IMPACT TENSION TESTING OF SHEET ALUMINUM ALLOYS FOR AUTOMOBILE STRUCTURAL USES

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ABSTRACT Impact tension tests on a sheet Al alloy 5182-O for automobile structural applications are conducted by means of the split Hopkinson bar apparatus. Small sheet tension specimens having thicknesses varying from 1.0 to 2.47 mm are used in the tests. Tensile stress-strain relations at strain rates of over 10^3/s are presented and compared with those obtained at quasi-static strain rates. It is shown that the sheet Al alloy 5182-O is insensitive to strain rates, at least up to strain rates of about 10^3/s, independent of the sheet thickness. The limitations on the applicability of the apparatus are also discussed.

Keywords: *Impact tension, Hopkinson bar, Strain rate, Sheet Al alloy, Serration*

1. INTRODUCTION

The crash simulation of vehicles has often been performed by implementing general-purpose finite element codes such as PAM-CRASH and DYNA-3D on supercomputers. The reliability and accuracy of the simulation depends mainly on the material model as well as on the structural model used in calculations. Consequently, an accurate knowledge of the mechanical behavior of materials under impact loading is essential for the safety performance evaluation of automobile structures. The exterior bodies of cars have recently been made of sheet Al alloys in an attempt to achieve weight saving. The mechanical properties of the sheet Al alloy at high rates of strain, however, have not been fully investigated owing to the experimental difficulties associated with impact tensile testing of sheet materials [1].

The objective of the present study is to determine the dynamic tensile stress-strain characteristics of a sheet Al alloy 5182-O for automobile structural uses. A tensile version of the split Hopkinson bar apparatus [2] was employed in the impact tests. Tensile stress-strain data for the sheet Al alloy 5182-O with thicknesses ranging from 1.0 to 2.47 mm at strain rates above 10^3/s were obtained and compared with those obtained at quasi-static strain rates. The test results demonstrate that the sheet Al alloy 5182-O exhibits almost non strain-rate sensitivity up to strain rates of about 10^3/s, independent of the sheet thickness.

2. TEST PROCEDURE

2.1 Tensile Hopkinson bar apparatus

Figure 1 shows a schematic diagram of the tensile split Hopkinson bar apparatus used in the impact tests. The apparatus consists principally of a striker bar, a gun barrel, two Hopkinson bars (bar No. 1 and bar No. 2) and associated recording system. The striker bar is a 350- mm long carbon tool steel rod with a 16-mm diameter. The Hopkinson bars supported on V-shaped blocks are made of 16-mm diameter bearing steel rods. The sheet tension specimen with specific threaded (M8 x1.0) grip ends was attached to the two Hopkinson bars as depicted in Fig. 2(b). After the specimen was screwed into one of the two Hopkinson bars, a split collar was placed over the specimen, and the specimen was then screwed in until the Hopkinson bars fit tightly against the collar. The split collar has the same outer diameter of 16 mm, and an inner diameter of 8 mm just to clear the specimen. The ratio of the cross-sectional area of the collar to that of the Hopkinson bars was 3:4, whereas the ratio of the area of the collar to the net cross-sectional area of the specimen was 50:1. Further details of the test procedure has been described elsewhere[3].

