EFFECT OF Li AND Cu CONTENTS ON THE MECHANICAL PROPERTIES OF Al-Cu-Li ALLOYS

Takuzo Hagiwara, Kazunori Kobayashi and Toshimasa Sakamoto

ALITHIUM Ltd.,
2-2-2, Ogosohigashi Yokkaichi, Japan

Abstract

The alloys used in this study had near 2219 compositions with various Li and Cu contents. To discuss the effect of Li, Cu contents on the mechanical properties and precipitation structure, tensile test,instrumental charpy impact test,TEM and SEM observation have been conducted.The tensile strength and elongation at the low temperature are increased, but reduction ratio in area is decreased, when compared with the properties at room temperature. As Li contents has increased, precipitation density of θ' has not changed,but T_1 phase and strength has increased. Strength ductility balance is the best in the alloy of 1.25% Li content.

Introduction

2219 alloy is known as a heat-resistant high strength alloy having excellent weldability. As this is one of the high density commercial aluminum alloys, an important subject on it is to lower the density. Addition of lithium to 2219 alloy not only reduces its density but also improves its strength and modulas. Therefore, specific strength and specific modulas are also increased largely. As to the aluminum alloy, Li was added in attempt to improve its specific strength and specific rigidity. Kojima et al. has already prepared a report explaining high temperature tensile properties and creep properties of an alloy with the addition of lithium by 1.24 mass %[1]. Virtually, no report has ever been made on mechanical properties of this lithium contained alloy at a low temperature. In this study, we manufactured alloys by adding lithium to 2219 alloy which has various quantity of coppe. In order to clarify influences of lithium and copper contents on its mechanical properties such as strength and toughness at low temperature,it was examined that how the mechanical property would be influenced by the testing temperature, chemical compositions and aging conditions.

Experimental procedure

Table.1 shows chemical compositions of specimens used in this study. Lithium content is 0.5 %,1.0%,1.2%,1.25%,respectively. As for the specimen containing less than 1.2%Li, copper were added about 6%. For the specimen with 1.25% Li, copper were reduced to 5.2%. All the specimens were cast into sheet ingots, scalped, homogeneously heated and hot rolled into sheets of approximately 8mm in thickness. After solution treated at 773K for 60 minutes, they were streched by 4%, provided with aging treatment at 443K and finished into T8 materials having the highest strength. Aging conditions for these materials were decided by seeking 443K isothermal aging curves of vikers hardness. Further, as for the specimens containing 1.2% Li, in order to evaluate influences on aging conditions, under-aged and over-aged materials were prepared in addition to peak aged materials. This study were consisted of tension tests and instrumented charpy impact tests to evaluate the mechanical properties, and also of observations of SEM fractured surfaces , microstructures and TEM structures. The tensile test were conducted at room temperature, at the nitrogen liquefying temperature of 77K and helium-liquefying temperature of 4.2K using INSTRON type tension test machine.Tensile test materials were machined into round bar specimens of 3.5 mm in diameter and 10mm in gagelength along the logitudinal direction. These specimens were tested at initial strain rate of 8.3×10^{-4}/sec to seek tensile strength, yield strength, elongations and reduction in area. The charpy test were made on the only those two specimens with 0.5% and 1.2% Li, at the room temperature and 77K in L-T and T-L directions respectively. In order to remove Li absent layer, surface layers were scalped to a depth of 6.5 mm and machined into JIS number 4 V-notch charpy test pieces. The values of absorption energy such as EiA, EpA,and EtA per unit area are mesured. Microstructures of heat treated specimens were observed using optical microscope. In addition, precipitation structures were observed by TEM.

Table.1 Cemical compositons of specimens (mass%)

Specimen	Alloy	Li	Cu	Mn	Zr	Ti	V
1	2219+0.5%Li	0.53	6.10	0.28	0.14	0.04	0.12
2	2219+1.0%Li	0.99	6.20	0.27	0.14	0.04	0.11
3	2219+1.2%Li	1.20	5.82	0.28	0.15	0.04	0.12
4	2219+1.25%Li	1.25	5.22	0.28	0.15	0.04	0.12

Test Results

Tensile Tests

Deformation Behavior Fig.1 shows load stroke curves of the tensile tests specimens at room temperature and low temperature.The room temperature load stroke curve indicates that there is a region corresponding to local elongation where load decreases as an increase in strain after the maximum load [2). However, in case of low temperature of 4.2K except a specimen containing 0.5% Li, this behavior is different from that of room temperature to such an extent that the specimen does not show the tendency in the room temperature. And it tends to break during the work hardening process or at the final stage of this process, while occurring of serration due to non-uniform deformation. After all, the low temperature behavior does not show such a region that a load decreases with increase in the strain after the maximum load.

