STRAIN RATE DEPENDENCE OF IMPACT TENSILE PROPERTIES IN 6061 ALUMINUM ALLOY

Shigeki Morita*, Toshiro Kobayashi and Hiroyuki Toda****

*Graduate School of Toyohashi University of Technology,
Toyohashi-city, AICHI 441-8580 Japan
**Department of Production Systems Eng., Toyohashi University of Technology,
Toyohashi-city, AICHI 441-8580 Japan

ABSTRACT

Tensile properties of a 6061-T6 aluminum alloy is investigated over a wide range of strain rates between 10^{-3} and $10^{3}s^{-1}$. In the strain rate range between 10^{-3} and $10^{1}s^{-1}$, tensile strength and 0.2% proof stress are a weak function of the strain rate. Beyond this range, the tensile strength and 0.2% proof stress increase with increasing strain rate. The influence of strain rate on total elongation is not so significant. While, the uniform elongation increases with increasing strain rate. The tendency of the strain rate dependence of strain hardening exponent is similar to that of the uniform elongation.

Keywords: *6061 aluminum alloy, impact tensile test, strain rate, strength, elongation*

1. INTRODUCTION

Numerous applications of structural materials involve dynamic or impact loading. In order to analyze the behaviors of dynamically-loaded structures exactly, it is necessary to know the mechanical properties and its constitutive equations of the materials under the dynamic loading. The mechanical properties of most materials are to some extent dependent on the strain rate. Recently, automobiles are required to lighten the weight for saving fuel and assuring safety for various accidents. Especially, automotive industry shows a considerable interest in the application of aluminum alloys for car body. It becomes, therefore, important to know the mechanical properties of 6061-T6 aluminum alloy at high strain rates.

The purpose of this study is to investigate the dynamic deformation behavior of 6061-T6 aluminum alloy in tension over a wide range of strain rate.

2. EXPERIMENTAL PROCEDURE

The material used in the present study is a commercial 6061-T6 aluminum alloy. The chemical composition is given in **Table1**. The impact tensile specimens were machined parallel to the extrusion direction. Its geometry is shown in **Fig.1**. The specimens have a gage length of 8mm, and the gage diameter of 4.5mm, and 7.0mm respectively. The strain gages are attached directly on the specimen surface to measure an applied load exactly[1].

Table1 Chemical composition of the 6061 aluminum alloy (mass%)

Si	Fe	Cu	Mg	Cr	Ti	Al
0.68	0.20	0.37	0.89	0.08	<0.01	bal.

The static tensile test was carried out using an Instron-type test machine (AGS-1000). The impact tensile test was carried out using a Shimazu hydraulic testing machine (EHF-U5H-20L). All the tests are conducted at room temperature. Fracture surfaces of the specimens after tensile test ware observed with a JSM-6300 scanning electron microscope.

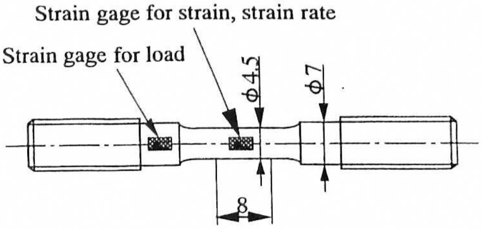


Fig.1 Geometry of an impact tensile specimen in mm.

3. RESULTS AND DISCUSSION

3.1 Influence of strain rate on strength

Figure 2 shows an example of the stress-strain curves obtained from the impact tensile test conducted at 10^{-1}, 10^{1} and $10^{3}s^{-1}$. The results show that entire stress strain curves are raised by increases in strain rate.

Figure 3 shows ultimate tensile strength and 0.2% proof stress as a function of strain rate. In the strain rate range between 10^{-3} and $10^{1}s^{-1}$, the tensile strength slightly increases with increasing the strain rate, however, the tensile strength remarkably increases from 320 to 350MPa when the strain rate is over $10^{1}s^{-1}$. Such variation of strength with strain rate can be described as follows[2]:

$$\sigma_x = \sigma_{sx} + \ln(1 + a\dot{\varepsilon})^b \qquad (1)$$

where σ_x is tensile strength and 0.2% proof stress at given strain rate, $\dot{\varepsilon}$. σ_{sx} are those in static condition and a and b are constants. Various types of the strain rate dependence of stress which are on basis of several plastic deformation mechanisms, have been summarized as follows.

