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The Effect of Transition Elements on Work Hardening of Al-4.8%Mg Alloy Extrusions

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Al-Mg system alloys are mainly used as a cold forging material. In order to obtain long-life of die, formability and light-weighting of parts, the forging material is expected to be soft before forging and be hard through work hardening after forging.

In this study, the effect of transition element on work hardening properties of Al-4.8mass%Mg alloy extrusion was investigated by means of microscopic observation and tensile test. Work hardened specimens were prepared by using cold rolling technique. Small amount(<0.2mass%) of Mn, Cr, Zr or V was added to the base-Al-4.8mass%Mg alloy. It was clarified the largest increase in work hardening, ΔYS (yield stress of cold rolled sheet minus yield stress of extrusion), caused by the addition of Mn and the order of effect was Mn = V > Cr > Zr.

The effect of solute and dispersoid of Mn were investigated with Al-4.8mass%Mg alloy. The alloys were heat treated(550℃ for 24 hours and then water-cooled) to obtain Mn solute or Mn dispersoid. As for the 0.2%Mn-added alloy, the as-extruded specimen showed higher yield stress, higher tensile strength and higher effect of work hardening than the heat treated specimen. It was clarified Mn in solution has a higher contribution to work hardening than Mn in precipitates.

Keywords: *Aluminum, Extrusion, Work hardening, Transition element*

1. Introduction

The 5000-series alloys, which are Al-Mg alloys, are strengthened through solid solution hardening and work hardening. For example, alloy 5083, with the highest strength among the 5000-series alloys, are used in ship body structures, and alloys 5154 and 5056 can be used for cold forging. From perspectives of long-life of die, improving formability, and light-weighting of parts, materials for cold forging need to be soft when forging and to present high strength through work hardening after forging.

On the other hand, transition elements added to aluminum-based alloys are known to form solid solutions and intermetallic compounds, which influence mechanical characteristics of the alloys. Few systematic studies have been published on transition elements and work hardening, although the effect of small elements on extrusion characteristics of aluminum alloys [1] and also the effects of Fe, Co, or Ni on work hardening and softening of several types of alloy [2]-[4] have been reported.

In this study, it was investigated to clarify the effects of addition of transition elements on work hardening behavior of Al-4.8mass%Mg extrusions. The transition elements selected are Cr, V, Mn or Zr. The influence of precipitation heat treatment was also studied for the Mn-added alloy.

2. Experimental Procedure

2.1 Effect of transition elements

Ingots (ϕ155) of Al-4.8mass%Mg base alloy and of the alloys with transition element, added were produced by direct-chill casting, and homogenized them at 470°C for 4 hours. Compositions of those alloys are shown in Table 1. The ingots were extruded at 450°C with the extrusion speed of 2.5 m/min and the extrusion ratio of 16.1 into10-mm (thickness) x 125-mm (width) shapes. The shapes were cold-rolled to 65% in reduction. Specimens for tensile test, which is in accordance with the JIS

No.5 were cut from each of the extruded and cold-rolled sheets in parallel to the direction of extrusion and cold rolling. The tensile test was performed at room temperature with the cross head speed of 5 mm/min. Microstructure of the quarter of thickness of the cross section parallel to the extrusion direction was observed with an optical microscope and the mean grain size was measured using the intercept method. The extruded specimens were observed subjected to transmission electron microscopy (TEM) to observe the distribution, shape, and size of precipitated/dispersed particles.

Table 1 Chemical compositions of specimens (mass%)