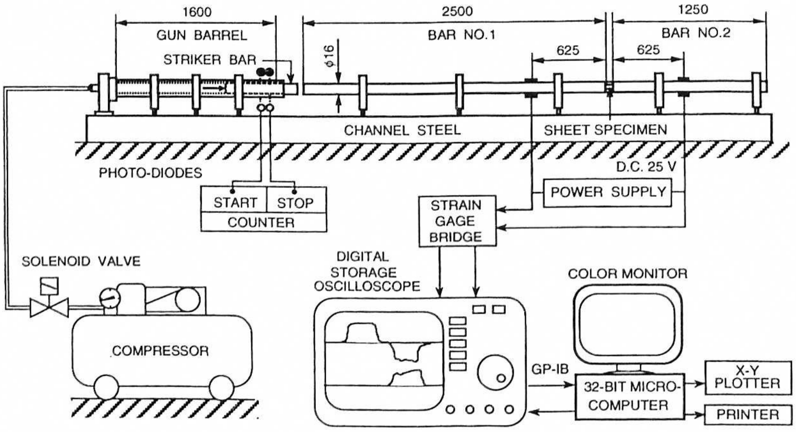
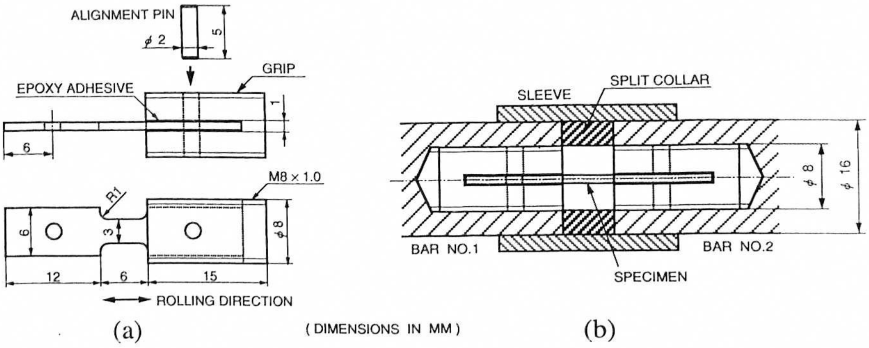


Fig. 1 Tensile split Hopkinson bar apparatus and associated recording system



(a) (b)

Fig. 2 Geometry of sheet tension specimen and its attachment to Hopkinson bars

2.2 Method of data analysis

The theory and analysis of the tensile split Hopkinson bar test is almost identical to that [4] of the compressive one, except for the change in sign of the strain pulses. By application of the elementary theory of elastic wave propagation [5], the average strain e, strain rate $\dot{e}$ and stress s along the gage length of the specimen are determined from the Hopkinson bar test records as

$$e(t) = \left(\frac{c_0}{L}\right) \int_0^{t} \left| \varepsilon_i(t') - \varepsilon_r(t') - \varepsilon_t(t') \right| \mathrm{d}t' \tag{1}$$

$$\dot{e}(t) = \left(\frac{c_0}{L}\right) \left| \varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t) \right| \tag{2}$$

$$s(t) = \left(\frac{E\,A}{A_s}\right) \varepsilon_t(t) \tag{3}$$

Here E, A and c_0 are Young's modulus, the cross-sectional area, and the longitudinal wave velocity of the Hopkinson bars; L and A_S are the initial gage length and the cross-sectional area of the specimen; and t is the time from the start of the pulse. Equations 1 and 3 provide the nominal strain and nominal stress in the specimen as a function of time t, respectively. Eliminating time t yields the nominal stress-strain curve for the specimen at the strain rate given through Eq. 2. All the nominal stress and strain data are converted to the true stress σ, the true strain ε and the true strain rate $\dot{\varepsilon}$ using

$$\sigma = s\,(1 + e), \qquad \varepsilon = \ln\,(1 + e), \qquad \dot{\varepsilon} = \dot{e}\,/\,(1 + e) \tag{4}$$

In practice, the data analysis was carried out on the 32-bit microcomputer.

3. TEST RESULTS AND DISCUSSION

3.1 Material and specimen preparation

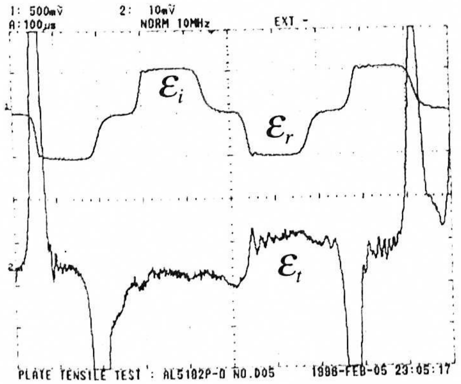
Small sheet tension specimens were prepared from a cold-rolled sheet Al alloy 5182-O having thicknesses of 1.0 mm, 1.5 mm and 2.47 mm. The specimens were machined to the nominal dimensions given in Fig. 2(a). The grip regions of the specimen were fixed into parallel-sided slots of the threaded grips made of an Al alloy 7075-T6 using an epoxy adhesive (Toyodagosei, EA #9460). The chemical composition of the sheet Al alloy 5182-O is given in Table 1. Quasi-static tension tests were performed on an Instron universal testing machine (Instron, Model 4505) at a constant crosshead speed of 0.36 mm/min using a special fixture on the same design of specimen as used in the impact tests.