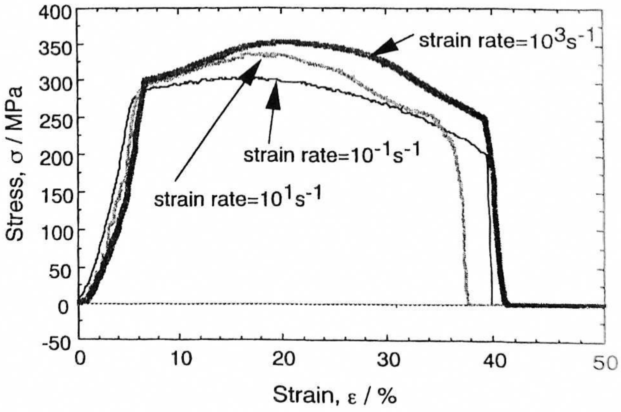


Fig.2 Stress-strain curves at three different strain rates.

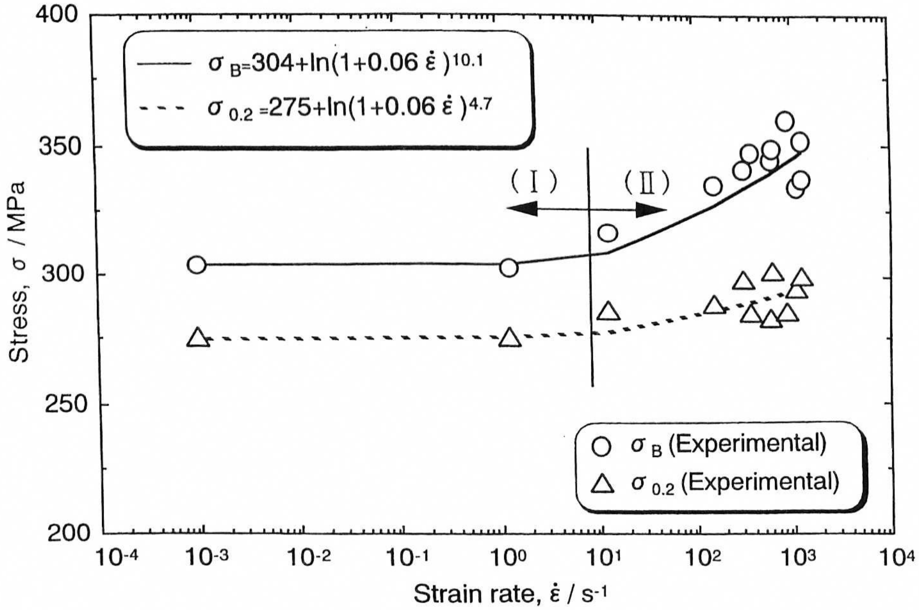


Fig.3 Variations of tensile strength and 0.2% proof stress as a function of strain rate.

Region Ⅰ: The stress is a function of strain and temperature only. The log-range stress fields are the main factor that affect the motion of dislocations.

Region Ⅱ: The stress is a function of the strain and temperature, as well as of the strain rate. The dependence upon strain rate is described by models for dislocation motion, which are based on the concept of thermally activated process[3,4].

Region Ⅲ: This region is characterized by the reduced sensitivity of the stress to the strain rate and temperature. Plastic deformation occurs mainly *via* twinning.

Region Ⅳ: There is a considerable increase in the sensitivity of the stress to the strain rate, as compared with region Ⅱ. Although thermally activated processes also occur in this region, other causes for the attenuation of dislocation motion exist.

As can be noted in **Fig.3**, two regions of strength *vs* strain rate dependence can be identified in the tensile strength and the 0.2% proof stress data. Although, in most materials, region Ⅱ and region Ⅳ are the dominant modes of deformation, it is obvious that the material in this study exhibited deformation modes corresponding to regions Ⅰ and Ⅱ.

3.2 Influence of strain rate on elongation

Figure 4 shows the total elongation and the uniform elongation as a function of strain rate. No significant influence of strain rate on total elongation is found. While, the uniform elongation increases with increasing strain rate.