Specimen	Si	Fe	Mn	Mg	Cr	Ti	Zr	V
4.8Mg	0.03	0.13	Tr.	4.91	Tr.	0.02	-	-
0.05Cr	0.03	0.14	Tr.	4.65	0.05	0.02	-	-
0.10Cr	0.02	0.13	Tr.	4.96	0.09	0.02	-	-
0.20Cr	0.02	0.13	Tr.	4.76	0.22	0.02	-	-
0.05V	0.02	0.14	Tr.	4.88	Tr.	0.02	-	0.06
0.10V	0.02	0.13	Tr.	4.86	Tr.	0.02	-	0.09
0.20V	0.03	0.14	Tr.	4.90	Tr.	0.02	-	0.23
0.05Mn	0.02	0.13	0.05	4.73	Tr.	0.02	-	-
0.10Mn	0.02	0.13	0.10	4.72	Tr.	0.02	-	-
0.20Mn	0.02	0.15	0.19	4.72	Tr.	0.02	-	-
0.05Zr	0.02	0.14	Tr.	4.85	Tr.	0.02	0.04	-
0.10Zr	0.02	0.14	Tr.	4.78	Tr.	0.02	0.09	-
0.20Zr	0.02	0.15	Tr.	4.87	Tr.	0.02	0.18	-

Tr.<0.01

2.2 Effect of Mn

Ingots with base alloy and Mn added alloys(0.10Mn, 0.20Mn) were extruded at 500°C with extrusion speed of 2.5 m/min and the extrusion ratio of 40.3 into 5 mm (thickness) x 100 mm (width). The extrusions were heated at 550°C for 24 hours and then water-cooled so that Mn compounds could precipitate (hereafter precipitate treated specimen). The tensile test was performed with the same way as section 2.1. Specimens for a tensile test were cut from each as-extruded extrusions(hereafter H112 specimen) and precipitation treated extrusions. As to the microstructure of each specimen, the surface layer and the middle part of thickness of the cross section which was in parallel to the extrusion direction were microscopically observed.

3. Results and discussion

3.1 Effect of transition elements

3.1.1 Tensile strength

Fig. 1 shows stress - strain curves of the two specimens 0.20V and 0.20Mn together with the base alloy (4.8Mg). Increasing the amount of transition elements, strength of the specimens also increases in the following order: 0.20Mn > 0.20V > 4.8Mg. The tensile test showed that the specimens with transition element have higher tensile strength than the base alloy. They had almost the same elongation (strain). Fig. 2 shows the effect of transition elements on yield stress of cold-rolled sheets. Addition of Mn and V by 0.2 mass% raised yield stress of the alloy by 13 N/mm^2 and 11 N/mm^2, respectively, as compared with the base alloy. Fig. 3 represents the amount of work hardening by cold rolling as ΔYS (yield stress of cold-rolled sheet minus yield stress of extrusion). With an addition of 0.10 mass% or greater, ΔYS of the Mn or V specimens were equal to or slightly higher than that of the base alloy. On the other hand, ΔYS of the Cr or Zr specimens tends to decrease with increasing Cr or Zr content.