Table 1 Chemical composition of Al alloy 5182-O

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 5182-O	0.12	0.13	0.04	0.22	4.48	0.04	0.00	0.01	Re

3.2 Tensile stress-strain curves

A number of impact tension tests were carried out using the tensile Hopkinson bar apparatus at room temperature. Figure 3 gives a set of typical strain-gage records from the tensile Hopkinson bar test on the sheet Al alloy 5182-O with a 1-mm thickness. The upper trace records an incident strain pulse (ε_i) with tension up and a reflected strain pulse (ε_r) with compression down; the lower trace records the strain pulse (ε_t) transmitted through the specimen. Figure 4 shows the resulting tensile stress-strain curve (A) together with the corresponding static curve (S). The drop in flow stress revealed in the dynamic curve is caused by stress wave unloading during the impact testing, not indicating the onset of necking in the specimen. The strain rate $\dot{\varepsilon}$ quoted indicates the average true strain rate during the plastic deformation. The sheet Al alloy 5182-O exhibit distinct yield point phenomena at high rates of strain and the serrations (discontinuous yielding) appear on the static



Sweep rate : 100 μs/div.
Vertical sensitivity
upper trace: 1140$\mu\varepsilon$/div.
lower trace: 23$\mu\varepsilon$/div.

Fig. 3 Typical strain-gage records from tensile Hopkinson bar test on sheet Al alloy 5182-O (t = 1 mm)

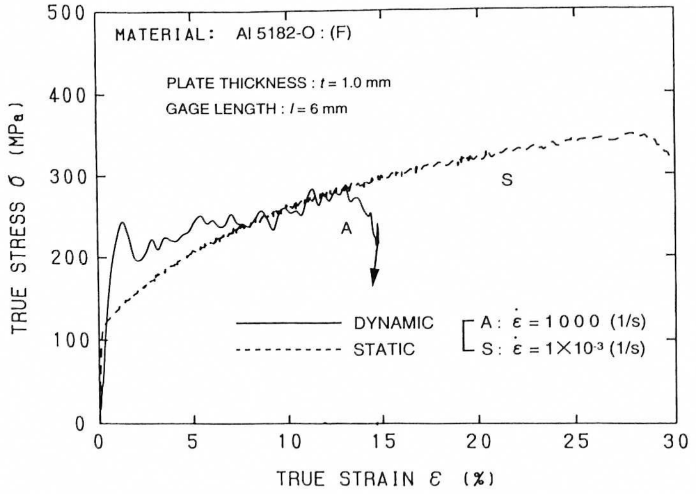


Fig. 4 Tensile stress-strain curves for sheet Al alloy 5182-O (t = 1 mm) at static and impact strain rates

stress-strain curve. Figure 5 displays the strain rate-strain relation together with the dynamic stress-strain curve (A). Note that the strain rate is almost constant during the plastic deformation, although the stress oscillates significantly in the early portion of the dynamic stress-strain curve. Figure 6 shows the tensile stress-strain curves for the sheet Al alloy with a 2.47-mm thickness at static and impact strain rates. Similar phenomena (or yield-point phenomena at high rates of strain and serrated flow) can be observed on the stress-strain curves. It appears that the serrated character of stress-strain behavior increase slightly with increasing strain rate. The Al alloy 5182-O shows almost non strain-rate sensitivity up to strain rates of aprroximately 10^3/s, irrespective of the sheet thickness. Figure 7 also indicates the tensile stress-strain relations for the sheet Al alloy 5182-O with a 1.0-mm thickness