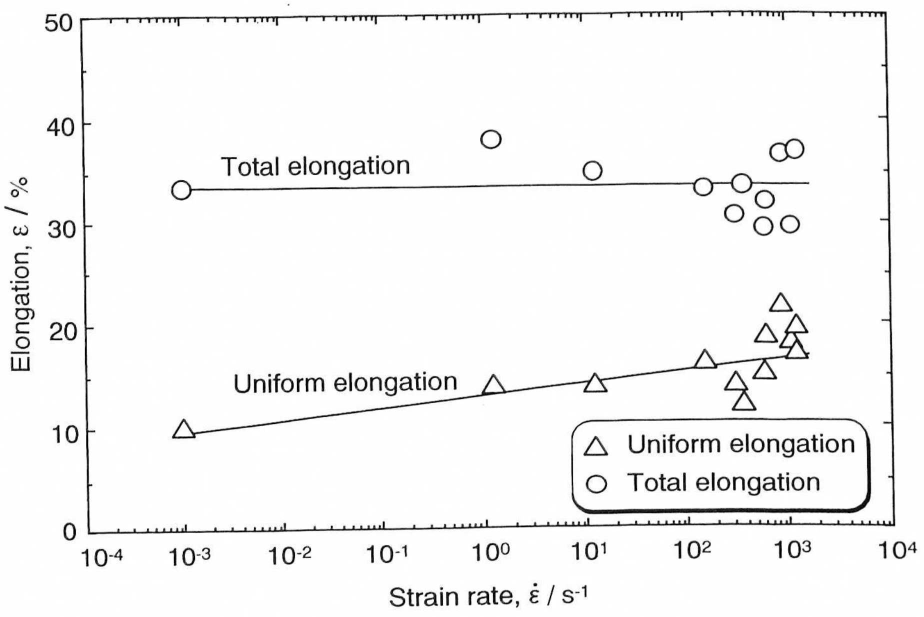


Fig.4 Variations of uniform elongation and total elongation as a function of strain rate.

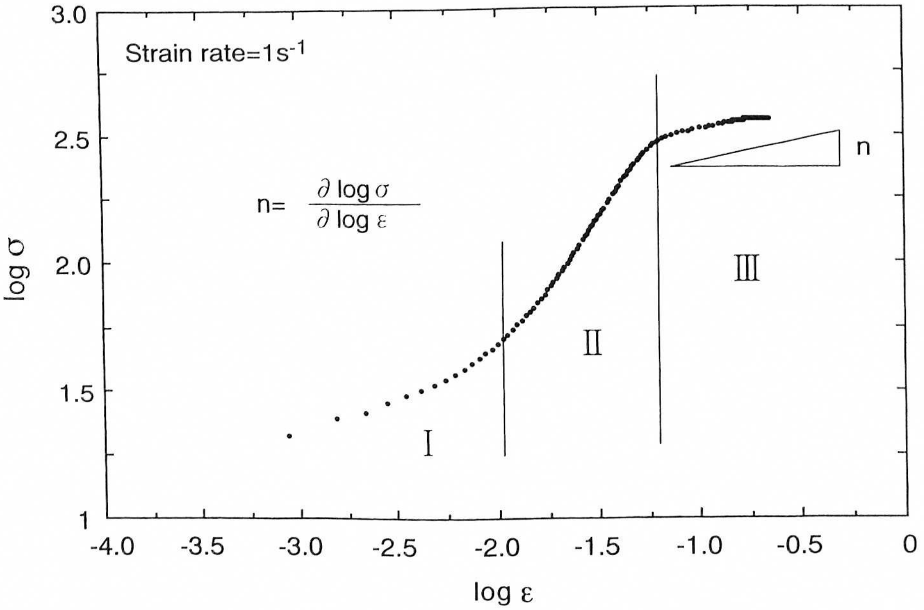


Fig.5 Typical relationship between true stress and true strain in logarithmic scale.

To investigate the influence of strain rate on the uniform elongation, the strain hardening process is investigated here. The strain hardening process is strongly concerned with uniform deformation, because the strain hardening is caused by the interactions between dislocations and inclusions and precipitations. It has been reported that the strain hardening exponent $n = d\log\sigma / d\log\varepsilon$ corresponds to the uniform elongation[5]. Typical relationship between true stress and true strain on a logarithmic scale is shown in **Fig.5**. The strain hardening exponent *n* is calculated from the slopes of curves. The curves are divided into three stages of the strain hardening process. In the third stage, necking of the specimen takes place. The influence of the strain rate on the strain hardening exponent is shown in **Fig.6**. The shape of the curve is similar to that of uniform elongation.