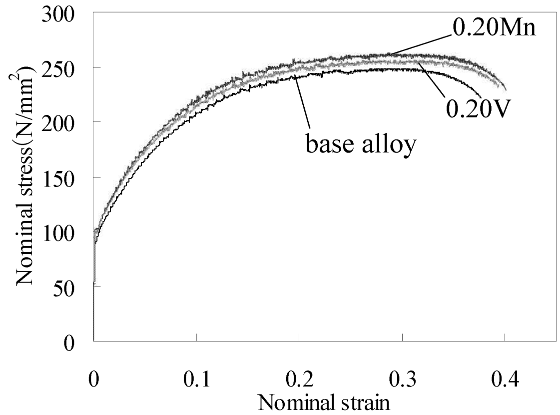


Fig. 1 Nominal stress – nominal strain curves of extrusion

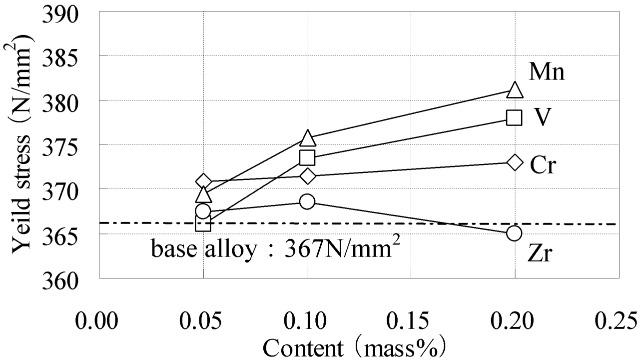
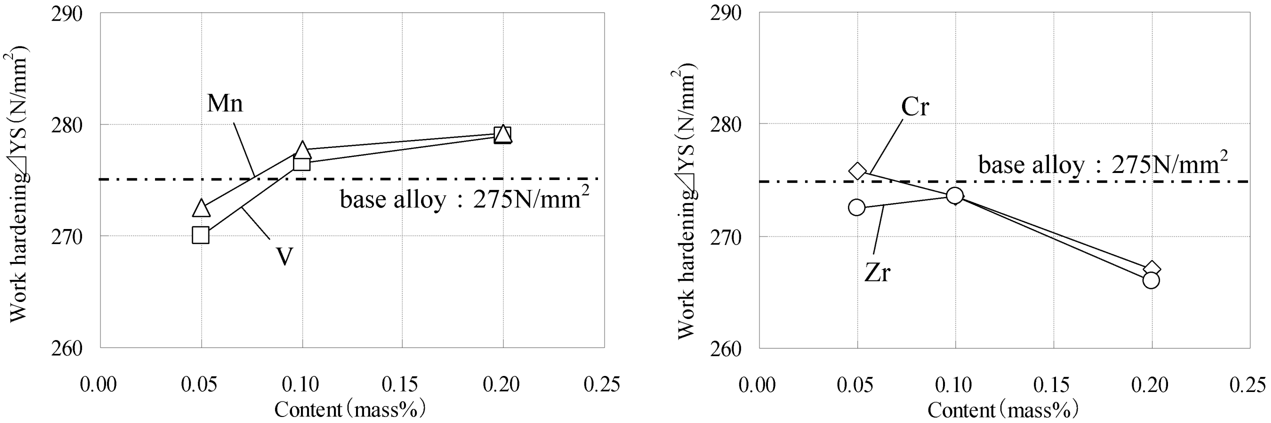


Fig. 2 Yield stress of cold rolled sheet v.s. content of various transition elements



