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Author(s)	Hisa, Masaaki; Kondo, Hiroshi; Watanabe, Katsuya
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Cryogenic Deformation Behavior of Al–Mg Binary Alloys

Masaaki HISA, Hiroshi KONDO and Katsuya WATANABE

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Abstract

Mechanical properties of Al–Mg alloy (4.1 and 4.6at% Mg) were investigated by tensile test at 77K and 293K.

Both the ultimate tensile strength and the 0.2% proof stress increased with decreasing temperature, and the increment of the ultimate tensile strength was larger than that of the proof stress. The elongation also increased at the low temperature.

The mechanical property changes were thought to be the increase of work hardening exponent at the low temperature. At 77K the strength increased with strain rate, while the dependency at 293K was obscure. This was considered to be affected by the reverse temperature dependence of strength for this alloy.

1. Introduction

In recent years, along with accompanying the applications of superconducting magnets kinds of field, it has become active to develop new structural materials for cryogenic use⁽¹⁾. Aluminum alloys are considered one of such materials due to their high specific strength, non brittleness at low temperatures, non magnetism, good weldability and additional excellent properties. Aluminum–magnesium alloy, such as 5083–O, is a strong candidate material⁽²⁾.

The mechanical properties of this alloy at low temperatures, however, have not been clarified sufficiently. In this study the tensile tests of Al–4.1 and 4.6at% Mg alloys were carried out at 77K to investigate their mechanical properties at lower temperatures. In order to examine the effect of temperature, the tests at 293K were also performed. In this report, the experimental results of dependencies of tensile strength on temperature, strain rate, alloy composition and grain size are presented, and the anomaly of strain rate dependency at 293K is discussed in detail.

2. Experimental Procedures

2.1 Specimen Preparation

Al-4.1 and 4.6at% Mg alloys were used in the present work. The alloys were made from 99.9992% purity aluminum and 99.95% purity magnesium. They were melted in the air, de-hydrogenated by chlorine gas, and then casted. Ingots were homogenized at 723K for 180ks in vacuum after cold rolling up to 20% reduction. Subsequently, they were cut into rods of 40mm length and 10mm diameter, and were further cold rolled up to the total reduction of 80%. Tensile specimens were spark cut out from the cold rolled sheets. After they were reformed and annealed at 623K for 3.6ks to remove residual strains, electro-polished in a solution of 80vol% ethyl alcohol and 20vol% perchloric acid. Fig.1 shows the shape and size of the tensile specimen, which has the total length of 40mm, and length, width and thickness of the tested portion were 20, 3 and 2mm respectively.

2.2 Tensile Test

In the present work, Instron type tensile machine shown in Fig.2 with a cryostat for the cryogenic test was used. Tensile tests were carried out at 77K and 293K. For 77K tests, the specimen was immersed in liquid nitrogen. Copper-constantan thermocouples which were set on the machine were used for temperature measurement. Initial strain rates were $2.08 \times 10^{-2} \text{s}^{-1}$, $2.08 \times 10^{-3} \text{s}^{-1}$ and $4.17 \times 10^{-4} \text{s}^{-1}$.

3. Results and Discussion

3.1 The Temperature Dependence of Strength and Elongation

Fig.3 shows typical stress-strain curves obtained at 77K and 293K. The serration appeared on the stress-strain curve at 293K. It was caused by dynamic strain aging, so—

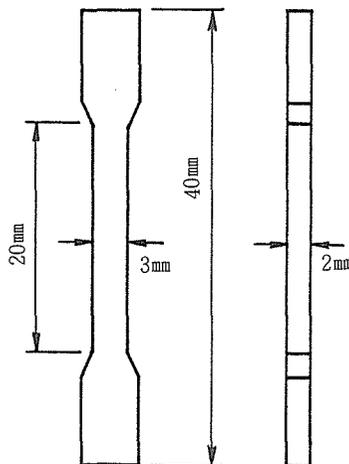


Fig. 1 Geometries of specimen.

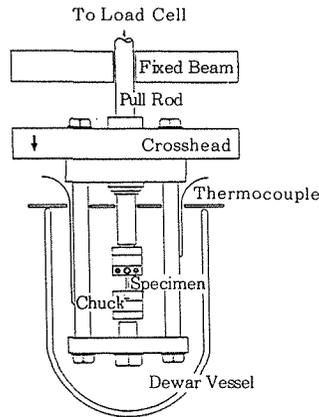


Fig. 2 Schematic figure of cryostat for low temperature test.