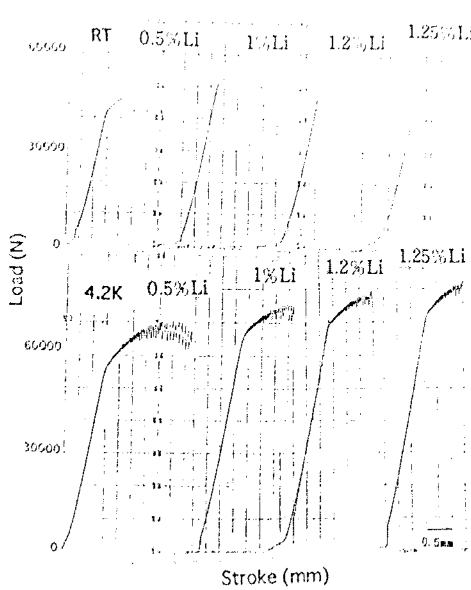


Fig.1 Load stroke curves of the tensile test specimens

Cu, Li Quantities, Strength and Elongation Fig.2 shows relations between yield strength, elongation and reduction in area. Yield strength of all the materials tend to improve as the lithum quantity increase in both cases of room temperature and low temperature. Elongation and reduction in area tend to decrease with the decrease in yield strength. In case of the 1.25% Li alloy, however, while the value of yield strength and elongation tend to increase at room temperature, such tendency is not observed at a low temperature. It is conceivable from Fig.2 that material of the highest strength with a well strength and elongation ballance is obtainable in case of specimen 4 which has 5.2% Cu and1.25% Li.

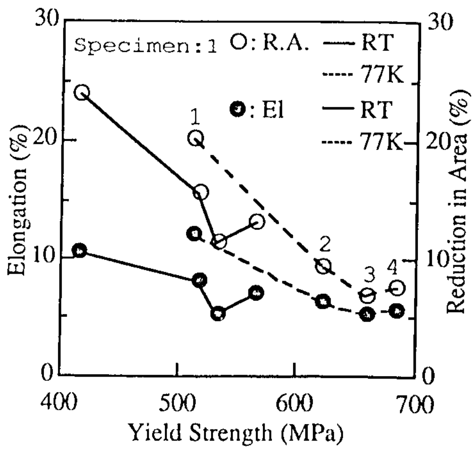


Fig.2 Relation between yield strength, elongation and reduction in area

Influence of testing temperature Influence of testing temperatures on tensile properties were shown in Fig.3 in terms of relations between elongation values and reduction in area. Yield strength of all the specimens increased with the decrease in the testing temperature. Elongations did not vary substantially between

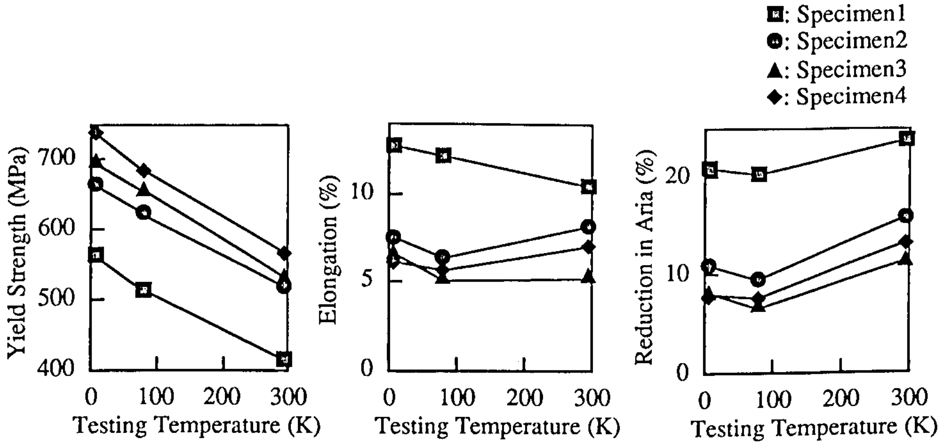


Fig.3 Influence of testing temperatures on tensile properties

low temperature and room temperature, but reduction in area tend to be smaller with decreasing in testing temperature.

