A NEW HEAT-TREATMENT PROCESS FOR 2014 ALUMINUM ALLOY AND ITS MECHANISM[①]

Wang, Lingyun Huang, Guangjie Chao, Denju
Chongqing Univsrsity, Chongqing 630044, China

ABSTRACT

The plan of heat-treatment process for 2014Al alloy is designed using orthogonal method, the heat-treatment experiments are made and the mechanical properties are tested according to the designed plan. The effect of solid solution temperature, ageing temperature, ageing time on microscopic mechanism of the mechanical properties of the 2014Al alloy is studied using microscope, transmission electron microscope. The best heat-treatment process of the 2014Al alloy is developed. The experimental results indicate that the strength σ_b, yield stress $\sigma_{0.2}$, percentage elongation δ of the alloy reach separately 490～500 MPa, 450～490 MPa, 10～12% adopting the new heat treatment process. Compared with GB, the strength increases 20～30%, the percentage elongation increases 30～40%. The mechanism of the new heat-treatment process is also discussed.

Key words: 2014Al new heat-treatment process mechanism ultimate tensile strength yield stress percentage elongation

1 INTRODUCTION

2014 aluminum alloy is an important material for aviation and space flight. Its heat treatment standards of 500±5 ℃ solid solution and 152 ℃, 6～10 h artificial ageing are being used in China all the time. The longitudinal mechanical property standards of the forgings with a certain thickness are σ_b= 382 MPa, $\sigma_{0.2}$=320 MPa, δ=6%, HB=120. In practical production, some of them can' t be reached completely. The potential of the alloy has not been brought into full play. Therefore, after studying its heat treatment process, it is possible to make the strength and percentage elongation of the 2014 aluminum alloy reach a new level.

2 EXPERIMENTAL

The smelted 2014 alloy is cast into and forged through soaking, upsetting, turning, bearizing (chemical composition can be see in Table1). A segment is cut from forgings and seperately made into samples with request dimensions for metallographic, electron microscope and mechanical property tests. Then, they are solid solutioned in salt bath, quenched in water and aged in air furnace.

The heat treatment technical parameters of quenching and ageing for the 2014 aluminum alloy include solid solution temperature and time, quenching medium and temperature, ageing temperature and time. On basis of refering to the standards of America, the Soviet Union and China, 500 ℃ solution temperature and 20～30 ℃ quenching temperature are fixed without change. Others are within experimental range. Therefore the effect of other three elements on properties is studied through the orthogonal design $L16(4)^5$(See Table 2).

The elongation property test at normal

① Manuscript received Aug. 3, 1992

Table 1 Composition of 2014 aluminum alloy and experimental materials/wt. -%

alloy	Cu	Mg	Si	Mn	Fe	Zn	Ti	Ni	Al
2014*	3.9~4.8	0.4~0.8	0.6~1.2	0.4~1.0	0.70	0.30	0.15	0.10	balance
2014 for experiment	4.45	0.61	0.89	0.71	0.26	0.10	0.05	—	balance

* Refering to GB 3193-82

temperature is performed under conventional conditions on a 10-ton universal material test machine. The metallographic test is carried out on a PME metallographic microscope and the transmission electron microscope checking is completed on a JEM- 100x transmission electron microscope.

Table 2 The levels of orthogonal experimental elements factors

level	solution time/min	ageing temperature/ C	ageing time/h
1	60	152	4
2	90	160	6
3	150	167	9
4	300	175	12

3 EXPERIMENTAL RESULTS AND ANALYSES

First, the range analysis (See Table 3) is performed to the experimental results of σ_b, $\sigma_{0.2}$ and δ after the experiment completed according to the plan on Table 2. Later, the optimum standard of each element is selected with consideration of effect of solution time, ageing temperature and time on mechanical properties of the alloy (See Fig. 1) and then proceed to determine the optimum heat treatment process for the 2014 aluminum alloy.

From Table 3, it is known that the most important element which affects the properties is ageing temperature. The second is ageing time and the third is solution time. These three elements affect the strength very obviously but affect the percentage elongation only a little. Among them the solution time just has a minimum effect on the percentage elongation, which can be neglected.