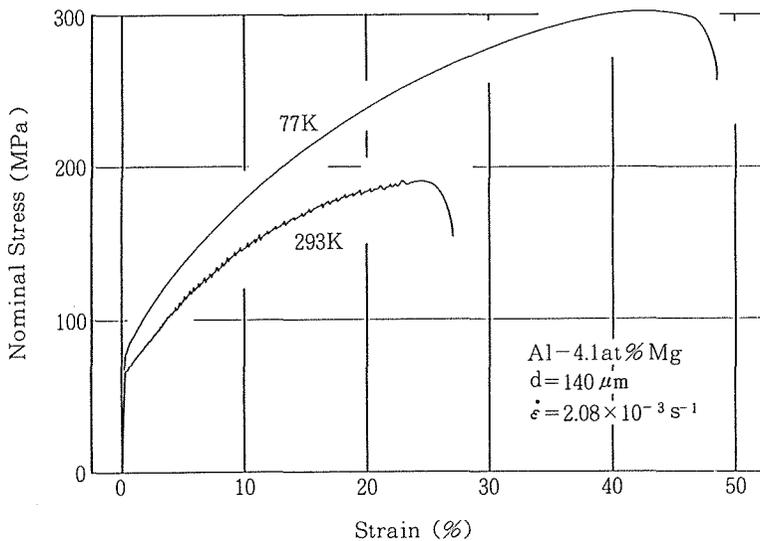


Fig. 3 Typical stress-strain curves obtained from 77K and 293K tests.

called the Portevin Le-Chatelier effect⁽⁹⁾. On the other hand, no serrated flow occurred at 77K. Both the ultimate tensile and the 0.2% proof stresses increased with the decreasing temperature. The increment of ultimate tensile strength was larger than that of 0.2% proof stress when the temperature decreased. The total elongation was larger at the low temperature. In particular, the uniform elongation, namely the elongation up to the necking initiation increased as the temperature was decreased. It seems that these results were due to an enlargement of the work hardening exponent at low temperature. Fukushima et al.⁽⁴⁾ reported that an increase of elongation of copper at liquid nitrogen temperatures could be attributed to the enlarged work hardening exponent. The work hardening exponents obtained in Fig.3 were shown in Fig.4. The exponent seems to be independent of the strain

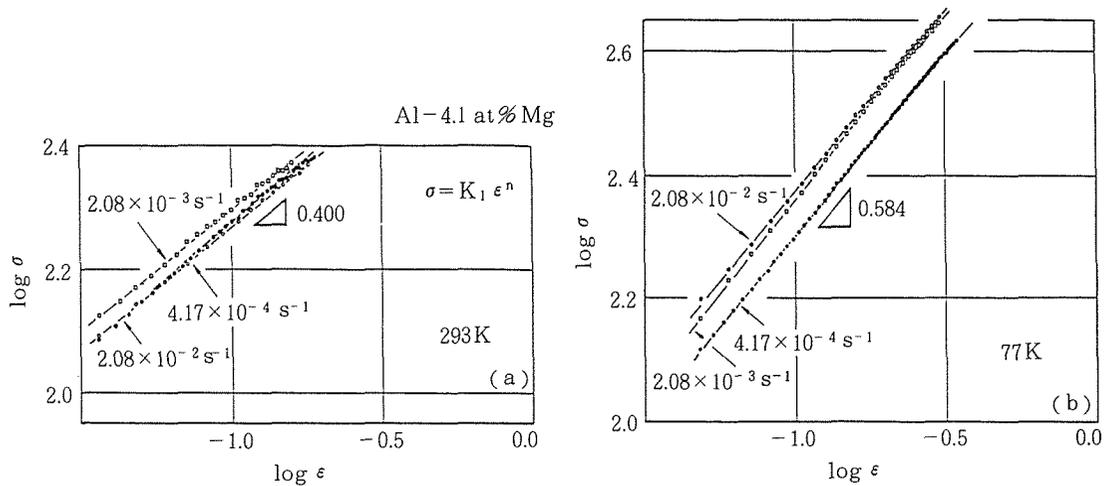


Fig. 4 Work hardening exponent calculated from Fig. 3 ;
(a) for 293K, and (b) 77K.

rate in the range of the present work, but it is clear that the exponent is larger in the decreasing temperature. One of the reasons why the work hardening exponent becomes large at low temperature is considered that cross slips of screw dislocation would become more difficult to take place. The cross slip is believed to occur with the assistance of thermally activated process⁽⁶⁾, and under a decreased temperature, the frequency of the thermally assisted cross slip decreases. Under this condition, the deformed region in a specimen is strongly hardened because of the large work hardening exponent. Subsequent deformations cannot be performed in that region, and in another soft region the next flow must occur. Repeating the flow process, the specimen is deformed uniformly without the initiation of necking. As a result, the total elongation of the specimen increases.