Effect of Aging Condition Fig.4 shows effects of aging conditions on the tensile properties. When the specimens undergo aging treatment at room temperature using two aging conditions of peak aging and under aging, in case of under aging its strength goes down to approximately 40 - 50 MPa and its elongations improves, but reduction in area does not change at all. When it is further aged to overaging,yield strength and reduction in area also go down, but elongation does not change at all. On the other hand, at the temperature of 77K yield strength changes are much

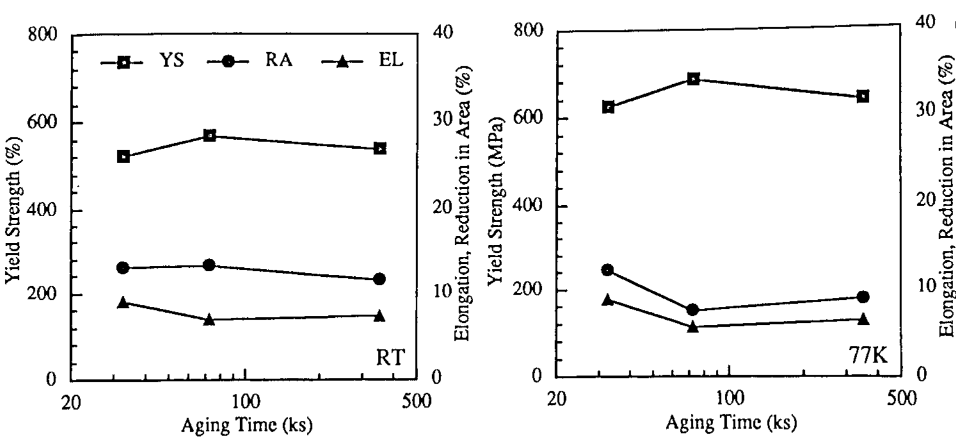


Fig.4 Effects of Aging Conditions on the Tensile Properties

larger than those of room temperature in all case of aging, that is approximately 60MPa at under aged side and 50 MPa at over aged side. While elongation and reduction ratio of under aging become fairly improved than those of peak aging, the values of over aging are almost same as those of peak aging. After all influences to be brought about by the aging conditions are considered that both the yield strength and reduction in area are improved by under aging and effects of temperature on the mechnical properties in the low temperature are larger than those of room temperature.

Observations of Fractured Tensile Specimens Fig.5 shows SEM observations of fractured surfaces on tensile specimens at room temperature. Fracture of tensile test pieces, regardless of testing temperatures (whether a room temperature or a low temperature) show matrix shearing ductile breakages with occurrence of dimples in grains[3], and this well agrees with the fact that elongation values do not go down appreciably at a low temperature. Further laminated cracks are not observed on tensile fractures. As shown in Fig.6 for the specimens which have a large quantity of copper, coarse Al-Cu-Ti-V type or Al-Cu type compounds were observed on the fracture surface. Fig.2 illustrate the specimen with 5.2% Cu and 1.25% Li additives proved to be material having the best strength and elongation ballance. This is considered to be caused by a reason that in case of a specimen which has a large quantity of copper about 6.0%, the coarse compounds bring about an adverse effect to ductility with decreasing elongation.

