EFFECT OF THERMO-MECHANICAL TREATMENT ON STRENGTH AND DUCTILITY OF 2024Al-3Fe-5Ni PM ALLOY

Tetsuo AIDA*, Kenji MATSUKI*, Ryouichi KITANO,**
Takamasa YOKOTE*, Jun KUSUI***** ***and*** **Kazuhiko YOKOE*****

*Department of Mechanical and Intelligent Systems Engineering,
Toyama University, 3190 Gofuku, Toyama, 930-8555 JAPAN
**Graduate School, Toyama University, 3190 Gofuku, Toyama, 930-8555 JAPAN
(Present address : Aishin Light Metal Ltd., 12-3 Naganoe, Shinminato, Toyama, 943-8588 JAPAN)
***TOYO Aluminium K.K., Hino, Shiga, 529-1608 JAPAN

ABSTRACT Air atomized powders of 2024Al-3mass%Fe-5mass%Ni (3F5N) alloy up to 45 μm in diameter were cold isostatically pressed and further extruded at 623K in argon atmosphere. The age hardening behavior and tensile properties of the 3F5N extrusion specimens subjected to various thermo-mechanical treatments (TMT: RA, RSA and SRA) which included warm rolling (R), solution treatment (S), and aging (A) at 428K have been compared with those of the specimen after T6 treatment without warm rolling, with particular emphasis on the improvement of the strength and ductility. The values of the aging peak hardness of the specimens subjected to TMT with warm rolling were higher than those of the specimens subjected to T6 treatment. The increase in peak hardness is due to the improved precipitation behavior of the S' phase as well as work hardening. The tensile tests of the specimens aged to a peak hardness level at 428K reveal that TMT treatments cause a substantial improvement in the tensile properties. Electron microscopy of TMT materials revealed that the precipitates of the S' intermediate phase formed on dislocation lines, are finer and more uniform than those of T6 material. Such a fine and uniform distribution of the S' phase is considered to enhance the age-hardenability of TMT materials.

Keywords: *2024Al-3Fe-5Ni P/M alloy, thermo-mechanical treatment, age hardening, mechanical property, S' phase*

1. INTRODUCTION

Recent studies of rapidly solidified powder (RSP) Al-Si [1], Al-Fe [2], Al-Fe-Ni [3], and Al-Cr-Zr [4] system alloys have suggested the possibility of the development of a new alloy with good heat or wear resistance [5, 6]. The authors have previously studied [7, 8] the effect of nickel additions (0-10 wt%) for RSP 2024Al-3Fe-Ni alloys on mechanical properties of extrusions, especially in the temperature range from room temperature to 473K, which is required for automobile application. The study made clear that with increasing nickel addition, the tensile strength increased markedly but the elongation decreased. This was especially noticeable for an addition of 10 wt% Ni which resulted in brittle properties at room temperature, due to the increase of coarser intermetallic particles.

On the other hand, it is possible for the 2024Al based alloys to be improved the tensile strength by age hardening mechanism [9]. Moreover, it is known in many aluminum alloys that a dislocation substructure which can control the precipitation behavior of second-phase particles is able to be developed by thermo-mechanical treatments [9-11]. Sugamata et al [12] reported the influence of final thermo-mechanical treatment (FTMT) on the age-hardning behavior of IM Al-Cu-Mg alloys containing varied Mg/Cu atomic ratios. Electron microscopy of FTMT materials at their peak hardness revealed that the precipitates of the S’ intermediate phase are formed on dislocation lines more finely and uniformly than those of the θ’ phase. Such fine and uniform distribution of S’ phase is thought to enhance the age-hardenability of FTMT materials in alloys of Mg/Cu atomic ratio above 0.7 [12]. Singh and Goel [13] have reported that a significant improvement in the tensile properties of 2014 Al alloy was attained by the optimized thermo-mechanical aging treatment including warm rolling which resulted in the dense precipitate-dislocation tangles.

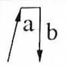
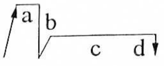
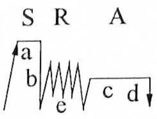
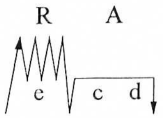
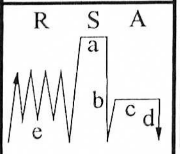
The objectives of the present work were to examine the possibility of the improvement of tensile strength keeping the ductility of the PM 2024Al-3Fe-5Ni alloy extrusion by thermo-mechanical treatment (TMT) including warm rolling.