In addition to this, the work hardening exponent at a high strain region was observed to be smaller than that of the low strain region. Saji et al. reported a similar result for 7075 alloys⁽⁶⁾. The reason for this, however, has not been clarified as yet.

3.2 The Composition Dependence of Strength

With two kinds of specimens, Al-4.1 and 4.6at% Mg, the effect of temperature on the composition dependence of strength was studied. The results were shown in Fig.5. At 77K and 293K, the strength increased with increasing magnesium content. Then, the composition dependence of strength is considered to be not affected by the decrease of temperature.

3.3 The Grain Size Dependence of Strength

In order to investigate the grain size dependence of strength at 77K and 293K, several grain size controlled specimens were used. These samples were made by isothermal annealing in vacuum until the grains grew to the desired sizes. Fig.6 shows stress-strain curves obtained. It is known in the figure that the strength becomes higher as the grain size decreases at each temperature. Therefore, decreasing the temperature seems not to influence the grain size dependence of strength.

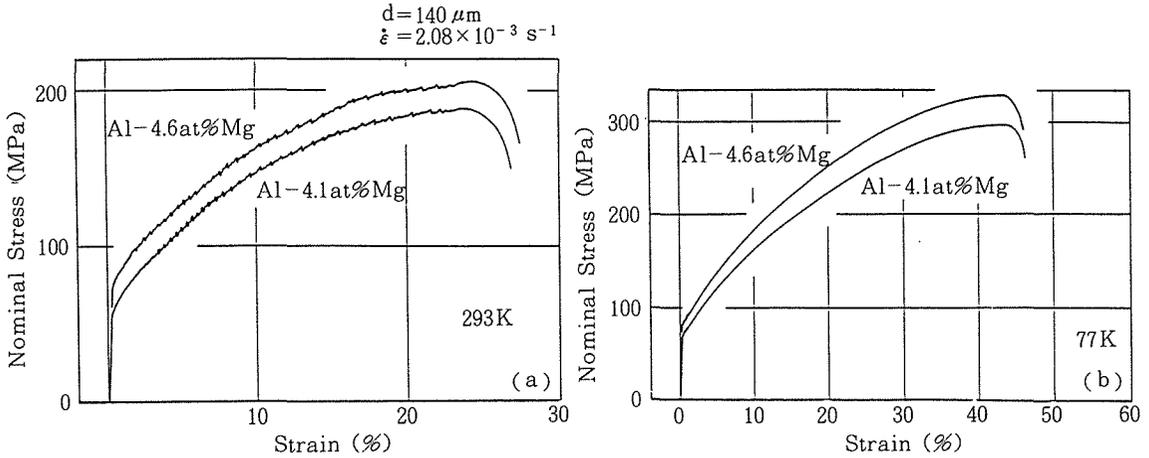


Fig. 5 Effect of temperature on composition dependence of strength ;
(a) for 293K test, and (b) for 77K test.

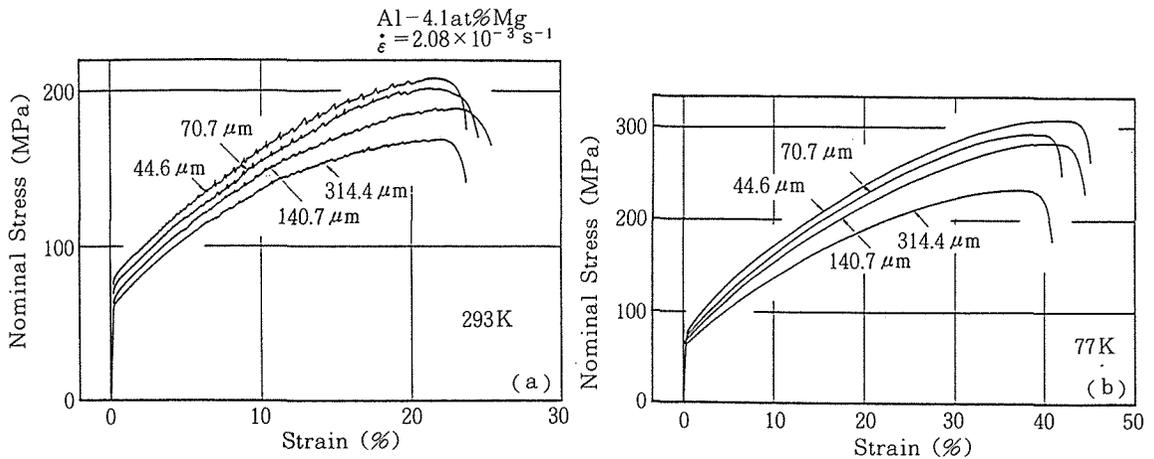


Fig. 6 Effect of temperature on grain size dependence of strength ;
(a) for 293K test, and (b) for 77K test.