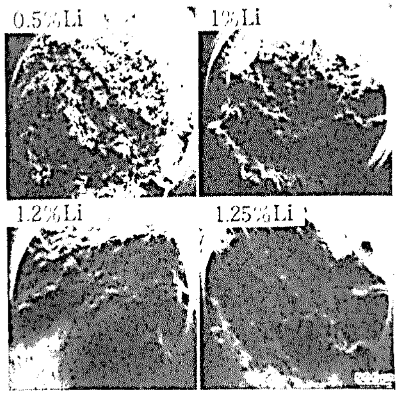


Fig.5 SEM observations of fractured surface on tensile specimens at room temperature

Fracture Toughness

Table.2 shows instrumental charpy impact test's results of specimens. Toughness evaluated total absorption energy EtA indicates that low lithium content and low strength material have excellent value at room temperature. At low temperature of 77K, nominal crack initiation energy EiA becomes higher than that of room temperature, but nominal crack propagation energy EpA remains the same or becomes a little lower. Particularly

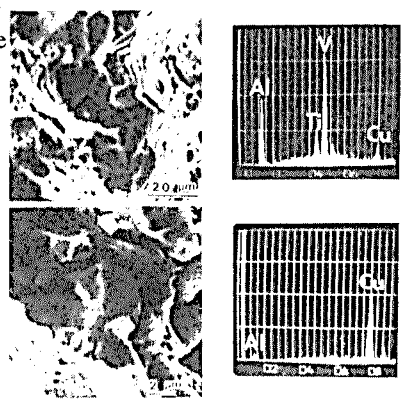
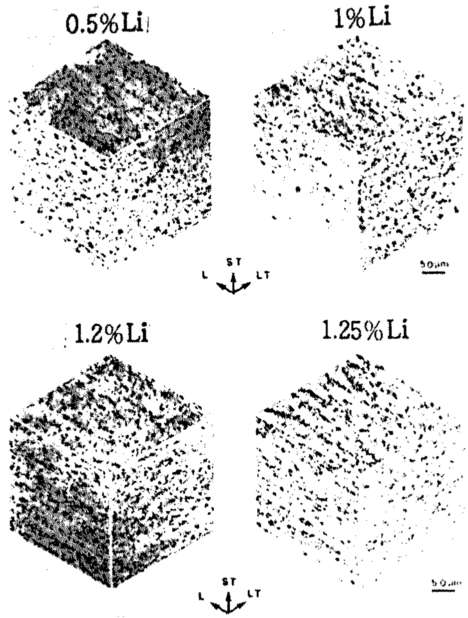


Fig.6 SEM observations of fractured surface on specimen 3

Table.2 Results of Instrumented Charpy Impact Tests [KJ/m2]

specimens	Testing Temperature	Direction	Nominal Crack Initiation Energy	Nominal Crack Propergation Energy	Total Absorbed Energy
0.5mass%Li Alloy	RT	L-T	24.7	22.9	47.6
		T-L	18.3	16.4	34.7
1.2 mass%Li Alloy	RT	L-T	9.6	5.1	14.7
		T-L	7.6	4.3	11.9
1.2mass% Li Alloy	77K	L-T	9.9	4.3	14.2
		T-L	9.3	4.3	13.6



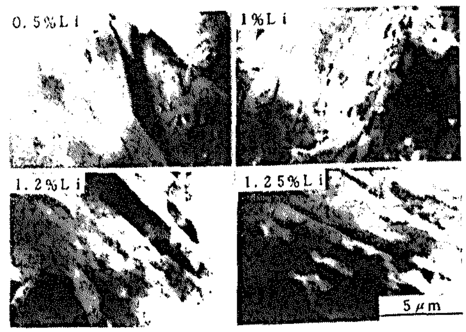


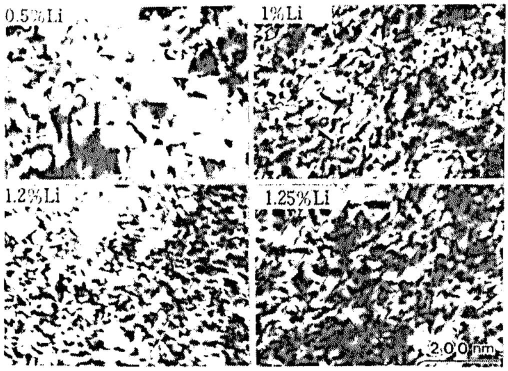
Fig.8 Results of TEM substructure observations

