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Investigation on the Thermal-Mechanical Treatment of 2A12 Al-Alloy during Spinning Process

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Abstract. Combined with the spinning process of cylindrical parts, the thermal-mechanical treatment of 2A12 Al-alloy was discussed in detail in this paper. Effects of deformation amount and aging temperature on the mechanical properties of 2A12 Al-alloy were analyzed based on extensive experimental results, which further provided an optimized choice of thermal-mechanical treatment parameters for practical production, and served as reference in spinning similar products.

1. Introduction

With a rapid development in the high-tech fields of aerospace and shipbuilding, great changes in the service performance and service environment of traditional structural materials such as Al-alloys have taken place, which puts forward higher and higher requirements for material properties. To narrow the gap between material properties and product design, new structural materials need to be constantly developed. Meanwhile, improved heat treatment processes and forming processes which can significantly stimulate the potential of traditional structural materials should also be actively explored to enhance what the traditional structural materials have got [1-2]. It has been shown by experimental and productive results that the thermal-mechanical treatment and spinning forming are frequently used as means to improve the properties and product quality of traditional Al-alloys. The combination of these two processes can achieve a good complementary roles, as shown in figure 1, thus becoming the focus of material processing technology [3].

In this paper, the thermal-mechanical treatment of Al-alloy during spinning process was focused on. The mechanical properties of the specimens treated under different process parameters were measured to systematically investigate the effects of deformation amount and aging temperature on the mechanical properties of the treated Al-alloys. The results of this study therefore provide a basis for optimizing the thermal-mechanical treatment process, and sheds new light on the engineering application of spinning products.



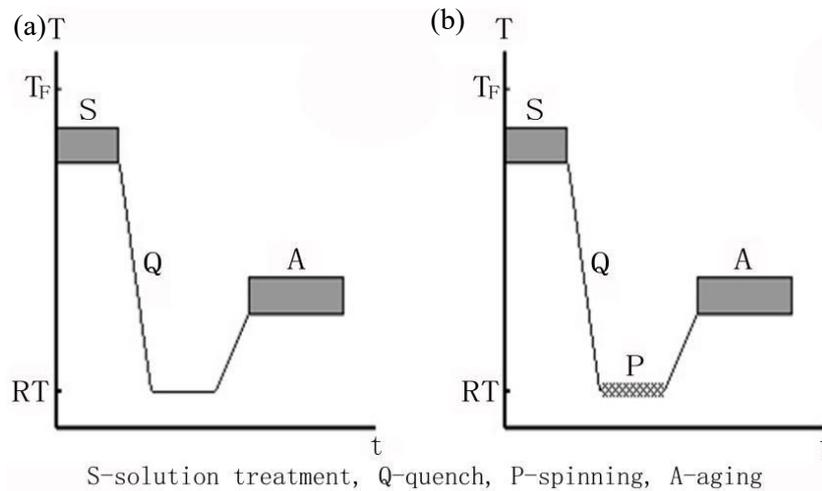


Figure 1. Conventional heat treatment and thermal-mechanical treatment: (a) conventional heat treatment, (b) thermal-mechanical treatment.

2. Experimental Procedure

A 2A12 Al-alloy that is used as the structural material in aerospace was selected for this study, with details of its composition given in table 1. Cylindrical specimens were machined from this alloy to a external diameter of 360mm, internal diameter of 340mm and a height of 400mm.

Table 1. Composition of 30Cr2Ni4MoV steel (mass %).

Cu	Mg	Mn	Zn	Fe	Si
4.06	1.46	0.56	0.086	0.30	0.22

Experiments were conducted according to the thermal-mechanical treatment process shown in figure 1(a). Specific parameters were as follows.

(1) Solution and quench treatments

These specimens were pre-treated by heating to 498°C and holding for 60min, and were then cooled to room temperature at a fast cooling rate of 498±3°C/60min to achieve the supersaturated solid solution. Solution and quench treatments were carried out in the chamber electric furnace.

(2) Spinning

After solution and quench treatments, all specimens needed to be spun within 60min to avoid the hardening and strengthening caused by the natural aging. These specimens were spun with a deformation ratio of 4%, 5%, 6%, 8%, 10% and 15%, respectively.