3.4 The Strain Rate Dependence of Strength

The strain rate dependence of strength was studied at the strain rate of 10^{-4} , 10^{-3} and 10^{-2} s^{-1} . The results were shown in Fig.7. At 77K, the strength increased with the increasing strain rate, and the dependence became indistinct at 293K. In order to appraise this results quantitatively, the strain rate sensitivities were calculated for each temperature. The results were shown in Fig.8. It is clear that the strain rate sensitivity m is smaller at 293K than at 77K. This result means that the strain rate dependence of strength becomes less remarkable at 293K. The reason is considered as follows ; the temperature dependence of yield strength of Al-Mg alloy single crystal was reported as shown in Fig.9(a) by Asada et al.⁽⁷⁾. Now, the following factors are considered as those of the affected strength of this

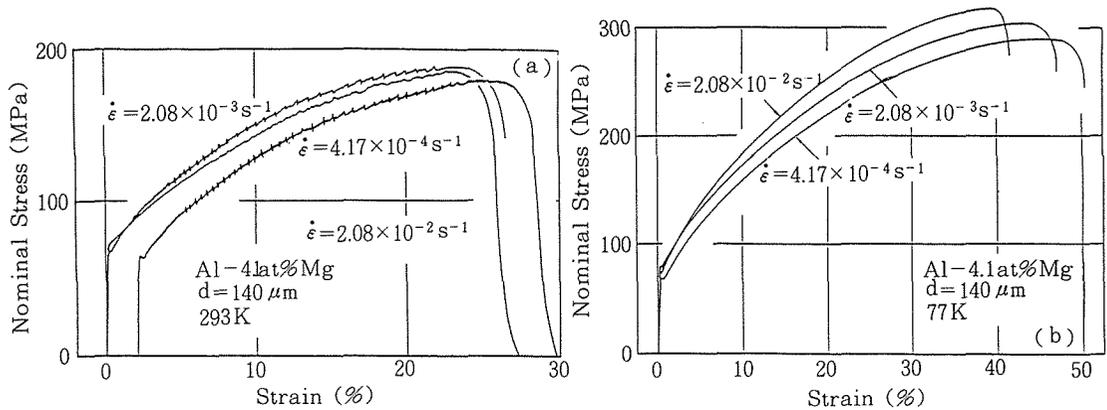


Fig. 7 Effect of temperature on strain rate dependence of strength ;
(a) for 293K test, and (b) for 77K test.

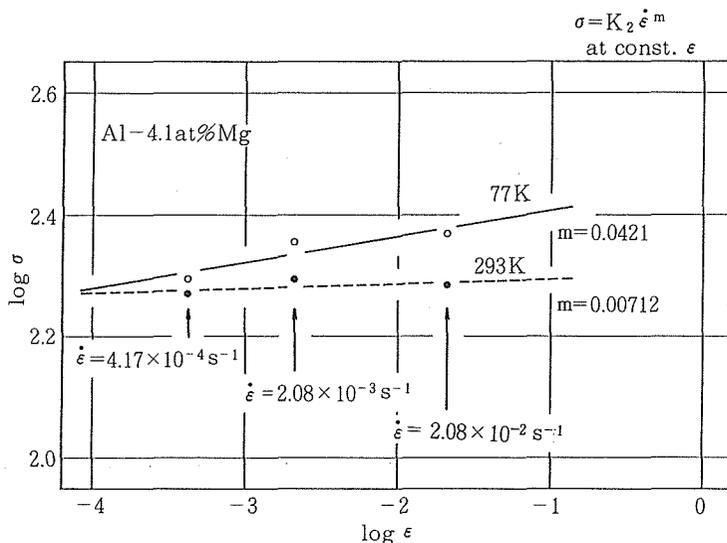


Fig. 8 Strain rate sensitivity at $\epsilon = 10\%$ in Fig. 7; dashed line is for 293K,
and solid line is for 77K.

alloy. The first one is the frequency of thermally activated dislocation motion. Since the frequency decreases with decreasing temperature, the strength determined by this factor would increase. The second factor is the degree of development of the Cottrell atmosphere around a moving dislocation. The diffusion rate of solute atom becomes smaller as the temperature decreases, and the Cottrell atmosphere grows insufficiently. This second factor affects the decrease of the strength of the alloy when the temperature decreases. The mobility of the Cottrell atmosphere is considered as the third factor. Solutes cannot move easily at low temperatures, and the Cottrell atmosphere is difficult to follow the moving dislocation at the decreased temperature. This third factor consequently works to lower the