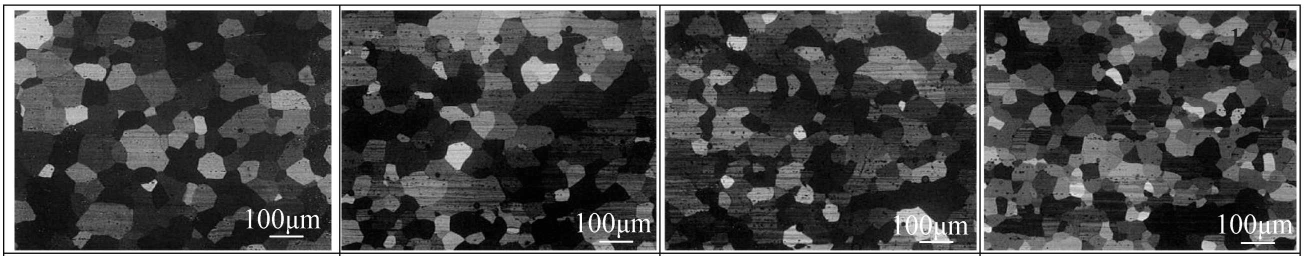
(a) V or Mn

(b) Cr or Zr

Fig. 3 Work hardening ΔYS v.s. content of various transition elements

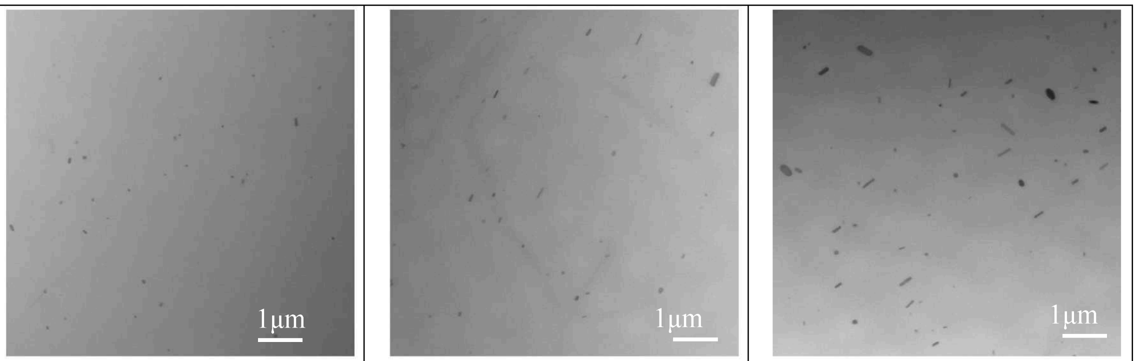
3.1.2 Microstructure

Fig. 4 shows optical microscopic images of the base alloy and the V-added extruded alloys as representatives among the element-added alloys. Mean grain sizes of the base alloy, 0.05V, 0.10V, and 0.20V were 81 μm, 81 μm, 75 μm, and 50 μm, respectively, decreasing as the quantity of addition increased. On the other hand, grain size of the Mn-added alloy and Cr-added alloy did not decrease in association with increases with transition element added. As a whole, no obvious correlation was found between changes in grain sizes of the specimens and their work hardening. Fig. 5 represents TEM images of the base alloy and 0.20V and 0.20Mn with relatively larger ΔYS. Although the base alloy was found to have precipitated/dispersed particles, 0.20V or 0.20Mn were found to have relatively larger precipitated/dispersed particles: 100 - 400 nm in ellipse or bar shapes. It has been reported that rolled sheets of Al-Mn-Mg alloy has been investigate the relationship between the accumulation of dislocations to (Mn,Fe)Al_6 disperse particles with mean size of 60 - 200 nm and significant work hardening of the alloy [5]. In this study, most of disperse particles in the 0.20Mn alloy were Fe-Mn-Al compounds and it is suggested that the accumulation of dislocations to disperse particles increased the work hardening. A large number of V-bearing compounds were found in the 0.20V alloy and it is suggested that disperse particles influenced the work hardening as is the case with the Mn alloy.



Base alloy	0.05V	0.10V	0.20V

Fig. 4 Microstructures of extrusions of base alloy with different V contents (L-ST plane)



Base alloy	0.20V	0.20Mn

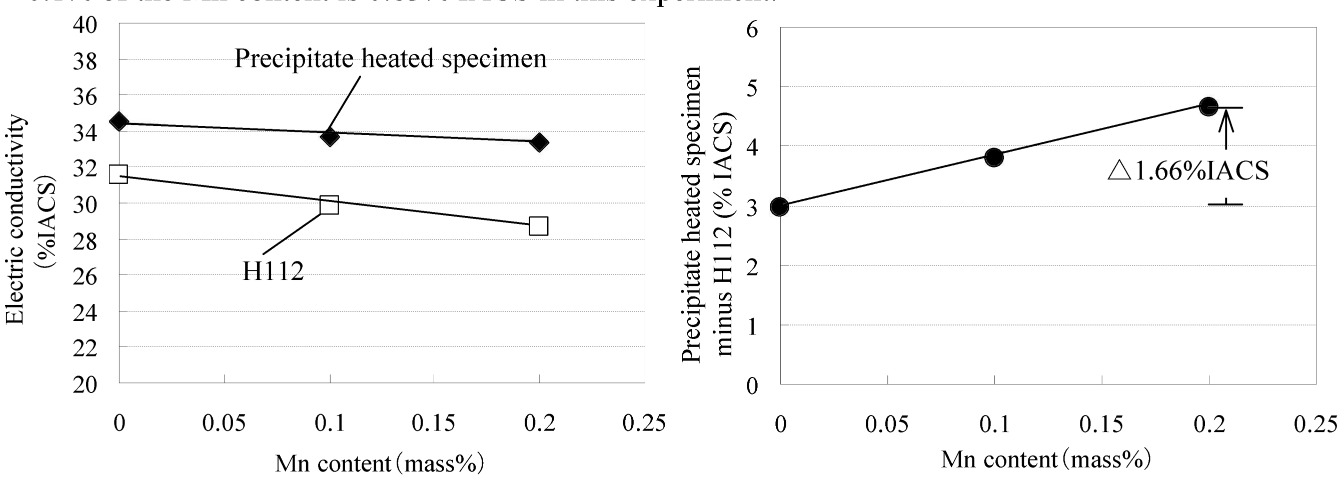
Fig. 5 TEM images of extrusions

3.2 Effect of Mn

In the above section, it was investigated the effect of small amounts of Cr, V, Mn, or Zr added to Al -4.8mass%Mg base alloy on its work hardening. Accordingly, Mn or V were found to have a positive effect. In the following, it was investigated the effect of in particular on work hardening of the alloy, both as extruded and as precipitation heat treatment.