2. EXPERIMENTAL PROCEDURE

Table 1 Chemical composition of 2024Al-3Fe-5Ni alloy (mass%)

Cu	Mg	Fe	Ni	Si	Mn	Zn	Cr	Ti	Al
4.28	1.16	2.88	4.98	0.43	0.56	0.05	tr	tr	bal.

Table 2 Details of TMT treatments

<table>
<tr><th>Treatment designation</th><th></th><th>Details of Treatment</th></tr>
<tr><td>As Quench (AQ)</td><td> </td><td rowspan="2">a.solution treated at 748K for 3.6ks
b.quenched in water
c.peak aged at 428K
d.quenched in water</td></tr>
<tr><td>T6 Treatment</td><td> </td></tr>
<tr><td>SRA Treatment</td><td> </td><td rowspan="3">e.warm rolled
SRA-252
Rolling temp.=523K (250℃)
Rolling reduction =20%
RA-252
Rolling temp.=523K (250℃)
Rolling reduction =20%
RSA-Treatments
<table><tr><td></td><td></td><td colspan="3">Rolling reduction / %</td></tr><tr><td></td><td></td><td>10</td><td>20</td><td>40</td></tr><tr><td rowspan="3">Rolling temp. /K</td><td>473</td><td></td><td>RSA-202</td><td></td></tr><tr><td>523</td><td>RSA-251</td><td>RSA-252</td><td></td></tr><tr><td>573</td><td>RSA-301</td><td>RSA-302</td><td>RSA-304</td></tr></table></td></tr>
<tr><td>RA Treatment</td><td> </td></tr>
<tr><td>RSA Treatment</td><td> </td></tr>
</table>

2024Al-3mass%Fe-5mass%Ni (3F5N) alloy powders were fabricated by an air atomization technique. The chemical composition of powders is shown in Table 1. The powders less than 45 μm in diameter were cold isostatically pressed and extruded to a rectangular bar shape at 623K, after holding for 1.8ks in Ar atmosphere. The extrusion ratio was 10, and the size of extrusions was 20 mm width by 4 mm thickness.

Details of thermo-mechanical aging treatment (TMT) used in this experiment are shown in Table 2. Tensile tests were performed at room temperature, 373K, 428K, 473K and 573K by using specimens (gage length : 18 mm, gage width : 5 mm) cut from the alloy sheets subjected to TMT as shown in Table 2. The tensile specimens were annealed for 360ks, respectively, at each tensile testing temperature before the tensile tests.

Microstructural changes with TMT treatments were studied by a transmission electron microscope (TEM). Thin foils for transmission electron microscopy were prepared by Jet polishing in an electrolyte of 30% nitric acid in methanol.

3. RESULTS AND DISCUSSION

3.1 Microstructure

Fig.1 shows a TEM micrograph of the 3F5N alloy extrudate from air atomized powders less than 45 μm in diameter. Mixed microstructure of extremely fine grains (sub-grain) and Al_9FeNi particles [7] are observed in Fig. 1. TEM micrographs of the 3F5N alloy extrudate after warm rolling at the temperatures of (a) 523K, and (b) 573K are shown in Fig. 2 (a) and (b), respectively. After warm rolling at 573K, Al_9FeNi particles were slightly coarsened and a few dislocations were observed within recovered subgrains (Fig. 2 (b)). However, after warm rolling at the lower temperature of 523K, high density of tangled dislocations were observed around the fine Al_9FeNi particles (Fig. 2 (a)). Thus, such uniformly distributed high density dislocations are expected to give preferential nucleation sites for S' during aging [12, 13] .

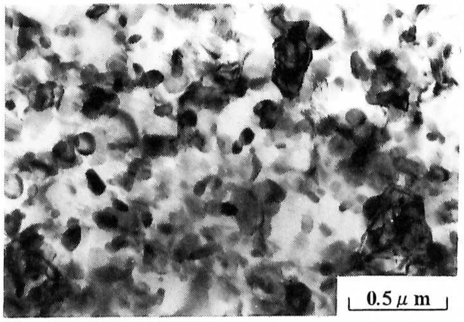


Fig.1 TEM micrograph of the 3F5N alloy extrudate from air atomized powders less than 45 μ m in diameter.

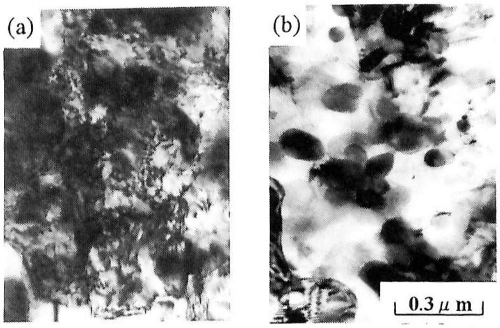


Fig.2 TEM micrographs of the 3F5N alloy extrudate after warm rolling at the temperatures of (a) 523K, and (b) 573K.

