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Effects of specimen geometry on elastic-bar type high strain-rate tensile testing for sheet metals

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ABSTRACT

The accuracy of materials data at high strain rate is one of the most important factors for reliable numerical analyses of high-speed forming. The split Hopkinson bar [1] and one-bar [2] methods are extensively used in high strain-rate tensile testing of sheet metals because the test force and displacement can be measured accurately by using one or two long elastic bars. In the specimen of these methods, the equilibrium of the propagated force wave and the uniaxial stress condition are required. In addition, the calculation of strain is also significantly affected by the specimen geometry, since the displacement can directly be known only on the line bordering the bar end. However, few comprehensive investigations were reported on the conditions required for specimen geometry [3]. In this study, the effects of specimen geometry, i.e., the length L_p and width of parallel part W and the radius of the transition zone R, were investigated by using dynamic explicit finite element (FE) analyses.

The specimen geometries investigated are listed in Table 1, where $L_p = L_t - 2R$ is the parallel length as shown in Fig. 1. In the simplifyed FE modelling of the one-bar method shown in Fig. 2, reflected waves propagating from A and D to the specimen between B and C were avoided by using the non-reflecting condition at the ends A and D, by giving a constant velocity in the tensile direction at the input side of the specimen C, and by using a sufficiently long elastic bar from the output side of the specimen B to the other bar end A. This condition only allows the wave propagations in specimen by input at C and by reflection at B and C where the abrupt changes of cross-section areas give large gaps of acoustic impedance. The tensile velocity v was determined for each specimen so that v/L_t = 1000/s was satisfied. For the materials of specimen, the Swift hardening rule and Cowper-Symonds strain-rate sensitivity were assumed:

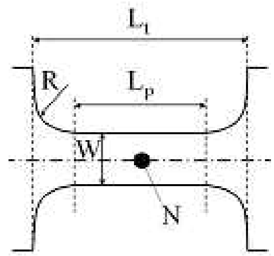

Fig1. Specimen geometry.

$$\sigma = K\left(\varepsilon_0 + \varepsilon_P\right)^n \left[1 + \left(\frac{\dot{\varepsilon}_P}{X}\right)^{\frac{1}{Y}}\right], \qquad \text{Eq. 1}$$

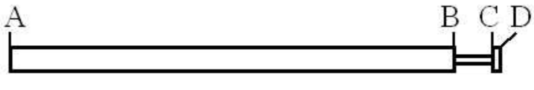

Fig.2. Simplified model of one-bar method.

where ε_P, $\dot{\varepsilon}_P$, and σ are the equivalent plastic strain, equivalent plastic strain rate, and

Table.1. Specimen geometries

Geometry	Thickness [mm]	L_t [mm]	L_p [mm]	W [mm]	R [mm]
1	1.4	10	9	5	0.5
2	1.4	20	19	5	0.5
3	1.4	30	29	5	0.5
4	1.4	10	7	3	1.5
5	1.4	10	7	5	1.5
6	1.4	10	7	10	1.5
7	1.4	10	0	5	5.0
8	1.4	90	60	12.5	25.0

equivalent stress, respectively. The materials parameters K, ε_0, n, X, and Y are 1650 MPa, 0.0004, 0.14, 3.1×10^{11} s^{-1}, and 6.4, respectively. These values are for an ultra-high-strength steel sheet which has lower strain-rate sensitivity than other grades with less strength.

The equilibrium of force was evaluated by $|F_B\text{-}F_C|/F_{max}$, where F_B and F_C are forces at B and C, respectively, and F_{max} is the largest force between F_B and F_C. It was then concluded that the shorter L_t is, the earlier the equilibrium reached. On the other hand, the uniaxial stress condition was evaluated by the transverse stress at the center of specimen. As is known in quasi-static testing, a better uniaxiality was obtained in a specimen with a larger L_p/W ratio. However, too large L_p/W, causes necking near the end of parallel zone before the center reaches a strain as large as uniform elongation. This is due to the plastic wave propagation which is sensitive to hardening behavior of specimen. Consequently, the uniaxial stress condition with small L_t is required. Small R is thus preferred to obtain small L_t without losing L_p.

Furthermore, R affects the calculation of strain. In an elastic bar system, strain is generally calculated from the difference of displacement at bar ends ΔL and gauge length L_t or L_p. However, an appropriate gauge length may depend on R of transient zone. Thus, the effective gauge length was calculated so that the true stress - true plastic strain curve (S-S curve) by the simulation of tensile test coincides with the input data. The evaluation of effective gauge length showed that the most accurate S-S curve can be obtained by using L_t as the gauge length for an appropriate R/L_t. Among the evaluated geometries, Geometry 4 gives the best agreement (Fig.3).

In this study, the specimen geometry necessary for high strain-rate tensile testing was comprehensively studied. In order to obtain the force equilibrium, uniaxiality, homogeneous plastic deformation at large strains, and accurate strain measurement in a bar system, small L_t, large L_p/W, and small R/L_t are required. The tolerance of these values will be presented. Needless to say, such cares in specimen cannot always ensure the best accuracy. A good quality of force measurement is of another importance in high strain-rate testing.

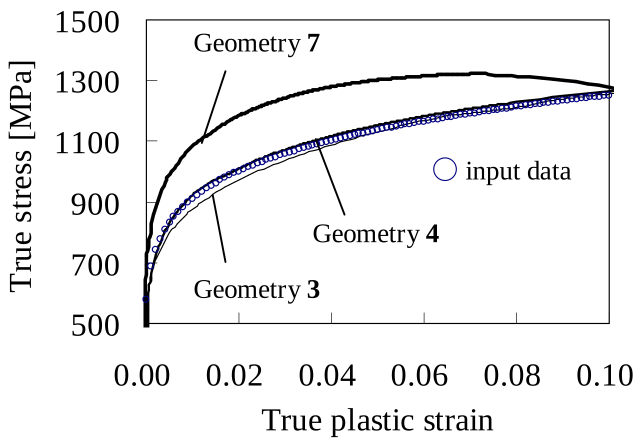

Fig.3 S-S curves

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