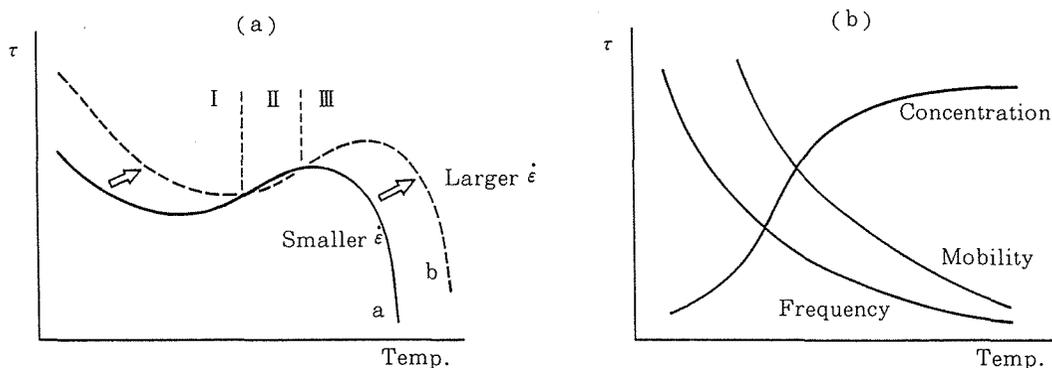


Fig. 9 Schematic illustration of temperature dependence of yield strength for Al-Mg single crystal.

- (a) Temperature and strain rate dependences of strength; solid line shows for lower strain rate, and dashed line shows for higher one.
- (b) Temperature dependence of various factors which is considered to affect to the strength of this alloy.

strength at low temperatures. On these bases, it was assumed that the temperature dependence of strength shown in Fig.9(a) appeared as a result of combining these three factors [Fig. 9(b)]. In addition to this, both the chance of dislocation motion assisted by the thermally activated process and the relative velocity of a solute atom against a moving dislocation is reduced when the strain rate increases. The position of curve (a) in Fig.9(a) would shift entirely to that of curve (b) by increasing the strain rate. In Fig.9 (a) three temperature regions of I, II and III are hypothesized. In the zones of I and III with the increasing strain rate will lead to observe a higher yield strength. On the contrary, in the medium temperature zone (region II) the effect of strain rate on the strength cannot be observed remarkably.

In view of the results, it seems that the 77K is in the region I and the 293K is in the region II.

4. Conclusion

To clarify the mechanical properties of Al-Mg binary alloy under cryogenic temperature, tensile tests of Al-4.1 and 4.6 at% Mg alloys were performed at 77K. The tests were also carried out at 293K in order to investigate the temperature dependence of the mechanical properties. The results obtained were as follows.

- (1) Both the ultimate tensile strength and the 0.2% proof stress increased with the decreasing temperature.
- (2) The increment of ultimate tensile strength was larger than that of 0.2% proof stress as the temperature decreased.
- (3) The elongation was larger at 77K than at 293K. These two results were considered to be that of the increased work hardening exponent at 77K.

(4) The strength increased by increasing the magnesium content and decreasing the grain size at 77K and 293K.

(5) At 77K, the strength increased when strain rate was increased. The strain rate dependence of strength, however, was not clear at 293K. It was considered to be due to the reverse strength dependence on temperature of this alloy.

References

- (1) Horiuchi T. : Bull. Japan Inst. Metals, 21 (1982), 12, p.965
- (2) Miyamoto Y., Tanaka K., Morioka O. and Kawate Y. : Kobe Steel Eng. Rep., 34 (1984), 3, p. 47
- (3) Oikawa H. : Zairyo-Kyodo no Genshi-Ron, Ed. by Japan Inst. Metals, (1985), p. 263, Japan Inst. Metals
- (4) Fukushima E. and Goto A. : J. Mater. Sci. Soc. Japan, 9 (1972), 12, p. 317
- (5) Dieter G. : Mechanical Metallurgy, 2nd. Ed., (1976), p. 146, McGraw-Hill
- (6) Saji S., Yasuhara K. and Hori S. : Trans. JIM, 28 (1987), 10, p. 773
- (7) Asada H., Horiuchi R., Yoshinaga H. and Nakamoto S. : Trans. JIM, 8 (1967), 3, p. 159