3.2 Age Hardening Characteristics

In Fig.3, the Vickers hardness (HV) vs. aging time curves at T_A=428K for 3F5N specimens given the various thermo-mechanical treatments including warm rolling at 523K (SRA-252, RSA-252 and RA-252) are compared with that for specimen given T6 treatment. The HV values of 3F5N specimens given T6 as well as TMT gradually increased and reached to the peak values after aging of about 10^2 ks. However, in Fig. 3, a substantial difference is observed between the maximum HV values (HV_{max}) for the specimens given T6 treatment and the other thermo-mechanical treatments. The higher HV_{max} values were obtained after TMT including warm rolling. Additionally, the difference in HV_{max} between the specimens after T6 and SRA-252 is larger than that in HV values between the specimens as rolled condition in SRA-252 and as quenched

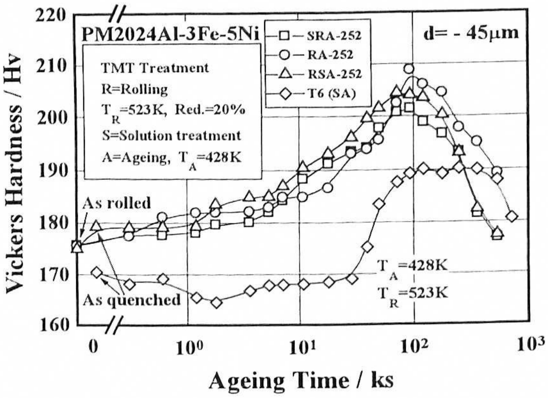


Fig.3 Age hardening curves at T_A=428K of the 3F5N specimens given the various thermo-mechanical treatments.

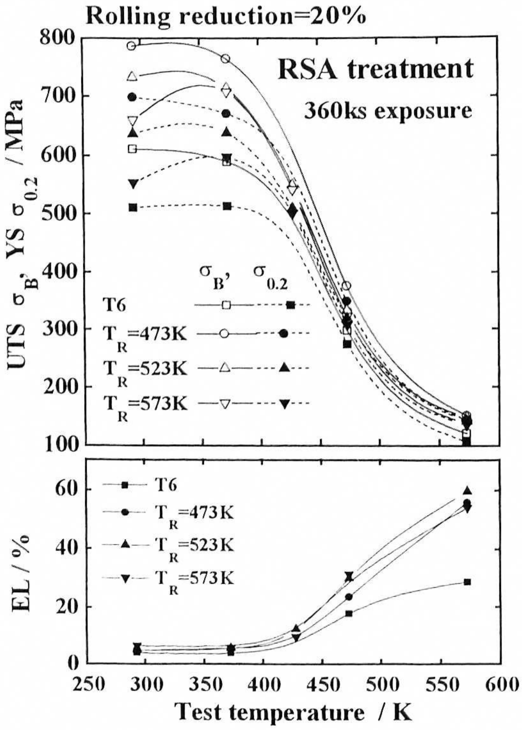


Fig.5 Effects of warm rolling temperature in RSA treatment on mechanical properties of the 3F5N extrudate. Specimens were annealed for 360ks at each testing temperature before tensile tests.

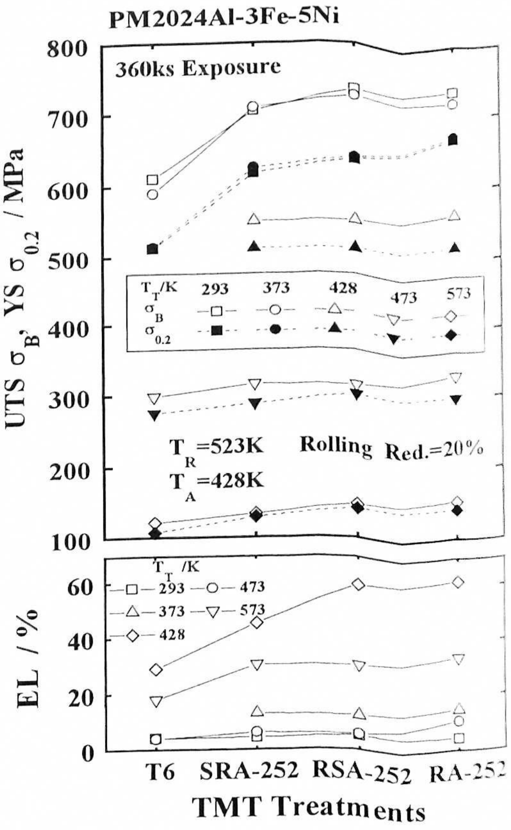


Fig.4 Effects of thermo-mechanical treatments (SRA-252, RSA-252, and RA-252) and testing temperature on mechanical properties of the 3F5N extrudate. Specimens were annealed for 360ks at each testing temperature before tensile tests.

condition in T6 treatment. This suggests that the effect of warm rolling in TMT could contribute much to the improvement of age hardenability of 3F5N alloy extrudate.

