CHARACTERISTICS OF SUPER-HIGH STRENGTH Al-Zn-Mg-Cu P/M ALLOYS

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Practical characteristics of super high strength P/M alloy of Al-Zn-Mg-Cu with Ag addition were investigated. Mechanical property could be controlled with Zn and Mg concentration and combination of tensile strength and elongation varied from 800MPa, 5% to 700 MPa, 9%. With tensile test at elevated temperature this alloy showed high elongation and low strength at 773 K and it suggested this alloy has good hot workability. Hot workabilities were investigated with drawing, upset forging, hot rolling and this alloy shows good performances. Welding cycle test was carried out and degassed extruded bar showed no pores in the weld metal. Also anodizing test was done with H_2SO_4 and 9μm anodized film was successfully formed on the surface.

Keywords: *Rapid Solidification, Powder Metallurgy, Atomized Powder, Al-Zn-Mg-Cu alloy, High Strength, Porosity, Anodizing, Welding, Hot Workability*

1. Introduction

The advanced P/M (Powder Metallurgy) methods for aluminium alloys with rapidly solidified powder were commercially used since 1980's in Japan[1]. Rapidly solidified powder, for which usually atomized powders are used as raw materials, are consolidated to 100% density by powder extrusion or powder forging and its consolidates show the excellent properties, such as high strength, wear resistance, heat resistance, high modulus, and so on.

Recently we have developed the 7000 series super-high strength aluminium P/M alloys (Mesoalite series)[2,3,4]. There are two different alloys in this series;①Al-9.5Zn-3Mg-1.5Cu-0.04Ag and ②Al-9.5Zn-3Mg-1.5Cu-0.04Ag-4Mn. The Mn free alloy ① has ultimate tensile strength (UTS) of 800 MPa and elongation of 5%. Mn containing alloy ② has UTS of more than 900 MPa and elongation of 1% and that its strengthening effects were attributed to the three different mechanisms, fine grain size, precipitation hardening and fiber reinforcement with Mn containing intermetallic compounds.

In this report, alloy ① which has less strength and more ductility than alloy ② was chosen and several characteristics, such as tensile strength at elevated temperature, hot workability, welding characteristics, anodizing characteristics, which were necessary for practical applications were investigated.

Required properties for materials are strongly dependent on the applications. In some applications, strength is more important than ductility, and in other applications, ductility is more important. Usually there is some trade-off between these two properties which is controlled by changing the concentration of Zn and/or Mg. Tensile properties were investigated with several different alloys which contained different amounts of Zn and Mg.

2. Experiments

Four different alloy powders from No. 1 to No. 4 shown in table 1 were gas atomized with pressurized air from the melts and collected after sieving under 150 μm. These powders were used as raw materials for extruded specimens.

Table 1 Chemical composition of the P/M alloys in mass%

No.		Zn	Mg	Cu	Ag	Fe	Si
1	Al-9.5Zn-3.0Mg-1.5Cu-0.04Ag	9.64	3.09	1.64	0.05	0.02	<0.01
2	Al-9.0Zn-2.7Mg-1.5Cu-0.04Ag	9.14	2.74	1.53	0.04	<0.01	<0.01
3	Al-8.2Zn-2.7Mg-1.5Cu-0.04Ag	8.24	2.74	1.65	0.04	<0.01	<0.01
4	Al-7.0Zn-2.4Mg-1.5Cu-0.04Ag	7.07	2.42	1.57	0.04	<0.01	0.02

The powders were cold isostatic pressed (CIP) to ϕ30 × 100 mm preforms, heated in Ar atmosphere, and extruded into ϕ10 bar, flat bar with 20mm × 4 mm cross section (extrusion ratio : 10), and into ϕ7 (extrusion ratio : 20).

Production size extrusions for No. 1 alloy powder were done in two different conditions. The powder was cold isostatic pressed to ϕ180 × 600 mm preform, heated up to 773 K in N_2 atmosphere and extruded by 1500 ton press to flat bar with 70mm × 14 mm cross section (extrusion ratio : 26). Also canned and degassed powder were extruded by 530 ton press to flat bar with 61mm × 16 mm cross section (extrusion ratio : 7).