(3) Aging

Each spun specimen should be aged within 60min. These specimens were respectively heated to 100±5°C, 120±5°C, 130±5°C, 160±5°C, 190±5°C and aged for 15h. After being sectioned longitudinally and mechanically polished, standard samples were machined from the aged specimens. These specimens were then used for tensile test at room temperature. The tensile rate was set as 5mm/min. Tensile strength, yield strength and elongation corresponding to each condition were measured to evaluate the influence of aging temperature on the reinforcement during thermal-mechanical treatment.

3. Results and Discussion

3.1 Experimental results

Tensile strength, yield strength and elongation of the specimens treated under different thermal-mechanical treatment processes are listed in table 2. It can be seen that remarkable effects on the strength and plasticity of 2A12 Al-alloy have been induced by the deformation amount and aging temperature.

Table 2. Mechanical properties of 2A12 Al-alloy after being thermal-mechanically treated with different deformation ratios and temperatures.

Deformation ratio (%)	Temperature (°C)	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
4	100	420.2	291.2	19.10
	120	420.3	297.8	17.18
	130	401.2	288.6	15.98
	160	467.4	453.0	7.96
	190	392.4	365.4	6.92
5	100	397.2	280.4	14.30
	120	427.2	314.8	17.52
	130	430.6	341.2	15.26
	160	454.0	443.0	7.72
	190	386.4	353.0	10.06
6	100	390.4	279.0	14.66
	120	425.7	323.6	16.14
	130	437.2	344.0	14.26
	160	457.2	448.4	5.48
	190	404.8	379.4	7.42
8	100	384.8	287.6	13.97
	120	429.8	339.8	15.26
	130	454.0	362.4	15.08
	160	407.6	384.6	8.86
	190	413.4	389.8	9.23
10	100	406.8	304.4	15.08
	120	419.2	320.2	15.68
	130	403.4	297.8	14.60
	160	405.6	385.0	8.16
	190	407.8	378.4	9.64
15	100	437.2	343.8	15.80
	120	429.6	341.2	15.62
	130	441.8	354.2	14.64
	160	422.0	404.4	8.30
	190	459.2	446.8	7.92

3.2 Effect of deformation amount on the mechanical properties

Effects of deformation amount on the strength and plasticity of 2A12 Al-alloy aged at temperatures of 120°C, 130°C and 190°C are shown in figure 2(a), figure 2(b) and figure 2(c), respectively. It can be seen from figure 2(a) and figure 2(b) that after being aged at lower temperatures such as 120°C and 130°C, the tensile strength and yield strength of the specimens rise with the increasing deformation ratio. The trend of strength increasing with deformation ratio is especially obvious for these specimens deformed at the deformation ratio less than 8%, while the change of strength with deformation ratio tends to be gentle for these specimens deformed at the deformation ratio greater than 8%. The elongation decreases evidently with the deformation ratio increasing to 8% and remains at a relatively high level thereafter.

The tensile strength and yield strength of 2A12 Al-alloy aged at 190°C decrease firstly then increase greatly with the increment of deformation ratio (see figure 2(c)). While the strength increases rapidly, the plasticity of the material does not decrease significantly. The elongation fluctuates slightly with the increase of deformation ratio and remains at an acceptable level.

