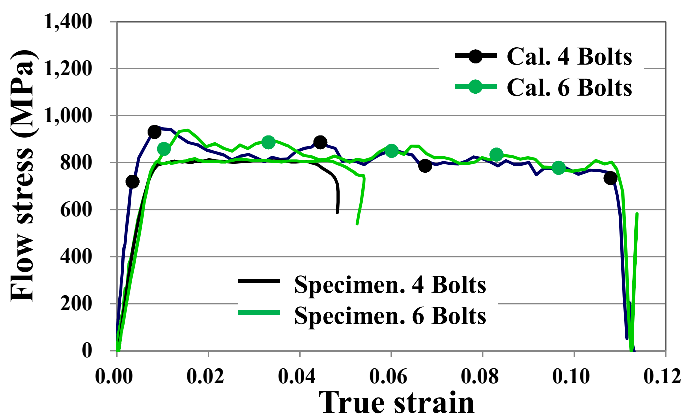


Fig. 6Comparison of the measured flow stress with the specimen data for various numbers of bolts.

**Summary**

Tensile SHPB was analyzed by finite element method to verify the measurement accuracy. It was shown that the clearance betweenthe bolt and the specimen and the clamping force have great effects on the accuracy. A new design was proposed to obtain accurate flow stress.A fairly accurate flow stress could be obtained with the new design, which has 6 bolts. However, the total strain still could not be measured accurately.

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