2-1. Tensile properties

The test pieces were machined from the extruded bars, heat treated (T6: 763 K × 7.2 ksec. → Water Quench → 393 K × 86.4 ksec.), and tensile tested at room temperature.

Elevated temperature tensile tests for No. 1 alloy were done at 373 K, 423 K, 573 K, 673 K and 723 K after being kept at the same temperature of its tensile test for 360 ksec.

2-2. Hot workabilities

ϕ10 extruded bar of alloy No. 1 was hot drawn into ϕ5 with 15 passes, and ϕ7 extruded bar of the same alloy was drawn into ϕ2 with 30 passes after heated up to 673 K.

Upsetability test was carried out at 573 K and 673 K. ϕ8 × 12mm cylindrical piece was heated up to test temperature and upset forging was done without lubrication by 5 ton press.

Hot rolling were applied with 70mm × 5mm × 100mm plate machined from the extruded flat bar with 70 × 14mm cross section. 5mm thick plate heated up to 723 K was rolled down to 1mm with 18 passes with heat treatment at 723 K after every 4 passes.

2-3. Weldability

Welding cycle test using TIG welding machine with Ar was carried out. 55mm× 55mm ×4mm specimens were machined from two different production size extruded bars; 70× 14mm cross section bar without degassing treatment and 61mm×16mm cross section bar with degassing treatment.

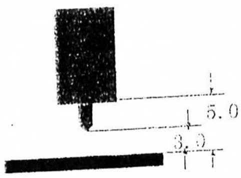
After welding cycle test, specimen with degassing was cut through the center of weld metal and cross section was polished. Vickers hardness was measured on the cross section along the center line of the thickness direction. Then this specimen was T6 heat treated and hardness was measured in a same manner.

Arc condition is listed in Table 2.

Total gas and hydrogen concentration of these two specimens were measured by Ranslay method.

Table 2 Arc condition and arrangement of the specimens

Arc current (A)	100
Arc Time (sec.)	10
Ar Flow Rate (liter/Min.)	7.5
Plate	As-extruded



2-4. Anodizing test

Anodizing test was done for flat bar with 20mm×4 mm cross section. Treatment condition was given in Table 3.

Anodized bar was salt-spray tested at 307 K for 360 ksec. with 5 mass% NaCl solution.

Table 3 Anodizing conditions

Pretreatment	60 sec. in 1 N NaOH solution
Neutralizing Treatment	50vol% HNO_3 solution
Rinsing	Deionized water
Anodizing Bath	20 mass% H_2SO_4 solution
Constant Current Density	$2A/dm^2$

3. Results and Discussion

3-1. The influence of Zn and Mg contents on the tensile properties

Fig. 1 shows the tensile test result of No. 1, 2, 3 and 4 at room temperature. Tensile property of 7075 from the data book is also given in Fig. 1[5]. The influence of Zn and Mg contents on the mechanical properties are clearly seen in this figure, that is:the less Zn and Mg content, the less UTS (ultimate tensile strength) and the more elongation. Alloy No. 1, Al-9.5Zn-3Mg-1.5Cu-0.04Ag, has UTS of 790 MPa and elongation of 5.0%, while alloy No. 4, Al-7.0Zn-2.4Mg-1.5Cu-0.04Ag, has UTS of 701 MPa and elongation of 8.5%. According to applications the alloy which has the most suitable tensile properties could be chosen among these alloys.