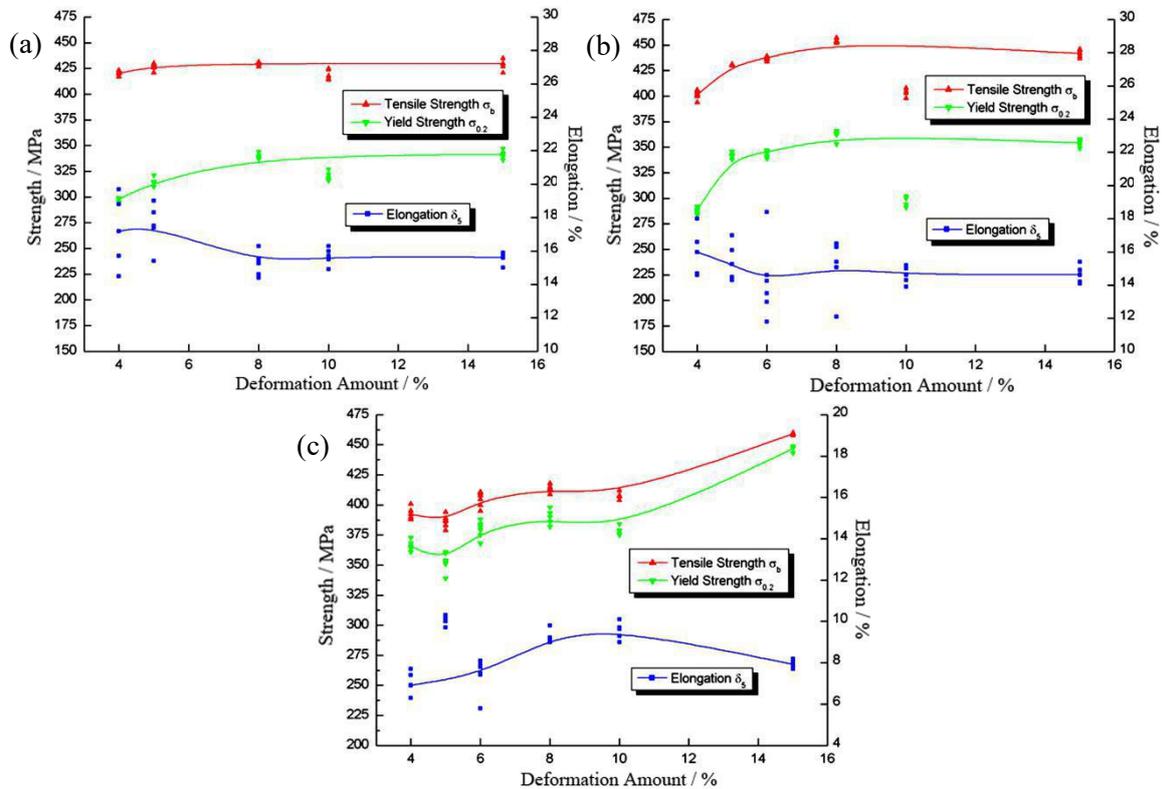


Figure 2. Effect of deformation amount on the strength and plasticity of 2A12 Al-alloy aged at different temperatures: (a) 120°C, (b) 130°C, (c) 190°C.

The effect of deformation amount on the mechanical properties of 2A12 Al-alloy basically conforms to the principle of thermal-mechanical treatment. While maintaining good plasticity, the strength of the alloy increases with the increase of deformation amount. This is due to the large number of crystal defects introduced by plastic deformation before ageing, which either promote the nucleation and precipitation of strengthening phases during ageing or retain a certain number of entangled dislocations in the matrix [4]. However, it should be noted that with the increase of deformation, the internal stress of the alloy will increase. Higher stress level in alloy is not conducive to the resistance to fatigue and stress corrosion. Therefore, better comprehensive properties for 2A12 Al-alloy can be obtained when the deformation ratio is less than 10%.

3.3 Effect of aging temperature on the mechanical properties

Effects of aging temperature on the strength and plasticity of 2A12 Al-alloy deformed at different deformation ratios are shown in figure 3, figure 4 and figure 5, respectively. It can be seen from figure 3 and figure 4 that the effect of aging temperature on the strength of the alloy presents different rules corresponding to different deformation amounts. When the deformation ratio is small, taking 4%, 5% and 6% for examples, the strength of the alloy increases first and then decreases with the increase of aging temperature, and peak appears in the range of 150°C-170°C. When the deformation ratio is greater than 8%, the yield strength of the alloy increases with the increase of aging temperature, while the tensile strength does not change significantly.