Table 3 Range analysis to the effect of each element on the perentage elongation and strength

element	$\sigma_{0.2}$/MPa	σ_b/MPa	δ%
solution time	57	26	0.6
ageing temperature	110	39	7.7
ageing time	93	36	5.2

Fig. 1 shows that within design range the $\bar{\sigma}$ (average value of strength) monotonously increases with increasing solution time, ageing temperature and time. The $\bar{\delta}$ (average value of percentage elongation) monotonously decreases along with increasing ageing temperature and time and is almost not affected by solution time. There isn't bad effect on percentage elongation by obviously increasing strength through extending solution time. Therefore, 300 min of solution may be selected. The effects of ageing temperature on strength and percentage elongation are contradictory. 175 C ageing can get a high strength but unideal percentage elongation. 167 C ageing can get ideal strengths ($\bar{\sigma}_b$ = 491 MPa, $\bar{\sigma}_{0.2}$ = 462 MPa) and a percentage elongation $\bar{\delta}$ of 10.6%. Thus, it is thought that 167 C ageing is reasonable. Comprehensively considering the strength and percentage

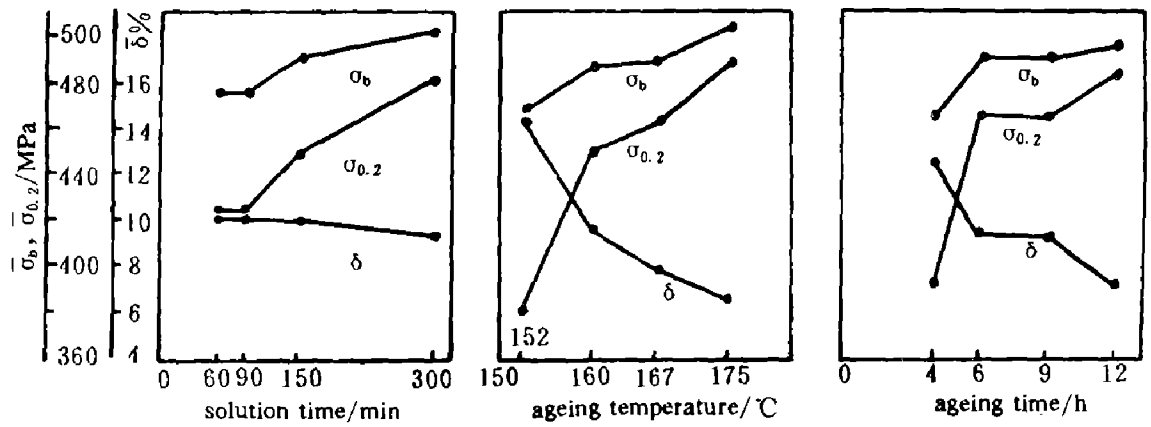

Fig. 1 The effect of solution time (a), ageing temperature (b), ageing time (c) on mechanical properties

elongation. The optimum ageing time is decided as 6～10 h.

From the above analysis we get the optimum heat treatment process for the 2014 aluminum alloy: $500\pm^{5}_{1}$ C solid solution for 300 min, quenching water temperature 20 ～30 C, ageing temperature 167 C and ageign time 6～10 h.

In order to make further verification on the above selected optimum heat treatment process and use ageing curves to make a visible analysis, we fix the solution time as 300 min, and change the effect of ageing temperature and time on σ_b, $\sigma_{0.2}$, δ. We get the ageing curves of the 2014 aluminum alloy (see Fig. 2).

Fig. 2 shows that the peaks of strength appears at 167 C and 175 C ageings. With increasing ageing temperature, the peaks move to the left. It means that the time needed to reach ageing peaks has been shortened. The stability of 167 C ageing strength is better than 175 C ageing. The 167 C ageing still has a higher strength after ageing. When the ageing temperature becomes higher, the percentage elongation doesn' t change too much.