3.2.1 Electric conductivity

Fig. 6 shows results of measuring electric conductivity of the specimens. Both H112 and precipitate treated specimens showed a linear decrease in electric conductivity as the addition of Mn increased. The precipitated treated specimen(550℃ for 24hours and then water-cooled) was larger than the H112 specimen in electric conductivity, probably because of decreases in solid-solution atoms. As shown in Fig. 6(b), differences in electric conductivity between the precipitate treated specimen and the H112 specimen were 3% IACS for the base alloy and 4.66% IACS for 0.2Mn, respectively. The difference of 1.66% IACS between these two values (4.66 minus 3.00) was caused by the precipitation of Mn compounds. This value indicates that the difference in electric conductivity per 0.1% of the Mn content is 0.83% IACS in this experiment.



(a) Mn content v.s. electric conductivity

(b) Mn content v.s. value of presipitate treated specimen minus H112 specimen

Fig. 6 Electric conductivity

3.2.2 Microstructure

Fig. 7 shows the microstructure of the surface layer of the H112 specimens and precipitate treated specimens of each alloy. The H112 specimens decreased in grain size as the content of Mn increased. The mean grain size in the middle of thickness was approximately 210 µm in base alloy, 104 µm in 0.10Mn, and 100 µm in 0.20Mn, respectively. As for precipitate treated specimens, recrystallized grains were observed over the entire cross section of base alloy. In 0.10Mn, recrystallized grains were found in the area 1 mm deep from the surface. However, it was not seen in 0.20Mn that contained a relatively larger amount of Mn added, and no change due to precipitation treatment was found in grain sizes. It was suggested that recrystallization was inhibited by Mn precipitates.