3.3 Tensile Properties

On the basis of the results shown in Fig.3, all tensile tests were carried out for the specimens aged for 100ks at 428K. Fig.4 shows the effects of thermo-mechanical treatments (SRA-252, RSA-252, and RA-252) and testing temperature on mechanical properties of the 3F5N extrudate. The specimens were annealed for 360ks at each testing temperature before tensile tests. It is found from Fig. 4 that tensile strength (σ_B) and yield strength ($\sigma_{0.2}$) at R.T. and 373K for the specimens after TMT including warm rolling at 523K are about 100-150 MPa higher than those after T6.

The effects of warm rolling temperature in RSA treatment on mechanical properties of the 3F5N extrudate are shown in Fig. 5. The improvement of σ_B and $\sigma_{0.2}$ by RSA are more remarkable after warm rolling at lower temperature. It is interesting to be pointed out that the improvement of strength is observed even at 473K and is attained without ductility loss. The effects of thermo-mechanical treatment on the relationships between tensile strength and elongation at 293K of 3F5N alloy sheets is summarize in Fig.6. The values of σ_B and EL at room temperature are 786 MPa and about 5%, respectively, for RSA-202 specimen.

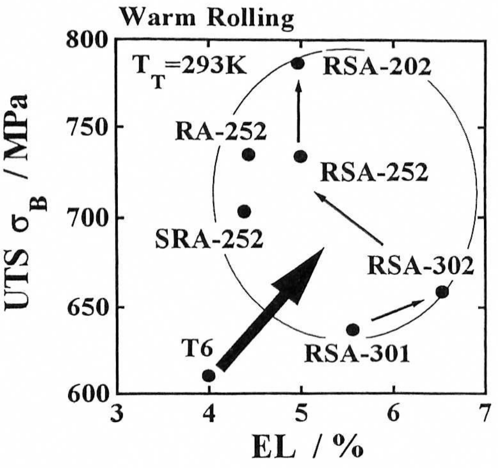


Fig.6 Effects of thermo-mechanical treatment on the relationships between tensile strength and elongation at 293K of 3F5N alloy sheets.

Fig.7 shows TEM micrograph of the 3F5N alloy extrudate after solution treatment and aging for 900ks at 428K. Relatively large S' phase are seen within matrix. On the other hand, Fig. 8 shows TEM micrograph of the 3F5N alloy extrudate after warm rolling at 523K to 20% reduction, solution treatment and aging for 1080ks at 428K. S' phases are seen to be precipitated preferentially on dislocations introduced during warm rolling at 523K. The precipitates of the S' intermediate phase formed on dislocation lines are finer and more uniform compared with those of T6. Such a fine and uniform distribution of the S' phase is considered to be resulted the

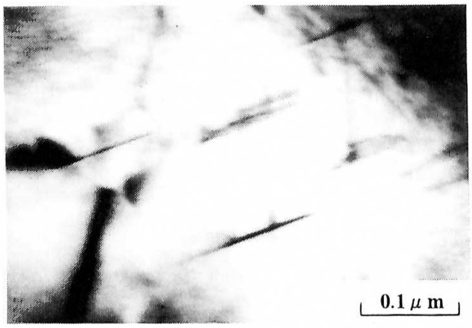


Fig.7 TEM micrograph of the 3F5N alloy extrudate after solution treatment and aging for 900ks at 428K.

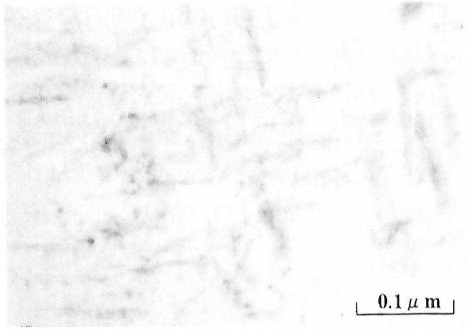


Fig.8 TEM micrograph of the 3F5N alloy extrudate after warm rolling at 523K to 20% reduction, solution treatment and aging for 1080ks at 428K.