If 167 C, 6～10 h ageing is made on the 2014 aluminum alloy, the mechanical properties at normal temperature are as follows: $\sigma_b = 490 \sim 500$ MPa, $\sigma_{0.2} = 450 \sim 490$ MPa, δ is over 10%. Compared to traditional process, σ_b and $\sigma_{0.2}$ increase 20～30%, δ increases 30～40%.

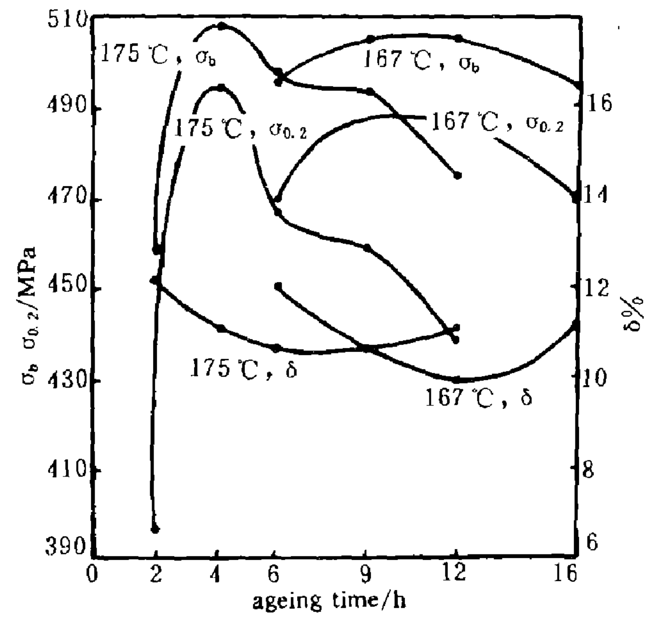

Fig. 2 Ageing curves of the 2014 aluminum alloy

4 DISCUSSION

4.1 *Analysis of Ageing Process of 2014 Alloy*

Almost like all kinds of alloys that can be hardened through heat treatment, the ageing of the 2014 aluminum alloy needs to experience the processes of supersaturated solid solution→G. P. zones → intermediate phases (θ′ , β′ , S′) →equibibrum phases(θ, β, S). The ageing also starts from G. P. zones. The composition, form, structure, amount, size, distribution etc. of G. P. zones are all related to the composition of the alloy and its ageing temperature. Under lower temperatures, although there is a big phase transferation driving force seperated out, it is controlled by atomic diffusion. Thus the seperating speed is slow. It is still in G. P. zones during a longer time and the size is very small. Along with increasing ageing temperature, the seperation of G. P. zones and the transferation speed to intermediate phase becoming faster, the size of precipitates increase accordingly. When the microstruture of G. P. zones and intermediate phase is formed in mixture, the strength peak appears in the alloy. It is called full ageing at this time. Along with the extending of ageing time, the transferation from intermediate phase to stable phase becomes stronger, the alloy steps into overageing stage. The microstructrue enters into balancing state.

4. 2 *The Relationship Between Heat Treatment, Microstructure and Properties*

A metallographic microscope is used to observe the quenched microsturctures solid solutioned at different time. The result is shown in Fig. 3. The burning hasn't been found in the alloy solutioned at $500\pm^{5}_{1}$ ℃.

From Fig. 3, we can see that a large amount of unsolutioned second phases (See Fig. 3a) exsisting in the alloy solutioned with traditional process. The alloy has lower properties at this time. As the solution time increases, the amount of unsolutioned second phase particles becomes smaller (See Fig. 3b). The strength of the alloy increases accordingly. Even if the solution time is extended to 300 min, there are still a certain amount of unsolutioned phases existing. After the solution time is extended, the alloy elements are solutioned more completely, distributed more homogeneously and has a higher concentration of vacancies in solution body. By thermodynamic and dynamic analysis, the above results make the seperating driving force of strength phase and the nucleation rate increase, the diffusion speed of alloying elements and the number of seperating phase also increased. It is more dispersive and smaller. For this reason, the strength of alloy increased[1, 2]. Moreover, increasing solution time caused the strengthing result of solution improved[3]. So the strength obviously increased with extending solution time.