Fig.7 Optical micrographs of T8 specimens

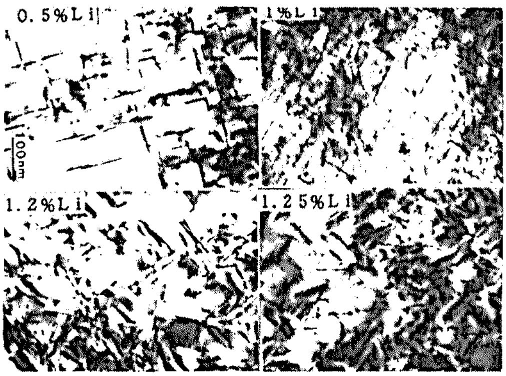
EiA value in T-L direction which has low toughness at room temperature is improved at the low temperature, and anisotropy does not appear at all in the low temperature. This tendency agrees with a phenomena that prior to reach the maximum load in tension test, work hardening region increases and local elongation disappears.

Observation of Structures Fig.7 shows optical micrographs of the T8 specimens. It is clarified in Fig.7 that while the specimen having the smallest lithium content is completely recrystallized during solution heat treatment, recrystallization ratio tends to decrease with higher lithium content. Thus it causes a partially recrystallized structure to appear in a non-recrystallized structure.

Fig.8 shows results of TEM substructure observations. It was clarified that there was not much difference in subgrain grain sizes in the non-recrystallized regions of all the specimens. Such changes in the recrystallization behavior of lithium quantity were considered that the increase in volume fraction of Al_3Zr particles in which lithium substitute zirconium, and lithium provides an effect to zirconium's recrystallization inhibiting effect. Fig.9 shows T_1 and θ' precipitation structure observations by TEM. As for the precipitation phases, while precipitation density of T_1 phase tend to increase in Li contents, those of θ' phase do not vary appreciably between the specimens.



(a) Precipitation state of T_1 phase



(b) Precipitation state of θ' phase

Fig.9 Results of TEM observations

Conclusions

(1) In case of Al-Cu-Li alloy, increas in lithium content causes high density precipitation of T_1.

As a result, elongation and reduction in area are diminished by the improvement in strength. Copper quantity takes a little effect on elongation at room temperature. It is considered that a higher copper content increase in volume fraction of Al-Cu-Ti-V type compounds and decrease elongation. The best strength elongation relations are obtained to the specimen containing 5.2% Cu and 1.25% Li. Further, adjusting aging conditions to under aged state, it is also possible to improve the values of elongation and reduction in area.

(2) While the elongation is not appreciably influenced by lowering temperature, reduction in area tend to be smaller. This is considered to be following reasons that in the low temperature increase in resistance against dislocation sliding plays a role of increase in work hardening region on the stress strain curve. That allows the stress concentration on the grain boundaries or subgrain boundaries to increase. And as this causes a local elongation to decrease, when an increase in triaxial stress reached a certain level, the test piece breaks without occurrence of sectional

eductions in area. It is estimated that this phenomenon is closely connected with an increase in EiA value and also with a decrease in EpA value at low temperature. Therefore, in case of Al-Cu-Li alloy, strength and ductility increase at a low temperature are largely influenced by the workhardening as a consequence of the increase in resistance against dislocation sliding.

(3) A fracture on a Al-Cu-Li alloy shows shearing breakage with dimples and any laminated crack was not observed. Therefore, it is conceivable the tested materials have a different breakage mechanism from that of Al-Li commercial alloys which shows delamination cracks.

(4) As for changes in microstructure of specimens by the increase in lithium content, the recrystallized structure was observed to have changed to the non-recrystallized structure including partly recrystallized structure. It is considered to be a phenomena that increase in volume fraction of Al_3Zr particles containing lithium provides a recrystallization inhibiting effect, and that lithium might be playing a role of assistant to zirconium's recrystallization inhibiting effect.

Aknowledgements

We are very thankfull of Dr Kanno and Kuramoto for their usefull advice and suggestions in order to proceed this reserch.

References

1.Y.Kojima,Y.Fukuzawa et al.,Journal of Japan Institute of Light Metals,**36** (1986),737.

2.T.Hagiwara,Y.Tuji,T.Zinkouji,S.Kuramoto,M.Kanno,84th Lecture Meeting of Japan Light Metal Academy(1993),383.

3.G.Itoh,S.Kuramoto,M.Kanno, Development of An Aluminum Alloy for Croyogenic Use Having High Strength And Toughness(1990),102.