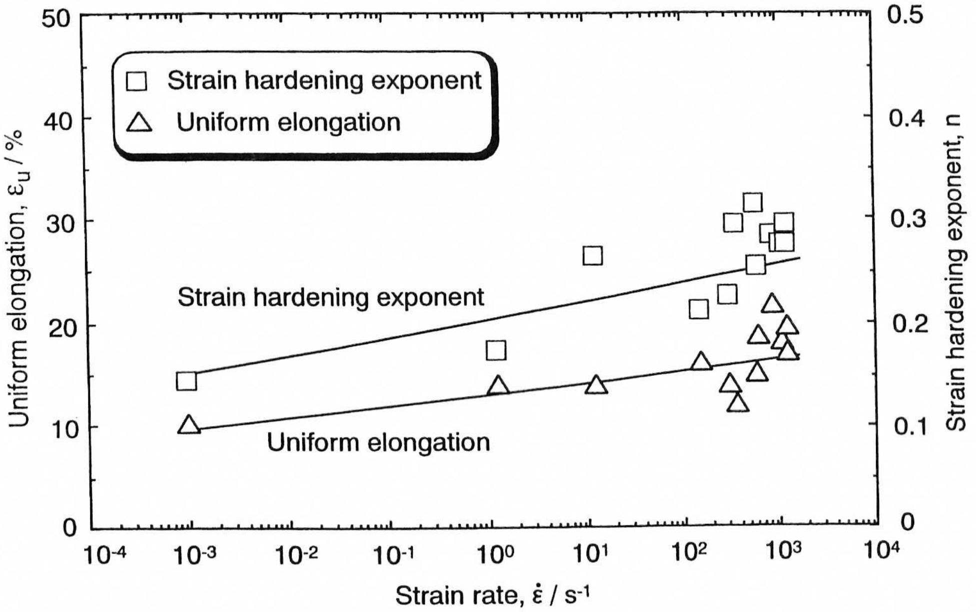
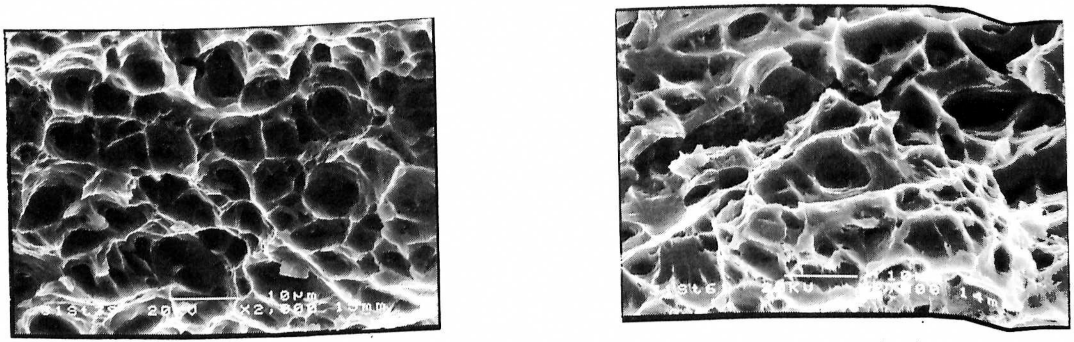


Fig.6 Variations of strain hardening exponent and uniform elongation as a function of strain rate.

3.3 Fracture surface

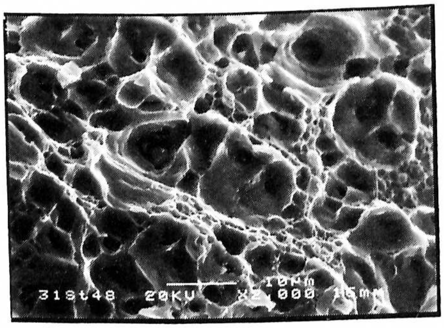
Figure 7 shows the typical fracture surfaces of the specimens after tensile testing at various strain rates. The fracture surfaces of the impact tensile tested specimen appears quite similar to that of the static condition which essentially ductile fracture. The micromechanisms of the fracturing process are transgranular fractures and ductile rupture consisting of dimples. In this investigation, the size of dimples increases with the strain rate.



(a) $\dot{\varepsilon}=10^{-3}s^{-1}$

(b) $\dot{\varepsilon}=10^{1}s^{-1}$

20μm



(c) $\dot{\varepsilon}=10^{3}s^{-1}$

Fig.7 SEM micrographs of fracture surfaces at various strain rates.

4. CONCLUSIONS

The uniaxial deformation behavior of 6061-T6 aluminum alloy over a wide range of strain rates has been investigated. The main results and conclusions are summarized as follows.

1. In the strain rate range between 10^{-3} and $10^{1}s^{-1}$, tensile strength is a weak function of strain rate. Beyond this strain rate range, the tensile strength increases with increasing strain rate. Strain rate dependence of the 0.2% proof stress is similar to that of the tensile strength.
2. The total elongation is almost independent of the strain rate. While, the uniform elongation increases with increasing the strain rate. Tendency of the strain rate dependence of the strain hardening exponent is similar to that of the uniform elongation.

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