Their microstructures under different

Fig. 3 The microstructure solutioned in different times (×200)
(a) —60 min solution; (b) —300 min solution

aeging system are observed with transmission electron microscope. The results are shown in Fig. 4. And the traditional heat treatment process standards for the 2014 aluminum alloy materials are 152 ℃, 6 h ageing (See Fig. 4a). In this case there are a large amount of G. P. zones exsisting in the alloy. The mechanical property tests and electron microscope analysis shows that high density G. P. zones still distribute in the alloy homogeneously when aged under this temperature before 9 h. The alloy is in a typical zone ageing conditions.

It is still far away from full ageing conditions. Since G. P. zones are coherent with the matrix and have the same structure as the matrix. Comparing it to intermediate phase, the atomic permutation is not easy to be disturbed by dislocation cutting. The created "chemical" hardness effect is not so large as intermediate phase[2]. The initial strain resistance will not creat when the dislocation is cutting across the G. P. zones. In this case. the alloy has a lower strength but good percentage elongation. There is intermediate phase seperated out till to 12 h. The strength of the alloy increases a lot at this time. That's why the potential of the alloy hasn' t been brought into full play by the traditional process.

The time needed to reach full ageing will be shortened with increasing ageing temperature. The higher the ageing temperature is, the quicker the strength decreases during overageing. When aged at 175 ℃, it needs only 4 h to reach full ageing. Fig. 4c showed a large amount of seperated materials out of the alloy. Ageing for 12 h, the seperated materials are very wide and big and form a constant plate (See Fig. 4d). This indicates the alloy has been overaged. Its sterength decreased and percentage elongation is bad.

Fig. 4 The microstructure of 2014 aluminum alloy, ageing at different temperatures and ageing time (×37 000)

(a) —152 ℃, 6 h ageing; (b) —167 ℃, 16 h ageing;
(c) —175 ℃, 4 h ageing; (d) —175 ℃, 12 h ageing

The reason is the seperated materials of stable phase are always non-coherent with the matrix and there isn't coherent elastic stress field. As there is a big distance between them and only a little stress needed for dislocation to surround the seperated materials of stable phase. It just play a small role to harden the precipitation. It is obvious that the exsistence of wide and constant plate seperated materials will not increase the percentage elongation of the alloy.

Aged at 167 ℃, the time to reach peaks is about 6 h, high density metastable phase particles can be seen under an electron microscope and it is partially coherent with the matrix. Thus the alloy has a higher strength and better aggregative properties. Since there is a high density of intermediate phase and a bigger microstructural difference to the matrix than to G. P. zones, their atomic arrangement is easier to be disturbed by dislocation and a stronger "chemical" hardening is caused to make the initial stress resistance increase rapidly. The strength increases much though the percentage elongation decreases somewhat, but still over 10%. This is a part of typical phase ageing stage. Moreover, the 167 ℃ ageing is moderate and there is a smoother ageing curves change than 175 ℃ ageing, for this reason a higher strength and fine percentage elongation are maintained during 6～16 h. Thus the process stability is guaranteed in a wider range. It is shown from electron microscope that the seperating phase still keeps small dispersion plate at 167 ℃, 16 h ageing (See Fig. 4b). This is the right reason why a higher strength and better percentage elongation are maintained.

5 CONCLUSIONS

(1) The optimum quenching temperature is $500\pm^{5}_{1}$ ℃. The holding time is 300 min.

(2) The optimum ageing system is 167 ℃, 6～10 h.

(3) After this new heat treatment process was used for the 2104 alloy, the longitudinal mechanical properties of σ_b, $\sigma_{0.2}$ and δ are 490～500 MPa, 450～490 MPa, 10～12% respectively. Compared to the national standards, 20～30% of strength and 30～40% of percentage elongation are increased.

REFERENCES

1 Writting group of nonferrous metals and their heat treatment. Nonferrous metals and their heat treatment (in Chinese). Beijing: National defence industrial press, 1981. 36-51.

2 Novikov, E E; Wang, Eiyou (trans). Theory of metal heat treatment. Beijing: Mechanical industrial press, 1987. 277-316.

3 Shercliff, H R. Acta Metallurgy, 1990, 38 (10): 1789-1802.