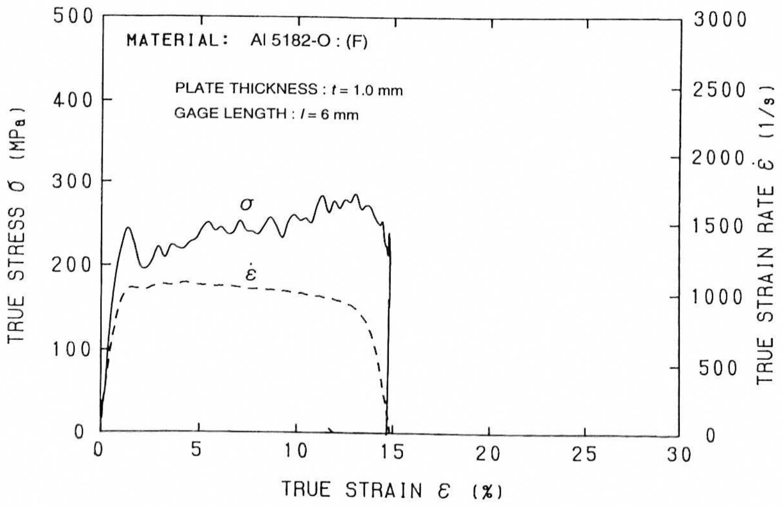


Fig. 5 Variations of stress and strain rate with strain for sheet Al alloy 5182-O (t =1mm)

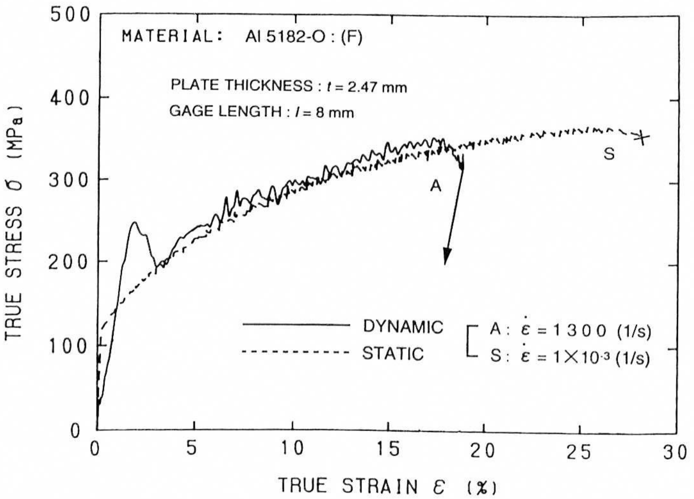


Fig. 6 Tensile stress-strain curves for sheet Al alloy 5182-O (t =2.47 mm)
at static and impact strain rates

at static and impact strain rates. This sheet Al alloy was supplied by another aluminum company. Although small serrated flow occurs on the stress-strain curves, the yield-point phenomena at high rates of strain are not significantly found. The mechanical properties of the Al alloy 5182-O slightly differs from manufacturer to manufacturer. This difference may be possibly due to the different processing conditions.

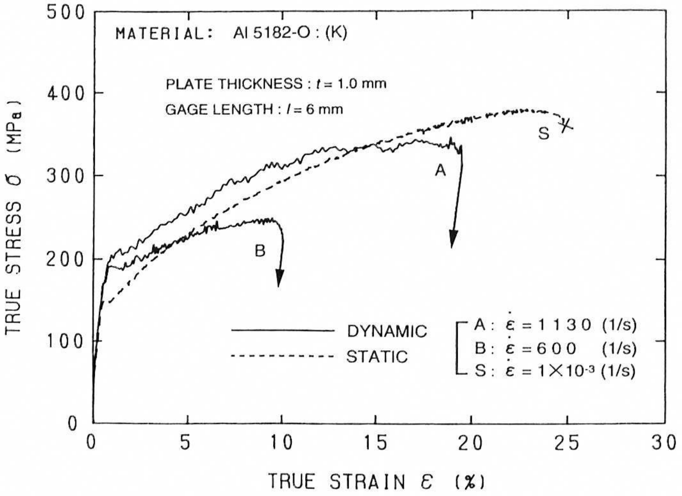


Fig. 7 Tensile stress-strain curves for sheet Al alloy 5182-O (t = 1 mm) at static and impact strain rates

4. CONCLUDING REMARKS

The tensile stress-strain curves for the sheet Al alloy 5182-O with thicknesses ranging from 1.0 to 2.47 mm at high rates of strain were successfully determined with the split Hopkinson bar technique. It is demonstrated that the sheet Al alloy 5182-O shows serrated flow at low and high rates of strain, but is insensitive to strain rate, independent of the sheet thickness (or the reduction ratio). The present technique is not applicable to sheet materials with thicknesses less than about 0.7 mm due to the large impedance mismatch between the specimen and the Hopkinson bars.

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