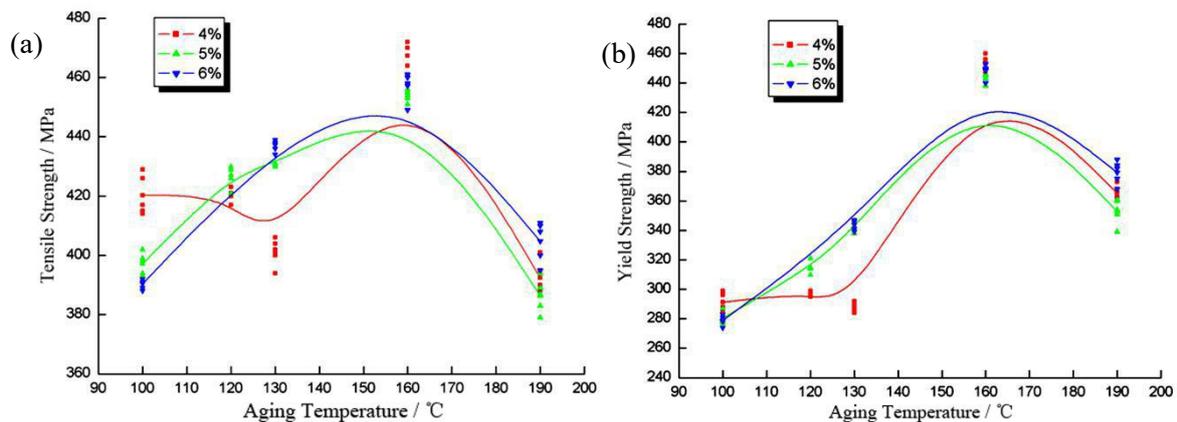


Figure 3. Effects of aging temperature on the tensile strength and yield strength of 2A12 Al-alloy deformed at deformation ratios of 4%, 5% and 6%: (a) tensile strength, (b) yield strength.

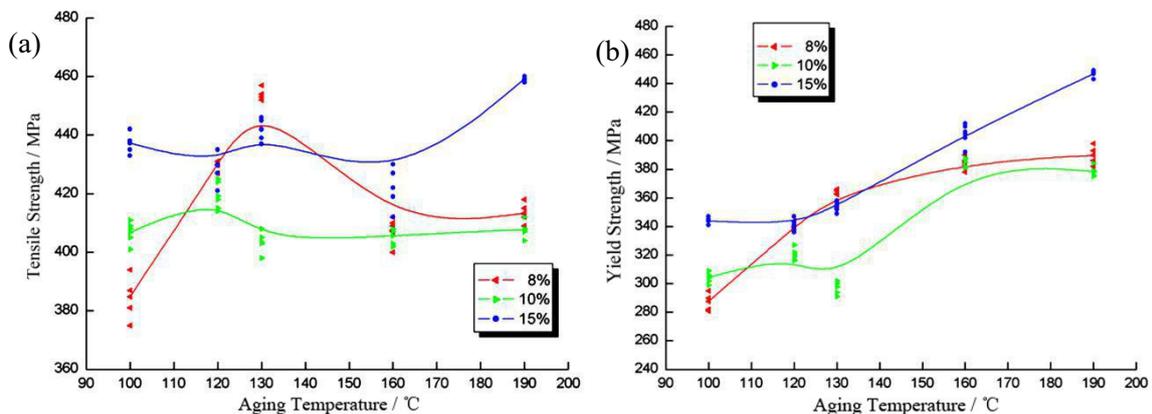


Figure 4. Effects of aging temperature on the tensile strength and yield strength of 2A12 Al-alloy deformed at deformation ratios of 8%, 10% and 15%: (a) tensile strength, (b) yield strength.

The effect of aging temperature on the strength of 2A12 Al-alloy is related to the change of the deformed structure during aging. After being deformed with a small deformation amount, the crystal defect density in the alloy structure is low. Then the increase of aging temperature can promote the nucleation and precipitation of strengthening phase, therefore increasing the strength of the material [5]. However, in the process of aging treatment at higher temperature, the deformed microstructure usually recovers obviously, reducing the defect density and weakening the effect of deformation strengthening. At the same time, the precipitates grow unevenly and the precipitate density decreases, which is favorable for the production of equilibrium phase. Based on these reasons, the effect of heat treatment strengthening is reduced, resulting in the decrease of strength. These can explain the change regulation shown in figure 3 and figure 4. For large deformation, the strength of the alloy increase with the increase of aging temperature because of the high defect density and no significant recovery during aging treatment. As mentioned earlier, excessive deformation is not conducive to the comprehensive properties of materials. So aging treatment at higher temperature is not appropriate with a low deformation. This principle coincides with the effect of aging temperature on the plasticity of the alloy.