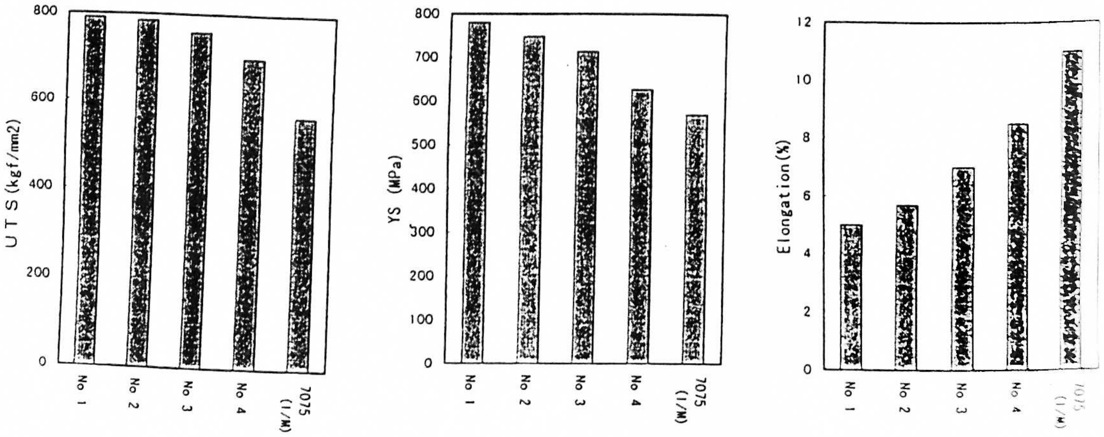


Fig. 1 Effect of Zn and Mg concentration on the UTS, YS (Yield Stress) and EL (Elongation)

3-2. Tensile properties at elevated temperature

The tensile test results of alloy No. 1 at elevated temperature is given in Fig. At 473 K the elongation was increased rapidly up to 30%, while UTS was dropped 227 MPa. At 673 K the elongation was increased up to 38%, while UTS was dropped 55 MPa. It suggests that this alloy has good hot workabilities with low strength high ductility.

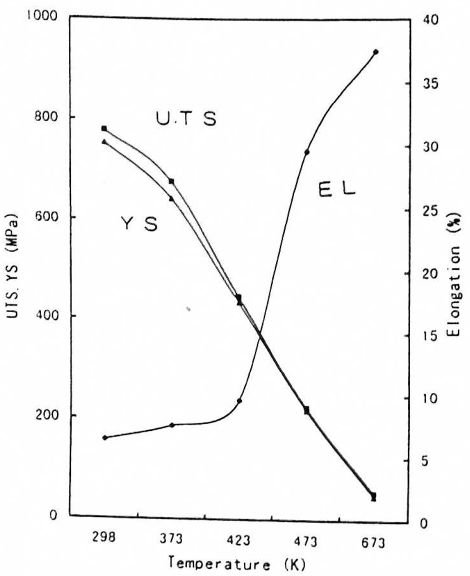


Fig. 2 Tensile properties of alloy No. 1 at RT and at elevated temperatures

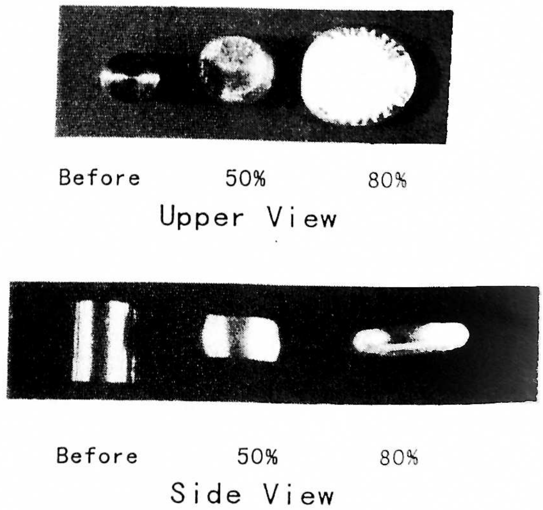


Fig. 3 Appearance of upset test and 80% reduction in height 1 alloy at 573 K

3-3. Hot workabilities

On the drawing test, no surface cracking was observed after finishing pass for $\phi 5$ drawn bar from $\phi 10$ with 15 passes, and $\phi 2$ drawn bar from $\phi 7$ with 30 passes.