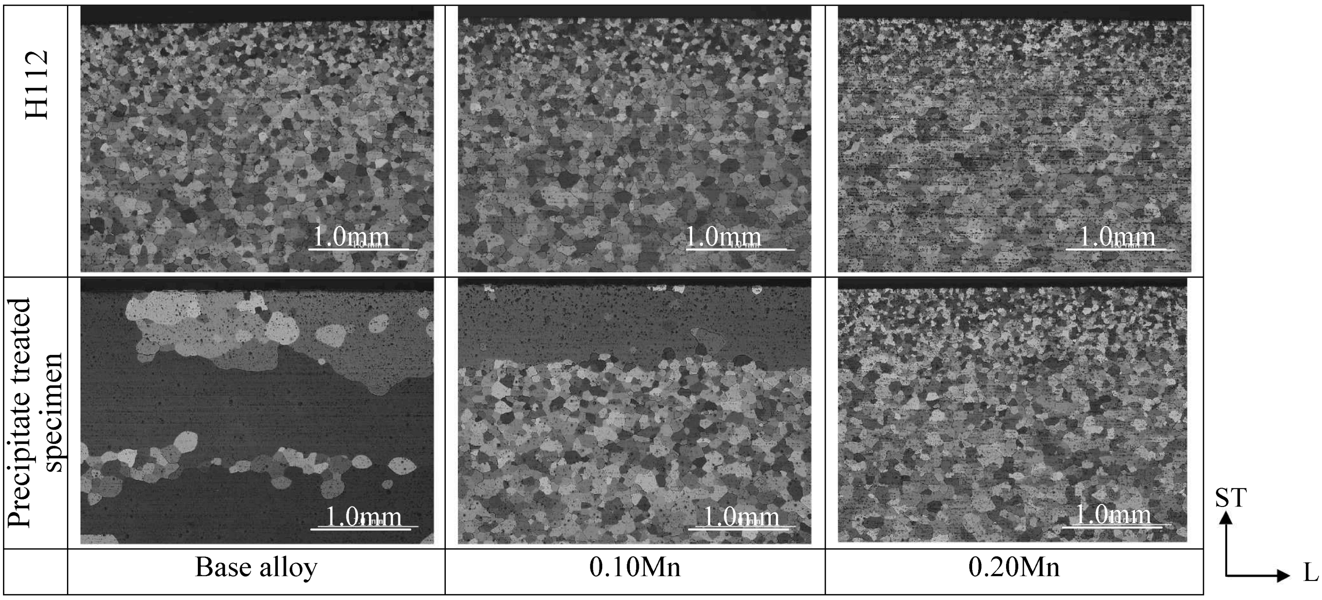


Fig. 7 Microstructures of base alloy with different Mn contents (L-ST plane)

3.2.3 Tensile strength

Fig. 8 shows stress-strain curves of the H112 specimen and precipitate treated specimens of 0.2Mn and Table 2 lists its tensile characteristics. The H112 specimen has generally higher strength than the precipitate treated specimen by 20 N/mm^2 in tensile strength and 6 N/mm^2 in yield stress. These specimens were nearly equal to each other in elongation. In terms of TS minus YS that is defined as a value representing work hardening, the H112 specimen was higher by 14 N/mm^2 (163 minus 149). On the other hand, no difference was found in *n* value. The H112 specimen contained a larger amount of Mn in solution than the precipitate treated specimen, and it is suggested that the Mn in solution has larger effect on work hardening than the content of Mn in precipitates. The serration was observed in the stress - strain curves. It was suggested that the interaction of dislocations and solute atoms of Mg[6].

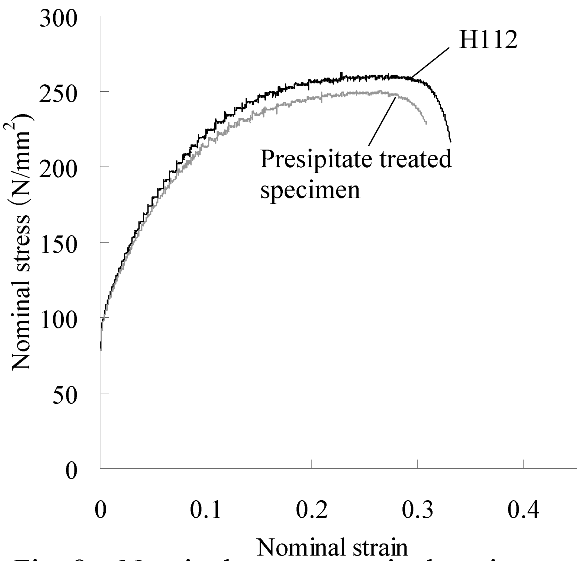


Fig. 8 Nominal stress- nominal strain curves of 0.20Mn alloy

Table 2 Tensile characteristics

Alloy	Tempering	Tensile strength (N/mm^2)	Yield stress (N/mm^2)	Elongation (%)	TS-YS (N/mm^2)	*n* value*
0.20Mn	H112 specimen	262	99	33.4	163	0.401
	Precipitate treated specimen	242	93	33.0	149	0.391

* Measurement range: Strain of 0.04 – 0.14% (Mean value of H112 specimen (n=2) and precipitate treated specimen (n=4)

4. Conclusion

(1) The amount of work hardening of Al-4.8mass%Mg alloy extrusions increased by the addition of transition elements (Cr, V, Mn, Zr). It was clarified the largest increase in work hardening caused by the addition of Mn and the order of effect was Mn = V > Cr > Zr.

(2) No obvious correlation was found between grain sizes and work hardening behavior.

(3) As for the 0.2mass%Mn-added alloy, the as-extruded specimen showed higher yield stress (by $6N/mm^2$), higher tensile strength (by $20N/mm^2$) and larger TS minus YS (by $14N/mm^2$) than the precipitate treated specimen. It was clarified Mn in solution has a higher contribution to work hardening than Mn in precipitates.

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