It can be seen from figure 5 that the effect of aging temperature on the elongation of 2A12 Al-alloy is basically independent of the deformation, which is different from the effect of aging temperature on the strength of this alloy. With the increase of aging temperature, the elongation of the alloy fluctuates in a wavy manner and reaches the highest value in the range of 120°C-130°C. When the aging temperature ranges from 160°C to 190°C, the elongation is relatively low and the plasticity of the material is reduced.

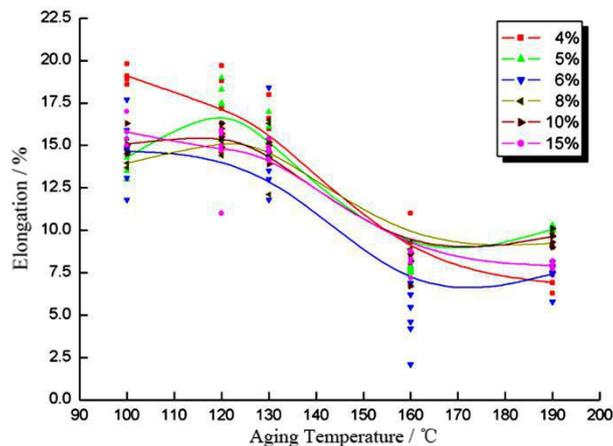


Figure 5. Effect of aging temperature on elongation.

3.4 Optimization of process parameters of thermal-mechanical treatment

From the above analysis, it has been known that there are many factors affecting the thermal-mechanical treatment process of Al-alloy, and the interaction is complex. Therefore, it is necessary to explore the influence law of the relevant process parameters through experiments and summarize an effective way to optimize the process route.

The basic principles for optimizing the process parameters of thermal-mechanical treatment of 2A12 Al-alloy are as follows:

- (1) Deformation ratio should not be more than 10%. Otherwise, the internal stress increases rapidly, which is not conducive to the improvement of the comprehensive properties of the alloy.
- (2) Aging temperature should not be too high, and it is suitable between 120°C and 130°C. Excessive aging temperature will cause the recovery of deformed microstructure, resulting in the decrease of strength and plasticity of the alloy.

Based on the analysis and discussion of the tested results, the optimum thermal-mechanical treatment process of 2A12 Al-alloy is determined as “8% plastic deformation+130°C/15h aging treatment”.

4. Conclusions

The strength of 2A12 Al-alloy increases with the increase of deformation. When the deformation amount is large, the change of strength with deformation tends to be gentle. The elongation decreases slightly with the increase of deformation. After being deformed with a deformation ratio less than 8%, the strength of 2A12 Al-alloy increases first and then decreases with the increase of aging temperature; while the strength of the alloy increases with the increase of aging temperature when the deformation ratio exceeds 8%. With the increase of aging temperature, the elongation of the alloy fluctuates in a wavy manner. The plasticity of the alloy aged at lower temperature is better than that achieved at higher aging temperature. The results show that “8% plastic deformation+130°C/15h aging treatment” is the optimal thermal-mechanical treatment process, which can ensure the performance and accuracy of the spinning cylinder.

References

- [1] Li Q L, Li J B, Li B Q, Zhu Y Q, Liu D X, Lan Y F and Wang S 2018 *J. Mater. Eng. Perform.* **27** 3498
- [2] Anna Z, Nikita M, Vadim S, Denis Z and Andrey K 2019 *Mater.* **12** 981
- [3] Chang S C, Wang C C, Huang C A, Chang Y and Chen T L 2001 *J. Mater. Process. Technol.* **108** 294
- [4] Ji Z, Chen Y H, Qiang Y H, Shen C J and Li H W 2018 *Mater. Sci. Eng. A* **723** 29
- [5] Li K, Shan J G, Wang C X and Tian Z L 2016 *Mater. Sci. Eng. A* **669** 58