With upsetability test, test pieces before and after upset forging at 573 K were given in Fig. 3. Even at 80% reduction in height there was no surface crack at 573 K and 673K. This alloy had more than 80% of critical reduction in height even at 573 K which was relatively low temperature for hot forging. This alloy shows better upsetability than other P/M alloys[6]

On the hot rolling test, no hot tear was observed at the edge of the sheet which was rolled down from 5mm to 1mm with 18 passes.

As suggested by the tensile result at elevated temperature, hot workabilities of this alloys was good and better than other high strength P/M aluminium alloys, such as Al-Si or Al-Fe system.

3-4. Weldability

Many pores were observed for the extruded plate without degassing before extrusion. Degassed and extruded plate shows almost no pore after melting (Fig. 4).

Hardness result shows the weld metal has equal hardness as the heat affected zone in this plate (Fig. 5). This specimen seemed to be too small to estimate the influence of the heat.

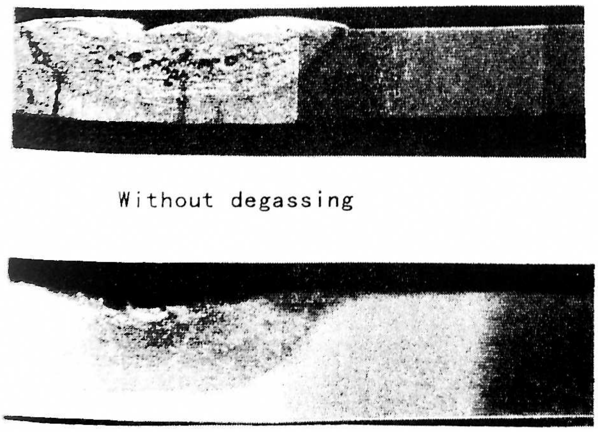


Fig. 4 Cross section of the welding cycle test specimen

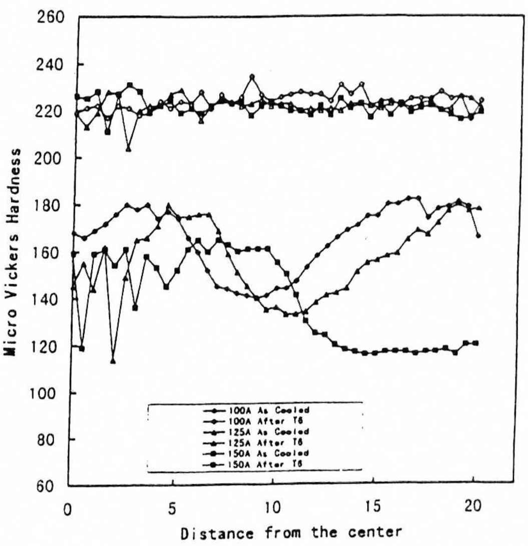


Fig. 5 Hardness of the cross section of the welding heat cycle test for as-cooled and T6 condition

Total gas and hydrogen concentration was given in table 4 for these two specimens.

Table 4 Result of gas concentration (Ransley method)

	Total gas (cc/100g)	H_2 gas (cc/100g)	H_2/total gas (%)
Degassed	1.7	1.6	94
Without degassing	26.7	26.6	100

Hydrogen gas was liberated from H_2O on the surface of powder[7]. With degassing treatment hydrogen concentration was drastically decreased and porosity after welding could be avoided.

3-5. Anodizing test

Anodized film (10 μm thick) was successfully formed on the surface of No. 1 alloy. After the salt-spray test, no corrosion was observed and any defect of the anodized film was observed on the surface.

4. Conclusions

(1) This P/M alloy series have a super-high strength around 600 to 800 MPa with 5 to 9% elongation. Depend on applications, the most suitable alloy could be chosen among these.

(2) Tensile properties at elevated temperature shows the high elongation and low strength above 427 K. It suggested this alloy has good workability at high temperature.

(3) Hot workabilities, such as drawability, upsetability, hot rolling, were done and this alloy showed the good hot workabilities.

(4) With the welding cycle test, there was no pore was observed for degassed and bar. Weld metal and heat affected zone showed the same hardness after T6 treatment

(5) Anodizing film was successfully made on the surface and no corrosion was observed on the anodized surface after salt spray test.

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